UNESCO SCIENCE REPORT

The race against time for smarter development

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Cover photo: A medical operator hands a box of Covid-19 test samples collected from rural hospitals to a drone flight operator at Zipline's distribution centre in Omenako for delivery to the Noguchi Memorial Institute for Medical Research in Accra, in this composite image.
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UNESCO SCIENCE REPORT

The race against time for smarter development

SHORT SUMMARY

The clock is ticking for transitioning to digital and 'green' societies

It is striking how development priorities have aligned over the past five years. Countries of all income levels are prioritizing their transition to digital and 'green' economies, in parallel. This reflects a double imperative. On the one hand, the clock is ticking for countries to reach their Sustainable Development Goals by 2030. On the other, countries are convinced that their future economic competitiveness will depend upon how quickly they transition to digital societies. The report's subtitle, 'the race against time for smarter development', is an allusion to these twin priorities.

For developing countries, this imperative is obliging them to accelerate a process of industrialization and infrastructure development that would normally take decades. This process can be an opportunity for them to reduce their dependence on foreign technologies, as long as governments can ensure that industrialization and infrastructure development intersect with capacity-building in research and innovation. Since the private sector will need to drive much of the dual transition, governments everywhere are designing new policy tools to facilitate technology transfer to industry.

32 countries raised their research spending by 0.10% of GDP or more between 2014 and 2018

This seventh edition in the series arrives at a crucial juncture, as countries approach the halfway mark for delivering on their Sustainable Development Goals. The report finds that sustainability science is not yet mainstream in academic publishing at the global level and that it is developing countries which are publishing most, proportionately, on related topics. This trend, combined with greater government support for start-ups and small businesses in many countries, suggests that the current knowledge gap could narrow in the coming years, as long as the challenge of chronic underfunding can be overcome: four out of five countries still spend less than 1% of GDP on research and development.

The *UNESCO Science Report* series targets policy-makers, academics, the intergovernmental and non-governmental communities, the media and other groups interested in understanding how science governance is shaping countries' development agendas.

'Since wars begin in the minds of men and women, it is in the minds of men and women that the defences of peace must be constructed'

Acronyms

ACAE	Association for Aeronautics and Space
AI	Artificial intelligence
AfDB	African Development Bank
ANSO	Alliance of International Scientific Organizations in the Belt and Road Regions
AU	African Union
BRI	Belt and Road Initiative (China)
BRICS	Brazil, Russian Federation, India, China and South Africa
CCA	Council of Canadian Academies
CCAD	Central America Commission for Environment and Development
CEMAC	Central African Economic and Monetary Community
COMESA	Common Market for Eastern and Southern Africa
CYTED	Ibero-American Programme of Science and Technology for Development
EAC	East African Community
EAEU	Eurasian Economic Union
ECCAS	Economic Community of Central African States
ECOSOC	United Nations Economic and Social Council
ECOWAS	Economic Community of West African States
EAEU	Eurasian Economic Union
EFTA	European Free Trade Association
ERC	European Research Council
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FDI	Foreign direct investment
FTE	Full-time equivalent
GCF	Green Climate Fund
GDP	Gross domestic product
GERD	Gross domestic expenditure on research and development
HC	Head count
IDB	Inter-American Development Bank
ICT	Information and communication technology
IDB	Inter-American Development Bank
IDRC	International Development Research Centre
IGAD	Intergovernmental Authority on Development
IMF	International Monetary Fund
INGSA	International Network for Government Science Advice
IRENA	International Renewable Energy Agency
IUCN	International Union for the Conservation of Nature
NATO	North Atlantic Treaty Organization
NGO	Non-governmental organization
ODA	Official development assistance
OECD	Organisation for Economic Co-operation and Development
OECS	Organisation of Eastern Caribbean States
PCT	Patent Cooperation Treaty
PIDA	Programme for Infrastructure Development in Africa
PISA	Programme for International Student Assessment (OECD)
PPP	Purchasing power parity
QIS	Quantum information science
R&D	Research and development
RICYT	Network for Science and Technology Indicators – Ibero-American and Inter-American
SADC	Southern African Development Community
SICA	Central American Integration System
SIDS	Small Island Developing States
SKA	Square Kilometre Array
SME	Small and medium-sized enterprises
STI	Science, technology and innovation
STEM	Science, technology, engineering and mathematics
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNESCWA	Nations Economic and Social Commission for Western Asia
USMCA	United States–Mexico–Canada Agreement
UWI	University of the West Indies

Preface

António Guterres, *United Nations Secretary-General*

The Covid-19 pandemic has underscored three important lessons.

The first is that we are all deeply interconnected. No-one will be safe from the virus until everyone is safe.

The second lesson is that the same human activities that drive climate change and biodiversity loss also increase the risk of pandemics through their impact on the environment.

The third lesson is the vital importance of science.

This year's *UNESCO Science Report – the Race Against Time for Smarter Development* – focuses on the global shift towards economies that are greener, knowledge-based and make the best use of digital technologies. We must work to ensure that the pursuit of advanced technology and sustainable development go hand in hand.

The *Report* finds that the global researcher population continues to grow, yet there is a strong imbalance around the world. For example, in 2018, sub-Saharan Africa was home to 14% of the global population but only 0.7% of the world's researchers.

International collaboration among scientists is also on the rise, which augurs well for research on challenges such as climate change, biodiversity loss and infectious diseases, which do not respect borders.

These research communities, however, depend on supportive policies and funding and four out of five countries devote less than 1% of GDP to research and development.

Many countries are aligning policies on science, technology and innovation with the Sustainable Development Goals. These include ambitious plans for decarbonizing the economy and reducing waste. But, despite the prioritization of sustainable development, sustainability science has not yet gone mainstream.

UNESCO has found that developing countries focus more of their research efforts on topics vital for their development such as agro-ecology, climate-ready crops and sustainable waste management – but publications on these issues remain marginal in the overall research ecosystem.

Meanwhile, there were almost 150 000 publications on artificial intelligence and robotics in 2019. This field dominates scientific output on other cross-cutting technologies that have potential benefits for developing countries, such as energy, materials science, nanotechnology and biotechnology.

As this report makes clear, we need to step up our commitment to sustainable development, in both economic and human terms.

By aligning policies and resources, we can make far greater progress towards achieving the Sustainable Development Goals.

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The complete statistical annex and datasets are freely available from the *UNESCO Science Report* web portal.

Statistical annex

Foreword

Audrey Azoulay, *UNESCO Director-General*

Every five years, the *UNESCO Science Report* offers an overview of science and the way it is shaped by public policy. To browse the pages of this report is to get a glimpse of a rapidly changing world – a world in which, for instance, artificial intelligence is increasingly permeating our everyday lives.

We also gain greater insights into the major challenges of our time: how to reconcile ecological goals with economic needs, particularly in terms of employment; and how to effect a smooth transition towards green and digital economies, without exacerbating inequalities.

As the title of the report suggests, we urgently need to set common objectives if we want science to be a tool for equitable and sustainable development, in the service of all humankind.

To do so, we must deploy the potential of science everywhere. Even though countries around the world have committed to this, the sums they have allocated are still inadequate, given the high stakes. The report finds that a minority of countries are providing the bulk of investment: four out of five countries still devote less than 1% of GDP to research.

The stakes are indeed high, if we are to prevent the technological gap between countries from widening. This means supporting researchers and research – in both the public and private sectors – and embracing international scientific co-operation. Indeed, the last five years have seen a welcome increase in scientific co-operation across borders, even before the tremendous collective effort to fight Covid-19.

But the results are still not good enough. For example, over 70% of publications remain inaccessible to the majority of the world's scientists. These barriers to research – sources of both inequality and inefficiency – cannot be justified. They must be lifted, through the elaboration and implementation of new models for communicating and disseminating scientific knowledge.

Since 2019, UNESCO has been working towards this goal, by developing a global standard-setting instrument for open science, to make science more transparent, more inclusive and more responsive.

For science to be more effective, it must also be more representative, drawing on the diversity of our world. Yet, as this report highlights, only one in three researchers is a woman. Whereas gender parity has nearly been achieved in the life sciences, it remains a distant goal in fields such as engineering, where only 28% of graduates are women, and artificial intelligence, where only 22% of professionals are women.

Effective science systems inspire trust. The past few months have shown the importance of scientific literacy in empowering the general public to make conscious choices and informed decisions. Much remains to be done, however, especially through education, to ensure that science stays in sync with our societies.

To inspire trust, science must also be ethical and respond to the complex issues that inevitably accompany scientific progress. This has long been a focus of UNESCO's work, through the World Commission on the Ethics of Scientific Knowledge and Technology and the International Bioethics Committee and through our elaboration of a Recommendation on the Ethics of Artificial Intelligence.

In short, what this report demonstrates is that science is not just about producing knowledge, techniques and innovation; sometimes, in a broader sense, science paints an unforgiving picture of humanity.

We need to be able to look at this picture with pride. That means not letting science and technology develop to our detriment but rather mobilizing it to serve the common good.

The shifting landscape for scientists: a collection of essays

In Brazzaville, Huster Akiera, CEO of the start-up HOZ 3D, readies his machine to begin printing visors and valves. His invention was one of many displayed at an exhibition organized jointly by the Ministry of Scientific Research and Technological Innovation and UNESCO in December 2020 to showcase Congolese ingenuity in tackling the Covid-19 pandemic. © HOZ 3D

What the Covid-19 pandemic reveals about the evolving landscape of scientific advice

Peter Gluckman and Binyam Sisay Mendisu

Contested perspectives

The relationships between science, society, policy and politics have always been complex and contested. We only need to consider the headwinds encountered by the scientific community over the past few decades in their attempts to persuade the global political community to recognize and act on anthropogenic-driven climate change, or the ongoing contestation over the role of genetically modified crops in ensuring food security, or the difficulty in persuading governments to address obesity and its consequences.

Many, if not most, policy decisions have a scientific dimension. Whereas science advisory systems originally evolved in large advanced economies to deal largely with matters of defence and technology, they now have critical roles to play in areas such as the environment, social progress and health.

The Covid-19 pandemic has brought these relationships into unprecedented focus. From the earliest days of the pandemic, governments have had to make far-reaching decisions in the context of incomplete and evolving knowledge about the virus. These decisions have been perceived by many as involving trade-offs between health, economics, social well-being and individual rights, such as the lockdowns which have slowed economic activity and curbed individual mobility. Many governments have acknowledged the critical importance of scientific analysis and advice in assisting their decision-making.

Although the present essay focuses on the interaction between science and the policy community during the current Covid-19 pandemic, effective use of science in informing policy-making ultimately springs from public trust in both the scientific community and the institutions of government. The lessons learned during the Covid-19 pandemic may, thus, have broader implications for how countries might better use scientific evidence to develop and implement policies in the future.

Beyond the essential and ongoing role of new knowledge generation by the scientific community during the pandemic, the two central components of scientific advice have been in play: *evidentiary synthesis* (synthesizing available and often incomplete scientific evidence to assist governments) and *evidentiary brokerage* (communicating synthesized and interpreted scientific evidence to both governments and their citizens).

Vectors of evidentiary synthesis

To be of value, evidentiary synthesis must be a balanced and comprehensive presentation of what is known and not known, as opposed to biased advocacy. Evidentiary synthesis

Box 1: **Uruguay: the public and private research sectors step up to the plate**

After the first four cases of Covid-19 were detected in Uruguay on 13 March 2020, the government immediately declared a 'state of health emergency'.

Weeks earlier, in anticipation of the inevitable arrival of the virus, the health authorities had contacted a team of researchers at the main public university, the Universidad de la República, and the Institut Pasteur de Montevideo, to explore the potential for local development of diagnostic testing. This led to the signing of an agreement in March between the academic sector and the government which saw much of the scientific biomedical community shift its focus towards providing expertise, personnel, equipment and reagents to combat the virus.

Within about a month, the locally produced molecular tests had been validated for distribution. In parallel, research laboratories began designing and developing serological tests to detect antibodies in patients with acquired immunity that were validated in August 2020 by the Ministry of Public Health.

The efforts of the public sector were paralleled by private initiatives, generating a large and well-distributed testing capacity.

In April 2020, the government created a Scientific Advisory Group composed of three coordinators, one with a general mandate and one each for health and data science and modelling. This trio selected a group of 55 top national scientists and experts to generate weekly reports for the government whose advice ranged from recommended health measures to reviewing and reducing social restrictions.

The Scientific Advisory Group also gave interviews to the press and held press conferences to provide the public with scientific evidence of the biological, epidemiological and pathological dimensions of the virus and the rationale for social and public health interventions, such as the re-opening of schools as part of the deconfinement process.

There is a national consensus that this multifaceted strategy has succeeded in minimizing the disease burden at the individual and social levels in Uruguay.

Source: Prof. Rafael Radi, MD, PhD, Professor and Chair of Biochemistry, Director, Centro de Investigaciones Biomédicas (CEINBIO), Facultad de Medicina, Universidad de la República Montevideo, Uruguay should be informed by a plurality of disciplines, as illustrated by the case study of Uruguay (Box 1).

Too often in the past, perspectives from the social sciences and humanities have been overlooked, despite the reality that human behaviour and sociological dimensions are key to successful decision-making, as demonstrated by the debates on both the Covid-19 pandemic and climate change.

Evidentiary synthesis is most often conducted by national science academies. However, national technical and science-based commissions, scientific advisory offices, ad hoc committees, research institutes and university departments can all provide evidentiary synthesis.

It is gratifying that a growing number of lower-income countries have invested in developing science academies in recent years, including 28 African countries. The South African academy has produced evidentiary synthetic reports for policy-makers which are particularly robust and of global value.[1]

Prof. Madiagne Diallo of the Economic, Social and Environmental Council of Senegal[2] observes that a growing number of African governments had already been reaching out to science academies for advice prior to the pandemic. For example, in 2015, the Government of Cameroon tasked its science academy with developing a national biotechnology policy framework. In 2019, the Government of Senegal tasked its science academy with providing an evidentiary synthesis of the state of the art of genetically modified organisms and related challenges and prospects for Senegal.

In addition, there is a growing body of young academies, as well as international groups such as the World Association of Young Scientists and the Global Young Academy. These young academies are providing a valuable intergenerational voice and have been proactive in grasping the importance of transdisciplinary approaches.

The emergence of a regional or subregional approach to the provision of scientific advice has been an important development. This approach may take the form of regional agencies. For example, the Pacific Community based in Noumea, New Caledonia (France), provides many small Pacific island states with technical and scientific support in areas such as public health and marine resources. The African Academy of Sciences also provides evidentiary analyses for African nations.

Notwithstanding this co-operation, institutional and individual capacities and capabilities still need building in many countries and regions. With pilot funding from the International Development Research Corporation, the International Network for Government Science Advice (INGSA) established the Southeast Asian Science Advice Network (SEA-SAN in 2020) to facilitate joint evidentiary synthesis and information-sharing among senior scientists with advisory responsibilities via an online platform; the focus is on issues of shared regional concern related to the United Nations' Sustainable Development Goals to 2030. This platform will develop, share and access reports and analyses of common relevance and undertake evidentiary synthesis on common issues, allowing each individual country to consider how to incorporate that knowledge appropriately into its policy-making. Over time, as the benefits of structured inputs become visible, it is hoped this initiative will lead to greater institutionalization of scientific advice.

Global assessments are a further form of evidentiary synthesis. Two examples are the assessments undertaken by the Intergovernmental Panel on Climate Change, sponsored by the World Meteorological Organization and United Nations Environment Programme (UNEP), and those undertaken by the Intergovernmental Policy Platform on Biodiversity and Ecosystem Services (IPBES), sponsored by UNESCO, UNEP, the Food and Agriculture Organization and United Nations Development Programme.

The facets of evidentiary brokerage

Evidence brokerage is the process of effectively transferring scientific understanding to the policy community and political decision-makers, while acknowledging that many other factors affect policy decisions. Brokerage may, or may not, be provided by the same actors who undertake evidentiary synthesis.

Brokerage must be sensitive to the reality that policy decisions are based on many other factors beyond the scientific evidence. Societal values, public acceptance, political ideology and priorities, electoral contracts, diplomatic and economic factors are all part of decision-making.

Although science advice may have its historical origin in the natural sciences and technology, effective brokerage is increasingly transdisciplinary. Increasingly, social sciences and the humanities are central to both evidentiary synthesis and brokerage. A particularly sensitive aspect is how to deal with other sources of knowledge that claim authority but are not based on scientific processes. Integrating indigenous knowledge with formal scientific knowledge requires particular understanding and respect.

Evaluating options

All policy-making involves choosing between options (including that of maintaining the status quo), each of which has different implications and trade-offs. When offering scientific advice, the primary objective is to assist the policy community in choosing between the available options.

In so doing, the brokerage function must always consider inferential risk, namely, what are the implications of uncertainties (which are always present)? In order to reduce the risk, the broker defines what is known and not known and the caveats of any synthesis, particularly in relation to probabilities and an explanation of assumptions made. The decision-maker must understand the potential implications of different options in the context of uncertainty. This challenge is apparent in the different choices that countries have made in how they approached Covid-19. For example, early decisions made by some countries appear to have been based on inferences about the early development of herd immunity that were not substantiated by later events. Having recognized the risk in that inference, other countries chose much more restrictive approaches.

It is also critical for the broker to avoid the trap of selecting the evidence to meet predetermined political outcomes.

The difficulties of decision-making and balancing competing interests, even when informed by evidence, has been illustrated repeatedly by the Covid-19 crisis. When most countries in Africa and many around the world chose to impose strict lockdowns, Ethiopia took a different path. It focused on enforcing public health measures, including the promotion of personal hygiene, the wearing of protective masks and social distancing in public places. Although strict lockdown measures made sense from a public health perspective, it would have made life unbearable for many poor households reliant mainly on income from the informal sector. Even though the jury is still out on the long-term effectiveness and benefit of these alternative choices, the policy decisions made need to be understood in the local context of competing demands. This highlights the need for a plurality of scientific input, including from the humanities and social sciences but it also illustrates the reality that decision-making ultimately depends on a range of values-based judgments by politicians.

Navigating the interface

The interface between synthesis and brokerage is, of course, complex. Whereas evidentiary synthesis tends to be transparent in the form of a policy brief or report, and while some brokerage is similarly in the form of formal reports, much is informal, particularly in the early stages of policy formulation or in emergencies, and takes the form of a conversation between the broker and the policy community. Who participates in this dialogue will depend on the mechanism in play, whether the brokerage mechanism is a committee or commission, a science advisory panel or whether the national science academy takes on that role. In emergencies, effective ad hoc mechanisms can be created, as in Sri Lanka (Box 2) and Jamaica (Box 3) but such ad hoc approaches will not ensure appropriate input for the myriad of non-acute policy-making domains where science can assist.

Brokerage often involves direct interpersonal contact with the political decision-maker and, thus, involves individuals such as a science advisor or a senior academician. It is increasingly recognized that the brokerage function requires a particular set of skills and contextual understanding of both the science and policy systems. Specific training programmes have been developed by INGSA and partners to support development of these skills.

Science, policy and values

It is important to recognize that science has embedded values. These include considerations of what questions to study, how to study them and what use to make of the information acquired. However, the scientific method also demands that scientists set aside their individual biases and values when collecting and analysing raw data, as these biases and values may distort empirical observations or evidentiary synthesis, the basis of good science.

By contrast, policy-making is largely a values-based process of choosing between options that affect different stakeholders in different ways. Even the decision as to whether to take any policy action at all is a values-laden decision. The values at stake include political ideology, world view, the fiscal situation, public opinion and reputational issues.

Furthermore, scientific assessments of risk are different to the perceptions of risk by citizens, the latter being primarily

Box 2: **Sri Lanka's generous prevention programme**

After the first Covid-19 patient was identified in January 2020, an ad hoc Presidential Task Force and separate Technical Committee were set up to prevent and manage the spread of infection in Sri Lanka, in the absence of an established science advisory body.

The need for a strong preventive strategy was recognized as a key priority, in light of the health system's limited curative capacity, in particular as concerns intensive care services. The medical profession made a strong case for a complete nationwide lockdown accompanied by the closure of international airports to passengers, as well as contact tracking and tracing.

More than nine months into the pandemic, life in Sri Lanka has gradually returned to normal. As of November 2020, the caseload has been limited to a little over 17 000 confirmed infections, with a low death rate of just 0.27 per 100 000 population – even if the threat of an uptick remains. Success thus far has been attributed to the following factors:

- focused, harmonized and coordinated strategies mobilizing all stakeholders and both public and private resources;
- prevention of community spread, thanks to prompt and stringent contact-tracing enhanced by the intelligence services, quarantine and follow-up measures;
- the rapid conversation of existing institutions into dedicated quarantine centres, Covid-19 hospitals and polymerase chain reaction testing laboratories;
- clear messaging to the nation on the code of conduct to follow, conveyed by a single authority, the director-general of health services;
- frequent programmes promoted through digital and social media to make people aware and accepting of the preventive measures they needed to adopt at individual and societal level during lockdown and re-opening phases; for example, all households were provided with essential items during lockdown and returning Sri Lankan students and migrant workers were given a comfortable stay in quarantine centres.

Source: Prof. Sirimali Fernando, Professor and Chair of Microbiology, Faculty of Medical Sciences, University of Sri Jayewardenapura, Gangodawila, Sri Lanka

Box 3: **Jamaica: a wide range of expertise**

The government has not developed a permanent mechanism for the provision of scientific advice, even though it places a premium on the role of science in informing policy. Rather, it has chosen to use a fit for purpose, ad hoc approach, wherein the government, politicians and technical ministerial staff identify institutions and individual experts from academia, the business sector and civil society to form multidisciplinary, multi-agency teams, with the participation of international agencies. These teams are co-chaired by a government technocrat and an independent expert.

This model was used in the Covid-19 pandemic. Rather than appoint a Covid Czar, the government used the pre-existing Essential National Health Research framework put in place a decade ago to respond to such crises and appointed government technocrats, academics, business owners and civil actors to fulfill specific technical roles. The team has produced a twice-weekly briefing for the Cabinet and the Parliamentary subcommittee established specifically to assume this oversight role.

Three factors stand out as having contributed to Jamaica's relative success in managing the early stages of the pandemic. Firstly, there was a widely felt public sentiment of legitimacy towards the government of the day, resting as it does on an electoral system. Secondly, the pre-existing framework acknowledged the vital role played by scientific evidence in informing policy. The third factor has been the enormous commitment needed in a low-resource country to collect, curate, analyse, interpret, share and utilize a range of data. This has been largely a manual exercise conducted in silos that has only produced the requisite information thanks to a Herculean effort.

Source: Prof. Terrence Forrester, Professor of Experimental Medicine and Chief Scientist at UWI Solutions for Developing Countries at the University of the West Indies (UWI)

determined by cognitive biases. In turn, politicians will understandably look at issues through the lens of their political risk. Translating and communicating between these two domains is, thus, a sensitive and evolving boundary function.

Inferential risk can affect the policy process

From the perspective of scientific advice, the most important value concerns the sufficiency and quality of evidence on which inferences are made by scientists and policy-makers alike in reaching conclusions that might affect the policy process, or, in other words, inferential risk.

Often, decisions must be made on the basis of complex science where many uncertainties remain, owing to the superior value of science in the policy process. Even so, normative arguments would suggest that effective and timely insertion of appropriate knowledge into policy decisions will lead to better policy-making.

Different perceptions of uncertainty by science and policy

However, due to the different perceptions of uncertainty by science and policy-making, collaboration between the two groups does not always go smoothly. Whereas scientific knowledge is always provisional and accepts both epistemic and methodological uncertainties, policy-makers need to act, especially in times of crisis. Politicians prefer to be certain in their communication.

This divergent understanding of the quality of evidence can make collaboration between the scientific and policy-making communities a challenging affair. Hence why one cannot overemphasize the crucial role of effective communication between the policy and scientific communities in such a context.

Developing the advisory ecosystem

No singular model for a science advisory ecosystem has demonstrated its effectiveness in all situations. These range from the provision of advice in an emergency to advice and dealing with longer term issues of sustainability and human development. Even in the mature systems of many high-income countries, multiple components are needed to create a complete science advisory ecosystem, although, in some cases, the pandemic has exposed issues of effectiveness.

The emergence of the Covid-19 pandemic serves as a stark reminder of the crucial importance of establishing well-functioning, formal science advisory institutions, processes and guidelines in low-and middle-income countries and, indeed, in many higher-income countries.

For instance, in Ethiopia over the past two years, politicians and policy-makers have openly requested support from the scientific community in reforming existing policies and developing new ones – an unprecedented move. However, the promising engagement between scientists and policy-makers noted in this period of social and political reform still lacks institutionalization in Ethiopia, being largely ad hoc. This is also true of Sri Lanka (Box 2) and Jamaica (Box 3).

The relatively successful response to Covid-19 from several African countries, including Ethiopia and Ghana (Box 4), throws light on the importance of building on previous experience in tackling an epidemic, to ensure preparedness and effective communication. In particular, handling a crisis efficiently is less a matter of financial means than of effectively communicating options that are well informed by evidence.

One may even go further and conclude from the experience of some lower-income countries which have done relatively well in terms of disease control during the Covid-19 pandemic[3] that there does not seem to be a correlation between their public health response and the country's research intensity. Indeed, as the examples in the present essay demonstrate, the political leadership in many lower-income countries reached out rapidly and effectively to their scientific community.

Box 4: **Ghana: public–private partnerships have boosted self-reliance**

With the closure of many borders around the world, Ghana has had to turn inwards for survival and sustenance. In the face of disrupted supply lines and difficulties in importing goods, local ingenuity has proved vital. Research institutions and universities have provided gene sequencing research and assisted in the production of sanitizers, test kits, ventilators, tracker software and so on. Individuals, state institutions and corporate institutions have come up with innovative ways of manufacturing personal protective equipment, solar and touchless handwashing basins, walk-through full body sanitizer spray machines and so on.

A national Covid-19 team with a strong background in public health was set up to advise the president. The team consists of the Presidential Adviser on Health, a former Deputy Director-General of the World Health Organization and the Deputy Minister of Health.

The strategy adopted by Ghana has focused on regular information updates, including periodic addresses by the president, and a massive public education campaign. The Ministry of Health and Ghana Health Services continue to use their websites and social media platforms to educate the public. Pedagogical materials were translated into eight local languages early on in the fight to boost the uptake of information.

By the time the first two cases of Covid-19 were detected on 12 March 2020, there had already been some public education on safety protocols, as well as checks of body temperature for travelers crossing the border.

Collaboration between the public and private sectors has cushioned the impact of the pandemic. The Ghana National Trust Fund set up by the president in 2020 to alleviate the burden on the poor has attracted contributions in cash and in kind. Some faith-based organizations and individuals have also offered their facilities to the government for conversion into treatment centres.

A new centre for the treatment of infectious diseases was constructed in mid-2020 through a public–private partnership. The 100-bed centre was constructed by the Ghana Armed Forces at the Ga East Municipal Hospital in Accra. The Ghana Medical Association ensured that the centre would be fit for purpose; it houses a biomedical laboratory, pharmacy, recovery court yard and 21-bed intensive care unit, among other facilities. The project was carried out by the Ghana Covid-19 Private Sector Fund, in conjunction with the Ministry of Health.

By November 2020, Ghana had a caseload of just over 50 000 and a low mortality rate of 1.08 per 100 000 inhabitants.

Source: Prof. Marian Asantewah Nkansah, Department of Chemistry. Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Ad hoc scientific advice has its limitations

For scientific advice to be effective, there are at least two essential prior considerations. Firstly, the government and policy community must accept the value of scientific advice across a broad range of issues.

The first of these criteria is not broadly appreciated in many countries lacking formal advisory mechanisms. A further limitation of ad hoc mechanisms is that they may be biased in terms of the knowledge presented, if the experts consulted lack the requisite skills for advisory mechanisms.

Secondly, there must be a local scientific and academic community that can contribute scientific advice; this is amply demonstrated by the integrated Ghanaian response to Covid-19 (Box 4). This does not mean that the only knowledge of value is locally derived. Indeed, most scientific knowledge is inevitably transnational in origin but existing knowledge must, nevertheless, be interpreted in the local context. Institutions like universities are critical to the development paradigm. They must have the necessary skills to transmit knowledge to the policy community and the political process must be willing to incorporate that knowledge into its decision-making. The public will feel confident when it is communicated to them that policy is informed by evidence (Box 2). In communicating scientific evidence and ensuing recommendations both to policy-makers and the wider public, advisors must be transparent about the sources of this evidence to garner trust.

Although ad hoc science advice mechanisms can deal with a particular issue, they do not create long-term value. We suggest that scientific advisory mechanisms be institutionalized. Simple but effective mechanisms have been developed and institutionalized in countries such as New Zealand (Box 5), albeit that the shape of such advisory systems may vary, depending on constitutional, cultural and historical contexts.

Although institutionalizing the scientific advisory process obviously has great longer-term benefits and permits forward planning, it runs the risk of politicization and institutional competition. Appropriate protections need to be in place to ensure the independence and integrity of the advice given. Academia has a critical role to play in providing that accountability, as long as it enjoys sustained independence itself.

Scientific advice must not be limited to crises

Effective and trusted scientific advice is not simply a function of linkages with the policy-maker. It also involves an effective conversation with stakeholders and the public. In the presence of misinformation, a growing challenge globally, trusted honest communication to all citizens takes on critical importance.

The role of structured scientific advice must not be limited to emergencies. Much of a government's decision-making in areas ranging from education to transport, from energy to agriculture, from innovation policy to social welfare, can

Box 5: **New Zealand has managed to eliminate the virus**

New Zealand has done well in handling the pandemic since the first case was reported on 28 January 2020. Arguably key to New Zealand's success was the relatively early clear scientifically informed determination that elimination rather than suppression was a viable option, even if this policy took time to put in place. Elimination was a feasible option, as New Zealand is made up of a group of islands.

A strict border closure was introduced on 20 March 2020, accompanied by a two-week period of quarantine for returning New Zealanders, aggressive contact tracing and a seven-week national lockdown.

The virus was considered to have been eliminated after more than 100 days without any community cases. A subsequent small outbreak was nipped in the bud by locking down the country's largest city, Auckland, for a few weeks. A handful of isolated cases have been rapidly identified and managed through well-developed testing and contact tracing.

The population has been highly compliant and co-operative, reassured by clear communication on the different levels of social restraint and lockdown. The prime minister used sporting analogies to encourage a united ambition. She referred, for instance, to the New Zealand population being 'a team of 5 million'. Both the prime minister and director-general of health held daily press conferences for many months. The quality of science communication by scientists both within and without the advisory system was exemplary.

A novel aspect of the response was the establishment of a parliamentary select committee headed by the leader of the opposition to monitor the response. The committee's deliberations were webcast live, thereby giving the public insights into the complexities of the national response. This served to enhance the transparency of decision-making and build trust in the system.

There is a lot of respect for science in New Zealand, which has a well-developed science advisory system. The country's emergency response system was largely built to handle natural disasters. It is based on a co-ordination committee chaired by the Chief Executive of the Department of the Prime Minister and Cabinet. The Chief Science Advisor to the Prime Minister sits on the committee. The lead ministry for the emergency response to the Covid-19 pandemic was the Ministry of Health. It has well established scientific advisory mechanisms and its own science advisor. The ministry brought in appropriate modelling and epidemiological expertise.

The whole of government response included working with research institutes, universities and the private sector to build testing and other requisite capacities.

The challenge now will be to judge when and how to re-open the border, the closure of which over the past eight months has had significant implications for many families and for components of the economy.

Source: Prof. Peter Gluckman, former Chief Science Advisor to the Prime Minister of New Zealand

be assisted by appropriate skilled evidentiary synthesis and brokerage. Issues such as whether to adopt new technologies such as gene editing or how to use artificial intelligence and big data to enhance productivity will be best addressed when the science is properly considered. Anthropogenic climate change creates particular challenges which demand input from both natural and social sciences. With the rapid pace of technological development, governments will be faced with many expectations and choices to make on a regular basis. Sound, holistic scientific advice can do much to assist governments in such contexts.

Currently, advisory systems are at highly variable stages of development across high-, middle- and low-income countries. They cannot be effective or meet their objective if they are unable to present and digest the evidence independently of political interference. This requires maturity within the political and policy communities.

Ultimately, it is up to government to make decisions that incorporate a broader range of input. However, these decisions will have a greater likelihood of meeting government objectives when properly informed by evidence.

There is no singular model to copy but recent experiences highlighted in the examples on these pages suggest that low- and middle-income countries are finding a range of approaches to meet their acute needs in effective ways.

The challenge will be to learn from these lessons, to determine how the science advisory ecosystem and related institutions might evolve in every country.

Sir Peter Gluckman (b. 1949: New Zealand) is Chair of the International Network for Government Science Advice and President-Elect of the International Science Council. He is Distinguished Professor, Koi Tū- of the Centre for Informed Futures at the University of Auckland and former Chief Science Advisor to the Prime Minister of New Zealand.

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ENDNOTES

1 See: http://research.assaf.org.za/handle/20.500.11911/81
2 Professor Diallo is also an executive member of the African chapter of the International Network for Government Science Advice (INGSA).
3 See: https://www.ingsa.org/covid/policymaking-tracker-landing/

Covid-19: from crisis management to sustainable solutions

Eric D'Ortenzio, Evelyne Jouvin Marche, Oriane Puéchal, Inmaculada Ortega Pérez and Yazdan Yazdanpanah

Shared observations have been key to understanding a new problem

In France in late January 2020, five patients were diagnosed with infections caused by a new virus. Two of them were almost asymptomatic and made a rapid recovery. The condition of another two was initially reassuring before deteriorating after ten days and the fifth patient immediately developed a serious form of infection that led to multiple organ damage. These five patients were the first known cases in France of a novel coronavirus disease (Covid-19) caused by a severe acute respiratory syndrome (SARS). Since the first known epidemic of this type of coronavirus dated back to 2003, the new coronavirus was dubbed SARS-CoV-2.

SARS-CoV-2 was not known as an infectious agent in humans until January 2020, when it was identified as the causative agent of Covid-19, against which human beings had no natural immunity. Although six other coronaviruses that infect humans have been studied, including the coronavirus that causes the common cold, there was no known treatment or vaccine against SARS-CoV-2.

Since the first cases were described, over 4 000 patients hospitalized across France for Covid-19 have been enrolled in an observational study (French Covid), with their willing participation, in order to improve our understanding of the disease, its symptoms and how patients respond to treatment. The data and information collected have been crucial in helping medical staff fight Covid-19.

In addition, biological samples collected from this observational cohort have been used in basic and clinical research. They have been used to study the genome of the virus, for example, and its interaction with the immune system. Such samples are valuable because the way in which the immune system responds to the virus varies widely from one individual to another. The majority of those infected with SARS-CoV-2 quickly recover. However, around 20% of infections require hospitalization and one-quarter of patients present severe forms of the disease. These cases generally involve acute respiratory insuf¬ficiency and, sometimes, thrombosis: blood clots form in the veins, reducing blood circulation and intensifying respiratory problems.

Rapid solutions relied on multinational adaptive trials

Without any known treatment to target the virus directly, health care professionals initially found themselves powerless to fight the disease.

In this type of health emergency, the most effective strategy in the early days is to repurpose existing drugs. The rapid spread of the disease from one country to another spurred a practical push for shared solutions. A European clinical trial known as the Discovery Trial was set up in record time. Co-ordinated by the French National Institute of Health and Medical Research (INSERM), it began evaluating the efficacy of potential drugs against SARS-CoV-2 on 22 March 2020.

The Discovery Trial has been an integral part of Solidarity, the consortium grouping clinical trials that was announced by the World Health Organization (WHO) on 18 March 2020. As of 2 October 2020, this consortium grouped almost 12 000 patients from over 30 countries. The advantage of having such a consortium is that medical researchers participating in clinical trials use standardized methods to evaluate the same molecules, allowing international comparisons.

Solidarity and Discovery were designed as adaptive trials. The high level of adaptability of these studies makes it possible to adapt research protocols constantly, in order to incorporate the most recent and most robust international findings. In April 2021, discussions are under way with regard to testing new treatments.

In the fight against a viral disease, a vaccine is the most appropriate preventive treatment because it confers immunity to the virus. Although vaccine development is a gradual process that can take as long as a decade, the timeline has been compressed for Covid-19. Thanks to the rapid rallying of investment and previous knowledge of the infectious mechanisms of similar coronaviruses such as MERS-CoV and SARS-CoV-1 and immune responses to these, multiple projects for vaccine development could be launched within months of the publication of the SARS-CoV-2 genomic sequence in January 2020. Within a year, the first vaccines had been approved by the US Food and Drug Administration, the European Medicines Agency and other regulatory bodies and were already available in the market.

The pace of vaccine development and the longevity of vaccine effectiveness also depends on the biology of the virus. SARS-CoV-2 has a much lower mutation rate than the human immunodeficiency virus (HIV) or the influenza virus, for instance. However, as SARS-CoV-2 continues to replicate freely among the large segment of the population that is yet to be vaccinated, it is mutating. Several variants have emerged, some of which appear to be more virulent than the original form of the virus.

Vaccines are being developed to stimulate an immune response to a molecule found on the virus called an antigen. In the case of Covid-19, this antigen is the characteristic spike protein found on the surface of the virus which enables it to enter human cells. It is this protein that can trigger an immune response. Not surprisingly, it is this viral protein that has been targeted by most of the 182 vaccines listed by the World Health Organization at the end of 2020.

Four types of Covid-19 vaccine are being developed in clinical trials: whole virus, viral vector, protein subunit and nucleic acid [ribonucleic acid (RNA) and deoxyribonucleic acid (DNA)]. Whereas some vaccines try to smuggle the antigen into the body, others use the body's own cells to make the viral antigen. Nucleic acid vaccines take the latter approach; they use genetic material – either RNA or DNA – to instruct cells to make the antigen. The rapid development of this type of messenger (mRNA) vaccine against Covid-19 has been made possible by groundbreaking vaccine research in the early 1990s which targeted cancer immunotherapy. One challenge for RNA vaccines is that they need to be kept at temperatures of about -20°C, which necessitates specialized cold storage facilities.

Vaccines need syringes – and recipients

The preparation of vaccine options and even the large-scale production of enough vaccine doses to serve the population are insufficient in themselves to conquer a pandemic. In any outbreak, an effective prevention campaign also relies on the availability of materials, a trained workforce and the population's willingness to be vaccinated.

Many countries are grappling with their vulnerability to global value chains. They have made the disconcerting discovery that a surge in demand on the other side of the world can delay their own purchase of critical components needed to ensure a sustained medical response and vaccination effort over time. The surge in demand for drugs and personal protective equipment in the early days of the pandemic, for instance, led to shortages not only for medical staff but also for other branches of research relying on the same materials, such as laboratory gloves.

Some countries were able to call upon the private sector to address these shortages by approaching other suppliers or by enhancing their own production capacity using measures similar to those created in times of war like the repurposing of factory space. For example, *Canada's Plan to Mobilize Industry to fight Covid-19*, released in March 2020, required the country's five Innovation Superclusters involving public–private partnerships, as well as the Strategic Innovation Fund and the National Research Council, to prioritize funding and support for goods and services targeting the Covid-19 pandemic (see chapter 4).

Mobilization improved by co-ordination

The Covid-19 crisis has demanded an unprecedented mobilization on the part of the international scientific community. Scientists have risen to the challenge, mobilizing across fields that span epidemiology, modelling, statistics, basic science and clinical research, as well as human and social sciences. This multidisciplinary approach to problem-solving has made it possible to guide decision-makers through the crisis. The objectives of this mobilization have been multifarious: to understand the disease, to improve its treatment, to develop vaccines rapidly and to anticipate future pandemic rebounds, in order to protect the population.

Around the world, research agencies and organizations have set up an array of newly funded research initiatives to tackle the crisis. In addition to national efforts, a number of international initiatives have been launched in key areas, such as vaccine development. In early 2020, the French Ministry of Higher Education, Research and Innovation began financing the effort by three INSERM units to develop second-generation vaccines against SARS-CoV-2. To this end, the INSERM teams have established contact with Sanofi and several other private biomedical companies.

A scramble for solutions can lead to quick results but also to duplication and wasted resources. To mitigate these concerns, French research institutions decided to form a consortium called REACTing in 2013 that has been co-ordinated by INSERM. REACTing has facilitated the provision of emergency seed funding for research from the Ministry for Solidarity and Health and the Ministry of Higher Education, Research and Innovation. It has also facilitated the fast-tracking of regulatory authorizations for clinical trials. It has been instrumental in collecting patient data and epidemiological information while co-ordinating national research efforts with other European countries.

REACTing has provided a link to funding mechanisms of the European Commission which have provided support for networks of national partners. The REACTing network has helped to identify a set of national research priorities based on those initially proposed by WHO. This has led to calls from various French research funding sources for projects that are expected to deliver results within 18 months. In 2020, 32 projects addressing Covid-19 were financed through the REACTing network for a total of € 1 775 000.

New agency to tackle emerging infectious diseases

Crisis management is temporary, by definition. To ensure that the French research and medical communities are better prepared to tackle the next emerging infectious disease, the government created a new research agency on 1 January 2021 by merging the Inserm-REACTing consortium with the French National Agency for Research on AIDS and Viral Hepatitis (ANRS). Going by the name of ANRS|Emerging Infectious Diseases, the new agency is responsible for facilitating, co-ordinating and funding French research on emerging infectious diseases. It enjoys great autonomy in terms of policy-making, priority-setting and budget management. Each year, the agency will launch calls for research proposals which, together with grant applications, will be reviewed by international advisory boards and scientific committees.

The new agency's research scope encompasses that of the two previous structures, addressing HIV/AIDS, viral hepatitis, sexually transmitted infections, tuberculosis and emerging infectious diseases, including emerging respiratory infections, viral hemorrhagic fevers and arbovirosis. The agency is active across a broad range of research disciplines: basic research, clinical research, public health research, epidemiology and social sciences. The new agency integrates the 'One Health' approach, addressing human and animal health, as well as the impact of human activities on the environment.

ANRS has previously sponsored hundreds of clinical trials to evaluate therapeutic strategies. Patient associations and civil society representatives will continue to play a key role in the new agency, with these ties being strengthened through the development of community-based research.

International collaboration is critical during a crisis

One priority of the new agency will be to strengthen collaboration with existing research platforms in low- and middle-income countries, particularly those directly affected by emerging infectious diseases. The research facilitated by the agency is intended to support national public health policies in these countries through the production of standardized research outputs. There are also plans to develop partnerships with national and international research institutes, universities and hospitals.

The new agency is also strengthening links with international public health organizations such as WHO, the European Commission, UNAIDS, the Global Fund to Fight AIDS, Tuberculosis and Malaria, Unitaid, the European and Developing Countries Clinical Trials Partnership, and the Global Research Collaboration for Infectious Disease Preparedness. The goal of such partnerships is to ensure optimal information exchange and to facilitate and accelerate the implementation of public policies based on scientific findings for the benefit of the global population as a whole.

A virus like SARS-CoV-2 will continue to spread – and mutate into potentially more threatening variants – until global immunity is achieved. This imperative has spurred the drive to ensure that as many people as possible around the world have access to immunization, supported by WHO's Covid-19 Vaccines Global Access Facility (Covax). International collaboration can serve national health interests: beyond the urgent need for immunization against Covid-19, the prevention of a future pandemic or, failing that, an effective response, could be driven by local research and monitoring capacity across the globe.

International collaboration is critical during a crisis but faces many obstacles, including geopolitical and economic considerations and the lack of harmonized standards for data-sharing and clinical trials. There is a need for effective new mechanisms to facilitate international collaboration and build trust among relevant national institutions.

Scientific research and public policies are mutually reinforcing

The current crisis has demonstrated the importance of science, including research, in leading the global response to crises (Akhvlediani *et al*., 2020). To build the foundations of an adequate response, research must be considered at its true value and financed in line with its ambitions. Research is an essential element before, during and after a crisis. Scientific research and public policies are mutually reinforcing. Scientific research provides evidence to inform and support decision-making and the implementation of public policies. In turn, policies that inform and support scientific institutions build resilience to future crises.

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The time for open science is now

UNESCO is developing a Recommendation on Open Science which will be submitted to member states for approval in November 2021.

Ana Persic, Fernanda Beigel, Simon Hodson and Peggy Oti-Boateng

An urgent need for open science

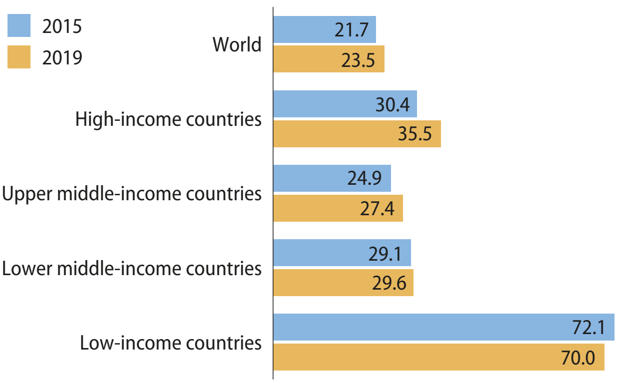
Many of the fundamental issues faced by people and planet today are multifaceted and know neither geographical, nor political borders. From climate change to biodiversity loss, global pandemics and natural disasters, the challenges are complex and interconnected.

To respond to these challenges, we need complex, interdisciplinary knowledge and reliable information accessible to all. We need timely, free access to the best-quality data, publications, information and innovation. We need a modern vibrant scientific community that extends beyond the walls of scientific organizations, beyond disciplines and traditional ways of doing science. We need an informed society well-equipped to fight misinformation and support evidence-based decision-making. Last but not least, we need the infrastructure and platforms to ensure that this wealth of information and data reaches us all.

Our increasingly digital world gives the scientific community an unprecedented opportunity to harness the immense potential of science for the benefit of society. The Internet has made it possible for scientists on opposite sides of the Earth to collaborate without meeting face to face. The trend towards international co-authorship is picking up speed, even in wealthy countries, according to a study conducted for the *UNESCO Science Report* (Figure 1; see chapter 1). Moreover, scientists in developing countries increasingly count their peers from the same region among their closest collaborators.

Scientists now have an opportunity to share their research data, methods, protocols and code, laboratory notes and other materials by making them freely available online, under terms that enable this research to be re-used, reproduced, redistributed and credited. This approach is at the very heart of open science. In a break from our traditionally closed science systems, the open science movement has vowed to make the scientific process more transparent, more inclusive and more democratic. The culture of sharing, at the core of open science, nurtures synergies and avoids duplication of scientific effort, leading to research that is conducted more quickly and efficiently, easier to scrutinize and, therefore, of higher quality.

Figure 1: **Share of publications involving co-authors from two or more countries, 2015 and 2019 (%)**



Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

The origins of open science

Of course, open exchanges among scientists were not born with the World Wide Web in 1993. Ever since the publication of the first scientific journals in the 17th century, ensuring broad access to scientific knowledge has been a matter of societal concern. The first scientific societies were established, in order to enable scientists to communicate and collaborate with one another, as well as to share the results of their experiments. To take one among innumerable examples, in 1800, Italian physicist Alessandro Volta wrote to Joseph Banks of the Royal Society in the UK to share details of his invention, an 'electric pile' (battery) which would go on to become the first viable source of electricity.

Over time, publishers of scientific journals would become the main owners of scientific knowledge. As a result, a major proportion of publicly funded research has ended up locked behind the paywalls of commercial scientific publishers, unavailable to all but those who could afford the journal subscription, such as wealthy universities and research institutes.

To counteract this trend, the global open access movement has taken advantage of the World Wide Web's potential to make scholarly research literature freely accessible online (Box 1).

One hub for this movement has been Latin America, where efforts to create public, unrestricted repositories date back to the founding of the Regional Library of Medicine (BIREME, for its Spanish acronym) in 1967. This endeavour was pursued with the creation of indexation databases (Clase, est. 1975; Periódica, est. 1978) and the regional repositories of Latindex (1997), SciELO (1998) and Redalyc (2005) established by public institutions.

A key actor in the open access movement has been the International Network for the Availability of Scientific Publications, established in 1992 by the International Council for Scientific Unions (ICSU), as it was then known.[1]

Today, UNESCO hosts the Global Open Access Portal, which monitors the status of open access to scientific information in 158 countries.[2] The portal also hosts a repository of scholarly resources available in open access.

Open access has spawned some unintended consequences

In broadening access to scientific findings, open access practices have spawned some unintended consequences. For example, scholarly journals currently charge an article processing charge (or publication fee) to cover the cost of the peer review process, editing, typesetting, graphic design, indexing, rights management, sales and dissemination of scientific articles. This publication fee, which is borne by the author, is a heavy burden for scientists with modest means, particularly in developing countries.

So-called predatory publishing exploits the open access publishing model by exploiting the pressure on scientists to publish, without providing such vital services as quality control, licensing, indexing and content preservation, in order to maximize profits. Predatory journals, thereby, significantly undermine the quality of published articles. There is a need for greater transparency of the peer review and journal publication processes to combat such predatory practices.

A need for new funding arrangements

This calls for new types of funding arrangement between universities and publishers or funding agencies and publishers that are in a position to offer sustainable alternatives to either the 'author-pays' or 'reader-pays' models.

Many funders currently cover publication costs as part of research grants, with some funders now conditioning funding of a proposal on a commitment by the beneficiary to open access publishing and/or communication of their research results.

Since January 2021, open access publishing has been compulsory for any grantee funded by cOAlition S, a group comprising 22 international organizations, European national research agencies and foundations. However, this can lead to inflation of the publication fees in open access journals. The group is now pushing for price transparency. From July 2022 onwards, science journals will have to disclose their publishing costs, in order to be eligible for payment in return for publishing any research funded by cOAlition S (Wallace, 2020).

The European Commission is launching another model in 2021. Through Open Research Europe, an open-access peer-reviewed publishing platform for projects funded through the Horizon 2020 (2014–2020) and Horizon Europe (2021–2027) research and innovation programmes, the European Commission will pay a flat fee of € 780 per publication.[3]

There is a growing number of viable alternatives to the author-pays system. These range from national or regional funding agreements to membership-based systems or co-operatives grouping multiple institutions. Among the latter is SciELO. This network now encompasses 16 countries in Latin America and Europe, along with South Africa. Similarly, AmeliCA and Latindex have been designed as regional networks composed of public institutions and research agencies from different countries.

Beyond the resources required to publish an article, the future reach of science will depend on its distribution and long-term storage. This responsibility may rest with the author (common in 'green' open access models) or with the publisher, considered the gold standard.

Moving beyond open access

The open access movement has gradually evolved into an open science movement that seeks to make the entire scientific process more accessible and transparent by sharing data, protocols, software and infrastructure. Moving beyond the traditional scientific community, the open science movement has also embraced engaging with citizen science and other epistemologies, such as indigenous and local knowledge systems. This openness strengthens the links between theory and practice, science and society. Open science also provides an opportunity to enhance synergies between research, development and innovation.

Since the early 2000s, scientists and other stakeholders, such as funders, knowledge societies, publishers and libraries, have joined forces to advocate a more systematic application of open science principles throughout the scientific process. Initiatives include the 2002 Budapest Open Access Initiative (Hungary), the 2016 *Amsterdam Call for Action on Open Science* (Netherlands) and the 2017 *Jussieu Declaration* for Open Science and 'bibliodiversity' (France).

In addition, key principles for open science have been developed to ensure good practices in data- and information-sharing. Examples include, the *OECD Principles and Guidelines for Access to Research Data from Public Funding* (2007) and the Royal Society report, *Science as an Open Enterprise* (2012).

In 2016, the European Commission adopted the guiding principle 'as open as possible and (only) as closed as necessary' and, in the same year, the *FAIR Guiding Principles* for scientific data management and stewardship.[6] The latter outline how

Box 1: **Facts and figures on open access**

As of 2020, over 12 500 journals are listed in the Directory of Open Access Journals, with 3 900 Open Repositories for Journal Articles.[4]

However, five commercial publishers are responsible for more than 50% of all published articles and about 70% of scientific publications are still unavailable in open access.

In Europe, an estimated € 475 billion is spent each year on periodicals big deals with five major publishers. This amount is growing by 3.6% per year, on average, and is fully paid by the public purse. The bulk of these costs (72%) come from university budgets.

Roughly 75% of predatory journals target researchers in low- or middle-income countries, according to Callaghan and Nicholson (2020).

The Covid-19 crisis has shown how rapidly things can change: according to the Digital Science Dimensions platform,[5] just 14% of all published articles related to the pandemic were not open access in 2020.

Source: compiled by authors

the utility of data can be maximized and whether they need to be protected or can be made open access. To comply with the complementary *CARE principles for Indigenous Data Governance* (2019),[7] any study which creates data must incorporate the principles of collective benefit, control, respect and ethics before any such data can be made open access.

Open science: a global movement

The open science movement extends across the globe. Latin America is seen as a model, with the main drivers for open access being public universities and government organizations, with no outsourcing to commercial publishers. Publicly funded, scholar-led initiatives (Latindex, SciELO, Redalyc) have helped journals in the region to improve quality, make the transition to open access without recourse to article processing charges and to provide initial open access indicators.

In the European Union (EU), the open science goal is materializing in the context of the European Open Science Policy Platform established in 2016 and through the development of a European Science Cloud initiated in 2016, new requirements for EU-funded research with respect to open access to scientific data generated by EU-funded projects and Plan S for open access to scientific literature, launched in 2018 (see also chapter 11).

The African Open Science Platform was launched in 2017 then extended in 2020. It is based on the principles of sharing and collaboration embodied in the concept of *ubuntu*.

Major open science and research data platform initiatives are also underway in China, Malaysia, Australia, Canada, Germany and elsewhere.

At the same time, a growing number of countries have developed national open science policies, including Canada, France and Serbia.

Lessons learned from the Covid-19 pandemic

The Covid-19 pandemic has further highlighted the critical need for prompt, universal access to science. It has also shown the incredible potential of scientific collaboration. It was thanks to international scientific collaboration that the coronavirus could be sequenced in record time.

The speed with which scientists, corporations and governments have mobilized to find a vaccine for Covid-19 is commendable. Pharmaceutical companies are publishing their data on vaccine development in specialized journals, where other specialists such as virologists and infectologists can see them, offering additional transparency that can serve to reassure the public. This shows the value of linking open science to open innovation to ensure the timely development of solutions for the benefit of all.

From the outset, the signatories to the Wellcome Trust (2020) statement committed to making all research and data on the Covid-19 outbreak available immediately, either via journal platforms or preprint repositories for those items that had not yet been peer-reviewed. These signatories included major scientific publishers, scholarly institutions and science funders.

However, as argued by Larivière *et al.* (2020), the papers and book chapters that have entered the public domain through this measure represent only a tiny proportion of the available literature on this coronavirus.

The outbreak has also highlighted two inefficiencies in the research system: the tendency to default to closed science and the overemphasis on the priorities of mainstream and English-language publishing, irrespective of the context and consequences of the research involved. As noted by the UNESCO Director-General, Audrey Azoulay, in October 2020, the key priority today is 'to ensure that open science does not replicate the failures of traditional closed science systems. It is these failures that have led to high levels of mistrust in science, the disconnect between science and society, and the widening of science, technology and innovation gaps between and within countries' (Azoulay, 2020).

Conditions for a smooth transition to open science

For open science to become a global reality, all scientists and all nations will need to participate. This will require adequate resources, capacity-building and investment in open science infrastructure. The opportunities of 21st century technology and open science are enormous but they require public investment: in data repositories, in the maintenance of the documentation, metadata and semantics that allow data, code and other resources to be accessed, combined and reused. However, the more pertinent question to ask is not how much needs to be invested by research funders but, rather, how much would be lost by *not investing* in open science? For example, a report commissioned by the European Commission (PWC, 2019) has established a conservative estimate of € 10.2 billion for the opportunity cost of *not* having FAIR data.

In addition, the current assessment, evaluation and reward systems for scientists, based on citation counts and the impact factor of publications, fuel competition to publish in prestigious journals at the expense of enhanced scientific collaboration, sharing of knowledge and engaging with society. The standard contribution to science is changing rapidly; this change needs to be facilitated.

The traditional human-readable article is no longer sufficient in most domains. Increasingly, output also needs to comprise a machine-readable summary of the key findings, the supporting data, code, analytical tools and algorithms such that the findings can be aggregated, scrutinized, reproduced and reused.

There is an urgent need for a global change to the science evaluation and reward system, in order to encourage the transition to open science, in particular for young scientists embarking on their career.

In the absence of a global policy framework for open science, mismatched practices and the absence of harmonized legal and technical frameworks for sharing information and data are already posing challenges for international scientific co-operation. Appropriate norms and standards also need to be established to address ethical and legal issues related to data collection and access to data.

A recommendation to set global standards for open science

With UNESCO being the sole United Nations agency with a mandate for science, it was logical that it should take up the question of open science. In 2019, UNESCO's 193 member states tasked the Secretariat with developing an international standard-setting instrument in the form of a Recommendation on Open Science, to be adopted in November 2021. These instructions emanated from the Organization's supreme governing body, the General Conference, which meets every two years.

Through recommendations, governments formulate global principles and norms for the international regulation of a given question, with the intention of influencing the development of national laws and practices in accordance with these norms.

The process of developing a global recommendation is as important as the recommendation itself, for it is through a series of multistakeholder consultations over the past three years that a common definition of open science will crystallize.

These consultations make it possible to pinpoint key benefits of open science and barriers to this practice, in order to identify regional priorities and specific challenges scientists and other open actors face, particularly in developing countries. It has been vital for this first international legal instrument on open science to acknowledge and address the possible unintended consequences of open science in different scientific and regional settings, as outlined above.

With this in mind, UNESCO has held a series of online and face-to-face consultations since December 2019 to stimulate an open debate. These consultations have brought together member states; policy-makers; the scientific community, including young scientists; key scientific institutions and other entities at both international and national levels; relevant United Nations agencies; ordinary citizens; and traditional knowledge-holders.

The potential of open science is universally recognized

All regions have acknowledged the potential of open science but regional priorities vary. For example, in **Western Europe and North America**, the need to align incentives for open science has been identified as a key priority. This process will mean reviewing the current systems of scientific evaluation and rewards based on the principles of open science. Other priorities include: promoting a new generation of innovative forms of collaboration, including with societal actors beyond the scientific community; respect for bibliodiversity; harmonization of data protection policies; and investment in shared and co-ordinated infrastructure to facilitate open science, taking into account regional and disciplinary specificities.

In **Eastern Europe**, key priorities include developing and aligning national initiatives on open science on the basis of good practices from other regions, in general, and the European Union, in particular. Another priority is to address some of the potential unintended consequences of transitioning to open science, such as high article processing charges for individual researchers or their research institutions, the publication of data and knowledge without proper quality control and the oversimplification of science.

Actors in **Latin America and the Caribbean** have argued for a comprehensive and globally co-ordinated approach to open science that addresses the structural needs of emerging and developing economies and ensures that the benefits of open science are fairly shared among all nations. They prioritize ensuring sustainable access to infrastructure and compatibility with national priorities, regulating the commercialization of open data, multilingual engagement and the fair and equitable inclusion of historically marginalized knowledge-holders. Practices for evaluating open science have been identified as priorities for the UNESCO Recommendation on Open Science to address.

In **Asia and the Pacific**, actors pointed to the need for a common vision of open science, a coherent regional policy framework and practical guidelines on different elements, practices and policies in relation to open science. They also highlighted the need to strengthen regional co-operation, including through the establishment of a regional platform for open science accompanied by regional capacity-building programmes.

For actors from **Africa**, it will be critical to invest in connectivity and infrastructure such as computer hardware and software, to dismantle barriers to open science. The transition to open science will also need to be accompanied by the development of an institutional capacity for science, technology and innovation and an enabling policy environment. More efficient scientific collaboration and networking, including the sharing and scaling up of good practices in regional collaboration, will be critical to counteract the negative impact of high dependence on international collaboration and retain more data and information in Africa, in order to generate new knowledge and attract more substantial research funds at the regional level.

In the **Arab States**, the transition to open science will primarily require a cultural shift from a competitive to collaborative mode for the practice of science. This shift will need to be accompanied by policies and the technical capacity to manage intellectual property rights in relation to open science. Infrastructure will need to be built and regional repositories established. Actors highlight the need for a greater awareness of open science as a key enabler of innovation and prosperity. It will also be imperative to ensure that research output is accessible, of quality and subject to a fair evaluation. In order for open science to flourish, there will need to be greater transparency and stronger links between research and societal impact.

Generally speaking, there are barriers that will need lifting, if we are to operationalize the concept of open science to its full potential. For one thing, there is still no common understanding of what is meant by open science. There is also the question of the cost of open science, possible misuse of open data and information, the low quality of some scientific output and the predatory behaviour of certain open access journals.

There is also a mismatch between the principles of open science and the current career evaluation systems. Moreover, it will be vital to deal with the vast differences in connectivity, capacities and resources which may deepen the North–South digital and scientific divide.

As we move towards a global consensus on the issue, the first draft text of the UNESCO Recommendation on Open Science has defined open science as an umbrella concept combining various movements and practices aiming to:

- make scientific knowledge, methods, data and evidence freely available and accessible to everyone;
- increase scientific collaboration and the sharing of information for the benefit of both science and society; and
- open the process of scientific knowledge creation and circulation to societal actors situated beyond the institutionalized scientific community.

This first draft Recommendation argues that scientific output should be as open as possible and only as closed as necessary, mindful of issues relating to security, privacy and respect for the subjects of scientific study.

Fulfilling the human right to science

Open science is increasingly perceived as a key accelerator for the United Nations' Sustainable Development Goals to 2030 and a powerful tool to bridge the science divide between and within countries.

It is also considered a potential game-changer in fulfilling the human right to science, as stipulated in Article 27 of the United Nations Declaration of Human Rights (1948) and reaffirmed in the UNESCO *Recommendation on Science and Scientific Researchers* (2017). The latter promotes science as a common good (see p. 24). It states that 'open science, including the sharing of data, methods, results and the knowledge derived from it, intensifies the public role of science and should be facilitated and encouraged.'

Article 21 of the *Recommendation on Science and Scientific Researchers* stipulates that, 'so as to ensure the human right to share in scientific advancement and its benefits, member states should establish and facilitate mechanisms for collaborative open science and facilitate sharing of scientific knowledge while ensuring other rights are respected.'

The UNESCO Recommendation on Open Science will fulfil this ambition.

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1 Later renamed the International Council for Science but preserving the same acronym, ICSU merged with the International Social Science Council in 2017 to form the International Science Council.
2 See: www.unesco.org/new/en/communication-and-information/portals-and-platforms/goap/
3 See: https://open-research-europe.ec.europa.eu/
4 See: www.doaj.org
5 See: https://www.dimensions.ai/
6 FAIR stands for Findable, Accessible, Interoperable and Reusable.
7 CARE stands for Collective benefit, Authority to control, Responsibility and Ethics.

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Scientific literacy: an imperative for a complex world

Susan Schneegans and Shamila Nair-Bedouelle

In the pandemic, the public has turned to science

Science communication has come to the fore during the Covid-19 pandemic, as the world struggles to understand the calamity that has befallen it. Science communicators have served as a bridge between decision-makers and the general public, answering questions such as: Where did the virus spring from? How does it infect human cells? Is there an effective treatment? How can I protect myself from infection? How long will it take to develop a vaccine?

From the outset, the public has turned to science for answers to these questions. Scientific institutions, advisors, journalists and others have taken up the gauntlet, communicating to the public on the science behind SARS-CoV-2 and on measures to tackle it through interviews, articles, blogs and other media. Their role has been vital in persuading the public to comply with collective efforts to curb the spread of the virus such as mask-wearing in public places, social distancing and quarantines.

Combating the 'infodemic'

However, as the World Health Organization (WHO) put it, there has also been an 'infodemic' of misleading information about the pandemic. The United Nations Secretary General has lamented that, 'as Covid-19 spreads, a tsunami of misinformation, hate, scapegoating and scare-mongering has been unleashed'.

In 2020, more than 130 countries signed a *Cross-Regional Statement on the 'Infodemic' in the context of Covid-19*.[1] It observes that 'the spread of the "infodemic" can be as dangerous to human health and security as the pandemic itself. Among other negative consequences, Covid-19 has created conditions that enable the spread of disinformation, fake news and doctored videos to foment violence and divide communities.'

The *Statement* recalls that the Covid-19 crisis has demonstrated the crucial need for access to free, factual, trustworthy and science-based information. It affirms that the pandemic has confirmed the key role played by free, independent, responsible and pluralistic media to enhance transparency, accountability and public trust.

The signatories go on to say that 'many countries, including ours, and international institutions, such as the WHO and UNESCO, have worked towards increasing societal resilience against disinformation, which has improved overall preparedness to deal with and better comprehend both the "infodemic" and the Covid-19 pandemic.' In order to counter the spread of disinformation, UNESCO has been promoting open educational resources, networks of fact-checkers and resources promoting media and information literacy.[2]

Trust science!

When UNESCO's High-Level Reflection Group met in October 2020, economist Fouad Laroui observed that 'science is in crisis. We have seen it clearly during the pandemic but also in relation to climate change. Over the last 20 years or so, we have seen growth in the idea that science is just a belief like any other. This is very dangerous.'[3]

He observed that, until recently, 'mass touting of superstition and niche conspiracy theories have been the exception, rather than the rule' but that, 'with the advent of the Internet and other methods of information-sharing that allow such untruths to spread widely and rapidly, it is becoming more and more common.'

For Dr Laroui, 'conspiracy theories like the idea that the world is flat can be largely harmless but, for example, the perspective that vaccines are bad and, more importantly, holding that perspective on a par with scientific proof to the contrary, leads to a very real impact on people's health – and it is incredibly problematic when you have these kinds of narrative perpetuated at higher levels of decision-making and communication. We have seen this happen during the pandemic, with disastrous results.'

When questioned in 2020 through UNESCO's *The World in 2030 Survey* about global challenges associated with health and disease, more than half of respondents described 'not knowing which information to believe or who to trust' as being a top concern.[4]

These findings led UNESCO and its partners[5] to make 'trust science' the theme of the International Day of Light on 16 May 2021. As part of this awareness-building campaign, supporters of science are being encouraged to sign a pledge to trust science. UNESCO has been among the first signatories.

Scientific literacy can combat disinformation

Scientific literacy can be an effective buffer against the anti-science movements which seek to sow doubt in the public's mind by disseminating information they know to be false. In their book, Oreskes and Conway (2010) show that the tactics used by the fossil fuel industry to disparage climate science, sow doubt in the minds of US citizens and block regulatory action were the same as those used by the tobacco industry to counter research on the harmful effects of smoking on health. Oreskes and Conway (2010) also show that many of the same individuals, public relations firms, advertising agencies and think tanks that were spreading disinformation about climate change had close ties to both fossil fuel and tobacco companies.

Conspiracy theorists, industrial lobbyists and other peddlers of anti-science can gain no traction with the scientifically literate, since the latter know that science is about evidence, not opinion.

The Covid-19 pandemic has emphasized the importance of scientific literacy both in the wider population and among decision-makers, such as local and central government officials and parliamentarians. Scientifically literate government leaders have been quick to understand the value of a science-based approach to tackling the pandemic; within weeks of the outbreak in early 2020, they had set up ad hoc scientific committees to manage the crisis.

Scientific literacy is not the same as science literacy. The latter focuses on the acquisition of scientific or technical knowledge for practical application, in order to train the next generation of scientists, engineers and technicians. This specialized group makes up a small proportion of the population. Even in a highly industrialized country like Germany, there were only 5 212 researchers and 2 018 technicians[6] per million inhabitants in 2018, according to the UNESCO Institute for Statistics.

Scientific literacy, on the other hand, targets the wider population. It seeks to impart the scientific way of thinking, to equip people to approach problems from an analytical perspective. The enquiry-based approach to learning advocated by UNESCO teaches children the scientific method, which hinges on observation, measurement and experimentation. Pupils learn to formulate hypotheses that they then test and adjust, in light of the results of their experiment. As Sir Peter Medawar put it in his *Advice to a Young Scientist* (1979), 'all experimentation is criticism. If an experiment does not hold out the possibility of causing one to revise one's views, it is hard to see why it should be done at all'.

The value of nuanced thinking

A critical component of scientific literacy is the ability to understand nuance. Much of the cultural misunderstanding between the public and the scientific community stems from the fact that the public thrives on certainty, whereas scientific discovery thrives on uncertainty.

This antagonism has been addressed in policy-making by the introduction of the precautionary principle. This principle dictates that, in the absence of scientific consensus, the burden of proof that an action or policy will not be harmful rests with those intending to act.

The scientist thrives on the eternal quest for answers. The scientific literate understands this process of continual readjustment as new facts come to light. The scientific illiterate, on the other hand, tends to perceive nuance as weakness. This places pressure on decision-makers to supply definitive answers to complex questions.

This dichotomy was illustrated by an exchange during the presentation of the Intergovernmental Panel on Climate Change's 2013 report on the physical science basis for climate change at UNESCO headquarters in Paris. A journalist in the room asked one of the scientists present to describe what a warmer world would look like in the year 2100. The scientist responded by outlining a range of scenarios, each reflecting a different pace of global decarbonization. The journalist laid down his pen. In this instance, the journalist was looking to convey certainty to his readership – 'this is what the world will look like in the year 2100' – , whereas the scientist was seeking to convey nuance. Climate sceptics have seized on this propensity for nuance to claim that there is no scientific consensus on climate change.

In response to public demand for certainty, the Intergovernmental Panel on Climate Change (IPCC, 2007) introduced measurable terms into its 2007 report on the physical science basis of climate change, such as 'very likely' (90% probability of occurrence). For instance, they wrote that 'most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations.' Climate sceptics seized upon this concession to claim a lack of scientific consensus and sow doubt about the human role in climate change.

The science communicator as 'interpreter'

The role of the science communicator is to provide accurate, timely information that helps the public to understand the key issues of the day and recognize disinformation. The science communicator plays a crucial role in spreading scientific literacy by acting as an 'interpreter' to facilitate the dialogue between scientist and citizen. A good science communicator explains the science behind the issues but also nuances this information, relating what is known without glossing over knowledge gaps.

In much the same way, the science advisor facilitates the policy dialogue between the scientific community and the executive and legislative branches of government by presenting the facts while underscoring information gaps and evoking different scenarii to inform policy action.

The more educated the citizen, the better they will understand nuance. This mental elasticity is vital when it comes to analysing options in relation to emotionally charged issues such as genetically modified crops, the implications of climate change, vaccination or the current Covid-19 pandemic. For instance, several promising treatments for Covid-19 were ultimately deemed ineffective after being trialled on coronavirus patients. It would be regrettable for such news to undermine public confidence in the capacity of the biomedical profession to identify solutions. On the contrary, the public should consider a failed experiment to be part of the normal process of trial and error in which scientists engage when faced with a new disease for which there is no known cure. That such experimental failures have been publicized should be embraced as a sign of transparency.

The growing practice of sharing research findings by publishing them in open access journals is accentuating the transparency of the scientific process. Moreover, since academic institutions are increasingly collaborating on research projects with industrial partners, many academic journals now compel researchers to disclose any potential conflict of interest, such as when their work has been financed by a particular industry. The disclosure of conflicts of interest is vital to reinforce public trust in the probity of the scientific process.

Science has value only if we know what to do with it

In 1999, UNESCO and the International Council for Science organized the World Conference on Science to establish a new social contract for science. The thinking behind this new contract was that, were science to become more attuned to society's needs through greater interaction between the various stakeholder groups (governments, parliamentarians, scientists, the business enterprise sector, civil society), this, in turn, would make society more supportive of science, leading to higher funding levels for research (UNESCO and ICSU, 1999).

For instance, citizens who are scientifically literate can make a valuable contribution to the design of public policies, such as when approached through public consultations. An interim report in late 2019 on the status of implementation of Iceland's *Policy and Action Plan 2017–2019* noted that the organization of public consultations had brought research priorities closer to the needs of Icelanders. These consultations revealed that Icelanders were most preoccupied by the state of the environment (see chapter 11).

A scientifically literate population can influence public policy in other ways. In 2020, UNESCO analysed scientific publishing trends for a sample of 56 research topics of relevance to the Sustainable Development Goals. The topic of floating plastic debris in the ocean showed the fastest growth, albeit from a low starting point. Consumer pressure and policy changes over the past decade – such as legislation regulating single-use plastic bags – have been informed by a growing body of research and related media reports documenting the extent and impact of floating plastic debris in the ocean (see chapter 2).

In the past few years, several European countries have set up committees composed of about 150 citizens drawn from all walks of life who have been invited to interact with experts with a view to proposing measures to reduce their country's greenhouse gas emissions. In France, for instance, the government has taken up a range of legislative proposals from its own Citizen Convention on the Climate; one such proposal concerns banning domestic flights to destinations that can be reached by train in two and a half hours.

It is vital that parliamentarians, themselves, be scientifically literate. This consideration led UNESCO to launch an international programme at the turn of the century to promote dialogue between parliamentarians, scientists and the rest of society, in order to foster an informed legislative process attuned to society's preoccupations.

In sum, science has value only if we know where to find it, what to do with it and how to integrate it into a wider system for the well-being of humanity and the planet. That system must include a scientifically literate population.

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1 See: https://www.who.int/health-topics/infodemic
2 See : https://en.unesco.org/covid19/communicationinformationresponse
3 See: https://en.unesco.org/news/building-trust-science-essential-general-interest-humankind
4 This survey collected responses from more than 15 000 people worldwide. Of these 57% were under 35 years of age.
5 The International Day of Light is administered by UNESCO's International Basic Sciences Programme through a multipartner Steering Committee. The Trust Science Campaign is cosponsored by the Day's Steering Committee, the Photonics Society of the Institute of Electrical and Electronics Engineers, the International Society for Optics and Photonics and The Optical Society.
6 In full-time equivalents

The integration of refugee and displaced scientists creates a win–win situation

Peter F. McGrath and Edward W. Lempinen

A global challenge

Worldwide, every two seconds, someone is forcibly displaced from their home by conflict or persecution, according to the United Nations Refugee Agency (UNHCR). There are currently some 79.5 million displaced persons in the world, the highest number on record. Of these, 45.7 million are internally displaced, 26.0 million are officially classed as refugees and another 4.2 million are asylum-seekers. Five countries account for 68% of all refugees: Syria (6.6 million), Venezuela (3.7 million), Afghanistan (2.7 million), South Sudan (2.2 million) and Myanmar (1.1 million) [UNHCR, 2020].

The scientific communities in these countries have been deeply affected by war, repression and dislocation. Consider Syria. Before the outbreak of civil war in 2011, Syria had scientific, medical and engineering institutions that were among the most respected and influential in the Arab region but, by 2015, the Syrian civil war had provoked perhaps the largest human migration seen since the Second World War.

By this time, Syria counted 340 researchers (in head counts) per million inhabitants, according to the UNESCO Institute for Statistics. A rough calculation, therefore, suggests there could be more than 2 200 researchers among the 6.6 million Syrian refugees. This figure most likely excludes trained medical personnel and PhD students.

Indeed, the Covid-19 crisis in Europe, and the concomitant urgent need for more trained medical personnel, has shone a spotlight on the 14 000 Syrian doctors living in Germany alone who are waiting for their qualifications to be approved (Connolly, 2020).

It is not only outbreaks of violence that compel people to flee their homes. Venezuela, for example, once had a vibrant research sector but has witnessed socio-economic and political instability that has propelled more than five million Venezuelans – almost 20% of the population – out of the country, as of 2020.[1] This exodus began more than a decade ago but it surged in 2015 and is still ongoing as conditions deteriorate. By one estimate, Venezuela counted an estimated 12 850 researchers in 2014 but only about 3 000 remained a few years later (Bolaños-Villegas *et al*., 2020).

According to a personal communication by Gioconda San-Blas, former president of the Venezuelan Academy of Physical, Mathematical and Natural Sciences, major Venezuelan universities have lost around 45% of their academic staff. This brain drain caused the country's scientific productivity to nosedive from 1 695 to 1 091 publications between 2014 and 2019 (see chapter 7).

Scientific expertise must not go to waste

It is the considered view of UNESCO and like-minded organizations that both the global scientific community and governments have a strong interest in understanding the experience of displaced scientists and supporting them, to ensure that their skills and training do not go to waste. To be effective, scientists, engineers and medical doctors must stay abreast of advances in their field. Time spent in refugee camps, travelling to and settling in new countries, perhaps caring for families and taking on menial jobs to ensure a basic income, all detract from the exigencies of a scientific career.

Governments and other stakeholders must be able to identify highly trained individuals rapidly and integrate them in universities, research institutions, teaching hospitals and private enterprises. In so doing, host countries will serve their own interests while enabling displaced scientists to preserve and develop their expertise and live in dignity until conditions improve enough for them to return home – for many of them will, ultimately, return to their countries of origin, where their expertise will be needed to help rebuild their societies.

No-one knows the numbers

The problem is that nobody is keeping track of precisely how many refugee and displaced scientists there are and their whereabouts, including in the top five host countries, in descending order: Turkey, Colombia, Pakistan, Uganda and Germany.

To address this issue, and as a contribution to Sustainable Development Goal 8 of achieving 'sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all', an expert group set up by the European Union and the United Nations in 2018 has recommended the use of indicators that identify the sector or industry of employment of refugees and which recognize foreign qualifications in the host country.

Without such a system, however, there can only be estimates. One such estimate puts the number of refugee and displaced scientists above the 10 000 mark (Treacy, 2017), although this figure is probably conservative, as it does not include the more recent exodus of scientists from Turkey and Venezuela.

It is clear, however, that thousands of scientists, medical professionals and advanced students of science and engineering in war-torn countries endure dislocation and insecurity. Even when they flee to the anticipated safety of a new homeland, the insecurity continues, owing to their often precarious status.

Given the nature of specialist training in science, engineering and medicine, each qualified individual represents a significant investment by their home country. This is especially true for least developed countries such as Afghanistan, Myanmar, Somalia, South Sudan, Yemen and others affected by an exodus of scientific expertise. These trained individuals represent national assets in short supply whose loss can seriously compromise national priorities and the training of the next generation.

Support structures do exist

Support structures for refugee and displaced scientists do exist, often in parallel with support structures for scientists and other academics suffering from persecution.

One such programme is the Institute of International Education's Scholar Rescue Fund. It has supported more than 880 scholars from 60 countries since its inception in 2002. Data provided by the institute attest to the growing problem of refugee and displaced scientists: the programme has received more applications in every successive year since 2017. In 2019, one-third of applications came from Yemen, a 58% increase over 2018. Also listed in the top five were Cameroon, Syria, Turkey and Venezuela. Applications from each of Cameroon and Venezuela even doubled between 2018 and 2019.

Likewise, Scholars at Risk, founded in 2000 at the University of Chicago (USA), provides sanctuary and assistance to more than 300 threatened scholars worldwide each year by arranging temporary academic positions at member universities and colleges among its network.

In the UK, the roots of the non-governmental organization, the Council for At-Risk Academics (CARA) go back to 1933 and the expulsion of many leading academics from Germany's universities by the Nazis. CARA focuses uniquely on helping those who are in immediate danger, rather than those already in exile, providing them with two- or three-year stipends and helping to place them in one of the 120 British universities within its network.

The Alexander von Humboldt Foundation's Philipp Schwartz Initiative provides universities and research institutions in Germany with the means to host threatened foreign researchers for a period of 24 months on fully funded research fellowships. The initiative is funded by the German Federal Foreign Office, with additional support from other foundations. In this case, researchers cannot apply on an individual basis but must do so in tandem with a research-performing institution based in Germany.

Many German universities also provide support for refugee students wishing to pursue their studies, often through volunteer student groups that provide mentoring, language training, counselling and other services.

In France in 2017, the government initiated the National Programme for the Urgent Reception of Scientists in Exile (*Programme national d'aide à l'accueil en urgence des scientifiques en exil*, PAUSE), with the support of civil society and financial partners. Its mission is 'to accommodate and protect researchers from countries in which the political situation places their work and their families in danger.' PAUSE provides long-term support for such scholars to help them integrate into French society and the research community.

One of the most recent initiatives is the Refugees in Science programme, which was launched in the Netherlands in 2018. During the shaping of the programme and the drafting of the initial call, the idea of 'positive discrimination' was addressed via a careful communication strategy designed to defuse any political sensitivity around the term. As part of this strategy, it was made clear that the programme was not offering charity but, rather, a way to empower scholars who felt a responsibility towards their new society but were not yet in a position to assume that responsibility.

In its first year of operation, the Refugees in Science programme, funded via a € 750 000 contribution from the Dutch Research Council (NWO), supported 12 individuals with one-year fellowships. After a review of this pilot phase, it seems that the programme (now renamed Hestia) will run for at least two more years (KNAW, 2019).

The European Union (EU) as a whole has a common policy to attract scientific talent to the bloc's laboratories and research centres. This is facilitated by a scientific visa for eligible candidates. During the final year of negotiations with the EU over its withdrawal from the bloc (Brexit), the UK instituted its own scientific visa system.

The European system is facilitated by the web-based EURAXESS platform, as well as EURAXESS Services, a network of more than 500 service centres located in 40 European countries. These centres help researchers and their families to plan and organize their move to a particular country within the bloc, assisting with issues such as accommodation, visas and work permits, language lessons, schools for any children, social security and medical care.

Embedded within EURAXESS is Science4Refugees, a platform established 'to help refugee scientists and researchers find suitable jobs that both improve their own situation and put their skills and experience to good use in Europe's research system.'

Science4Refugees enables suitably qualified refugees with asylum status to link with positions available at EU-based universities and research institutions. It also provides a mentoring system called Science4Refugees Research Buddies and a newsletter, *Bridges*, providing up-to-date news and information. However, refugee scientists participating in Science4Refugees must also compete with other applicants in an open competition for each position.

In recent years, it has become more difficult for scientists from affected countries to access positions at universities and research centres in the USA. President Donald Trump's Executive Order 13780 of February 2020 banned all travel to the USA by nationals of the Democratic People's Republic of Korea and Syria, as well as nationals of Eritrea, Iran, Kyrgyzstan, Libya, Myanmar, Nigeria, Somalia, Sudan, Tanzania, Venezuela and Yemen, with various exceptions.

Little attempt by developing countries to attract displaced scientists

Whereas most refugee and displaced scientists eye the high-income countries of the Organisation for Economic Co-operation and Development (OECD), some turn towards lower-income countries which are investing more in scientific research than they did previously. For example, The World Academy of Sciences (TWAS), a programme unit of UNESCO, is aware of scientists who have made their way to countries such as Malaysia and South Africa.

Despite their stated aim of attracting scientific talent, there would not seem to be any specific policy in lower-income countries for assisting refugee and displaced scientists. In the case of South Africa, they must go through the same process of validation as other refugees and asylum-seekers, which may take time. Once their work permit has been approved, they may take any job for which they have the requisite qualifications, including research and teaching positions or the practice of medicine. In theory, they could also work with an initial permit while awaiting confirmation of validation but employers are often reluctant to take the risk of hiring an individual whose application for a work permit may yet be refused.

It is clear from this brief overview that a number of countries and organizations are actively supporting refugee and displaced scientists – and this is just a selection.

However, it should also be apparent that, despite a growing tendency towards collaboration, such programmes remain scattered and fragmented, varying widely in scale from country to country.

There is, for example, no formal mechanism for taking the lessons learned from one successful initiative and replicating them more broadly. Even so, the scientific community in the Netherlands was able to refer to effective programmes run in Belgium and Germany, thereby helping to convince the Dutch authorities to establish the programme now known as Hestia.

In addition, although such programmes do provide much-needed support for refugee and displaced scientists in the short term (typically 1–2 years), the status of many remains profoundly insecure. Once a first fellowship or placement is complete, opportunities for follow-on support are largely lacking, even if the situation in their home country has not changed and it is not yet safe to return. Indeed, the latest report by the United Nations High Commissioner for Refugees confirms that, despite record numbers of displaced persons, fewer are able to return home than previously, leaving them in limbo for years (UNHCR, 2020).

A willingness to do more

A March 2017 workshop revealed a broad willingness to do more to assist refugee and displaced scientists. The workshop was run by TWAS, the Euro-Mediterranean University and the Italian *Istituto nazionale di oceanografia e di geofisica sperimentale* (OGS).

The event brought together more than 50 participants from 12 countries, including policy-makers, representatives of scientific and educational institutions and refugee agencies. Also attending were half a dozen current or former refugee scientists.

The workshop produced a series of practical recommendations for different sectors of society (TWAS, EMUNI and OGS, 2017). In particular, it recommended that host governments:

- accelerate approval of applications for visa and asylum to facilitate the social and professional integration of scientists;
- offer employment and career counselling;
- establish a focal point or welcome office that can guide and advise newly arrived scientists; and
- develop an Internet-based clearing house that collects available opportunities for affected scientists and allows affected scientists to post their biodata and research interests for browsing by host institutions.

It also recommended that research funding agencies:

- establish grant programmes (with rapid processing times) to help universities, research centres, teaching hospitals and other science-related institutions to employ qualified scientists with a level of remuneration enabling them to support their families; and
- provide ring-fenced funds for joint academic projects involving refugees and other displaced scientists.

The workshop also recommended motivating international donors and development banks and other funding entities to help rebuild and invest in the type of scientific and research infrastructure that would be essential to encourage the return of qualified personnel to their home countries, once it was safe for them to do so, thereby stimulating brain circulation rather than brain drain (TWAS, EMUNI and OGS, 2017).

Mass migration is here to stay

In sum, mass migration cannot be treated as a temporary or emergency phenomenon. Rather, it is likely to be a permanent feature of globalization and geopolitical instability.

There may also be situations caused by natural and human-made disasters requiring the evacuation beyond national borders of researchers and other academics who would again need assistance prior to returning home.

Indeed, more slowly unfolding environmental disasters such as prolonged droughts, land degradation and food scarcity – caused or exacerbated by climate change – are causing people to move in search of better lives. According to one estimate (Defrance, 2017), tens or even hundreds of millions of people could be forced to leave the Sahel region of West Africa by the end of this century owing to climate change and the related problems of water and food scarcity.

For these reasons, a holistic, cross-sectoral, global response is required.

The workshop document also proposed that international organizations should come together to organize a major conference on refugee and displaced scientists, to help formulate an effective and co-ordinated global response. Indeed, the document also proposed the establishment of an Intergovernmental Panel on Refugee Academics that could keep the situation under regular review and update recommendations as required (TWAS, EMUNI and OGS, 2017).

Only with such a co-ordinated and integrated response will it be possible to address the situation of refugee and displaced scientists in a sustainable way, allowing countries to get ahead of the curve rather than reacting in a permanent state of emergency.

In this regard, it is encouraging to see that three major international scientific organizations – TWAS, the

InterAcademy Partnership and the International Science Council – are now addressing this issue, with funding from the Swedish International Development Cooperation Agency (Sida). These bodies are planning to develop a strategy to ensure implementation of the recommendations contained in the workshop document (TWAS, 2020).

The scientific community can take the lead on this issue by serving as a model for what must be a co-ordinated, holistic response. In fact, we would argue that the global scientific community is duty-bound to do more for its vulnerable colleagues.

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ENDNOTE

1 See: https://r4v.info/es/situations/platform

Global standards now exist for a healthy ecosystem of research and innovation

April Tash

Science has evolved

In Paris in November 2017, UNESCO's 195 member states agreed to an international accord that sets common standards for science within a general framework. The *Recommendation on Science and Scientific Researchers* (2017), hereinafter referred to as the *Recommendation on Science*, was the fruit of four years of negotiations that had been strongly backed by representatives of scientists' associations, science academies and others.[1] 'This is a good day for scientists', commented Pascal Janots at the time. Speaking on behalf of the World Federation of Scientific Workers, he observed that 'the agreement confirms the growing importance of scientific activity and the need to support scientific personnel for their protection, recognition, training and responsibility in all corners of the world.'

Indeed, for almost five decades, scientific associations had called for common international standards of this type, to build on the foundations laid by the UNESCO *Recommendation on the Status of Scientific Researchers* (1974). The precursor to the current agreement had set out the rights and responsibilities of individual researchers, so as to liberate research from the vagaries of politics while securing freedoms known to encourage research collaboration and results. Nevertheless, many activists had argued that ethical practices and engagement with society needed supportive institutions and some form of regulation to be effective.

Over time, the scientific enterprise has also evolved, with the emergence of new technologies, such as artificial intelligence and the Internet of Things, new concepts like that of sustainable development and the growing preponderance of industrial research and development (R&D) and short-term employment contracts. This has made it necessary to update many of the provisions in the original agreement.

The need for research integrity and both ethical and ecological responsibility, in order to staunch brain drain and foster inclusion and sustainable development, point towards systemic change. Insights from many intense debates on how best to design science systems and make science more responsive to society are cast in the *Recommendation on Science*.

A legal instrument that takes a systems approach

The *Recommendation on Science* is a legal instrument. It draws together in a single text provisions related to human rights, the ethics of science and bioethics as well as standards for science governance that characterize other accords. This adds value, in part, because it codifies a single, common set of global norms and standards for the research and innovation system as a whole, thus constituting an overarching model for national law and policy. Common standards corral everyone to make the necessary institutional changes at roughly the same time. Once these changes are in place, the fact that they are common and reliable facilitates international research collaboration. However, whether this gambit works will hinge on the level of compliance and on how reliably each of the 195 signatory states takes 'legislative or other steps to apply [the provisions] within their respective territories'.

A systems approach is the key feature of this new general framework on which other regulatory efforts may build. For countries trying to improve their national innovation system, the new accord provides a checklist for minimal requirements. It also paves the way for future regulation to be more specific and advance science in new ways, as witnessed in proposals in areas as varied as open science, artificial intelligence and national security.

Back on the agenda: scientific freedom and the human right to science

The *Recommendation on Science* sets out a bill of rights and responsibilities for research staff and the public and private entities that employ them across the entire research and innovation ecosystem.

It details the components of scientific freedom, including autonomy, intellectual freedom, freedom of research, freedom of conscience, freedom of association, freedom of movement and freedom of expression. Scientific freedom also encompasses the right to publish and the right to protect one's intellectual property rights. This scientific freedom is distinct from academic freedom, in that it is not dependent upon having tenure or an academic affiliation.

An essential adjustment for many countries will be to ensure that each researcher enjoys work conditions and scientific freedom on a par with the standards of the *Recommendation on Science*. Researchers should feel safe in the conduct of their work. They should be free to express themselves freely and openly on the ethical, human, scientific, social or ecological value of research projects, to expound the truth as they see it, to report concerns and exchange with other scientists. They should be free to act as watchdogs of the public interest, providing public authorities with expert advice, such as by alerting to potential risks and emerging hazards. Providing these guarantees encourages researchers to risk working in a more open and creative way. Opennness and creativity, in turn, have downstream advantages for society by nurturing skills in problem-solving and innovation. The *Recommendation on Science* makes it explicit that openness in the practice of research is necessary to ensure everyone's right to science.

On 6 March 2020, an authoritative interpretation of obligations in the *International Covenant on Economic Social* *and Cultural Rights* (1966) closely followed the consensus lines expressed in the *Recommendation on Science*. By so doing, it confirmed that the *Recommendation on Science* offers states guidance on how to operationalize the Covenant's obligations with regard to human rights (2020c).

The *Recommendation on Science* also justifies its strong stance in favour of scientific freedom and openness by elaborating on science's role in society. '[O]pen communication of results, hypotheses and opinions […] lies at the very heart of the scientific process and provides the strongest guarantee of accuracy and objectivity of scientific results.' The *Recommendation on Science* balances researchers' and research-producing institutions' rights with their responsibilities, such as by indicating that the general norm is publication and peer review. It emphasizes that the norm for scientific publishing extends to publication of the data and methods used because this will facilitate independent replication of the results.

Finding the right balance between respect for human rights in science and other values and interests has implications for everyone. For example, the manner in which respect for the scientific process is balanced with economic and public health interests can affect the speed with which vaccines for Covid-19 are developed. How health and economic interests are balanced can affect the speed with which these vaccines are secured, as some licensing arrangements might cause scarcity and hardship by putting a price on a vaccine that makes it unaffordable to many.

On the issue of non-discriminatory participation, the *Recommendation on Science* places signatory states before their obligation to boost their human and institutional capacities for science substantially, as also recommended by *The 2030 Agenda for Sustainable Development* adopted in 2015. In many places, the most efficient way to enlarge the talent pool quickly enough to have any impact by 2030 will be to encourage a vocation for science among girls and young women, as well as persons from other underrepresented groups, and to incite those at risk of leaving the profession to stay in the scientific pipeline by ensuring an inclusive work environment (see chapter 3).

The *Recommendation on Science* has a specific norm dictating that states should support women and girls, as well as those from other underrepresented groups, wishing to pursue scientific careers, by providing them with non-discriminatory access to an education and improving their access to scientific literature and training, among other measures. The *Recommendation on Science* also dictates that employers, via appraisals, provide incentives for the inclusive, collaborative, ethical and sustainable practice of science.

The *Recommendation on Science* has been vetted for its coherence not only with internationally agreed human rights but also with the prescriptions of Responsible Research and Innovation applied to research funded by the European Union, as well as other normative prescriptive statements found in conventions and declarations, charters, ethical guidance and statements by academies and scientific associations, among others.[2]

Why global standards now need the support of researchers

Despite the *Recommendation's* enormous potential power to influence the science of tomorrow, challenges remain in terms of visibility and implementation. For example, the document is long and wordy; it has not yet been translated into most languages and it may call for some uncomfortable adjustments to be made to current practices. Fortunately, there has been a call for implementation to focus on just ten key areas, to clarify the message of the *Recommendation on Science* and set priorities for countries' policy responses (Box 1).

Topics such as inclusion and the promotion of women and other underrepresented groups, freedom of movement and talent retention, attracting new entrants, improving the general science culture through education, scientific advice to government and the use of research results are all included in the *Recommendation on Science*.

Secure and predictable protections of human rights to accompany the globalized digital scientific research of today also feature in this package, as does the call for better data about real working conditions, attention to career development and an adjusted incentives structure.

Check-ups every four years to monitor accountability

Countries have agreed to ensure that their provisions for research are compliant with the *Recommendation on Science* within a reasonable lapse of time, which could mean five or even ten years, depending on the country's starting point. Typically, there is a good alignment with pre-existing standards, so there should only be a few gaps to fill. Such gaps will become more apparent when they are analysed against common standards, once the first country-level reports monitoring implementation become available in 2021.

Three pathways for accountability

There are three principal pathways for accountability. The first pathway is citizens, who call to account their government and public and private institutions through political action. Governments are starting to adopt legislation and other measures to oblige institutions of the national innovation system to implement the *Recommendation on Science*.

Governments have also agreed to check-ups every four years, at which time they will undertake a detailed survey of national institutions. The ensuing report will then become a public record. This is the second pathway. The UNESCO Committee on Conventions and Recommendations supervises this process, ensures its transparency, acknowledges progress and receives petitions for redress in cases of grievous violation.

As for the third principal pathway concerning specific topics, accountability will be ensured here by future individual claims and petitions. These are possible because there are explicit links to internationally agreed human rights and provisions that are already part of the law. Scientific communities and institutions can also get involved, by endorsing and respecting the same pledge to transform practices, by helping the government to roll out the expected standards in every part of the ecosystem, by modifying

Box 1: **How to measure the research and innovation system: ten key messages**

From 2021 onwards, surveys and reviews undertaken by the United Nations will be asking countries to rethink their national statistics to measure new topics such as researchers' working conditions. In the same way that a measurement called gross domestic product has been deemed too narrowly focused to be able to capture the well-being of a population, the new approach will seek to broaden the range of indicators in order to meaningfully survey the health of the country's research and innovation ecosystem. Yet there is still a need to keep national statistics and monitoring focused. This is the purpose of a conceptual framework called the Ten Key Areas.

Monitoring of the *Recommendation on Science and Scientific Researchers* (2017) provides insights into what is to come, as topics are added to the current range. There are 35 topics in the first monitoring guidelines (Azoulay, 2020b), framed by just ten key areas as set out below. Instead of studying only research inputs (e.g. research expenditure, numbers of PhD graduates) and outputs (e.g. the number of patents and publications produced by a system), indicators will need to be created to understand researchers' working conditions. Future topics may include the scientific culture of the general population; inclusion and access to science during primary and secondary schooling; openness; how well research informs policy; the extent of scientific freedom; and the capacity for deliberation on ethics.

National statistics offices can already be guided to establish missing indicators for these Ten Key Areas and, at a next stage, to assemble a dashboard of these indicators and data so as to provide an improved survey of the health of a country's research and innovation ecosystem.

1. The responsibility of science towards the United Nations' ideals of human dignity, progress, justice, peace, welfare of humankind and respect for the environment

Science is part of Member States' efforts to develop more humane, just and inclusive societies and serves to further the United Nations ideals of peace and welfare of humankind (paragraphs 4, 5e, 5f, 13d).

2. The need for science to interact meaningfully with society and vice versa

Member States' governments and the general public alike recognize the value and use of science and technology for tackling global challenges. Society is engaged in science and research through the identification of knowledge needs, the conduct of scientific research and the use of the results (paragraphs 4, 5c, 13d, 19, 20, 22).

3. The role of science in national policy and decision-making, international cooperation and development

Member States should use scientific knowledge in an inclusive and accountable manner to inform national policy and decision making and to advance international cooperation and development (paragraphs 5g, 7, 8, 9).

4. Promoting science as a common good

Member States are urged to treat public funding of research and development as a form of public investment, the returns on which are long term and serve the public interest. Open science, including the sharing of data, methods, results and the knowledge derived from it, intensifies the public role of science and should be facilitated and encouraged (paragraphs 6, 13e, 16a–v, 18b–d, 21, 34e, 35, 36, 38).

non-compliant practices and by contributing evidence to each quadrennial survey and accompanying cases in the courts.

Robust metrics boost accountability

Accountability is boosted by robust metrics and reporting, as described above. For the first reporting exercise, each government has been invited to prepare its substantiated report addressing 34 topics organized in ten key areas by 31 March 2021 (Box 1). The report by each government will be surveying some matters for the first time, so someone will need to collect and analyse these new data. Whence will this new investment come? Scientific communities can help to ensure that surveys are thorough and evidence-based. In a number of countries, surveys of the scientific community have already begun and the first meetings have been held.

Since the world already has some standardized data at the United Nations level for certain aspects of science systems, such as on research expenditure and the researcher pool, the participation rate in the reporting exercise should be high.

Nevertheless, experts express a justified concern that, in some of the ten key areas, data has never before been collected (Box 1). As an illustration, one wonders how these reports can measure whether public decision-making uses scientific evidence and how well they can measure actual conditions of research work. Supporting studies, transparency and review, even in the interim between reporting exercises, can ensure robust data and accountability.

For internationally agreed human rights, scientific associations could advise on how to monitor science-related human rights as part of the Universal Periodic Review, which is a state-run procedure that reviews the fulfillment of a country's obligations with regard to human rights every four and a half years, under the auspices of the United Nations' Human Rights Council.

The aforementioned ten key areas (Box 1) are a conceptual framework that will help states to maintain the focus on their obligations under the *Recommendation on Science*. If all goes well, the first assessments covering all ten areas will set a baseline against which later data can be compared every four years.

The reports will fill gaps from other surveys of science systems. Building upon what has already been collected and

5. Inclusive and non-discriminatory work conditions and access to education and employment in science
All citizens enjoy equal opportunities for the initial education and training needed for, and equal access to employment in scientific research. Scientific researchers enjoy equitable conditions of work. The participation of women and other underrepresented groups should be actively encouraged in order to remediate inequalities (paragraphs 13a–c, 24b–c, 33, 34d).

6. Any scientific conduct is subject to universal human rights standards
Research should be conducted in a responsible manner that respects the human rights of scientific researchers and human research subjects alike. Open access to research results and the knowledge derived from it promotes the human right to share in scientific advancement and its benefits (paragraphs 18a, 18e, 20a–c, 21, 22p, 42).

7. Balancing the freedoms, rights and responsibilities of researchers
Scientific researchers respect public accountability and carry out their work in a humanely, scientifically, socially and ecologically responsible manner, while at the same time they enjoy the degree of autonomy and intellectual and academic freedom appropriate to their task and indispensable to the advancement of science and technology (paragraphs 10, 11, 16a,16b, 40).

8. Scientific integrity and ethical codes of conduct for science and research and their technical applications
Member states should establish suitable means to address the ethics of science and research integrity through developing education and training materials on the ethical dimensions of science, establishing and supporting science ethics policies and committees, and stimulating the professional ethics of researchers, including their intellectual integrity, sensitivity to conflict of interest and vigilance as to the potential consequences of their research and development activities, including their technical applications (paragraphs 5d, 14c, 14d, 16a, 18b,18d,18e, 20a, 25, 39a, 39b).

9. The vital importance of human capital for a sound and responsible science system
Human capital is the principal pillar of a sound science system. Member states should develop policies with respect to the training, employment, career prospects and working conditions of scientific researchers. These policies should address, inter alia, adequate career development prospects; lifelong learning opportunities; the facilitation of mobility and international travel; the protection of health and social security; and inclusive and transparent performance appraisal systems for scientific researchers (paragraphs 27, 28, 29, 30, 31, 32, 34, 41).

10. The role of states in creating an enabling environment for science and research
Member states – government and non-government stakeholders alike – should create a stimulating environment for a sound science system with adequate human and institutional capacities, by facilitating satisfactory work conditions, moral support and public recognition of successful performance of scientific researchers; by supporting education in science and technology; by promoting publishing and sharing of data and results that meet adequate quality standards; and by monitoring the implementation and impact of such efforts (paragraphs 5, 11, 14a, 17, 24a, 26, 37, 43, 44, 45, 46, 47).

Source: UNESCO General Conference 39 C/ Resolution 85; references to paragraphs relate to paragraphs of the *Recommendation on Science and Scientific Researchers* (2017)

standardized will be a distinct advantage because having data over a long time-series should help to pinpoint trends. Each national report might, thus, bring to light specific issues that open up a dialogue.

Moreover, least developed countries will have an opportunity to shine by performing well for new indicators that are not numerically based, such as if they have a functioning national committee on science ethics or academy of science.

Sharing information promotes system efficiency

On 3 January 2020, a research team in China shared the genetic code of the Covid-19 virus online. This enabled teams around the world to search for vaccines and treatments simultaneously, without duplicating the initial investment. The global research effort to tackle the pandemic reveals an underlying truth, namely, that sharing information promotes system efficiency. It is easy to infer that, for any global cause to succeed – quickly – research collaboration helps. Overnight, this crisis has tamed competition between nations. Why not take the same approach to achieve the Sustainable Development Goals as the next grand challenge?

Achieving broad, valuable system efficiencies is the central rationale for establishing some reliable standards on a global scale, even if not all input is equal. Arriving at a consensus on global standards for science should facilitate research collaboration, level the playing field for some opportunities, help discover talent and provide a system-wide benefit. It should lead to a more efficient digitalized and globalized scientific enterprise, making science possible in more places and innovation more likely.

Obviously, there will still be protections in place, such as patents and licenses and data protection rules. The transition towards more widespread research collaboration among nations will require clarity of purpose and information-sharing with researchers and their institutions to ensure that they are comfortably familiar with related norms and standards. Each should have confidence in the system, no matter where in the world they find themselves. There must be predictability. Even during a crisis, when new incentives are in play, all the players in the science system must know what to expect.

Overcoming data poverty in a generation

In 2021, during the first of many reporting cycles, baseline information and data will be gathered. Some aspects of this transition will be hard to measure and assess. To make this reporting workable, it will be necessary to develop new surveys and indicators, taking great care to maximize efficiency by drawing upon existing sources of information (Mejlgaard *et al.*, 2019; Bordt *et al.,* 2007; Hein *et al.*, 2020). To assess factors such as the level of scientific freedom and responsibility, of collaboration, of open science, or the working conditions for researchers in all settings, the methodology must not be simplistic. It would be misleading, for instance, to measure scientific freedom by the frequency of violations of such freedom.

Countries will collaborate through international statistics services, notably the UNESCO Institute for Statistics. Typically, countries will have to set priorities when introducing any new metrics because of the cost of collecting and collating data. Currently, all countries are being encouraged to use a dashboard with just ten key areas as their compass (Box 1). Social scientists will be helping governments to design, test and roll out the next metrics.

Four years hence, there will be a chance to build on the existing data and make them more robust. Thus, exercises over time will track not only systemic improvements but also ameliorations to the quality of assessment methods. It will be possible for scientific communities to signal their support by contributing to the revision of assessment methods and helping to publicize the transition to new metrics, thereby prompting better compliance.

Towards predictability, attractivity and inclusivity

There are prerequisites for a healthy, resilient research and innovation ecosystem. Those often cited are public funding, shared infrastructure and stability. The UNESCO Director-General, Audrey Azoulay, wrote in a major newspaper (2020a) that '[r]esearch communities are not born overnight; they must be developed over time and funding must be secure.' The accord of 2017, in which states have set out their consensus on a range of preconditions, is now being implemented; scientists themselves deserve to be acquainted with it.

The Recommendation on Science is wide-ranging: it emphasizes autonomy and freedom, careers, incentives, inclusion and access, knowledge circulation, responsibility, ethics and integrity and a long-term vision for structural support, infrastructure, continuity, regeneration and talent development. Individuals and institutions – both private and public – that produce, fund and publish science should adhere to the same standards, so that everyone can rely on them. Together, these many edicts address the entire ecosystem of research and innovation simultaneously.

Scientists, themselves, have advised making the ecosystem predictable, attractive and inclusive along these lines. Now, there is strong government support for their position. Consensus has led to new standards and a schedule of check-ups to ensure compliance with these standards, starting in 2021.

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ENDNOTES

1 Read the *Recommendation on Science and Scientific Researchers* online; see: https://tinyurl.com/UNESCO-recommendationonscience

2 The *Recommendation on Science* references many of these statements in an annex.

Global trends

AT A GLANCE

In Pointe-Noire, young Congolese undergo training in how to install and maintain solar photovoltaic panels in December 2020. Since its inception in 2011, the start-up Mac Services led by Moïse Makaya Ndende has trained 12 000 youth across the Republic of Congo. © Moïse Ndende/Mac Services

- Development priorities have aligned over the past five years, with countries of all income levels prioritizing their transition to digital and 'green' economies.
- To accelerate this transition, governments are designing new policy tools to facilitate technology transfer to industry.
- Yet, eight out of ten countries still devote less than 1% of GDP to research; they remain largely recipients of foreign scientific expertise and technology.
- Although countries are investing more in green tech, sustainability science is not yet mainstream at the global level, according to a UNESCO study.
- All governments need to ensure that policies and resources for their dual transition point in the same direction across different economic sectors, towards the same strategic goal of sustainable development.
- The Covid-19 pandemic has energized knowledge production systems.
- Among innovation leaders, the evolving geopolitical landscape and pandemic have stirred debate on how to safeguard strategic interests in trade and technology.

1 · The race against time for smarter development

Susan Schneegans, Jake Lewis and Tiffany Straza

INTRODUCTION

Countries pairing their digital and green transition

The world is engaged in a race against time to rethink development models by 2030, the deadline for reaching the United Nations' 17 Sustainable Development Goals (SDGs). The *UNESCO Science Report*'s subtitle, 'the race against time for smarter development', captures this urgency.

Since 2015, most countries have aligned their national policies with *The 2030 Agenda for Sustainable Development* and are engaged in a gradual transition to 'green' economies. Governments are stepping up support for smarter production and consumption systems. As the cost–benefit ratio of renewable energy rises, 'green' energy projects have multiplied.

However, many governments still fret about how to reconcile the preservation of markets and jobs with their commitment to the *Paris Agreement* (2015). Despite the growing impact of climate change, there is still insufficient support on the part of both governments and businesses for the necessary energy transition: over 80% of global electricity production was based on coal, oil and gas in 2018.

In parallel to their green transition, governments are digitalizing public services and payment systems to improve service delivery, support business and combat corruption and tax evasion. Policies are fostering the emergence of a digital economy, including smart manufacturing, smart finance (fintech), smart health care services like telemedicine and smart agriculture. The report's subtitle is also an allusion to this form of 'smarter development' driven by digital technologies such as artificial intelligence (AI) and robotics, big data, the Internet of Things and blockchain technology which are converging with nanotechnology, biotechnology and cognitive sciences to form the bedrock of the Fourth Industrial Revolution (also known as Industry 4.0).

Countries of all income levels are engaged in this dual green and digital transition. Science has become synonymous with modernity and economic competitiveness, even with prestige. For those countries bearing the brunt of climate change, science offers hope of greater resilience to destructive storms, fires, droughts and other calamities.

However, businesses are not always supporting this agenda, either for lack of motivation or capacity; many continue to import packaged technologies, rather than develop their own. They are often reluctant to collaborate with public research institutions. Governments everywhere are devising new incentives to foster technology transfer, such as by setting up labs where businesses can 'test before they invest' in digital technologies.

For their dual transition to succeed, governments will need to raise their commitment to research and development (R&D). The G20 still accounts for nine-tenths of research expenditure, researchers, publications and patents (Figure 1.1). Although research expenditure rose in most regions between 2014 and 2018 (Figure 1.2), 80% of countries still invest less than 1% of GDP in R&D. In some cases, the researcher population has risen faster than related expenditure (Figure 1.3), leaving less funding available to each researcher.

To succeed in their dual transition, governments will not only need to spend more on R&D; they will also need to invest these funds strategically. This will entail taking the long-term view and aligning their economic, digital, environmental, industrial and agricultural policies, among others, to ensure that these are mutually reinforcing. To be coherent, reforms, policies and resources will all need to point in the same direction, towards the same strategic goal of sustainable development.

For developing countries, the dual green and digital transition is accelerating a process of industrialization that would normally take decades. For all countries, this transition is demanding an integrated approach to long-term planning and a heavy investment in infrastructure.

The rapid societal transformation under way offers exciting opportunities for social and economic experimentation that could make life much more comfortable. It also presents the risk of exacerbating social inequalities and, for countries implementing ambitious infrastructure projects, of debt vulnerability. The Covid-19 pandemic has accentuated both of these risk factors.

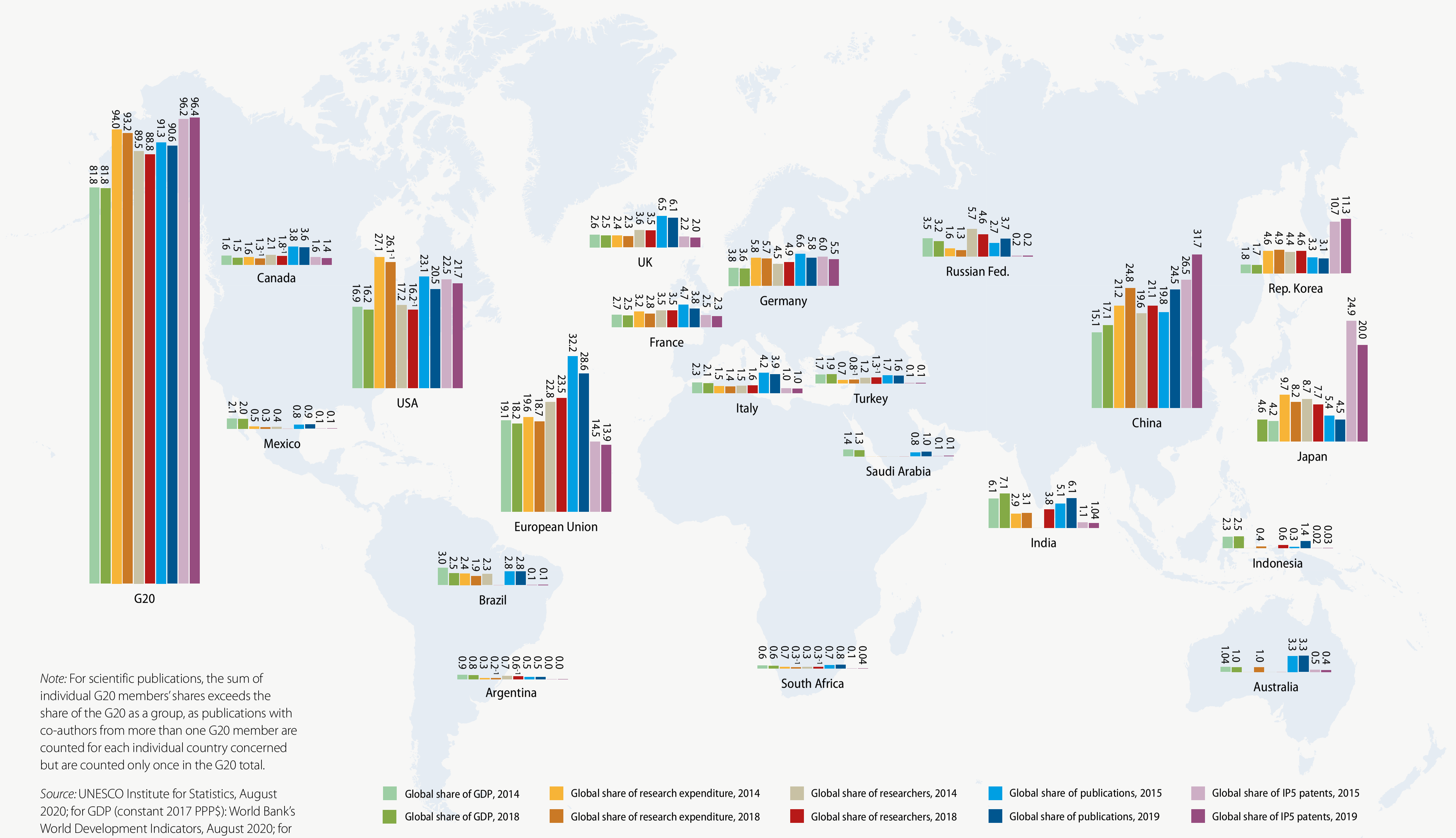
SCIENCE AND THE PANDEMIC

During the pandemic, countries have turned to science

In late 2019, a novel strain of coronavirus, dubbed Covid-19, was detected in China before spreading rapidly around the world. From the outset, scientists shared information and data with one another, beginning with the sequenced genome of the coronavirus in early January 2020. The pandemic has showcased the benefits of this culture of sharing both within and beyond borders (see The time for open science is now, p. 12). There has been a surge in international scientific collaboration in many parts of the world since 2015 (Figure 1.4).

Many governments rapidly established ad hoc scientific committees to manage the crisis. This enabled them to witness, first hand, the advantages of having local experts to monitor and control the progression of the virus. Crisis management is reactive, by definition. Permanent structures can provide governments with scientific advisory services on a wide range of issues over time to inform national strategic

Figure 1.1: **Global shares of GDP, research spending, researchers, publications and patents for the G20, 2014 and 2018 or closest years (%)**



Note: For scientific publications, the sum of individual G20 members' shares exceeds the share of the G20 as a group, as publications with co-authors from more than one G20 member are counted for each individual country concerned but are counted only once in the G20 total.

Source: UNESCO Institute for Statistics, August 2020; for GDP (constant 2017 PPP$): World Bank's World Development Indicators, August 2020; for publications: Scopus (Elsevier), excluding Arts, Humanities and Social Sciences, data treatment by Science-Metrix; for IP5 patents: PATSTAT, data treatment by Science-Metrix planning (see What the Covid-19 pandemic reveals about the evolving landscape of scientific advice, p. 3).

The pandemic has demonstrated the value of digital technologies in an emergency. Brazil was able to call upon 140 telemedicine and e-health centres during the pandemic to provide virtual consultations and remote monitoring of patients' health. The government adopted a law on telemedicine on 15 April 2020 which extended telemedicine services to rural areas and remote towns (see chapter 8).

Countries with virtual universities have been able to adapt their education systems rapidly to online learning during the pandemic. For instance, thanks to the existence of the Gulf's first virtual university, the Saudi Electronic University (est. 2013), Saudi Arabia was able to launch 22 educational channels within eight hours of the first lockdown.

A number of countries have deployed robots and drones to help curb the spread of Covid-19. For instance, in Saudi Arabia, drones have been used in markets to identify people with a high body temperature. Rwanda and Ghana have both utilized drone technology provided by the US firm Zipline to deliver blood samples recovered from remote health clinics to specialist institutes for testing (see cover photo).

Pandemic undermining social and environmental gains

The Covid-19 pandemic has devastated the global economy. Socio-economic and environmental gains made in recent years are in danger of being eroded or even effaced.

Madagascar had managed to reduce poverty levels over 2016–2019, thanks to an ambitious economic reform programme, coupled with a peaceful transfer of power in 2019 that had helped to restore investor confidence. These gains have been jeopardized by the Covid-19 pandemic. For instance, Madagascar had lost about US$ 500 million in tourism revenue by May 2020. This revenue contributes to national conservation efforts. One of the founders of Ranomafana National Park has predicted that, without the US$ 4 million that usually flows into the region from tourism and research, the community 'will be forced to return to cutting the forest and farming' (see chapter 20).

The Indonesian government has justified its 'omnibus' law (Law on Job Creation), which came into effect in November 2020, by the need to attract foreign direct investment (FDI) and stimulate economic growth to offset the impact of the Covid-19 pandemic. The law alleviates the regulatory and licensing burdens on firms with regard to worker protections and operates a shift from an approval process based on permits to one in which developers declare their own compliance. The law has triggered concern from 35 global investors and others about the environmental and social cost of the new legislation (see chapter 26).

The pandemic has energized knowledge systems

The Covid-19 pandemic has exacted a heavy human and economic toll but it has also energized knowledge production systems.

During the pandemic, the USA witnessed an unprecedented mobilization of the bioscience industry. By mid-2020, there were estimated to be more than 400 drug programmes in development aimed at eradicating the disease. These efforts were rooted in the White House's Operation Warp Speed, a public–private partnership that saw around US$ 9 billion allocated to developing and manufacturing candidate vaccines, including through advance purchase agreements (see chapter 5).

The National Council for Scientific Research – Lebanon issued a Flash Call for Covid-19 Management as early as March 2020. This led to the acceptance of 29 research projects addressing topics such as vaccination policy, rapid test development and the use of AI to support early diagnosis of the disease and measure its impact on the mental health of frontline workers (see chapter 17).

Many countries have accelerated their approval processes for research project proposals. For example, by early April 2020, the innovation agencies of Argentina, Brazil and Uruguay had all launched calls for research with an accelerated approval process. Peru's two innovation agencies shortened their own response time to two weeks (see chapter 7).

In October 2020, the World Health Organization[1] reported that Africa accounted for about 13% of 1 000 new or modified existing technologies developed worldwide in response to the pandemic, close to its share of the global population (17%). Of these, 58% involved digital solutions such as chatbots, self-diagnostic tools and contact-tracing apps. A further 25% of solutions were based on three-dimensional (3D) printing and 11% on robotics (see chapter 20 and photo, p. 2).

In April 2020, the government tasked the South African Radio Astronomy Observatory with managing the national effort to design, produce and procure 20 000 lung ventilators. The observatory was chosen for its experience in designing sophisticated systems for the MeerKAT radio telescope in the Northern Cape. By December 2020, 18 000 units had been produced and 7 000 distributed (see chapter 20).

India has focused its response to the pandemic on producing low-cost solutions predominantly in three areas, including for export: vaccine research and manufacturing; the manufacture of generic versions of 'game-changer' drugs; and frugal engineering of medical devices in high demand, such as low-cost lung ventilators (see chapter 22).

Pharmaceuticals were not a priority industry for Sri Lanka's *National Export Strategy 2018–2022* until the Covid-19 crisis spurred demand. This led the government and private sector to invest US$ 30 million in a new pharmaceutical manufacturing plant in 2020 within the Koggala Export Processing Zone (see chapter 21).

The Covid-19 crisis has recalled the desirability of strong linkages between the public and private sectors for the production of equipment such as lung ventilators, masks, medication and vaccines. In early 2020, a team of biomedical engineers from the University of Antioquia in Colombia designed a low-cost lung ventilator in collaboration with the Hospital San Vicente de Paul, through a project supported by the Ruta N Medellin business development centre. This ventilator was approved in mid-2020 by the medical licensing institute, INVIMA, then manufactured by firms specializing in home appliances and automobiles which had repurposed their assembly lines. Since the developers used open-source techniques, other manufacturers have been able to download the same design (see chapter 7).

Many governments have provided incentives for small and medium-sized enterprises (SMEs) to tackle the pandemic. In Iran, the Corona Plus campaign offered start-ups financial incentives in 2020 to help them produce medical equipment such as protective gear and ventilators (see chapter 15).

Canada's Industrial Research Assistance Program has provided financial support to help SMEs refine their Covid-19-related product or process and get it to market; in all, the federal government has allocated Can$ 1 billion to a national medical research strategy as part of its rapid response to the Covid-19 pandemic (see chapter 4).

Until 2020, when Covid-19 radically transformed Canadians' way of life, there had been no crisis to spark any serious national conversation about the direction in which Canada was taking science, technology and innovation (STI). The pandemic 'may, ultimately, redefine Canada's science processes, output and governance, in ways that cannot yet be foreseen. It will also affect the next generation of researchers and the mechanisms by which science itself is funded'.

The Covid-19 crisis raises broader, more fundamental questions than the Great Recession of 2008, such as with regard to the role of the state in the economy, the reshoring of supply chains, the organization of work or the value of proximity (see chapter 9).

THE DUAL DIGITAL AND GREEN TRANSITION

The pandemic has highlighted dependence on global value chains

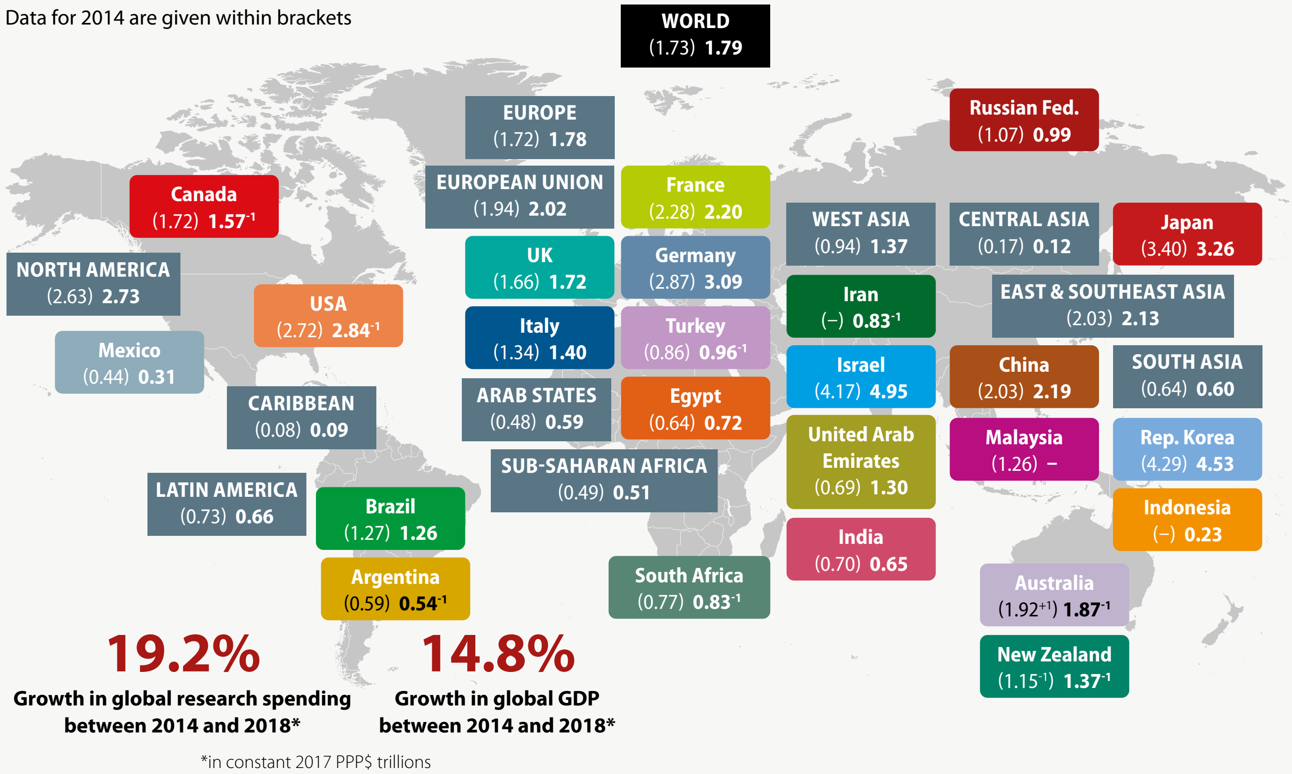
The pandemic has highlighted countries' dependence on global value chains for strategic resources. The complexity of components in modern everyday devices means that manufacturers have recourse to subcontractors abroad who specialize in a narrow field; they, in turn, rely on other suppliers for essential materials. Having such a tiered supply system, or value chain, makes it very difficult to reshore manufacturing, or repurpose a production plant overnight (see chapter 5). For instance, lung ventilators manufactured in the USA for Covid-19 patients contain key components sourced in Canada. That is why the closing of the border in early 2020 slowed the production of lung ventilators in the USA (see chapter 4).

The European Union (EU) is dependent on imported products like microprocessors and, for key technologies, on imported raw materials such as rare earth elements. For the European Commission's first annual *2020 Strategic Foresight Report: Charting the Course Towards a More Resilient Europe* (2020), this dependence poses potential threats to European economic sovereignty (see chapter 9).

Having relocated much of their production to the developing world in the 1980s, where cheap, unskilled labour was plentiful, industrialized countries found themselves

Figure 1.2: **Investment in research and development as a share of GDP, by region and selected country, 2014 and 2018 (%)**

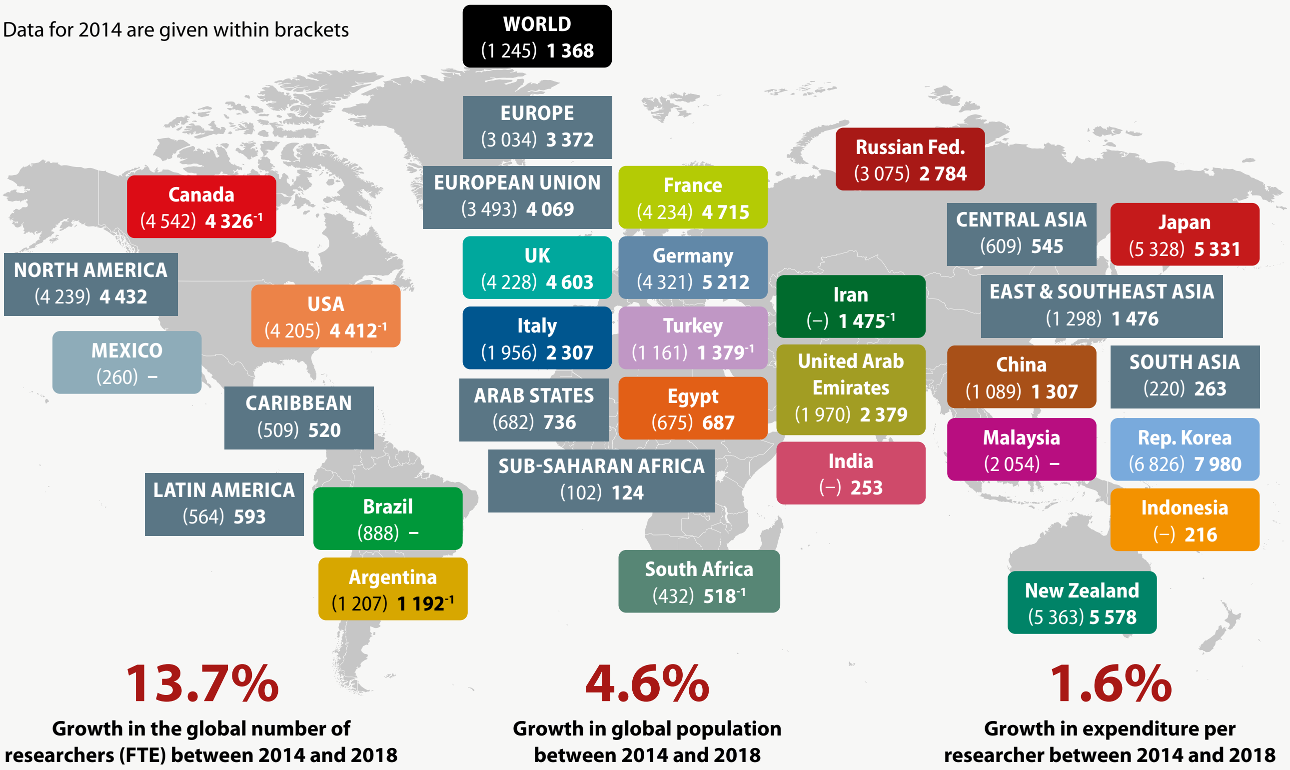
Data for 2014 are given within brackets



Source: global and regional estimates based on country-level data from the UNESCO Institute for Statistics, August 2020, without extrapolation

Figure 1.3: **Researchers (FTE) per million inhabitants, by region and selected country, 2014 and 2018**

Data for 2014 are given within brackets



Source: global and regional estimates based on country-level data from the UNESCO Institute for Statistics, August 2020, without extrapolation

dependent on imports of personal protective equipment and common drugs like paracetamol in the early days of the pandemic.

Countries with a strong manufacturing sector, on the other hand, were able to repurpose their assembly lines rapidly when the pandemic struck. This was the case for the Colombian firms specializing in home appliances and automobiles described above, for instance.

China has an increasingly sophisticated manufacturing sector. However, it remains dependent on imports of certain core technologies like semiconductors. This technological vulnerability is illustrated by the fate of the Chinese company ZTE, which was forced to shut down most of its operations within weeks of being cut off from its US suppliers of hardware components and Android services (Google) in April 2018, after the USA imposed trade sanctions on the company (see chapter 23).[2]

It was partly out of a desire to reduce reliance upon US high-tech suppliers that the Chinese government launched a ten-year, state-led industrial policy in 2015 called *Made in China 2025*. This policy encourages Chinese companies to expand their global market share of, *inter alia*, electric cars, advanced robotics and AI, agricultural technology, aerospace engineering, new synthetic materials, emerging biomedicine and high-end rail infrastructure and maritime engineering (see chapter 23).

Global value chains also affect countries with immature science systems but in a different way. The subsidiaries of multinational corporations integrated in global value chains tend to maintain a policy in developing countries of utilizing existing knowledge, rather than engaging in local research. This is the case in Latin America, for instance. These subsidiaries limit their local output to manufacturing, which requires limited new knowledge and does not promote linkages with local scientific institutions (see chapter 7).

Advanced manufacturing seeking to revitalize industry

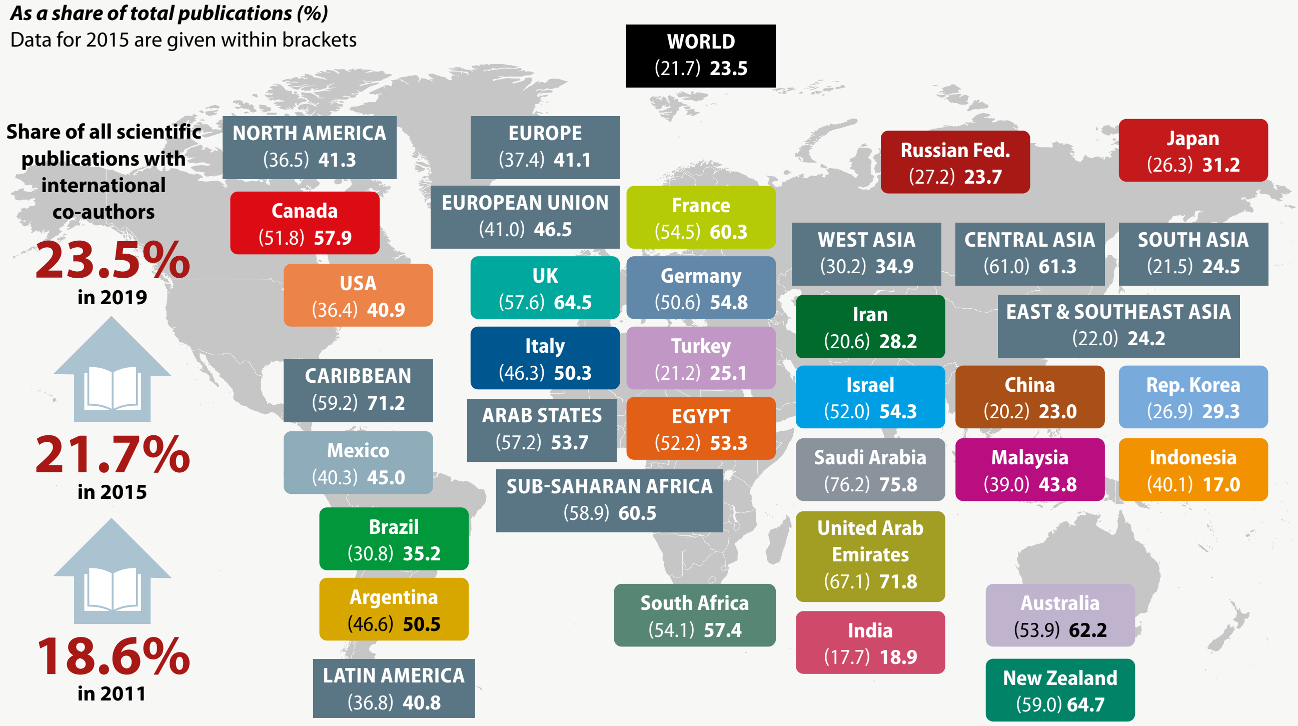
Prior to the pandemic, developed countries were already investing in advanced manufacturing technologies to revitalize their domestic manufacturing sector.

There is a consensus view in government that the USA needs to adapt to an increasingly competitive international environment. This has led the federal government to prioritize key strategic platforms in digital technology since 2016 in fields that include AI, quantum computing, advanced mobile network technology and cybersecurity. The three goals of the strategic plan for industry released in 2018 are to transition to new manufacturing technologies, train the manufacturing workforce and expand the capabilities of the domestic manufacturing supply chain. These new technologies include the foregoing, plus industrial robotics, 3D printing, semiconductor and hybrid electronics, photonics, advanced textiles, biomanufacturing and agrifood (see chapter 5).

The EU's revamped industrial policy (2021) supports the development of strategically important technologies for Europe's industrial future. These include robotics,

Figure 1.4: **International scientific co-authorship, by region and selected country, 2015 and 2019**

As a share of total publications (%)
Data for 2015 are given within brackets



Source: Scopus (Elsevier), excluding Arts, Humanities and Social Sciences; data treatment by Science-Metrix

micro-electronics, high-performance computing and data cloud infrastructure, blockchain, quantum technologies, photonics, industrial biotechnology, biomedicine, nanotechnologies, pharmaceuticals and advanced materials.

For the President of the European Council, Charles Michel, European strategic autonomy has become 'goal number one for our generation'. In 2020, the European Commission's report on *A New Industrial Strategy for Europe* highlighted the importance of safeguarding Europe's technological sovereignty and strategic interests in trade and technology in areas like AI and related digital technologies and infrastructure.

It is possible that the looming decoupling over technology between the USA and China, as they compete for technological superiority, may force other parts of the world 'to choose between two increasingly separate realms of technology, such as with regard to telecommunications, digitalization, AI and the Internet. Alternatively, the rest of the world could decide to safeguard its participation in both realms but this would be an extremely costly and inefficient option' (see chapter 9).

Industry 4.0 a common agenda

Digital technologies are considered vital for future economic competitiveness. Among cross-cutting technologies, it is the field of AI and robotics that dominated scientific output in 2018–2019 in countries of all income levels (Figure 1.5). The rise in publishing on AI by lower-income countries since 2015 has mechanically shrunk the G20's share of output (Figure 1.6).

Many countries have set up institutional mechanisms to foster the adoption of Industry 4.0 technologies. For example, South Africa appointed a Presidential Commission on the Fourth Industrial Revolution in 2019, consisting of about 30 stakeholders with a background in academia, industry and government. South Africa has also established an Interministerial Committee on Industry 4.0. The Republic of Korea has had a Presidential Committee on the Fourth Industrial Revolution since 2017. Australia has a Digital Transformation Agency (est. 2015) and the Prime Minister's Industry 4.0 Taskforce (est. 2016), which promotes collaboration with industry groups in Germany and the USA.

Countries of all income levels are adopting Industry 4.0 strategies. The Republic of Korea's *I-Korea* strategy (2017) is focusing on new growth engines that include AI, drones and autonomous cars, in line with the government's innovation-driven economic policy. Another example is *Making Indonesia 4.0*, with a focus on improving industrial performance (see chapter 26). Uganda adopted its own *National 4IR Strategy* in October 2020 with emphasis on e-governance, urban management (smart cities), health care, education, agriculture and the digital economy; to support local businesses, the government was contemplating introducing a local start-ups bill in 2020 which would require all accounting officers to exhaust the local market prior to procuring digital solutions from abroad (see chapter 19).

The digital economy is the focus of the *Digital Cameroon 2020 Strategic Plan* (2017). Cameroon has set up a high-tech centre specializing in robotics, digital manufacturing and computer-aided vision, as well as a 3D printing centre that is unique in sub-Saharan Africa. The National School of Posts, Telecommunications and Information and Communication

Technologies opened in Yaoundé in 2016 and a training centre for computer-aided design and drawing tools has been operational since 2017. Cameroon has 28 active tech hubs. In 2019, the country had the highest publication intensity in AI and robotics on the subcontinent (see chapters 19 and 20).

About one-quarter of African tech hubs are classified as co-working spaces, or 'makerspaces', where the use of 3D printers, drones and other Industry 4.0 technologies is commonplace, according to research by the Groupe Spécial Mobile (GSMA). The number of active tech hubs across Africa surged between 2016 and 2020 from 314 to 744 (see chapter 20).

Helping firms digitalize

Several countries are seeking to become regional digital hubs, including Australia, Djibouti and Morocco.

However, most businesses are not yet digitalized. The European Commission estimates that only about one in five EU companies have reached this point; it has introduced digital innovation hubs to allow companies of all sizes to 'test before they invest' in digital technologies.

Australia's Industry 4.0 strategy, *Tech Future* (2018), proposes establishing 'test labs' at five universities, to help businesses transition to 'smart' factories (see chapter 26).

Malaysia is helping firms to digitalize their business processes through the Smart Automation Grant launched by the Malaysia Digital Economy Corporation in July 2020, as part of the *National Policy on Industry 4.0*. This matching grant targets firms in the services sector which pay at least half of the total cost of their digitalization project. Due to be launched in 2021, the Smart Manufacturing Experience Centre will give SMEs access to existing platforms and technologies, in order to provide them with a 'test bed' to trial their innovation (see chapter 26).[3]

In the Philippines, meanwhile, SETUP 4.0 offers micro-enterprises and SMEs loans of up to PHP 5 million (*ca* US$ 100 000) to innovate in areas related to Industry 4.0; there were plans to support 800 companies in 2020, including through the provision of equipment and training (see chapter 26).

The AI race

Between 2016 and 2020, more than 30 countries[4] adopted dedicated strategies for AI. Whereas Canada is striving to assume a leadership role in the international conversation on the potential social impact of AI (see chapter 4), China, the Russian Federation and USA are vying for a competitive advantage in the field of AI itself.

The Russian president, Vladimir Putin, stated in 2017 that 'whoever becomes the leader in this sphere will become the ruler of the world' (see chapter 13).

By 2030, China aims to be 'the world's primary centre for innovation in AI,' according to its *New Generation Artificial Intelligence Development Plan*. China is already the world's biggest owner of AI patents but lacks top-tier talent in this field; it has launched megaprogrammes in science and engineering to 2030 that include quantum computing and brain science (see chapter 23).

The US government's 2020 research budget proposal for 2021 included major increases for quantum information science and AI as part of its goal of doubling government-wide investment in research in these two areas by 2022 relative to 2019 levels (see chapter 5).

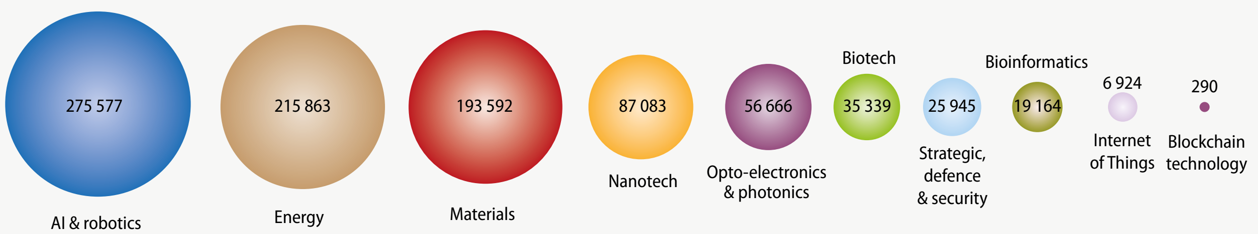
Digital and green agendas advancing in parallel

Most countries are convinced that their future economic competitiveness will depend upon how well they succeed in transitioning to digital societies.

Meanwhile, the adoption of the SDGs in 2015, combined with the rising cost of unsustainable development and the impact of climate change, has made countries' green transition a priority agenda. The converging phenomena of strong economic growth, heightened dependence on technology and rising temperatures are driving up energy needs. In Central Asia, for instance, two decades of rapid economic growth have raised demand for electricity, pushing up carbon emissions and eating into export revenue: 86% of Uzbek natural gas is now used for domestic consumption (see chapter 14).

Countries are keenly aware that their future economic competitiveness will depend upon how quickly they manage

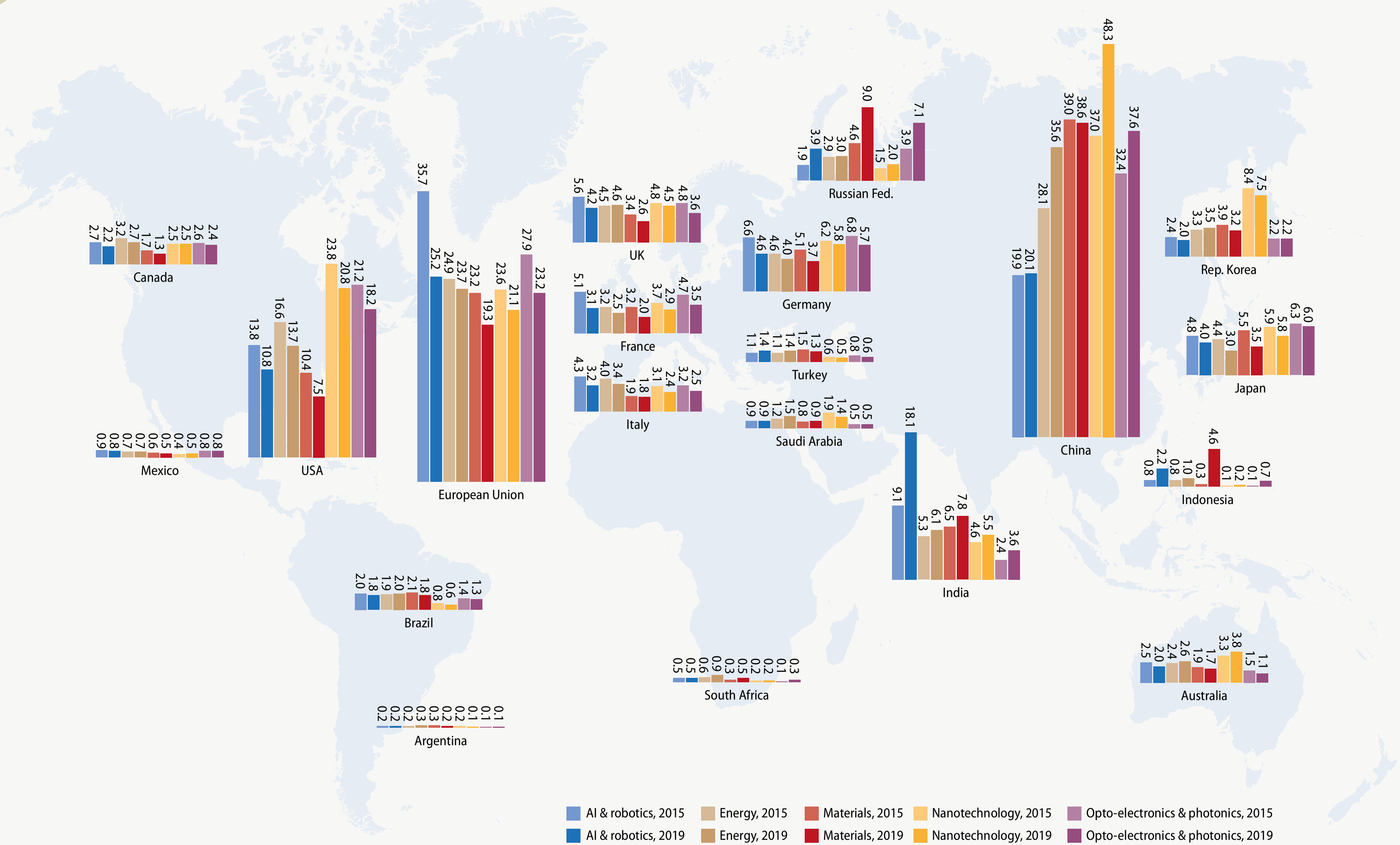
Figure 1.5: **Scientific publications by cross-cutting strategic technology, 2018–2019**



Note: Bibliometric data for the subfields of the broad field of cross-cutting strategic technology are based on a classification by journal; for details, see Annex 5. The first journals specific to blockchain technology appeared in 2018.

Source: Scopus (Elsevier), excluding Arts, Humanities and Social Sciences; data treatment by Science-Metrix

Figure 1.6: **Share of global publications on selected cross-cutting strategic technologies among the G20, 2015 and 2019 (%)**



Note: AI stands for artificial intelligence. The percentage values reflect non-exclusive contributions because papers with multiple authors from different countries are counted for each of these countries.

Source: Scopus (Elsevier), excluding Arts, Humanities and Social sciences; data treatment by Science-Metrix

to transition to a green and digital economy, in parallel. This dual agenda is reflected, for example, in the strategies adopted by the Caribbean Community (Caricom) through its regional *Energy Policy* (2013) and *Caricom Digital Agenda 2025* (2019). In 2018, member states established the Caribbean Centre for Renewable Energy and Energy Efficiency (see chapter 6).

The EU's industrial policy (2021) rests on three pillars: the green transition, the digital transition and global competitiveness. The bloc plans to spend € 1.8 trillion in public funds between 2021 and 2027, 30% of which is to be invested in countries' dual green and digital transition. One focus of the 'green' transition will be the circular economy (see chapter 9).

In 2018, the Russian Federation took advantage of its rotating presidency of the Eurasian Economic Union (EAEU) to propose a number of areas in which to 'readjust' the Union, including the formation of a common digital space and energy market for member states; and co-operation in the fields of green technology, renewable energy sources, bio-engineering, nanotechnology, ecology, medicine and space. Member states are keen to create a 'territory of innovation' which would take advantage of their different strengths (see chapter 13). The same year, the EAEU launched its *Digital Agenda* (see chapter 14).

Like other developing countries, Tunisia needs to diversify its economy to create jobs and attract more FDI. It is one of a growing number of countries choosing the path of knowledge-intensive industries. Inflows of FDI to Tunisia grew by 16% over 2017–2018, as foreign electronics companies were drawn to the country by the cost-competitive and highly skilled workforce, especially in the automobile and aeronautic subsectors. Some 41 electronics companies with cumulative annual sales of about US$ 1.2 billion launched their own ELENTICA cluster in May 2017 (see chapter 17).

In October 2018, ELENTICA entered into a partnership with the Tunisian Ministry of Higher Education and Scientific Research with the goal of promoting scientific collaboration and installing research centres in ELENTICA companies. These research centres will focus on areas such as the Internet of Things, smart cities, renewable energy and smart-grid technologies, electric cars and e-farming. Other tech-based sectors are experiencing rapid growth: exports in the aeronautics sector surged over 2010–2018 and more than tripled in the pharmaceuticals sector over 2012–2018 (see chapter 17).

Tunisia typifies the challenge facing countries of all income levels today: how to transition to an economy that is both digital and green over a short space of time, without neglecting investment in one or the other, or augmenting their debt burden. The world now has less than ten years to deliver on its SDGs to 2030.

Implementing these parallel agendas simultaneously demands a consequential, simultaneous investment in infrastructure development – data centres, high-performance computing facilities, solar and wind farms, etc. – combined with regulatory reform and an overhaul of education and technical and vocational training to equip youth for tomorrow's job market. To compound the challenge, many developing countries are modernizing their transportation networks in parallel, including roads, ports, pipelines and railways. Modern transnational transportation networks will be essential, for instance, to move goods around the future African Continental Free Trade Area.

Arguably, it is Japan which is embracing this dual green and digital agenda with the greatest vigour. Confronted with a low birth rate and an ageing population, the government adopted Society 5.0 in 2017 as its growth strategy for creating a sustainable, inclusive socio-economic system powered by digital technologies. The aim is to go beyond Industry 4.0 to transform the Japanese way of life. Towns will be powered by energy supplied in flexible and decentralized ways to meet the inhabitants' specific needs while conserving energy. Flying drones will deliver postal services to depopulated areas. In sectors where there is a shortage of labour, self-driving vehicles will plough the fields and robots will be deployed to care homes (see chapter 24).

The government is wagering that Society 5.0 will offer Japan the means to overcome its chronic economic stagnation. Japanese companies have reacted to the shrinking domestic market by purchasing companies overseas to 'buy time and labour'. As a result, investment is leaving Japan's shores, hollowing out the country's industrial base. Even though it has not taken the lead in digital industries so far, Japan may be able to take advantage of its traditional strengths in mechanical and material engineering to develop advanced cyberphysical systems. By actively introducing AI into the workplace, it is hoped that depopulation and ageing will cease to be disadvantages in a less labour-intensive economy (see chapter 24).

A risk of greater social inequalities

Digitalizing the economy presupposes that citizens have bank accounts and credit cards that allow them to engage in online transactions. The establishment of a digital payment system in developing countries will support the emergence of e-commerce and combat tax evasion and corruption but it is also likely to heighten the vulnerability of those employed in the informal economy where cash payments are the norm.

India is a cash economy. To reduce the size of the informal economy, the government took the radical step in 2016 of demonetizing two banknotes which accounted for about 86% of those in circulation at the time. Between 2014 and 2017, the proportion of citizens with a bank account surged from 53% to 80% and the digital marketplace expanded. Online payments have become a particularly attractive option in India and elsewhere during the Covid-19 crisis as a means of respecting physical distancing for financial transactions.

In Africa, the digital revolution is being buoyed by consistent growth in mobile phones and digital payment systems with advanced functionalities that draw on the confluence of mobile money and the Internet of Things. Kenya is one of the most mature digital credit markets in developing economies, where the volume of digital loans surpassed traditional loans in 2015. In 2020, Tanzania's National Data Centre launched the N-Card enabling digital payments. By 2019, 78% of adults in rural Tanzania could reach formal financial services within a radius of 5 km.

In October 2019, African ministers with a communication portfolio adopted the *Sharm El Sheikh Declaration* proposing a continental *African Digital Transformation Strategy*. They invited member states to ratify the *African Union Convention on Cyber Security and Personal Data Protection* (the *Malabo Convention,* 2014), which calls upon countries to set up a cashless financial system to nurture digital marketplaces and combat corruption, as well as to develop regulations to protect domestic data. [5] Ministers also urged member states to adopt a common African stance on AI and to set up a think tank on AI to assess and recommend collaborative projects aligned with the African Union's *Agenda 2063* and *The 2030 Agenda for Sustainable Development* (see chapter 18).

This would be an ambitious digital agenda for any region but Africa is still at the stage of extending Internet penetration to the masses. Between 2015 and 2019, Internet access progressed by only 0.24% to reach 24.2% of the African population (see chapter 19). Despite the extension of communication infrastructure, many African citizens and businesses cannot afford to access Internet, which remains costly for lack of market competition (see chapter 20). For instance, by October 2020, Madagascar had the second-fastest fixed broadband Internet service in Africa after Ghana, having connected to the Eastern African Submarine Cable System in 2010, but few Malgache could afford to access Internet.

India epitomizes the challenges that countries face in modernizing their economy and advancing their digital agenda in parallel by condensing into a few years what would normally be a more gradual process. At the same time that the Indian government was expanding citizen access to a bank account, a government think tank, the National Institution for Transforming India (NITI Aayog), was publishing a *National Strategy for Artificial Intelligence* in 2018 to leverage improvements in health care, education and agricultural yields. This strategy also sets out to foster smart cities, smart mobility and smart transportation. Blockchain technology is already widespread in government. NITI Aayog is exploring opportunities for deploying blockchain technology in the drug and fertilizer industries, electric and hybrid vehicles in the automobile industry and expanding renewable energy.

In 2015, the Indian government selected about 100 cities with a cumulative population of 99.6 million to become the country's first smart cities. There is no universally accepted definition of a smart city, despite the multiplication of these around the world. The Indian concept blends digital and sustainable technologies to provide water and sanitation, electricity, education and health care services, safe and affordable housing and efficient urban mobility. There is a risk that these smart cities may exacerbate social inequalities, however, since, according to the Ministry of Housing and Urban Affairs, 80% of funding for India's smart cities will be spent on area-based development, which benefits only part of a city's population (see chapter 22).

Concern about the potential of the dual digital and green transition to exacerbate social inequalities is particularly keen when it comes to the prospect of jobs being displaced on a wide scale. In the case of the digital transition, it is automation that is crystallizing concern; in the case of the green transition, it is the prospect of phasing out large-scale polluting industries like coal plants which are a source of mass employment. This has led some governments to approve new coal plants in full knowledge that these will prove to be uneconomical.

The European Commission is seeking to ensure that jobs lost in one industry to the green economy can be recreated elsewhere. The Just Transition Mechanism seeks to limit the turbulence to the most vulnerable member states through tailored resources. This mechanism is part of the *European Green Deal*'s *Sustainable Europe Investment Plan* mobilizing public and private investment to a cumulative total of at least € 1 trillion that was presented by the European Commission in January 2020 (see chapter 9).

Anxiety about automation

So far, Industry 4.0 does not seem to have led to widespread job losses. In Latin America, fintech and growing automation are beginning to steer investment towards products, processes and services that rely on innovation but the impact on employment has yet to be felt. If we take the example of Mexico, it counted 5 700 industrial robots in 2018, ranking ninth worldwide for automation. About half of these robots were installed in the automotive sector. Many industrial robots in Mexico have been imported from the USA, Europe and Asia by automobile manufacturers with local assembly plants (see chapter 7).

In India, too, the manufacturing sector accounts for the greatest share of imported robots.[6] Although their number increased by an average of 64% per year from 2000 to 2016, these do not account for more than 10% of total employment in manufacturing. However, with related technologies developing quickly, many tasks may become automated in the near future. This could radically alter the employment landscape in India and beyond (see chapter 22).

The decline of traditional manufacturing has become a sensitive issue in the USA. Manufacturing output in 2017 was at least 5% greater than in 2000 but the sector has become more capital-intensive and less labour-intensive, owing to the widespread introduction of automation. Some 5.5 million manufacturing jobs in the USA were lost between 2000 and 2017 (see chapter 5).

This drop can also be attributed to a skills mismatch in the USA for today's more sophisticated manufacturing sector. Individuals with a high-school degree or less who are performing standardized tasks are more than four times more likely to hold highly automatable jobs than those with bachelor's degrees. Twelve million such workers of Hispanic and Afro-American heritage have already been displaced by automation. In the coming decades, it is estimated that about 25% of US jobs (36 million in 2016) will face high exposure to automation (see chapter 5).

A relatively new phenomenon in the USA is that AI is threatening better-paid professional jobs in high-tech fields and metropolitan areas. This trend will require considerable restructuring of career pathways and training programmes (see chapter 5).

Energy at the heart of the dual transition

Renewable energy was the only energy sector to see growth at the height of the Covid-19 pandemic and demand is projected to grow further. Renewable energy systems have become more cost-effective than alternatives, thanks to advances in wind and solar energy technology, in particular (see chapter 2).

Energy is at the heart of both the digital and green transition. In sub-Saharan Africa, only half (48%) of the population currently has access to electricity, according to the International Energy Agency. Governments are well aware that there can be neither industrialization, nor a digital economy without universal access to energy. The African Union's *Agenda 2063* strategy places high priority on investment in renewable energy, to complement the extension of the grid.

The Southern African Development Community opened a Centre for Renewable Energy and Energy Efficiency in Namibia in 2015, to improve access to electricity in the subregion. Between 2015 and 2018, the overall share of renewables in Southern Africa's power capacity shot up from 24% to 39%. Most projects concern wind, solar energy and hydropower (see chapter 20).

In East Africa, geothermal power is now piped to more than 35% of Kenyan households. In November 2019, Kenya overtook Iceland to rank eighth worldwide for the capacity to produce geothermal energy. The development of geothermal energy has accelerated since the release of *Kenya Vision 2030* in 2008, with its emphasis on renewable energy.

For the island nations of the Caribbean and South Pacific, renewable energy is perceived as a means of reducing costly imports of fossil fuels and ensuring greater energy independence. Six Pacific Island countries aim to generate 100% of their electricity from renewable sources within a decade (see chapter 26). Five Caribbean countries have embarked upon a project to exploit their vast geothermal reserves with the support of the Green Climate Fund (see chapter 6).

A number of countries are abandoning hydropower projects as a consequence of unreliable rainfall (e.g. Sri Lanka and Zambia) or safety concerns. Following a report by Brazil's National Agency for Water and Sanitation in 2018 warning that 45 dams were at a high risk of failure, the government announced the end of megahydropower projects in the Amazon (see chapter 8). Meanwhile, a megahydropower plant is foreseen in the Democratic Republic of Congo (see chapter 20).

Projects for the development of renewable energy abound around the world. About 16% of electricity generation stemmed from hydropower and a further 10% from solar, wind, biofuels and biomass in 2018. However, many countries are still at the stage of importing packaged technologies, rather than adapting these or developing their own.

Industrialization and infrastructure development are often taking place in parallel to R&D when these paths should be mutually reinforcing (see chapter 21). More countries are linking the two processes, however. Iran's *Local Content Requirements Policy* (2016) introduced a clause requiring international agreements and major national projects to 'include local technology and training'. Saudi Arabia's *2030 Vision* fixes the target of manufacturing locally 50% of the military equipment it imports by 2030. In Ecuador, scientists have developed a specialization in smart-grid technologies since a series of rolling blackouts in 2009 prompted the government to prioritize investment in energy infrastructure and the transition to renewables (see chapters 2 and 7). Bhutan plans to establish ten FabLabs across the country by 2023; a pilot Fab4Fab programme is studying how to produce components of a FabLab locally as a substitute for imports (see chapter 21).

One policy challenge will be to ensure that countries' sustainable development agenda is implemented across different economic sectors. For instance, green industries do not figure among the priority sectors of Mongolia's *State Industrial Policy 2015–2030* (2015), despite the focus in the *State Policy on Energy* (2015) on the development of wind and solar energy and the 30% target to 2030 for renewables in total energy consumption in the *Green Development Policy* (2014–2030) [see chapter 14].

Nuclear power being phased in … and out

Nuclear power plants cost billions of dollars to build and have a lifespan of about 40 years. By 2025, 25% of existing nuclear capacity will probably need to be shut down (see chapter 2). A number of developing countries are planning to develop nuclear power plants, including Egypt and the United Arab Emirates (see chapter 17), Mongolia (see chapter 14) and Zambia (see chapter 20).

Meanwhile, the Republic of Korea is developing hydrogen energy to compensate for the gradual phasing out of nuclear energy, in line with its *Third Energy Master Plan* for 2019–2040. Since the Republic of Korea is a leading manufacturer of nuclear reactors, there is some concern that the phasing out of nuclear energy will erode the country's global competitiveness. Moreover, considerable investment in infrastructure will be necessary to reach the country's target of a 20% share of renewable energy by 2020, since renewables accounted for about 5% of the primary energy supply in 2017; one strategy involves helping farmers to convert degraded areas into solar farms (see chapter 25).

The development of hydrogen fuel cell technology is also a focus of Japan's *Long-term Energy Supply and Demand Outlook* (2015). In the wake of the Great East Japan Earthquake (2011), the country's nuclear power plants were shut down for mandatory inspections and upgrades between 2013 and 2015. To compensate for the loss of nuclear power, Japan increased its dependence on imports of oil, gas and coal. The installation of solar systems has been slowed down by the high price of electricity, which has been a burden for industry. This situation prompted, in 2018, a lowering of the fixed price consumers paid for solar and wind power and a liberalization of the retail market.

It is symbolic that Japan (see chapter 24) and Ukraine (see chapter 12) are both establishing solar plants on the sites of the world's worst nuclear disasters, Fukushima (2011) and Chernobyl (1986).

Energy transition encountering resistance

Developing countries are co-operating with international partners to access green finance. For instance, Kazakhstan's feed-in tariffs and solar auction scheme have been developed under the Kazakhstan Renewables Framework, a project co-financed since 2017 by the European Bank for Reconstruction and Development and the Green Climate Fund. One challenge for developing countries will be to balance competing demands for innovation from the mining sector, which often forms the bedrock of their economies (see chapter 14).

A growing number of developing countries are using revenue from mining and oil and gas exploration to fund their 'green' transition. In 2019, Guyana used the discovery of offshore oil and gas reserves to create a Sovereign Wealth Fund which is investing oil revenue to bankroll its transition to renewable energy (see chapter 6). Senegal's Sovereign Fund for Strategic Investments (est. 2012) uses state revenue from oil and gas to invest in capital funds targeting SMEs in sectors prioritized by the *Emerging Senegal Plan* (2014), such as solar energy, agriculture and health (see chapter 18). Mongolia's *Green Development Policy* (2014–2030) plans to balance the development of mining and smelting industries by, *inter alia*, creating a sovereign wealth fund from mining sector revenue to support long-term sustainable development (see chapter 14).

In industrialized nations, the process of gradually transitioning to renewables has met with some resistance from traditional energy backers. For instance, in the four years (2016–2019) following adoption of the *Paris Agreement*, 35 banks from Canada, China, Europe, Japan and the USA together invested US$ 2.7 trillion in fossil fuels (see chapter 2).

There is change in the air, however. In 2017, Ireland became the world's first country to commit to divesting the public purse fully from fossil fuels, when parliament passed legislation to remove investment in coal, oil and gas from the € 8 billion (*ca* US$ 9.5 billion) Ireland Strategic Investment Fund (see chapter 2).

In 2019, the Norwegian parliament passed a law requiring the Norwegian Sovereign Wealth Fund, the world's largest with a worth of over US$ 1 trillion, to drop investments of US$ 13 billion in eight coal companies and about 150 oil producers (see chapter 11).

Governments more attuned to climate-sensitive development

Governments have become more attuned to the need for climate-sensitive development policies. Mozambique is investing in climate-resilient infrastructure, for instance, and Zambia has adopted a *Climate-Smart Agriculture Investment Plan* (see chapter 20).

In 2021, Djibouti plans to inaugurate its Regional Observatory on Global Change. The International Atomic Energy Agency has provided sophisticated scientific equipment for the centre, which will be studying the impact of climate change on the fragile ecosystems of East Africa, as well as emergent diseases like Chikungunya and Covid-19 (see chapter 19).

In 2017, Cambodia reported having achieved its target of devoting 1% of public expenditure to addressing climate change, in line with the *Cambodia Climate Change Strategic Plan 2014–2023*. Progress is being hampered, however, by a lack of data and technologies and limited access to finance for firms wishing to make climate-smart investments (see chapter 26).

In the Caribbean, a succession of devastating hurricanes has focused attention on rebuilding more resilient infrastructure. This will require greater capital investment, accentuating the fiscal burden on Caricom members, which already have some of the highest public debt in the world, relative to the size of their economies. A 'coalition of the willing' formed in 2018 to establish the Caribbean Climate-Smart Accelerator Programme, which has the ambitious objective of making the Caribbean the world's first climate-smart zone. More than 26 countries and 40 private- and public-sector partners have joined the accelerator, including the Organisation of Eastern Caribbean States, the Inter-American Development Bank and World Bank (see chapter 6).

The industry of carbon capture and storage is still in its infancy, despite being considered vital to limit global warming. In Norway, Equinor is developing what may become the first industrial-scale project for carbon capture and storage in Europe (see chapter 11).

In federal governance systems, there tend to be disparities between federal and state policies that are preventing an overarching national strategy for climate change mitigation and adaptation. This is the case in Canada, the USA and Australia, for instance (see chapters 4, 5 and 26).

Sustainability research yet to enter mainstream

Of all the SDGs related to economic growth, it is those focusing on industry, innovation and infrastructure (SDG9) and sustainable cities and communities (SDG11) which received the most official development assistance between 2000 and 2013, with donors contributing US$ 130 billion and US$ 147 billion, respectively (see chapter 2).

Topics related to environmental sustainability, aligned with the SDGs for responsible consumption and production (SDG12), climate action (SDG13), life below water (SDG14) and life on land (SDG15), received the least donor attention between 2000 and 2013, attracting a cumulative total of less than US$ 25 billion in funding over this period (see chapter 2).

This funding pattern is reflected in outcomes. On average, national progress around the world has been weakest for the core environmental goals of climate action (SDG13), life below water (SDG14) and life on land (SDG15) [see chapter 2].

An analysis by UNESCO of 56 research topics of high relevance to the SDGs arrived at a similar conclusion (Figure 1.7; see chapter 2). It found that sustainability research was not yet mainstream in academic publishing at the global level. For instance, research into climate-ready crops accounted for just 0.02% of global scientific production between 2011 and 2019.

Topics related to industry, innovation and infrastructure (SDG9) fared better. Almost one-third (59) of the 193 countries studied at least doubled their output on the topic of greater battery efficiency between 2011 and 2019. There was a similar increase for smart-grid technologies (55 countries) and sustainable transportation, such as electric and hybrid vehicles (50) [see chapter 2].

Of note is that China increased its own share by more than 20% for publications on greater battery efficiency (to 53% of the global total), hydrogen energy (to 43%) and carbon pricing (to 41%) [see chapter 2]. China is poised to become the world leader for the topic of carbon capture and storage, its output having risen even as that of six other leading countries for this topic declined, namely Canada, France, Germany, the Netherlands, Norway and the USA (see chapter 2).

Despite the priority accorded to the global energy transition, publications on nine topics related to sustainable energy (SDG7), including cleaner fossil fuel technology and wind and solar power, still only accounted for 2.4% of global scientific output over 2016–2019, up from 2.1% over 2012–2015 (see chapter 2).

Sustainability topics form far greater shares of national output by small and developing science systems. It is in these systems that growth was most visible between 2011 and 2019, such as in Ecuador, Indonesia and Iraq (Figure 1.7). These countries also tend to be on the frontlines of climate change and reliant on commodity exports. The share of scientific publications on photovoltaics emanating from lower middle-income countries has surged from 6.2% to 21.2% and on biofuels and biomass from 7.6% to 21.6% since 2011. Low-income countries raised their own global share of publications on photovoltaics from 0.2% to 1.4% over the same period (see chapter 2).

POLICY TRENDS

A shift in focus towards well-being

Bhutan's 1729 legal code states that 'the purpose of the government is to provide happiness to its people.' Bhutan has had no difficulty in adapting its policies to the SDGs, since its Gross National Happiness philosophy is built on four pillars that mirror this agenda: sustainable and equitable socio-economic development; preservation and promotion of culture; conservation, sustainable utilization and management of the environment; and the promotion of good governance. In the government's *Twelfth Five-Year Plan* (2018–2023), these four pillars have translated into 16 national key result areas which are highly correlated with *The 2030 Agenda* (see chapter 21).[7]

The adoption of the SDGs has led more countries to stretch indicators of well-being beyond the mainstream focus on income and GDP. The *Living Standards Framework* adopted by the New Zealand Treasury in 2015 provides a novel means of assessing well-being, inspired by the *How's Life* document published by the Organisation for Economic Co-operation and Development (OECD). This New Zealand framework elevates 'sustainable intergenerational wellbeing' to the status of key objective of policy-making and natural resource management (see chapter 26).

Ecuador's *National Development Plan 2017–2021: Toda una Vida* (An Entire Life) provides a roadmap for 'humaniz[ing] indicators and chang[ing] the face of vulnerable groups, as a state policy.' All eight objectives are aligned with the SDGs but 60% of total investment is devoted to 'guarantee[ing] a decent life with equal opportunities for all' (see chapter 7).

Bolivia's *Voluntary National Review* (2015) of its progress towards the SDGs set out the concept of *Bien Vivir* (Living Well), defined as 'the civilizational and cultural alternative to capitalism, linked to a comprehensive vision […] in harmony with nature [for a] structural solution to the global climate crisis.' This report fixed the target of increasing the share of alternative energy sources in total electrical power capacity from 2% in 2010 to 9% by 2030 (see chapter 7).

Iceland's *Policy and Action Plan 2017–2019* emphasizes the role of R&D in ensuring 'quality growth' during the Fourth Industrial Revolution, as opposed to purely 'economic growth,' by taking into account the potential negative impact of technologies on future users. Although the *Policy and Action Plan* does not refer explicitly to technology assessment, this is the philosophy behind it (see chapter 11).

Iceland's *Policy and Action Plan 2017–2019* calls for citizens to be involved more closely in policy design, innovation and research. An interim report on the status of policy implementation published in late 2019 noted that the organization of public consultations had brought research priorities closer to the needs of Icelanders. These consultations revealed that Icelanders were most preoccupied by the state of the environment.

Smart specialization seeking to boost regional autonomy

One challenge for all countries will be to ensure that national economic growth benefits all regions. Research and innovation are often concentrated in conurbations. There is growing interest in a place-based approach to innovation, or smart specialization, to give regions greater autonomy.

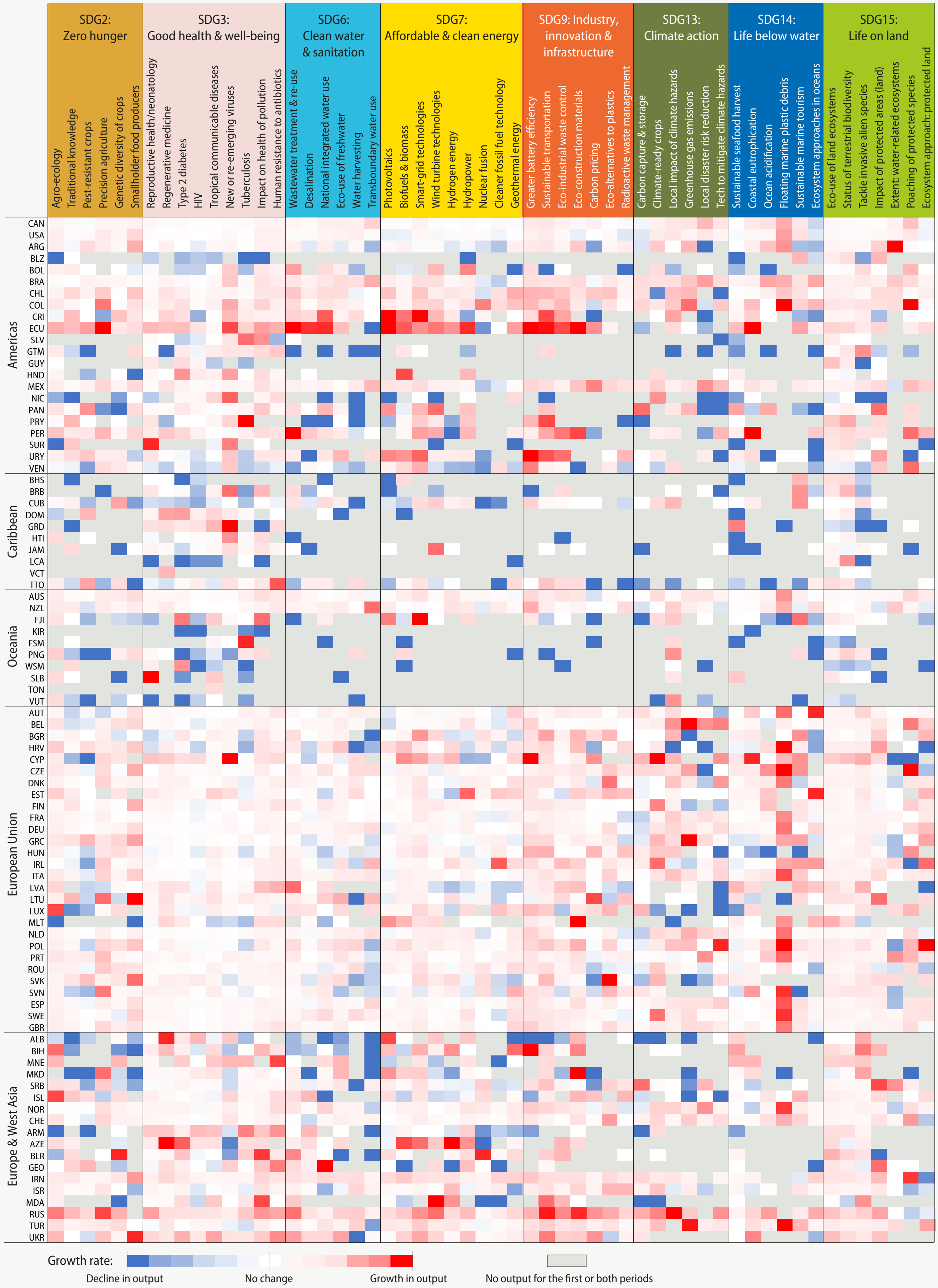
In the EU, receipt of resources from the European Regional Development Fund over the 2014–2020 period was conditional on member states developing smart specialization strategies for their regions, with the choice of technologies falling to local entrepreneurs. Regions with a similar specialization have been co-operating within thematic platforms on industrial modernization, energy and agrifood. The great majority of regions have chosen sustainable energy as one field for their smart specialization strategy.

Countries in Southeast Europe are developing their own smart specialization strategies in collaboration with the European Commission, as a prerequisite for integrating the EU (see chapter 10). The Commission is also collaborating with the United Nations on integrating this concept into implementation of the SDGs (see chapter 9).

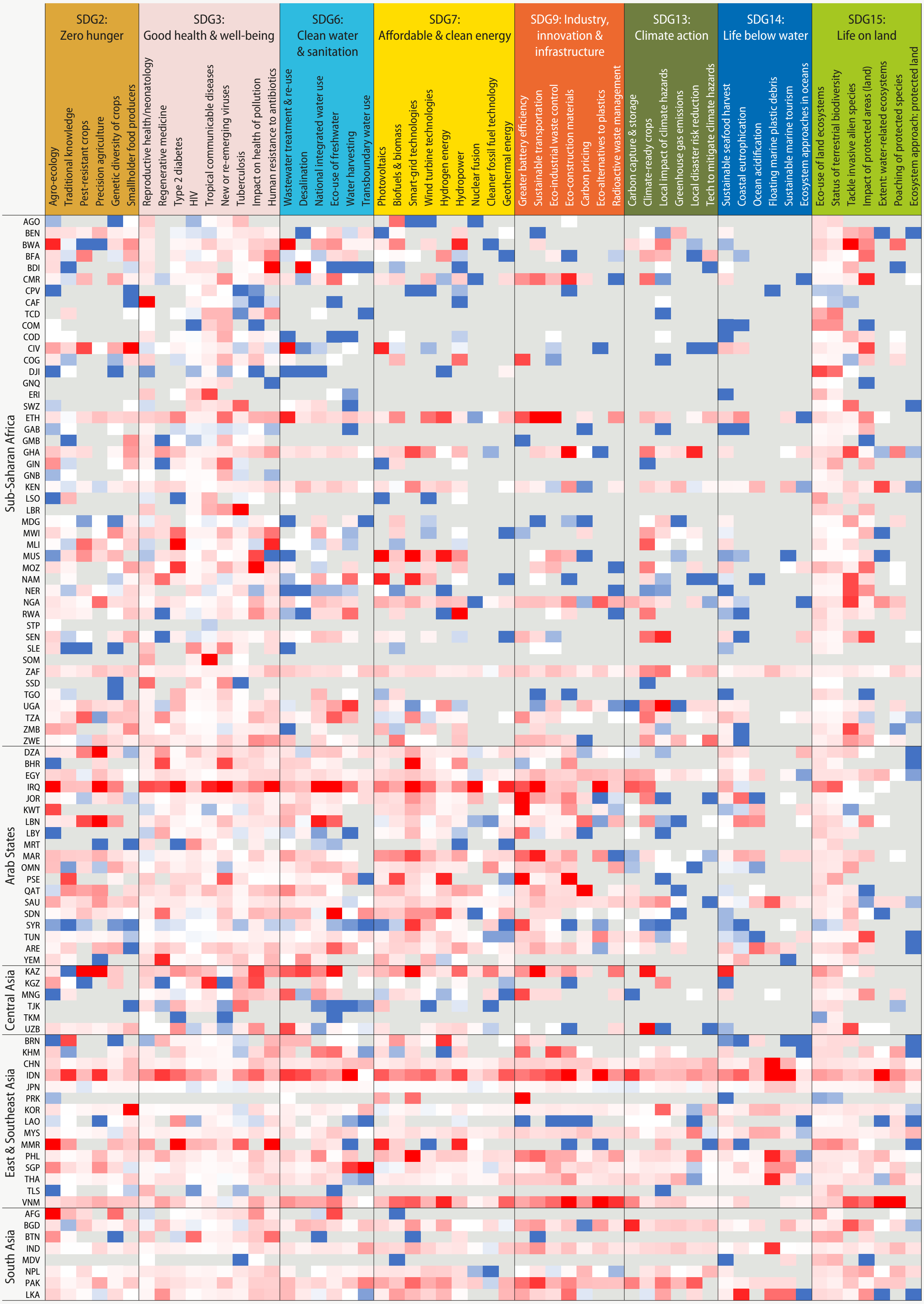
Fostering greater regional autonomy is a priority for the Republic of Korea, a highly centralized state. In 2017, each province was invited to create specialized clusters around their own priorities, under the *Fourth National Plan for the Regional Development of Science and Technology 2013–2017*. The development of these clusters has been supported by the relocation to the provinces of public institutions, including state-owned enterprises and government-supported research institutes (see chapter 25).

Panama has also adopted a smart specialization approach to defining territorial agendas for innovation in its *Strategic Plan 2019–2024*. Importantly, the plan also proposes

Figure 1.7: **Heatmap showing change in scientific publishing on 56 topics related to the Sustainable Development Goals, 2012–2019**



Note: The growth rate is calculated as the number of publications from 2016–2019 divided by the number of publications from 2012–2015. For country codes, see www.iso.org/iso-3166-country-codes.html. Countries with fewer than 120 000 inhabitants are not shown. The full dataset is freely available from the *UNESCO Science Report* web portal.



Source: Scopus (Elsevier), including Arts, Humanities and Social Sciences; data treatment by Science-Metrix

doubling gross domestic expenditure on R&D (GERD) to 0.33% of GDP by 2024 (see chapter 7).

The Russian Federation is decentralizing research to selected regions to create a 'new geography of Russian science'. The objective is to set up world-class research and education centres in selected regions, in order to develop new competitive technologies and products and train professionals in line with each region's smart specialization profile. These centres will be organized into consortia grouping leading research institutes and universities, in collaboration with interested businesses (see chapter 13).

Mission-oriented policies a new focus for Europe

Latin America has been a pioneer of mission-oriented policies. These were first introduced by Brazil two decades ago in the form of sectoral funds then emulated by other countries in the region, including Argentina, Colombia, Mexico and Uruguay. Sectoral funds are a key source of government research funding for strategic industries that may include agriculture, energy, environment, software development and health. Research by these targeted industries is irrigated via government taxes levied on specific industrial or service sectors, such as energy utility companies or casinos. In 2020, the Mexican government decided to eliminate the country's own sectoral funds as part of a curb on allocating resources to promote business innovation (see chapter 7).

In 2020, the EU embraced its own form of mission-oriented policies. Horizon Europe, the bloc's seven-year framework programme for research and innovation to 2027, introduces five concrete missions, each accompanied by specific targets: adaptation to climate change, including societal transformation; cancer; climate-neutral and smart cities; healthy oceans, seas, coastal and inland waters; and, lastly, soil, health and food. One target is to achieve 100 climate-neutral cities in the EU by 2030, a mission that will require innovation across sectors, such as by combining new solutions for transportation, digital management and electric vehicles (see chapter 9).

Meanwhile, the Russian *Strategy for the Development of Science and Technology* to 2035 (2016) has been touted as a new national policy model. It fixes seven mission-oriented priorities, namely: digital manufacturing; clean energy; personalized medicine; sustainable agriculture; national security; infrastructure for transportation and telecommunications; and readiness for the future (see chapter 13).

TRENDS IN RESEARCH EXPENDITURE

Science has become synonymous with modernity

Over the past five years, science, technology and innovation have become synonymous with economic competitiveness and modernity, as developing countries seek to diversify their economies and make them more knowledge-intensive.

Perhaps the most spectacular illustration of this trend is the United Arab Emirates' space programme, which launched the Hope probe towards Mars in July 2020, just six years after the birth of the national space agency. As it does not yet have a rocket-launching capability, the United Arab Emirates is partnering with leaders in space technology to realize its agenda, including with companies from the Republic of Korea and Japan. The Hope probe was designed and manufactured through a partnership between the Mohammed bin Rashid Space Centre and the Laboratory for Atmospheric and Space Physics in the USA (see chapter 17).

The United Arab Emirates almost doubled its research intensity to 1.30% of GDP between 2014 and 2018 (Figure 1.2). It now accounts for 0.42% of global research spending. Over the same period, the number of full-time equivalent (FTE) researchers surged by 20% to 2 379 per million inhabitants (Figure 1.3), well above the global average (1 368). The lead scientist on the Hope Project is 33 year-old Dr Sarah Al-Amiri and the average age of scientific and technical staff at the Mohammed bin Rashid Space Centre is 27 years. The share of Emirati publications in physics and astronomy with international co-authors progressed from 76% to 80% between 2015 and 2019, in line with the global trend towards greater international scientific collaboration (Figure 1.4).

Research investment has outpaced economic growth

The United Arab Emirates is one of 32 countries which boosted growth in global research expenditure between 2014 and 2018 (Figure 1.8). Over this period, global research spending (in PPP$ billions, constant 2005 prices) rose by 19.2%, outpacing the growth of the global economy (+14.8%). This translated into a rise in research intensity from 1.73% to 1.79% of GDP.

Almost half (44%) of this rise was driven by China alone (Figure 1.8). Without China, growth in research expenditure between 2014 and 2018 (13.6%) would still have outpaced economic growth (12.0%) but by a much smaller margin.

The second-biggest contribution to growth in global research expenditure came from the USA (19.4%), followed by the EU (11.0%). The Republic of Korea (4.7%) and India (3.8%) also made sizeable contributions. Japan, on the other hand, contributed just 0.3% to global growth in R&D.

The Republic of Korea has the second-highest research intensity in the world after Israel (Figure 1.2). It is estimated that Korean investment in R&D contributed to about 40% of national GDP over the 2013–2017 period (see chapter 25).

Several ASEAN governments are investing more than before in R&D. Malaysia is on track to reach its target of devoting 2% of GDP to GERD by 2020. The Indonesian government introduced a 300% tax reduction on research expenditure for firms in 2019 (see chapter 26).

For its part, Singapore now sets aside flexible 'white space funding' for emerging sectors or unanticipated needs and opportunities, under its *Research Innovation and Enterprise 2020 Plan* (2016). This has been inspired by the example of the cybersecurity sector, which emerged during the government's 2011–2015 funding cycle. This type of contingency funding for industrial research could potentially also be activated by a pandemic (see chapter 26).

In the EU, those countries which are leaders in innovation have, on average, a research intensity close to, or above, 3%; they are also the most advanced in terms of their transition to green and digital economies. Denmark and Germany have recently joined this group. Another 20 EU countries have fallen short of their own 2020 targets for research intensity (see chapter 9).

Looking ahead, the EU's weight in research investment will drop in the coming years. This change will be grounded not in science policy but in a geopolitical reshuffle: the departure of the UK (Brexit) reduces the bloc's research spending by 12%. Since the UK has a lower research intensity (1.72%), the bloc's average will mechanically rise without the UK from 2.03% to 2.18% of GDP (see chapter 9).

Most countries will see an artificial inflation of their GERD/GDP ratio in 2020, even if they do no more than maintain current levels of research expenditure, owing to the widespread decline in GDP during the early phase of the Covid-19 pandemic.

Research spending up in most regions

In 2018, 87% of research expenditure was concentrated in three regions: East and Southeast Asia (40%), grouping heavyweights China, Japan and the Republic of Korea; North America (27%); and the EU (19%) [Figure 1.8]. In 2014, these three regions concentrated 85% of global research expenditure.

Although gains were sometimes modest, research spending progressed in all but two regions between 2014 and 2018: Central Asia and Latin America (Figure 1.8).

Despite the stated desire of Central Asian governments to boost their research effort and investment in science and technology parks, GERD had dipped to less than 0.15% of GDP in all countries by 2018.

In Latin America, the end of the commodities boom has ushered in a period of stagnant economic growth, coupled with a drop in research intensity among the regional heavyweights of Argentina and Mexico (Figure 1.2). During the 'boom' period, investment had been channelled mainly towards economic expansion, rather than towards reinforcing existing infrastructure or supporting innovation and risk-taking.

Gains can be fragile

Lower middle-income countries have raised their global share by just 0.13% to 4.3% and that of low-income countries has stagnated at 0.10%, despite greater research spending by both income groups between 2014 and 2018.

Moreover, these gains can be fragile. By 2017, Burkina Faso had one of the highest research intensities in Africa (0.61% of GDP) but this was to be short-lived; following a spate of terrorist attacks in 2019, the government was compelled to channel most of this funding towards strengthening national security (see chapter 18). Iran devoted 0.83% of GDP to R&D in 2017 and Iranian banks and credit institutions increased their lending to knowledge-based companies by 75% in 2019. However, the USA's withdrawal from the *Joint Comprehensive Plan of Action*, or nuclear deal, in 2018 and subsequent snapback of US sanctions have created economic hardship that may undermine this trend in Iran (see chapter 15). Cuban plans to raise researchers' salaries received a setback when US sanctions were restored in 2017, three years after being lifted (see chapter 7).

Financial sustainability a challenge for African start-ups

Financial sustainability is a challenge for many of Africa's 744 tech hubs which rely on grants from development partners and international donors to survive, in the near absence of local business angels and seed capital. For instance, almost 80% of investment in Nigeria's 101 tech hubs comes from

Box 1.1: **Data gaps impeding monitoring of Sustainable Development Goals**

Available data on research expenditure and the researcher pool cannot paint a complete picture, since a minority of countries are publishing internationally compatible data.

Even though countries agreed in 2015 to monitor their progress in raising research intensity (SDG 9.5.1), and researcher density (SDG 9.5.2), as part of their commitment to reaching the Sustainable Development Goals by 2030, this undertaking has not spurred an increase in reporting of data.

On the contrary, a total of 99 countries reported data on domestic investment in research in 2015 but only 69 countries in 2018. Similarly, 59 countries recorded the number of researchers (in full-time equivalents) in 2018, down from 90 countries in 2015.*

Between 2015 and 2018, only 107 countries reported data for at least one of these four years on female researchers. Moreover, internationally comparable data are unavailable for populous countries such as Bangladesh, Brazil, China, India, Nigeria and the USA.

Even countries which have set up observatories to improve data collection and analysis are not yet surveying innovation in the private sector in many cases, leaving them with a 'blind spot' when it comes to assessing the strengths and unmet needs of the national innovation system.

The situation with regard to environment-related SDG indicators is no better. Progress towards 68% of these indicators cannot be measured for lack of data, according to *Measuring Progress: towards Achieving the Environmental Dimension of the SDGs*, published by the United Nations' Environment Programme in 2019.

These data gaps should be of concern, since policy formulation and revision need to be informed by reliable data collected on a regular basis. One cannot monitor what one cannot measure.

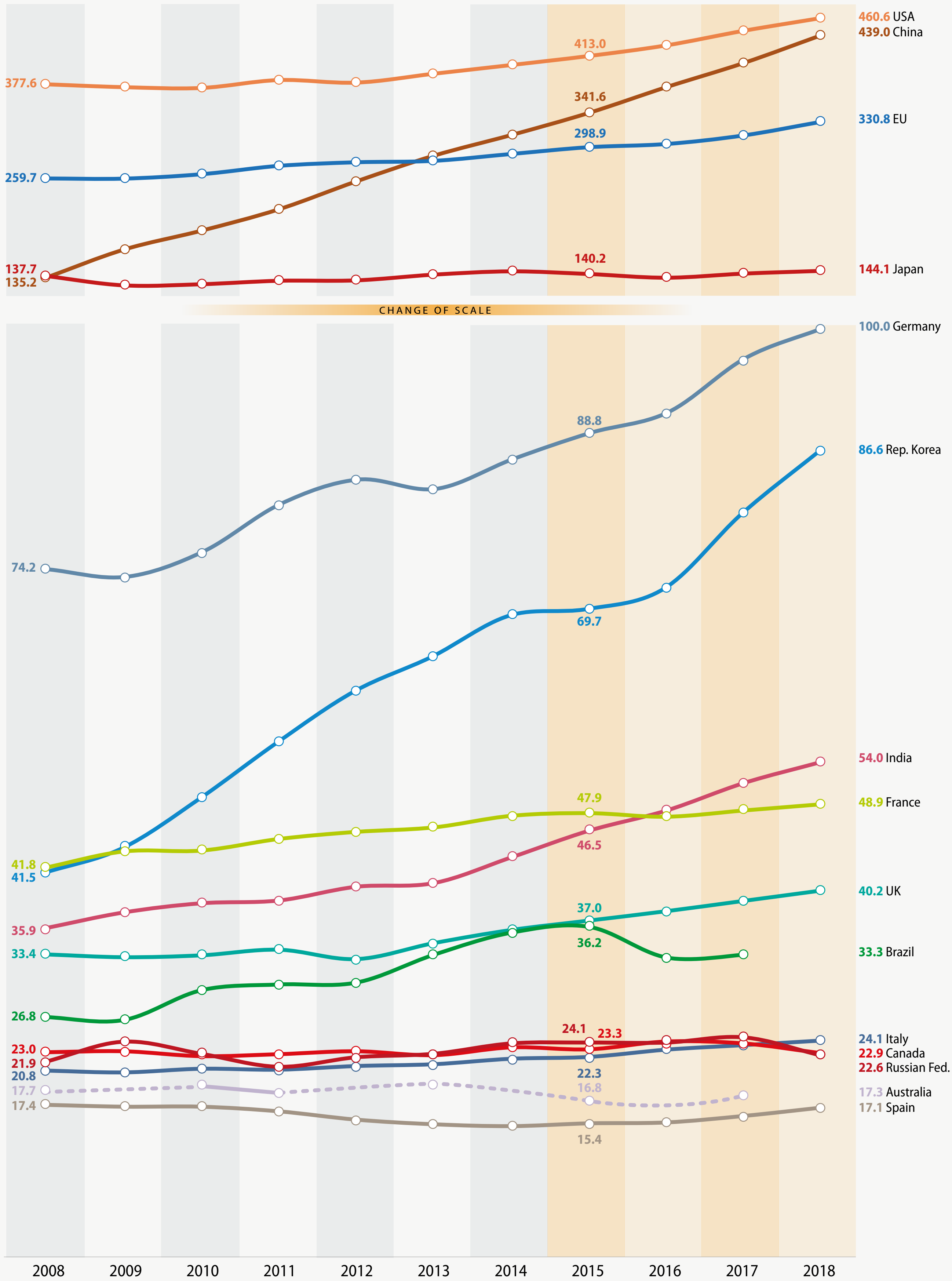
A related challenge for evidence-based policy-making concerns the omission, in many policy frameworks, of any mention of successes or failures experienced by earlier strategies. This oversight suggests that policies may not be drawing upon lessons learned from past experience.

Source: compiled by authors

*In 2018, 50 countries recorded the number of researchers (in head counts), down from 97 countries in 2015.

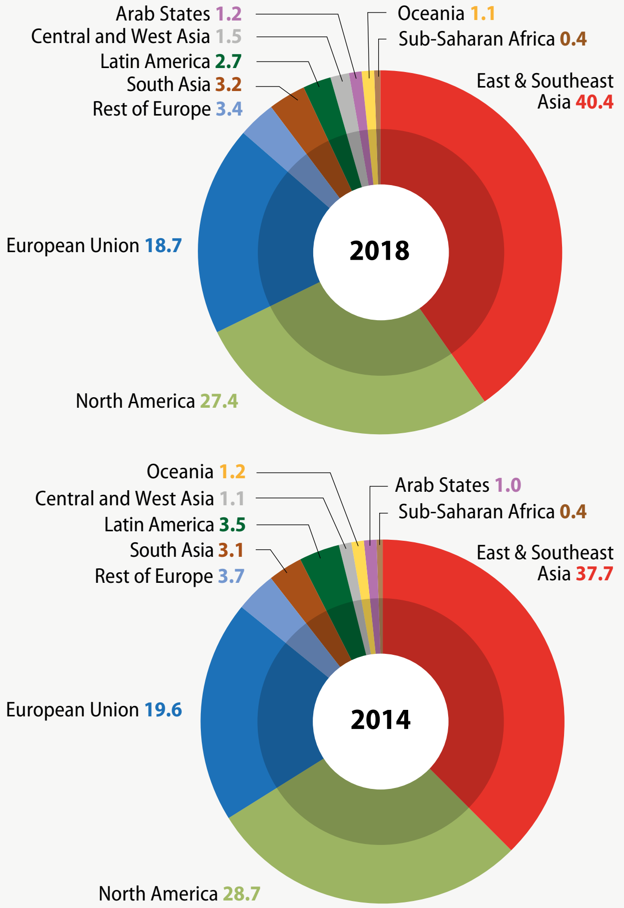
Figure 1.8: **Trends in research expenditure**

Top 15 countries for gross domestic expenditure on R&D (GERD), 2008–2018
In PPP$ billions (constant 2005 prices)

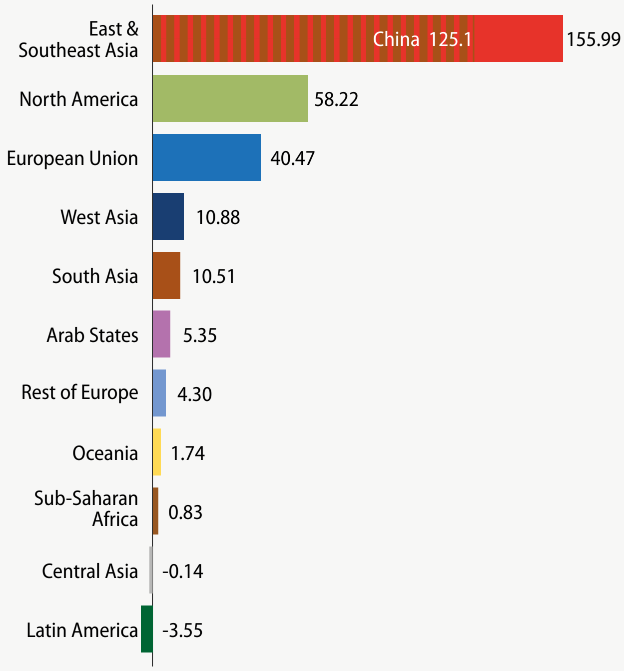


Note: Germany, France, Italy, Spain and the UK are also included in the value for the European Union (EU).

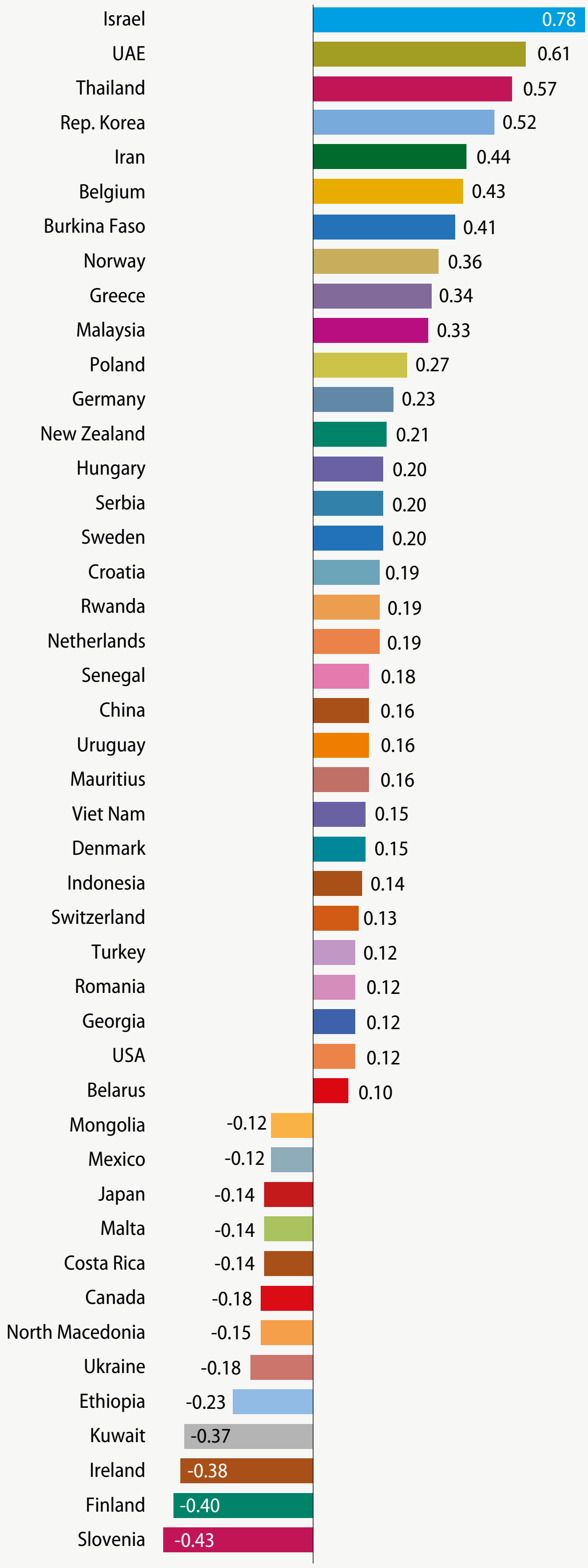
Global shares of GERD by region, 2014 and 2018 (%)



Change in research spending by region, 2014–2018
In PPP$ billions



Change in research expenditure as a share of GDP, 2014 and 2018 (%)
Among countries with a difference of at least ±0.10% of GDP



Source: global and regional estimates based on country-level data from the UNESCO Institute for Statistics, August 2020, without extrapolation

offshore sources. In 2019, the Nigerian CcHub acquired the Kenyan iHub, creating West Africa's first 'mega-incubator'. Since its inception in 2011, CcHub has incubated more than 120 early-stage ventures. Whereas CcHub has adopted a commercial model, charging for workspace and creating its own Growth Capital Fund – Nigeria's first fund targeting social innovation – iHub's donor-funded model ultimately proved unsustainable (see chapter 18).

Tunisia's Startup Act (2018) is purportedly the world's first legal framework to grant aspiring entrepreneurs a year of leave funded by the state to set up a new business, an opportunity that is open to both public and private sector employees (see chapter 17).

Under Zimbabwe's Education 5.0 programme (2018), public universities are being encouraged to work with communities and start-ups to solve local problems. The programme tasks universities with establishing an innovation and industrialization fund that draws on tuition fees and is managed by non-university staff (see chapter 20).

Efforts to boost university–industry ties

There tends to be little appetite among firms for collaboration with universities and public research institutes. So concluded a 2013 survey by the UNESCO Institute for Statistics of manufacturing firms active in innovation in 53 countries of all income levels.[8] There has been little change since. One of the countries surveyed at the time was New Zealand. A 2018 study of trends in this country found that just 1.5% of scientific publications involved co-authorship between the academic and business sectors (see chapter 26). A separate study on the same topic (see chapter 8) found a similar ratio for China over 2015–2017. The ratio of co-authorship was higher for the EU and Brazil (2.4%), USA (2.8%), the Republic of Korea (3.9%), Germany (4.4%) and France (4.5%).

In Canada, industrial research intensity declined from 0.78% to 0.63% of GDP between 2014 and 2019. The Canadian government is challenging domestic firms to enter into collaborative partnerships with public research institutions, in order to develop 'bold and ambitious' innovation strategies. In 2017, the government allocated Can$ 950 million to support five innovative 'superclusters' over the next five years, a scheme for which the private sector is required to match government funding. These superclusters specialize in next-generation manufacturing, the ocean economy, protein industries, digital technologies and AI. The latter two superclusters have both invested in leveraging technology to find solutions to the Covid-19 crisis (see chapter 4).

Armenia innovated in 2018 by issuing a call within its Targeted Projects Programme (est. 2010) restricted to research projects that involved both public institutes and industrial partners, to which the latter were obliged to contribute at least 15% of project funding.

Under the Collaborative Research and Development to Leverage the Philippine Economy Program (2016), a tertiary or research institution that forms a collaborative research partnership with at least one enterprise receives government funding up to PHP 5 million (*ca* US$ 100 000), with the partner company contributing 20% of the project funds.

In South Asia, the current push for infrastructure development and industrialization is largely taking place on a parallel path to R&D when each could be nurturing the other. Several countries are striving to incentivize public research institutions to forge ties with industry (see chapter 21).

For instance, Pakistan's Technology Transfer Support Fund (2019) provides grant funding to university laboratories that is matched by industry (see chapter 21).

Technology transfer is a priority of Sri Lanka's *National Policy Framework for the Development of SMEs* (2016), which is accompanied by a national technology development fund cofinanced by the government and private sector (see chapter 21).

Bangladesh's own *SMEs Policy* (2019) recognizes the need to give SMEs greater access to finance, markets, technology and innovation. This policy will be supported by the new Bangladesh Engineering Research Council for the commercialization of research results and adaptation of imported technology established by law in September 2020 as an outcome of the *National Science and Technology Policy* (2011).

Space industry spawning public–private partnerships

One industry with a growing appetite for public–private partnerships is space. The year 2019 marked a peak in global investment in the space economy, with firms headquartered in the USA accounting for 55% of the total. The USA was followed by the UK (24%), France (7%) and China (5%) [see chapter 5]. The African space market was estimated to be worth US$ 10 billion in 2014 (see chapter 18).

The space industry covers areas that include telecommunications, environmental monitoring and space debris monitoring (see chapter 24). On 3 January 2020, the SpaceX corporation became the first private company to launch humans into space when it transported astronauts to the International Space Station[9]. Increasingly, the US National Aeronautics Space Administration (NASA) is tasking commercial partners with developing the space economy, in order to leave the agency free to focus its own resources on deep space exploration (see chapter 5).

Japan is a relative newcomer to the 'space business'. Space companies remain dependent on government contracts for more than 80% of their revenue but this is gradually changing. The New Enterprise Promotion Department created in 2016 by the Japanese Aerospace Exploration Agency (JAXA) gives private companies access to JAXA's expertise, intellectual property and facilities to develop new products. In turn, the commercial applications developed by its industrial partners are breathing new life into JAXA's own patents and other intellectual property (see chapter 24).

The aerospace industry is also gaining traction in some developing countries. Mexican exports of aerospace products progressed by 14% per year between 2010 and 2016. Over the same period, the number of aerospace companies in Mexico rose from 241 to 330. The Querétaro Aerospace Cluster has hosted FAMEX, the biggest aerospace fair in Latin America, since 2019[10] (see chapter 7).

The *African Space Strategy* (2017) has four components: Earth observation, navigation and positioning systems, satellite communications and space science and technology. The ultimate aim is to create an African Space Agency, to be hosted by Egypt. The African Union signed a co-operation agreement with the EU's Copernicus programme in 2018 as a precursor to the launch of the African Outer Space Programme in 2019 (see chapter 19).

The weaponization of space is rapidly becoming a serious geopolitical and security concern, complicating international relations. Announced in February 2019, the Space Force, a new service of the US military, will be structured as a corps within the US Air Force. Several other countries have announced similar space commands, including China, France and the Russian Federation (see chapter 5).

Basic research: a new division of labour

Two global leaders for innovation, Switzerland (see chapter 11) and the USA (see chapter 5), have undergone a notable shift in the traditional division of labour whereby basic research is conducted and funded by the public sector while applied research and experimental development remain the preserve of the business sector. In 2017, Swiss businesses financed 27% of basic research, double the proportion in 2012. In the USA, the business sector funded 30% of basic research in 2017, up from 23% in 2010; in dollar terms, business spending on basic research has doubled since 2007 in the USA even as federal levels have remained stable (since 2011).

This trend may be partly a consequence of the avalanche of big data being generated through basic research which form an increasingly vital component of applied R&D. Big data are at the heart of tech-based companies spanning fields as varied as social media, the automotive and aeronautics industries and pharmaceuticals. AI is being used, for instance, to determine the structure of atoms and molecules for industrial applications in materials science and pharmaceuticals (computational drug design).

Big data are a vital resource for the health sector, which is a major economic driver for both Switzerland and the USA. As the cost of genome sequencing has dropped with the growing sophistication of related technologies, programmes have produced torrents of data on individual human genomes, spawning a booming pharmacogenetic industry. Precision medicine personalizes medicine by tailoring it to the patient's unique genome. In 2019, 25% of the 48 new molecular entities approved by the US Food and Drug Administration's Center for Drug Evaluation and Research were personalized medicines, according to the Personalized Medicine Coalition.

In order to analyse this burgeoning volume of data, pharmaceutical companies will become highly dependent on AI and cloud computing, obliging them to collaborate more with data giants (see chapter 5).

These trends suggest a potential for public institutions and large companies to co-finance selected joint research projects in basic science. Such a policy change would have the potential to strengthen domestic firms and attract other firms from abroad. It would also create a new layer of complexity in areas such as intellectual property protection and research freedom (see chapter 11).

TRENDS IN RESEARCHERS

Researcher density on the rise

Between 2014 and 2018, the researcher pool grew three times faster (13.7%) than the global population (4.6%). This translates into 8.854 million full-time equivalent (FTE) researchers. Without China, the surge in researcher numbers (11.5%) would have been only double the rate of population growth (5.2%).

In 2018, China accounted for 21.1% of global researchers, just shy of the EU's own share of 23.5%. The USA contributed a further 16.2% (2017).

Low-income economies have witnessed the fastest growth (+36%) in researcher density since 2014 but still account for only 0.2% of the world's researchers.

Some of the greatest percentage changes are occurring in developing countries such as Jordan, Mauritius, Iran and Ethiopia (Figure 1.9).

In 2014, Latin America crossed the symbolic threshold of counting one researcher per 1 000 labour force. Three years later, the regional average had inched up to 1.03. Argentina had the largest proportion of researchers (2.91), followed by Brazil, Chile, Costa Rica and Uruguay. Stagnating growth in research intensity in some countries could compromise these gains.

Measures to boost the status of researchers

Brain drain remains a chronic problem for many countries with low or stagnating research expenditure. In Central Asia, governments confronted with brain drain and an ageing researcher population are seeking to improve the status of researchers through measures such as pay rises, competitive research grants and greater interaction with institutional partners abroad (see chapter 14).

Brain drain is a severe problem in Southeast Europe, with the young being drawn to the more prosperous EU countries. With scientific and technical skills underutilized in the economy, governments are vowing to invest more in research and innovation from now on. Serbia is on the verge of reaching its own 1% target for research intensity (see chapter 10).

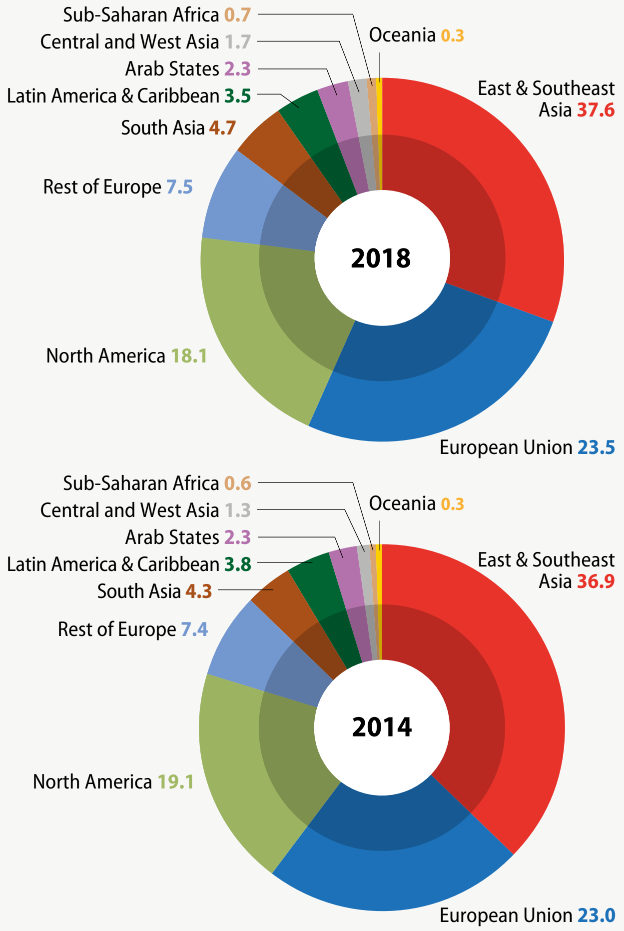
Between 2014 and 2018, Russian research spending dropped by 6% in constant prices and the researcher pool (in FTE) shrank by 9.5%. By 2018, the average age of Russian researchers was 47 years and almost one in four had reached retirement age. The introduction of wage growth policies and various research grant programmes targeting the younger age group is designed to inverse this trend (see chapter 13).

Women a minority in Industry 4.0 fields

Women accounted for one in three (33%) researchers in 2018. They have achieved parity (in numbers) in life sciences in many countries and even dominate this field, in some cases. However, they make up just one-quarter (28%) of tertiary graduates in engineering and 40% of those in computer sciences. Just 22% of professionals working in the field of AI are women. The irony is that these fields are not only driving the Fourth Industrial Revolution; they are also characterized by a skills shortage. Women remain a minority in technical

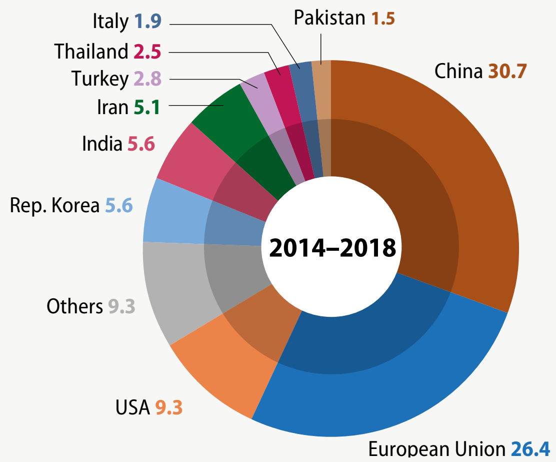
Figure 1.9: **Global trends in researchers (FTE)**

Global shares of researchers by region, 2014 and 2018 (%)



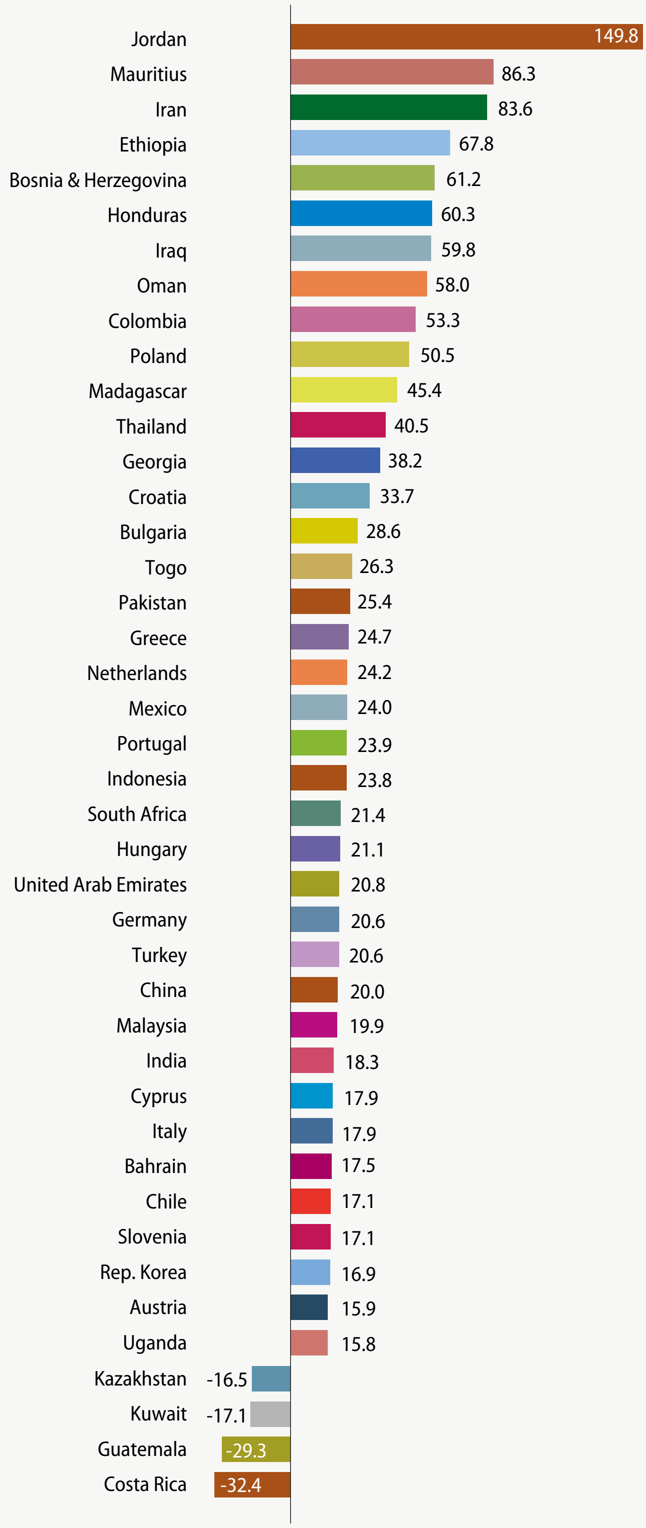
Contribution to growth in the number of researchers worldwide, 2014–2018 (%)

Top ten contributors and rest of the world



Change in researchers (FTE) per million inhabitants, 2014–2018 (%)

Among countries with a change of at least 15%



Source: global and regional estimates based on country-level data from the UNESCO Institute for Statistics, August 2020, without extrapolation; for population: World Bank's World Development Indicators, August 2020 and leadership roles in tech companies. In the USA, the main reason given by women for leaving their job in the tech world is a sense of being undervalued (see chapter 3).

Fewer than one in four researchers in the business world is a woman and, when women start up their own business, they struggle to access finance. In 2019, just 2% of venture capital was directed towards start-ups founded by women. Countries have introduced measures to support female entrepreneurs. For example, Chile introduced the Human Capital for Innovation in Women's Enterprises scheme in 2018. It provides tech-based start-ups founded by women with cofinancing of up to 30 million pesos (*ca* US$ 40 000) to help them hire staff for a given project, covering 80% of the hiring cost for men and 90% for women (see chapter 3).

TRENDS IN PATENTING

China opening up domestic market

China received the most patents from the top five patent offices in 2019: 29% (Figure 1.10). The USA (20%) and EU (14%) held steady, whereas Japan's share slipped to 18% from 23% in 2015. The trend in Japan may be tied to the decision by the Japanese Patent Office to raise fees to encourage inventors to be more selective in their patent applications.

There tends to be a close correlation between the size of a country's research intensity and its innovative performance. In most countries with a high research intensity, the business enterprise sector contributes more than half of research expenditure. In 2018, Japan and the Republic of Korea had a research intensity of 3.3% and 4.5%, respectively. The business enterprise sector funded 78% in Japan and 76% in the Republic of Korea (see chapters 24 and 25). These countries have the highest patent intensity in the world (Figure 1.11).

With the Foreign Investment Law, which came into effect on 1 January 2020, the Chinese government has passed landmark legislation to open up the domestic market and level the playing field for foreign businesses competing with state-owned enterprises and private firms.

The issue of intellectual property protection and enforcement has complicated trade talks between China and the USA for some time but China's own strategic industries expect better government protection of their intellectual property. Consequently, the Anti-Unfair Competition Law was amended in April 2019 and the Patent Law in 2020. The establishment of the first courts specializing in intellectual property in Beijing, Shanghai and Guangzhou in late 2014 was followed by 20 specialized tribunals across several provinces between 2017 and 2020 and a new national-level intellectual property court within the Supreme People's Court on 1 January 2019 (see chapter 23).

Reforms to make it easier to patent

A growing interest in innovation is leading more governments to enact legislation to make it easier for start-ups and other companies to protect their intellectual property (e.g. Liberia, Myanmar, Namibia, Uzbekistan, Viet Nam). For instance, the Liberia Intellectual Property Act in 2016 followed the Liberia Innovation Fund for Entrepreneurship in 2015, financed jointly with the Government of Japan. Between 2015 and 2019, 23 patents were granted by the top five patent offices to Liberian inventors. In 2018, ministers of the Southern African Development Community adopted a subregional Intellectual Property Framework to foster mutual co-operation on reforming national intellectual property regimes.

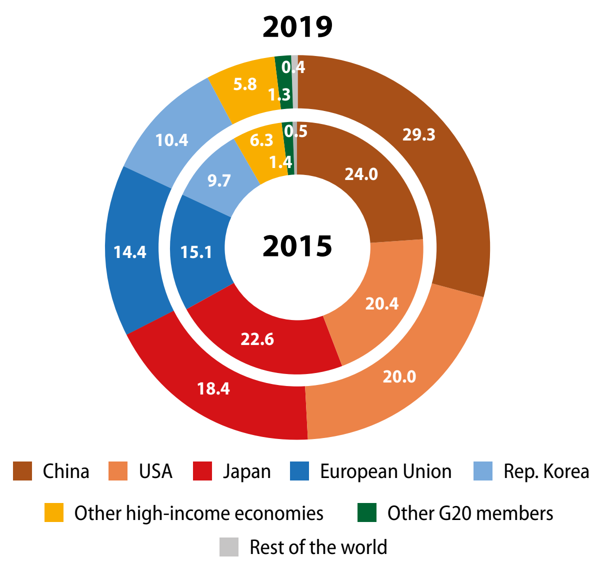
Around the world, procedures for filing patent applications can be complex and the cost of patenting high. European companies currently need to file for patent protection in all 27 member states. Once the process of ratification of the agreement for a Unified Patent Court (2013) is complete, companies will only need to file the unitary patent once with the European Patent Office. Procedural fees are, consequently, expected to drop (see chapter 9).

Between 2015 and 2018, there was a decline in the number of patent applications filed by domestic inventors at the Russian Federal Service for Intellectual Property (Rospatent). In response to the downturn, the government has reduced patent duties for applicants and offered tax cuts to alleviate the cost of patenting, loans and credit guaranteed by intellectual property rights. Subsidies are available to those filing patent applications abroad (see chapter 13).

In Africa, the high cost of registering intellectual property and lack of a common system is hindering patenting, despite the surge in tech hubs. This problem is unlikely to be resolved in the near future, since the Pan-African Intellectual Property Organization is taking longer than expected to become operational. It costs over US$ 37 000 at the African

Figure 1.10: **Share of global IP5 patents, 2015 and 2019 (%)**

Top four countries and selected groupings



Note: Patent counts are based on the full-counting method, according to the countries of inventors and years in which the patents were granted by the five patent offices, namely the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China. The sum across countries/regions is higher than the world total because of co-inventorship.

Source: PATSTAT; data treatment by Science-Metrix

Regional Intellectual Property Organization and US$ 30 000 at the Organisation africaine de la propriété intellectuelle to register and maintain a 30-page patent for the first ten years. This compares with US$ 5 216 in South Africa, US$ 4 330 in Malaysia and just US$ 2 500 in the UK (see chapter 19).

Start-ups being snapped up by foreign multinationals

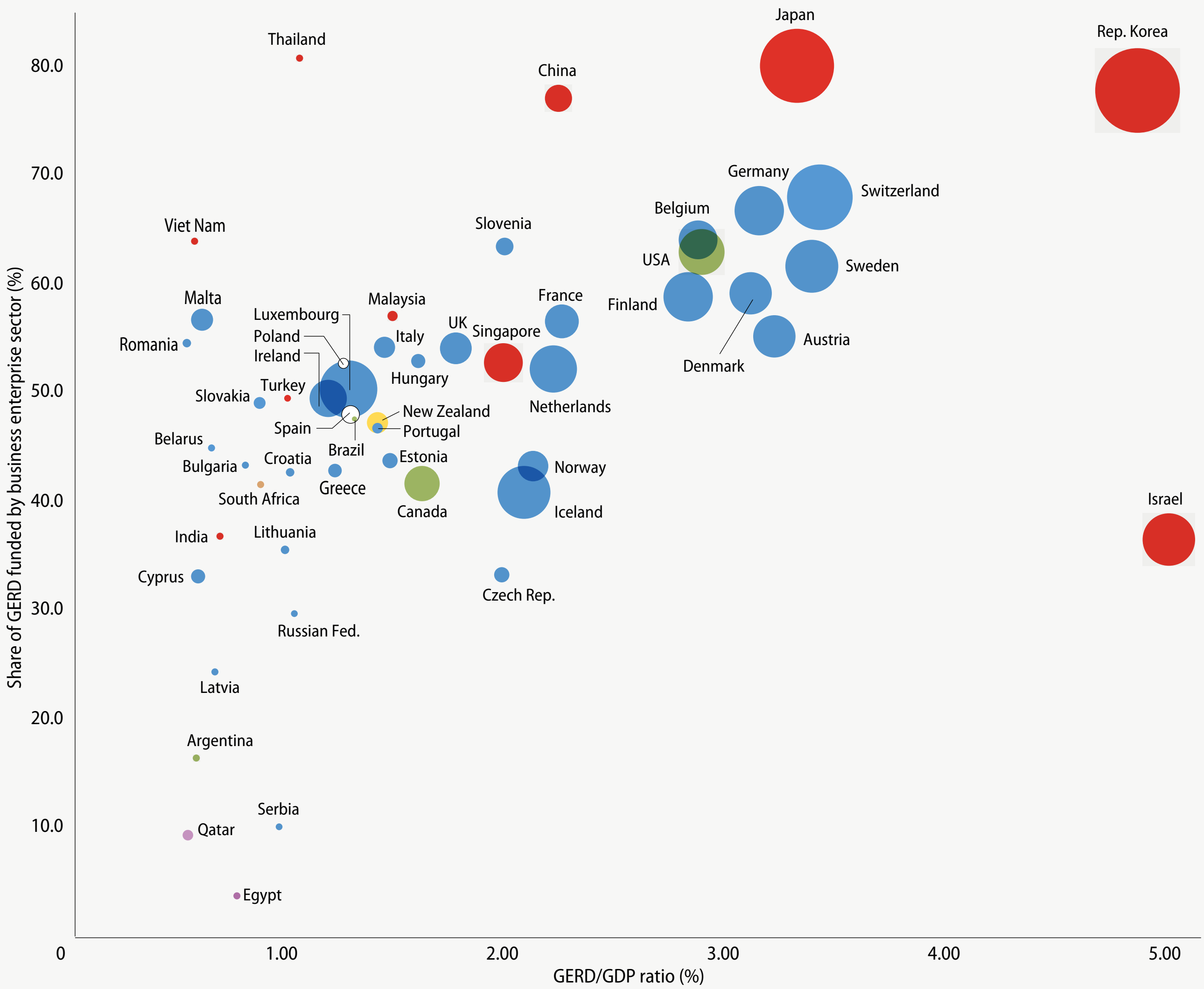
Fewer than half of the patents obtained by inventors from Israel are owned by Israeli companies. This means that knowledge is being created in Israel then transferred to a foreign company. Increasingly, Israeli intellectual property is being obtained by means of the acquisition of Israeli firms and start-ups. The most active corporate buyers of Israeli companies since 2014 have been Google, Microsoft and Intel. The potential consequences of this growing trend are that production and jobs could both migrate abroad (see chapter 16).

In Canada, foreign-controlled firms account for one-third of all in-house R&D. Industry is increasingly outsourcing research abroad: outsourced research expenditure by companies in Canada rose for the third consecutive year to Can$ 4.9 billion in 2017, according to Statistics Canada. Although macro-economic conditions and the regulatory environment appear to be conducive to business creation and development, Canada's promising start-ups are often being acquired and developed in other countries. Survey evidence from Canadian firms and technology stakeholders also suggests that a lack of managerial talent and experience in expanding domestic technology firms to scale is a critical impediment (see chapter 4).

Figure 1.11: **Mutually reinforcing effect on patenting of strong research investment by government and industry, 2018 or closest year**

Among countries with at least 100 granted IP5 patents and a research intensity of at least 0.5% of GDP in 2018

The size of circles is proportionate to the number of IP5 patents per million inhabitants



Note: The contribution from the business enterprise sector may be an underestimate for countries that do not comprehensively survey this sector.

Source: UNESCO Institute for Statistics; for patents: PATSTAT, data treatment by Science-Metrix

Developing countries with innovative industries are also affected by this phenomenon. Most patents in India concern pharmaceuticals and information technology. About 85% of assignees of patents issued by the Indian Patent Office and US Patent and Trademark Office are foreign inventors, commonly represented by multinational corporations specializing in digital technologies (see chapter 22).

Relinquishing patent rights for the common good

Leading tech companies like IBM are donating some of their patents to open-source initiatives, following the global trend towards more open knowledge-sharing (see chapter 20 and The time for open science is now, p. 12).

On 29 May 2020, Costa Rica and the World Health Organization launched a voluntary Covid-19 Technology Access Pool. It calls upon the global community to pool related knowledge, intellectual property and data in an online repository (see chapter 7).

TRENDS IN SCIENTIFIC PUBLISHING

Strong growth in cross-cutting technologies

Health research continues to dominate scientific output, accounting for 33.9% of publications in 2019. Among broad fields, environmental sciences showed the fastest growth between 2015 and 2019 (+45.7%), albeit from a low starting point: 3.6% of global output in 2015.

There was a general trend over this period towards more intense scientific publishing, with global output being 21% higher in 2019 than in 2015. Publications on cross-cutting strategic technologies even surged by 33% (Figure 1.12).

These trends extend to lower-income and low-income countries, which recorded some of the fastest growth rates in both publication categories. Scientific output overall grew by 71% among low-income countries and surged by 170% for cross-cutting technologies (Figure 1.12).

Cross-cutting technologies accounted for 18% of global scientific output in 2019, led by AI and robotics (Figure 1.13).

Between 2015 and 2019, the shares of China, the EU and USA in AI and robotics receded as developing countries boosted their own output in this field (Figures 1.6 and 1.13).

The second-most popular cross-cutting technologies relate to energy, followed by materials science (Figures 1.5, 1.14 and 1.15). Energy is the top field for China, Egypt, the Republic of Korea, Saudi Arabia and South Africa, for instance. Materials science ranks first for both Indonesia and the Russian Federation.

The fourth-fastest-growing field is nanoscience and nanotechnology, thanks largely to China, which produced just under half of all publications in this field in 2019 (Figure 1.6).

There were just 18 000 publications in biotechnology in 2019. This compares with 148 000 publications in AI & robotics over the same period, to which countries from all income groups contributed.

Rapid shifts in the publishing landscape

In 2019, the EU (28.6%), China (24.5%) and USA (20.5%) combined contributed to three-quarters of global scientific production. A further 13 countries accounted for 1% or more of publications: India (6.1%), Japan (4.5%), the Russian Federation (3.7%), Canada (3.6%), Australia (3.3%), the Republic of Korea (3.1%), Brazil (2.8%), Iran (2.3%), Turkey (1.6%), Switzerland (1.5%), Indonesia (1.4%), Malaysia (1.1%) and Saudi Arabia (1.0%).[11]

Looking forward, the EU will feel the UK's loss through Brexit most keenly in terms of scientific output, as the UK has the highest publication intensity in the bloc. In return for an upfront financial contribution, UK scientists will still be entitled to compete for grants in basic research from the European Research Council (ERC) from 2021 onwards but without the right to influence the shape of this key research programme. Between 2014 and 2020, the UK was the greatest beneficiary of ERC grants and a magnet for European talent: 43% of ERC grantees based in the UK in 2020 were citizens of this country and a further 37% were EU citizens (see chapter 9).

In Latin America, Ecuador's scientific output showed the fastest growth rate (152%). Over the dual periods 2012–2015 and 2016–2019, Ecuador's output on AI and robotics grew ninefold, one of the highest rates in the world (Figure 1.13).

There has been a substantial rise in Indonesia's share of global output (0.15% in 2011 and 0.3% in 2015) and in that of Saudi Arabia (0.43% in 2011 and 0.81% in 2015).

In 2017, the Indonesian government linked the publication of research in international, indexed journals to the review of scientists' career performance. As Indonesian output soared, the proportion of that output with foreign collaborators shrank, accelerating an already precipitous decline from the 2012 peak of 55% to merely 17% of publications having foreign co-authors by 2019.

Strong growth in scientific publications in Saudi Arabia (+43% between 2015 and 2019) can be linked to the policy whereby Saudi universities recruit highly cited foreign scientists. In 2019, 76% of Saudi publications had foreign co-authors.

Out of almost 6 100 highly cited researchers worldwide in 2018, only about 90 were based at universities in the Arab world, mostly in Saudi Arabia, and just six highly cited researchers originated from the Arab region, according to a study of the Web of Science database (see chapter 17).

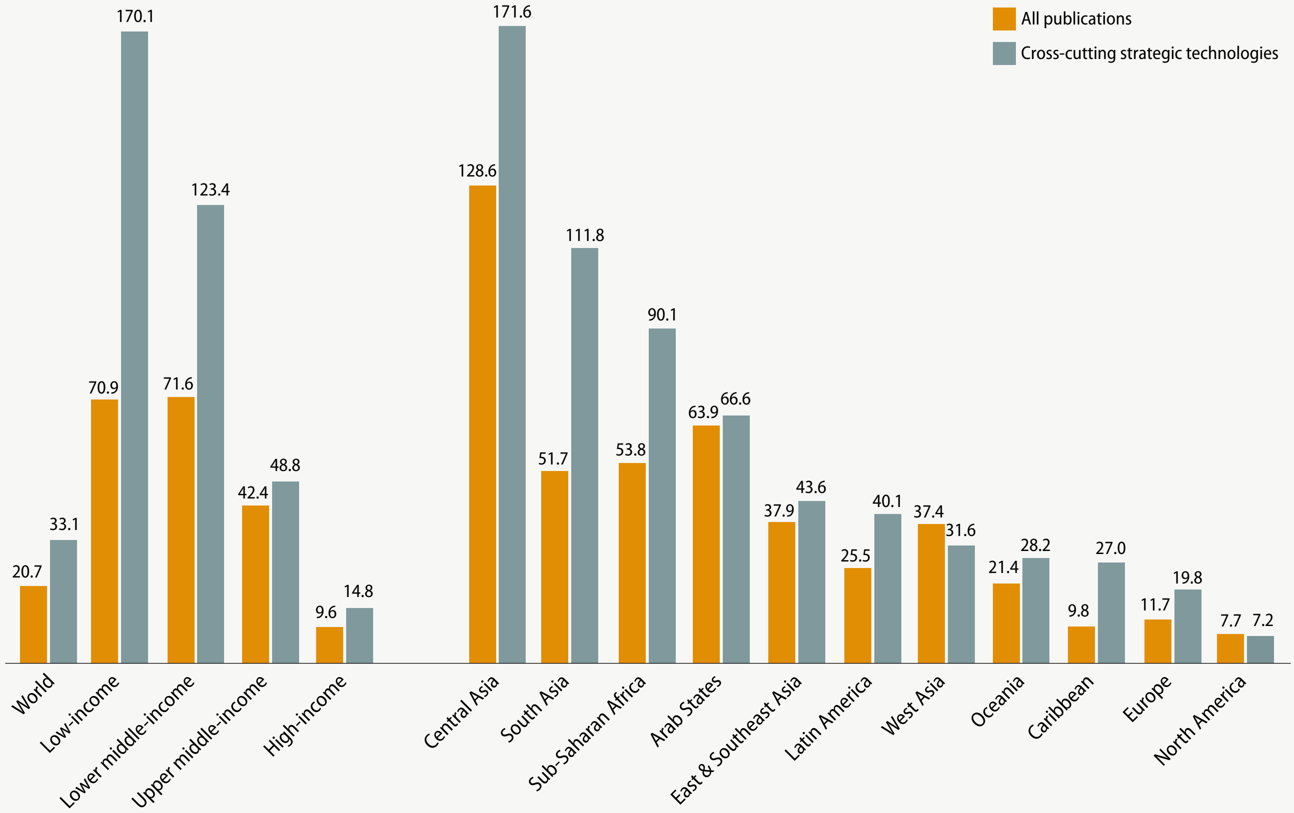
TRENDS IN INTERNATIONAL SCIENTIFIC COLLABORATION

More international scientific collaboration

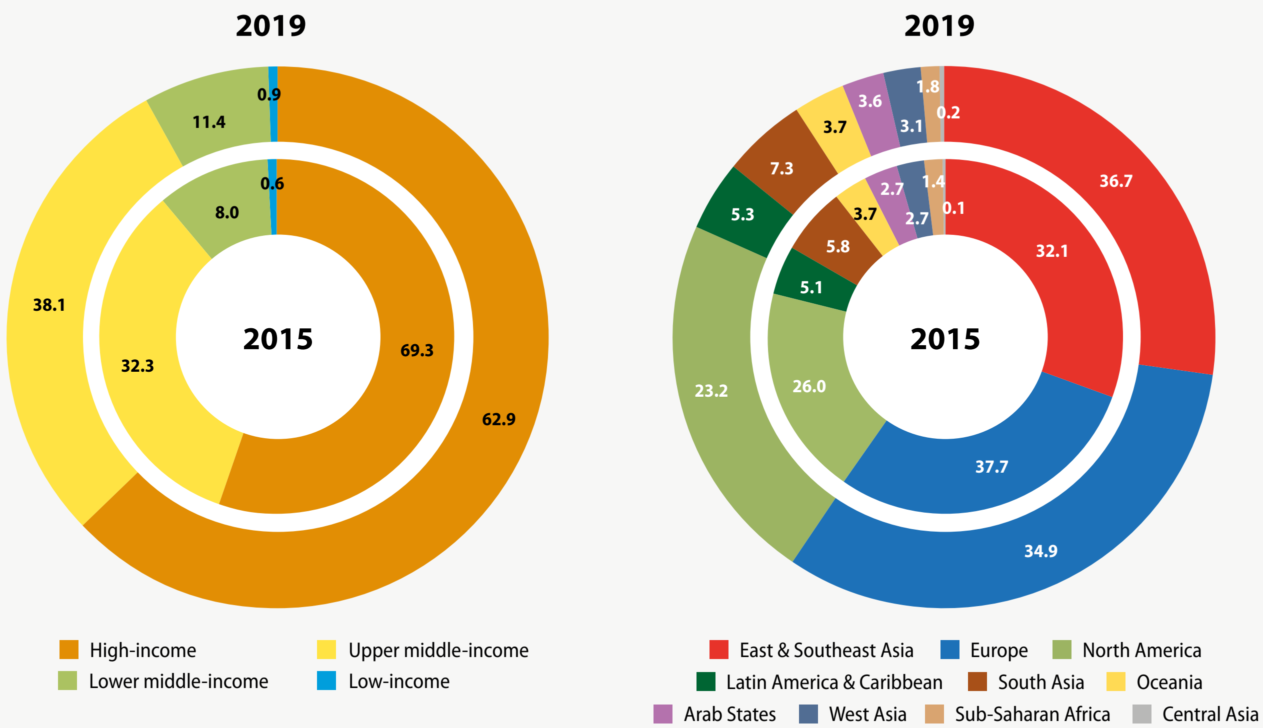
At the global level, the rate of international scientific collaboration rose from 22% to 24% between 2015 and 2019 (Figure 1.4). This average masks wide disparities among income groups and countries. Growth was fastest in high-income countries (from 30% to 36%). In the EU, the share of papers co-authored with third countries surged from 41% to 47%. In the USA, international scientific collaboration has risen from 36% to 41% and is now on par with the average for Latin America, suggesting that scientific collaboration has not been dented by the US retreat from the multilateral system since 2017 under the America First policy agenda

Figure 1.12: **Global trends in scientific publishing**

Change in volume of output, 2015–2019 (%)
By income group and region



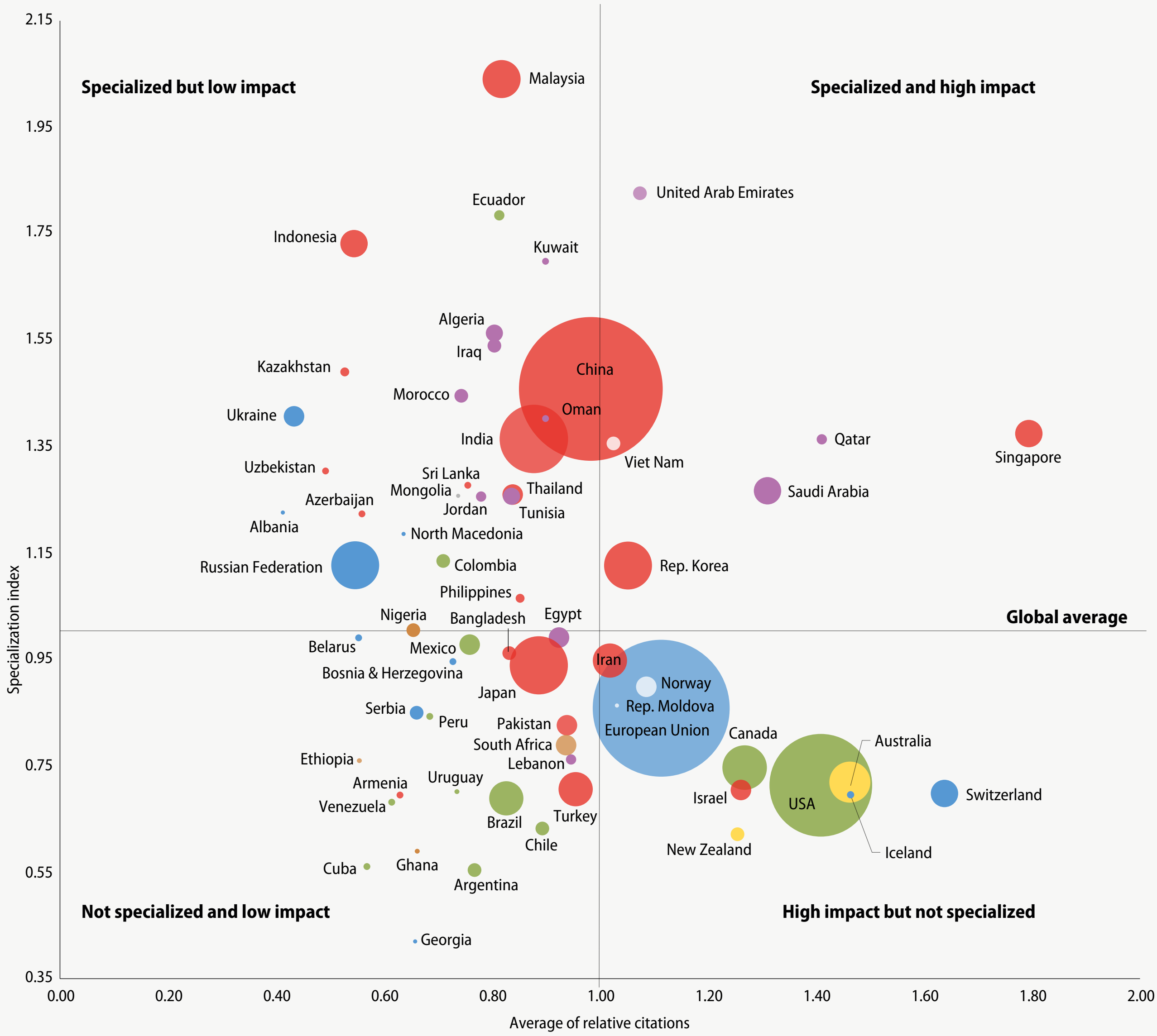
Global shares of scientific publications, 2015 and 2019 (%)
By income group and region



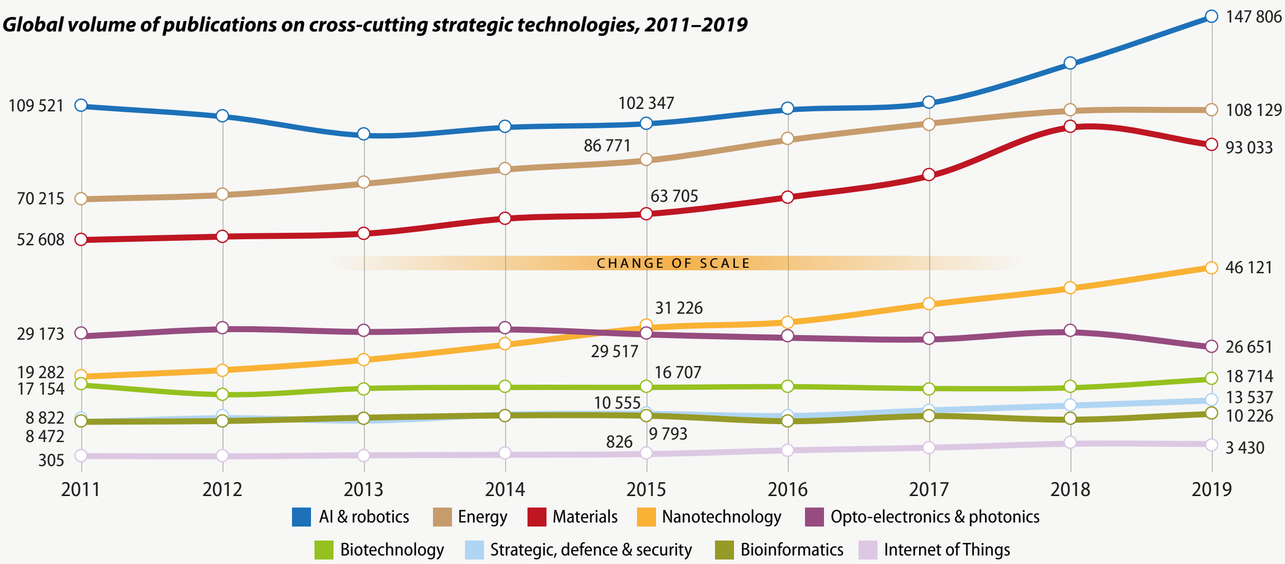
Source: Scopus (Elsevier), excluding Arts, Humanities and Social Sciences; data treatment by Science-Metrix

Specialization and average of relative citations for cross-cutting strategic technologies by country and region, 2011–2019

Among countries with at least 1 000 publications in this broad field over 2011–2019. The size of the circle is proportionate to the volume of publications



Global volume of publications on cross-cutting strategic technologies, 2011–2019



Note: The sum of the numbers for the various regions exceeds the total number because papers with multiple authors from different regions are counted for each of these regions. Cross-cutting strategic technologies encompass AI and robotics, bioinformatics, biotechnology, blockchain technology, energy, Internet of Things, materials, nanoscience and nanotechnology, opto-electronics and photonics and strategic, defence and security studies. No Scopus-indexed journal specialized in blockchain technology published papers prior to 2018. AI stands for artificial intelligence.

Source: Scopus (Elsevier), excluding Arts, Humanities and Social sciences; data treatment by Science-Metrix

(see chapter 5). China and the USA remain one another's top international scientific partners, despite tensions over trade and technology (see chapters 5 and 23).

In low-income countries, the level of international scientific collaboration remains high (from 72% to 70%). The modest ratios for China (23%) and India (19%) in 2019 (Figure 1.4) explain the lower average for upper middle-income and lower middle-income countries, respectively. Of note is that China has become one of India's top five scientific partners (see chapter 22).

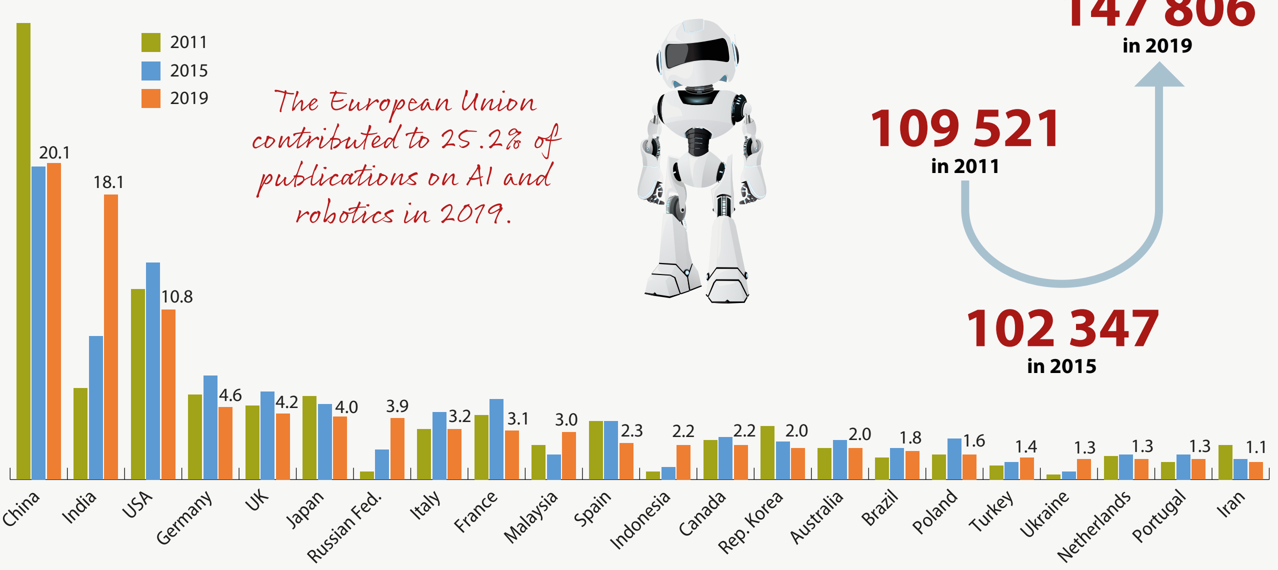
The Russian Federation has bucked the global trend, with its own level of international scientific collaboration having dropped from 27% to 24% over the 2015–2019 period (Figure 1.4).

South and Southeast Asia have the lowest levels of international scientific collaboration, at less than 25% on average. Iran has forged closer international scientific ties since 2015, with the ratio of co-authored publications surging from 21% to 28% (Figure 1.4); this trend may be a consequence of the lifting of economic sanctions in 2016.

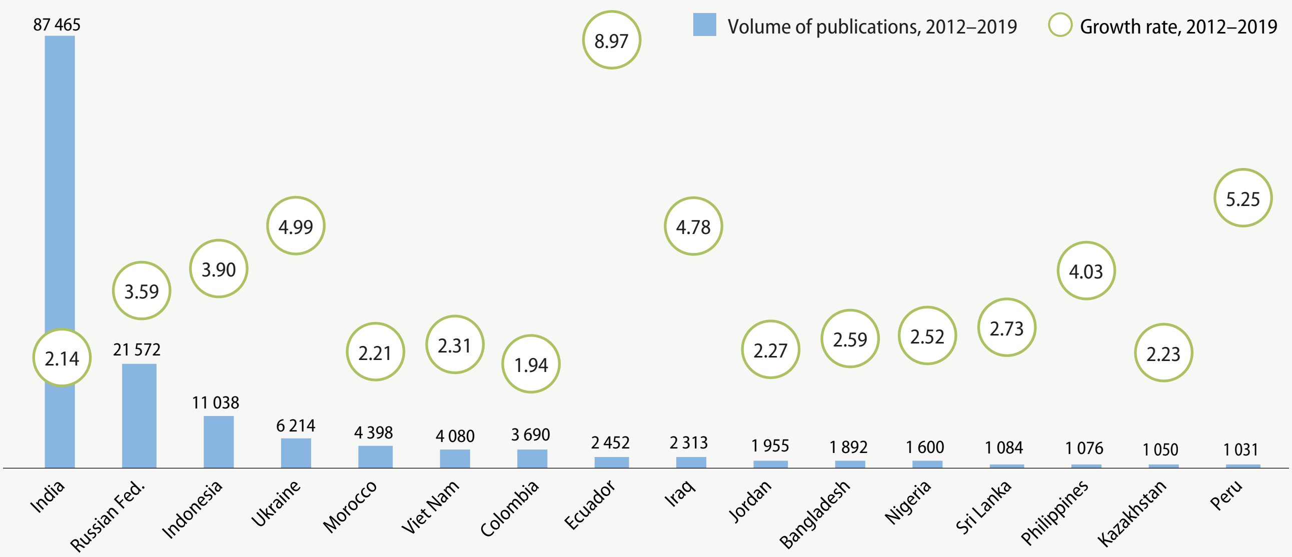
Figure 1.13: **Trends in scientific publishing on artificial intelligence and robotics**

Share of global publications on AI & robotics, 2011, 2015 and 2019 (%)
Among countries contributing to at least 1% in 2019; data labels are for 2019

Global publications on AI & robotics



Top 15 countries for growth rate in scientific publishing on AI and robotics, 2012–2019
Among countries with at least 500 publications, arranged by volume



Note: The growth rate is calculated as the number of publications from 2016–2019 divided by the number of publications from 2012–2015.

Source: Scopus (Elsevier), excluding Arts, Humanities and Social sciences; data treatment by Science-Metrix

Malaysia (44% in 2019), Pakistan (56%) and Singapore (71%) have some of the highest ratios of international scientific collaboration in Asia; moreover, all three have seen a rise of at least 5% since 2015.

Talent market and diaspora drivers of change

Highly cited scientists are being wooed by developing countries eager to enrich or augment their publishing record. A lucrative talent market has emerged that is pushing up the remuneration of leading scientists. This trend is boosting national statistics for scientific publishing and international collaboration.

Another contributing factor is the growing size of the diaspora. That Saudi Arabia should be Pakistan's second-largest scientific partner can be explained primarily by links to the diaspora (see chapter 21).

The diaspora includes scientists fleeing conflict zones. Output by scientists affiliated to Syrian institutions grew by 29% over 2015–2019. In Yemen, where more than 43 government scientific centres affiliated with Yemeni universities have had to suspend operations following structural damage to their facilities, research output grew from 281 publications in 2015 to 614 in 2019 (see chapter 17 and The integration of refugee and displaced scientists creates a win–win situation, p. 20).

By contrast, there has been a precipitous drop in international scientific collaboration in the Philippines since 2014 when six in ten articles had a foreign co-author. The reinforcement of the Returning Scientist Act[12] in 2018 may explain the steep decline in foreign-affiliated co-authorship from 49% in 2018 to 41% just a year later, assuming that much of international scientific collaboration was driven by ties with the diaspora.

Environmental sciences highly collaborative

International collaboration is most common in the geosciences, with one-third of global publications (36%) involving authors from more than one country in 2019, up from 33% in 2015. This is followed by collaboration in other environmental sciences (Figure 1.16); here, six out of ten (59%) EU publications in 2019 involved partnerships with third countries, a similar ratio to that observed for sub-Saharan scientists (64%).

International co-authorship in cross-cutting strategic technologies and engineering has hovered around the 20% mark since 2015. High-income economies have boosted their own collaboration with countries from other income groups on cross-cutting strategic technologies from 31% of publications in 2015 to 37% in 2019.

Science can serve a common cause

In the Arctic, a region targeted by one-tenth of Russian economic investment, the EU and the Russian Federation have worked together on issues that include wastewater management and the treatment of nuclear waste. In May 2017, the eight Arctic States signed an *Agreement on Enhancing International Arctic Scientific Cooperation*, namely Canada, Demark, Finland, Iceland, Norway, the Russian Federation, Sweden and USA (see chapter 13).

New Zealand's 2020–2021 Budget allocates NZ$ 35 million to the Catalyst Fund, which supports international research relationships. New Zealand is already involved in the Global Research Alliance on Agricultural Greenhouse Gases. In 2018, New Zealand increased its official development assistance by 30%, in response to the financing needs of developing countries to meet *The 2030 Agenda for Sustainable Development*. Some 60% of this assistance goes to the Pacific region, where New Zealand was one of the top five scientific partners over 2017–2019 for the Cook Islands, Fiji, Palau, Tonga and Samoa. Scientists from New Zealand co-authored 64% of publications with foreign partners in 2019, up from 59%.

Under the *Belt and Road Initiative Science, Technology and Innovation Cooperation Action Plan* announced by China in May 2017, five technology transfer platforms are to be created in countries belonging to the Association of Southeast Asian Nations (ASEAN), the Arab world, Central Asia and Central and Eastern Europe, along with a batch of joint research centres in Africa (see chapter 23).

Over the dual periods 2014–2016 and 2017–2019, the number of instances where one ASEAN country was a top-five collaborator for another rose from five to eight. China remained one of five top collaborators for six, and Australia for eight, out of ten ASEAN countries over this six-year period.

Greater intraregional scientific collaboration

There is a trend towards greater intraregional scientific collaboration. Brazil and Peru figure among Colombia's top five scientific partners, for instance. Ghana became a top-five collaborator for Burkina Faso, Liberia and Sierra Leone in 2017–2019. Uganda was among the top five collaborators for eight sub-Saharan countries and South Africa for as many as 23 countries over the same period.

South Africa has raised its ratio of internationally co-authored publications from 54% to 57% since 2015. The South African National Research Foundation is one of three sponsors of the Science Granting Councils Initiative launched in 2016, along with the Canadian International Development Research Centre and UK Department for International Development. Within this initiative, Malawi's National Commission for Science and Technology (NCST) developed collaborative calls for agricultural research with Mozambique and Zimbabwe in 2019. In August 2020, the NCST launched a trilateral call for collaborative research proposals in renewable energy with Zambia and Mozambique (see chapter 20). In Burkina Faso, the National Fund for Research and Innovation for Development (FONRID, est. 2011) has been partnering with Senegal to obtain joint research grants in food and agriculture through the Science Granting Councils Initiative (see chapter 18).

The Economic Community of West African States (ECOWAS) has, itself, been encouraging subregional scientific collaboration and mobility. Since 2018, the ECOWAS Research and Innovation Support Programme has awarded competitive annual grants to research teams from the subregion, with a focus on problem-solving research (see chapter 18).

A CLOSER LOOK AT COUNTRIES AND REGIONS

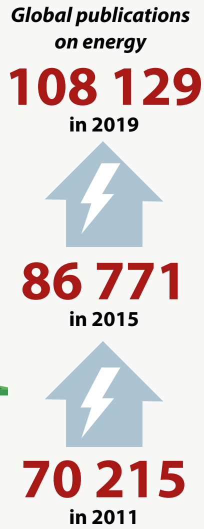
Public research infrastructure in **Canada** (chapter 4) is receiving a reboot after years of decline. The government has invested in new research facilities and novel modes of co-operation are being trialled between federal laboratories, academia and business.

Expenditure on industrial R&D as a share of GDP amounts to only half the OECD average. The government has launched initiatives to rectify the situation. As part of the *Innovation and Skills Plan* (2017), the Strategic Innovation Fund was created to foster innovation through large-scale projects with industry; by early 2020, it had funded more than 65 projects for Can$ 2.2 billion.

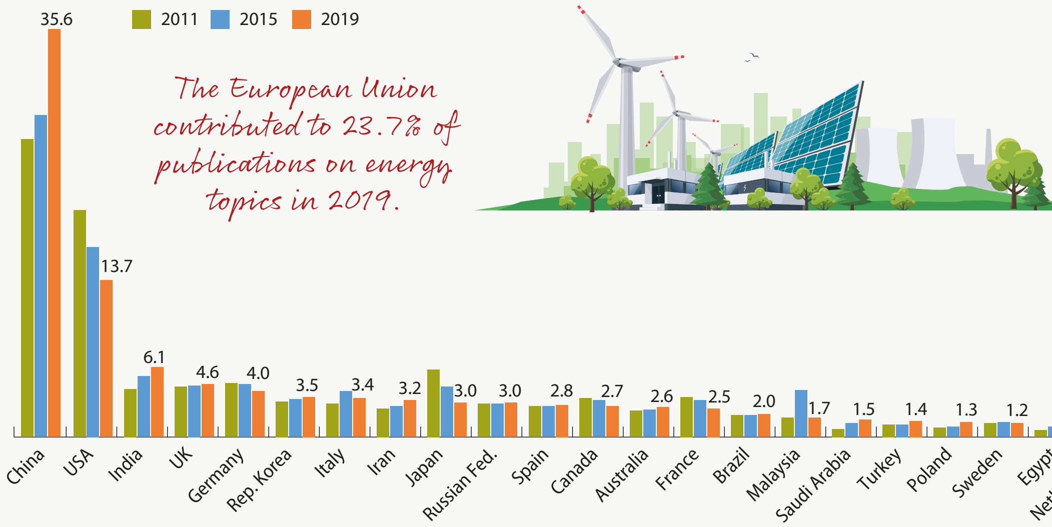
In 2017, the government challenged Canadian enterprises to partner with research institutions to develop 'bold and ambitious' innovation strategies, as part of the Innovation Superclusters initiative which is focusing on the ocean economy, next-generation manufacturing, digital technology, protein industries and AI.

Industry groups have argued that the federal and provincial governments operate on the basis of a supply-side, linear view of innovation. The lack of a national strategy for STI is an obvious

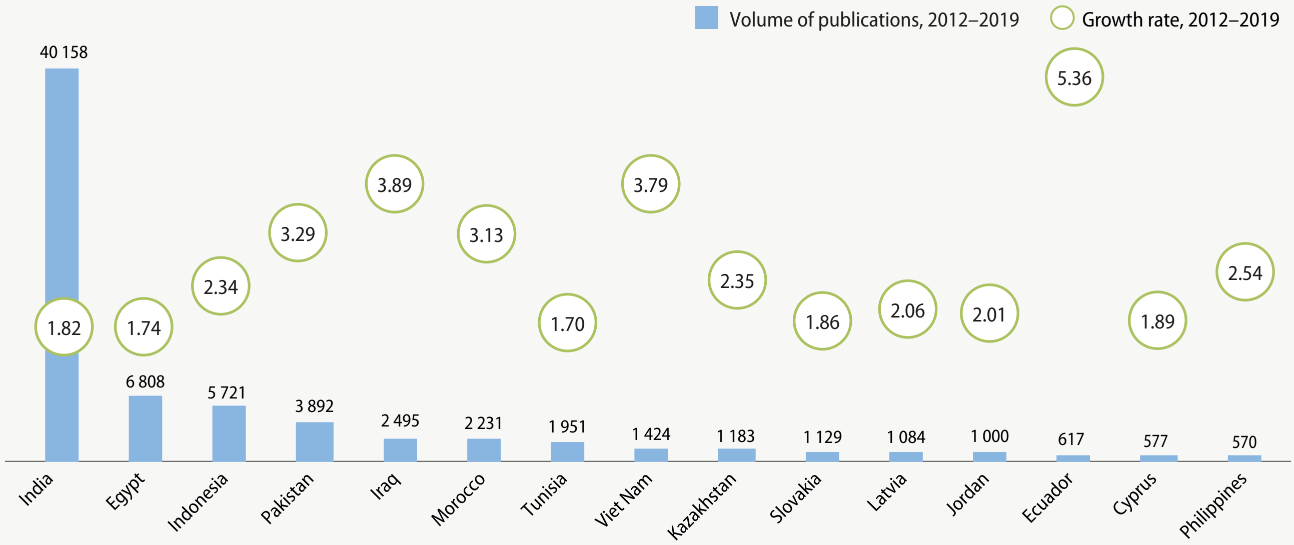
Figure 1.14: **Trends in scientific publishing on energy**



Share of global publications on energy, 2011, 2015 and 2019 (%)
Among countries contributing to at least 1% in 2019; data labels are for 2019



Top 15 countries for growth rate in scientific publishing on energy, 2012–2019
Among countries with at least 500 publications, arranged by volume



Note: The growth rate is calculated as the number of publications from 2016–2019 divided by the number of publications from 2012–2015.

Source: Scopus (Elsevier), excluding Arts, Humanities and Social sciences; data treatment by Science-Metrix

barrier to resolving this challenge, as it means that provinces and territories implement their own strategies and programmes.

The nascent Canada Research Coordinating Committee aims to improve co-ordination at federal level, including through the New Frontiers in Research Fund designed to bolster federal support for high-risk, game-changing research.

The *Pan-Canadian Artificial Intelligence Strategy* (2017) commits funds to raising the number of outstanding AI researchers and skilled graduates. Canada is striving to assume a leadership role in the international conversation on the potential social impact of AI.

Canada has set a target to 2050 for achieving net-zero carbon emissions, punctuated by five-year milestones that are set in law. Coal is to be phased out by 2030 but crude oil production is expected to increase by 50% over 2018–2040. The government is aiming to place a tax of Can$ 50 on each tonne of carbon pollution emitted by 2022.

In 2016, the government adopted a Can$ 1.5 billion *Oceans Protection Plan*. By 2018, nearly 14% of marine and coastal areas had been protected, up from around 1% in 2015.

Canada has also designed an *Arctic and Northern Policy Framework* (2019). Polar Knowledge Canada, a federal agency, is funding innovative research to support climate mitigation and adaptation, such as through community observatories for joint research with indigenous communities.

In the **United States of America** (chapter 5), the adoption of the America First priority in 2017 led to new sector-specific policy goals, including that of reducing the US trade deficit in goods with key trading partners through the imposition of tariffs.

The trade dispute with China since 2018 has spilled over into the arena of high technology, technology transfer and intellectual property protection, posing a real risk of decoupling between the two countries in terms of technology and talent.

More generally, there is a broad consensus between federal agencies and the executive and legislative branches that the USA needs to adapt to an increasingly competitive international environment.

The federal government has, consequently, prioritized key digital technologies viewed as critical to the USA's economic competitiveness and cybersecurity, including AI, quantum information science (QIS) and advanced mobile network technology. The first *National Artificial Intelligence Research and Development Strategic Plan* was published in 2016. Four years later, the federal government announced plans to double government investment in research in QIS and AI by 2022 over the 2019 baseline.

Space has re-emerged as a priority, as encapsulated by the *National Space Policy* of 2017. NASA was one of only four agencies targeted for an increase in the government's budget proposal for 2021. Public–private partnerships involving NASA have been key to developing the private space industry.

The America First policy agenda has led the USA to withdraw from several multilateral agreements, including the *Paris Agreement*. A number of states have, nevertheless, chosen to respect their own commitment to climate action and the new administration returned the USA to the *Paris Agreement* in February 2021.

Between 2017 and 2019, the government rolled back more than 90 environmental protections. This, coupled with technological advances that have reduced the price of natural gas and renewables, led to an expansion of oil, natural gas and renewables that has been supported by generous tax incentives and a 22% increase in research funding for the Department of Energy between 2015 and 2020.

Despite health care accounting for about 18% of GDP in 2017, access and equity remain an issue. Moreover, the share of health care financed by federal, state and local governments is expected to rise to 47% by 2028, an unsustainable trajectory. Precision medicine is opening up a wide range of therapeutic possibilities but also raising health costs. With pharmacogenetics a burgeoning field, pharmaceutical companies will need to collaborate more with data giants, in future.

In 2020, independent antitrust reviews were under way of the five leading digital tech giants, in response to growing concerns about their influence on society, the economy and politics.

The Covid-19 pandemic has killed more than half a million US citizens. Despite the pandemic, new company registrations surged in 2020, even as the amount of venture capital available to start-ups shrank.

The mounting cost of natural disasters has set the stage for bold collective initiatives by the Caribbean Community (**Caricom**, chapter 6) in areas that include climate resilience and green innovation. For instance, in order to relieve the financial and ecological burden of costly imports of fossil fuels, the Green Climate Fund is supporting an eight-year project to develop geothermal resources in Dominica, Grenada, St Kitts and Nevis, St Lucia and St Vincent and the Grenadines.

Guyana plans to use the recent discovery of offshore oil and gas reserves by ExxonMobil to develop renewable sources of energy. To this end, the government created a Sovereign Wealth Fund in 2019 which is financed primarily from oil earnings; one project concerns turning the town of Bartica into a 'pilot and model green town', with support from the Caribbean Community Climate Change Centre.

Strategic frameworks are closely aligned with *The 2030 Agenda for Sustainable Development* but detailed roadmaps and sustainable funding, monitoring and evaluation mechanisms are needed to support implementation.

Member states have adopted a *Caricom Digital Agenda 2025* and a roadmap approved in 2017 for the creation of a *Single Caricom ICT Space* to nurture an ICT-enabled borderless space. Training will be a key element, given the shortage of software engineers and low scientific output in this field.

Although the observed growth in scientific publications attests to a more vibrant research culture, the current emphasis on health research will not prepare Caribbean societies for the digital and green economies of tomorrow.

The near-total absence of data on R&D is penalizing science management at the national and regional levels. For instance, it has hampered implementation of the *Strategic Plan for the Caribbean Community 2015–2019*. In 2018, Caricom developed a Results-based Management System with support from the Caribbean Development Bank to guide systematic data collection, analysis and use, as well as reporting on progress towards regional integration and development.

With innovative firms in need of systemic, sustained support, Jamaica's new programme for Boosting Innovation, Growth and an Entrepreneurship Ecosystem could serve as a model for the region.

During the commodities boom, investment in **Latin America** (chapter 7) was channelled mainly towards economic expansion, rather than towards reinforcing existing infrastructure or supporting innovation and risk-taking.

The end of the commodities boom has, consequently, ushered in a period of stagnant economic growth, coupled with a drop in research intensity among the regional heavyweights of Argentina and Mexico.

The concept of an innovation system is now widely incorporated into STI policies. However, demand for knowledge in the productive sector remains weak. Latin American companies operating in more than one country (*multilatinas*) are playing a greater role than previously but are not closely connected to national innovation systems. Multinationals with subsidiaries in the region tend to utilize existing knowledge rather than engage in local research.

Figure 1.15: **Trends in scientific publishing on materials science**

Global publications on materials science

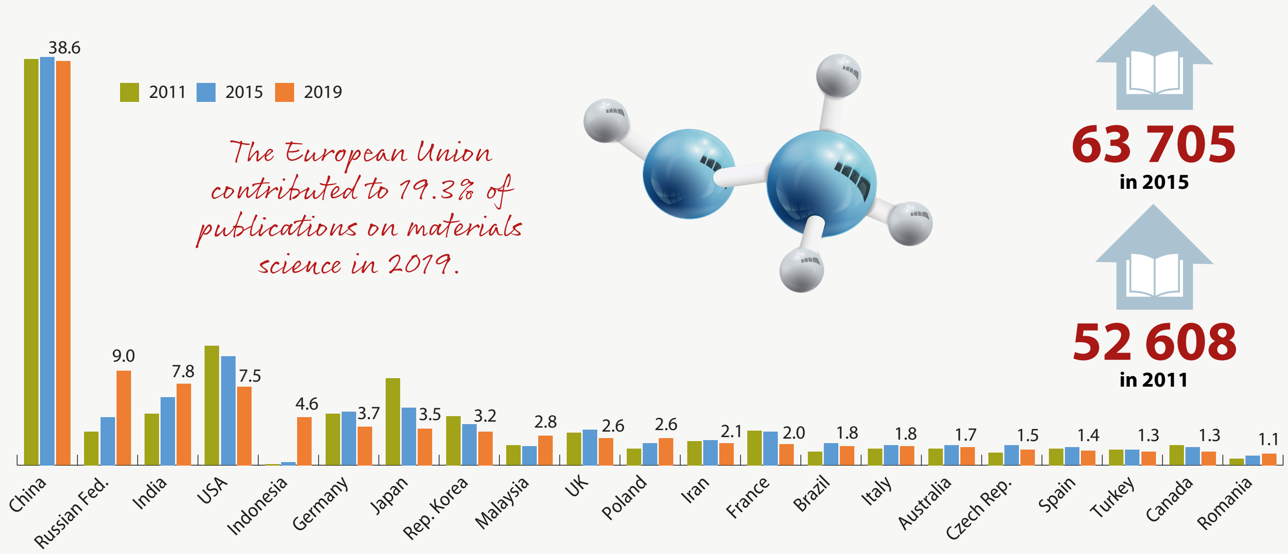
93 033 in 2019

63 705 in 2015

52 608 in 2011

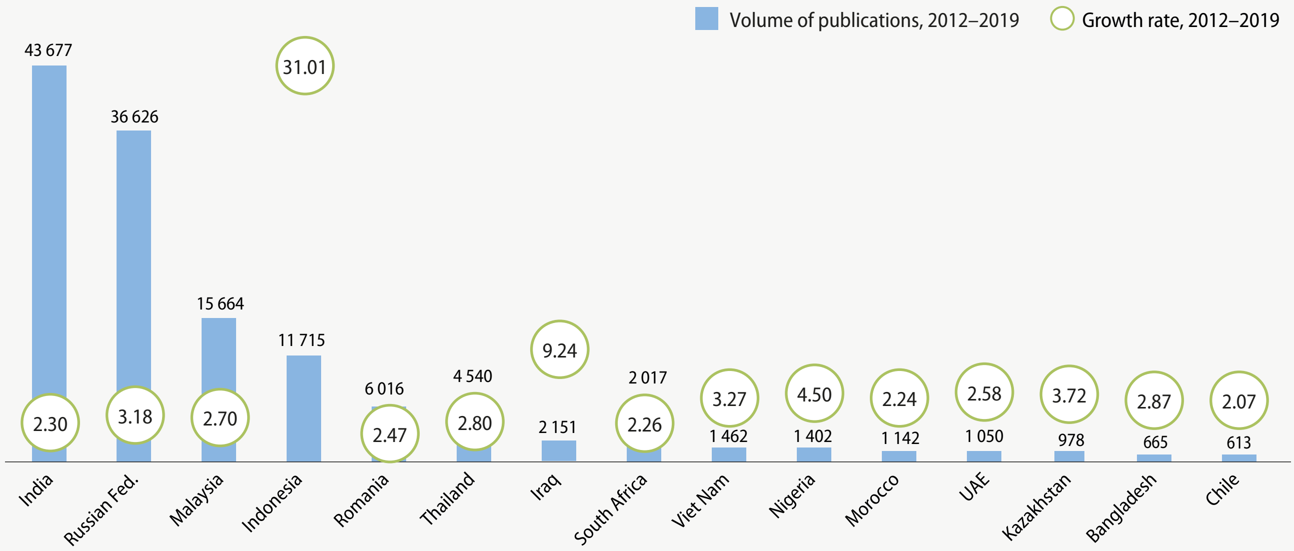
Share of global publications on materials science, 2011, 2015 and 2019 (%)

Among countries contributing to at least 1% in 2019; data labels are for 2019



Top 15 countries for growth rate in scientific publishing on materials science, 2012–2019

Among countries with at least 500 publications, arranged by volume



Note: The growth rate is calculated as the number of publications from 2016–2019 divided by the number of publications from 2012–2015. UAE stands for United Arab Emirates.

Source: Scopus (Elsevier), excluding Arts, Humanities and Social sciences; data treatment by Science-Metrix

More countries are developing 'home-grown' policies that involve experimentation, in preference to adapting policies designed abroad. These policies stress social innovation for sustainable development and are increasingly integrating local and indigenous knowledge systems.

However, policy-making remains characterized by U-turns that prevent long-term planning. This can undermine investor confidence and hamper innovation. Some countries are also backtracking on broad public participation in decision-making.

Sustainability science is emerging as a regional research focus. One example is the Colombia Bio programme, which aims to nurture a culture of respect for biodiversity; it is enriching the scant taxonomic record and supporting bioprospecting to foster the development of products and services with high added value.

Scientific output in mainstream journals has grown in all but Cuba and Venezuela. Better postgraduate education in some countries may be partly responsible for this trend. The downturn in Cuban output may be linked to the restoration of the US blockade in 2017, which has negatively affected resources for R&D, including planned salary rises to discourage brain drain following the lifting of restrictions on international travel in 2012. Venezuela is experiencing severe brain drain, with more than 3 million citizens having migrated to Colombia, Peru, Ecuador and Brazil in 2019.

One example of active multilateral collaboration is the Central American Integration System (SICA), which has been building resilience to climate change. In May 2020, SICA signed an agreement with Canada's International Development Research Centre for a project to strengthen the policy-making capabilities of the national research and innovation bodies of all member states.

At the regional level, there have also been bottom-up initiatives in biotechnology, space science and open science, among others.

Brazil (chapter 8) has recorded a number of achievements over the past five years. For instance, Sirius, one of the world's most sophisticated synchrotron light sources, is nearing completion.

There is also a growing uptake of digital technologies in both the government and business sectors in areas such as health, banking and agriculture. In e-health, medical big data and AI are being used to develop prediction models and new drugs.

The Brazilian scientific community has also mobilized rapidly during the Zika viral outbreak over 2015–2018 and during the Covid-19 pandemic since 2020.

Technological innovation hubs within universities have prospered, notably with regard to patent filing, collaboration with industry and the incubation of innovative start-ups.

Another positive development has been the rise in wind and solar energy, biofuels and biomass from 14.7% to 19.5% of total electricity generation between 2015 and 2018. Brazil has one of the world's cleanest energy matrices, with renewables contributing to 85% of electricity generation in 2020, two-thirds of which came from hydropower.

In 2018, the government announced the end of megahydropower projects in the Amazon, citing environmental concerns. A series of dam failures and the growing incidence of wildfires in the Amazon forest and Pantanal region attest to an insufficient environmental monitoring and disaster prevention system. In the past couple of years, some environmental protections have been rolled back.

Several indicators are flashing a warning for the national innovation system. Business investment overall is down, as is the share devoted to R&D. Businesses are filing fewer patents. In parallel, federal research agencies have recorded a sharp drop in budget outlays. Domestic research expenditure contracted by 16% between 2015 and 2017. The share of industrial output in GDP and participation in foreign trade, especially as concerns manufactured products, are also on the decline.

In mid-2020, the government published its *Strategic Plan 2020–2030*, which replaced the *National Strategy for Science, Technology and Innovation 2016–2022*. The latter had been influenced by *The 2030 Agenda for Sustainable Development*. Even though the new plan mentions sustainable development as an overarching objective, the map of indicators and related targets contains few socio-economic and no environmental targets. An integrated approach to innovation planning had been one of Brazil's policy strengths.

The UK's departure from the **European Union** (chapter 9) in January 2020 will not change the essence of the European project, which is tending towards closer integration.

The bloc's new growth strategy, the *European Green Deal* (2020), seeks to accelerate the 'green' transition in all five socio-economic systems (energy; agrifood; manufacturing; transportation; and buildings–housing) by pointing resource mobilization and regulatory and other reforms in the same direction.

The aim is to reach the 2050 target for carbon neutrality while making sure that jobs lost in one industry can be recreated elsewhere. A Just Transition Mechanism will help vulnerable countries weather the transition, such as in the event of widespread job losses tied to the phasing out of a polluting industry.

Twin engines of this transition will be smart specialization by regions and new mission-oriented policies, implemented within the Horizon Europe framework programme for research and innovation (2021–2027). Another new feature is the European Innovation Council, which has been fully operational since 2021; its role is to fill the financing gap for innovative start-ups and SMEs.

The *European Green Deal* is accompanied by an industrial strategy adopted in March 2021 which focuses on the dual green and digital transition, while leveraging the Single Market to set global social and environmental standards. A new policy framework will establish sustainability principles for all products. The EU will also support the development of key enabling technologies, including robotics, micro-electronics, blockchain, quantum technologies, biomedicine, nanotechnologies and pharmaceuticals.

According to the European Commission, only about one in five companies are digitalized. The bloc's digital strategy, *A Europe fit for the Digital Age* (2019), enables companies of all sizes to 'test before they invest' in digital technologies via digital innovation hubs, using competitive funding provided under Horizon 2020 and its successor, Horizon Europe. As of February 2020, 16 countries had published national AI strategies and another five had prepared an advanced draft.

In order to prepare the workforce for the digital economy of tomorrow, greater emphasis will be laid on lifelong learning in the *Digital Education Action Plan 2021–2027*.

Meanwhile, the new European Universities Initiative aims to create networks of tertiary institutions to enable students to obtain a degree by combining their studies in several EU countries while heightening a European sense of identity.

The bloc intends to reinforce its strategic autonomy and soft power in the coming years, including through its trade, digital and defence policies.

For countries in **Southeast Europe** (chapter 10), integrating the EU remains an overarching policy goal. There are some positive signs: the region has surpassed its target for the number of highly qualified persons in the workforce and is close to achieving its target for the balance of trade and overall employment rate.

However, economic reform has been prioritized over STI policy-making; this has eroded research capacity and impeded the shift towards the EU's science-oriented innovation model. As a result, brain drain towards EU countries remains a chronic challenge. Within Southeast Europe itself, the *Western Balkans Regional Research and Development Strategy for Innovation* (2013) has created few opportunities for co-operation.

Notwithstanding this, efforts have been made since 2015 to align with the European Research Area. Each country is applying the EU's Energy Efficiency and Renewable Energy Directives and developing energy policies in line with the EU's emissions monitoring regulation (#525/2013). All five non-EU countries in Southeast Europe have competed for research funding within the Horizon 2020 programme.

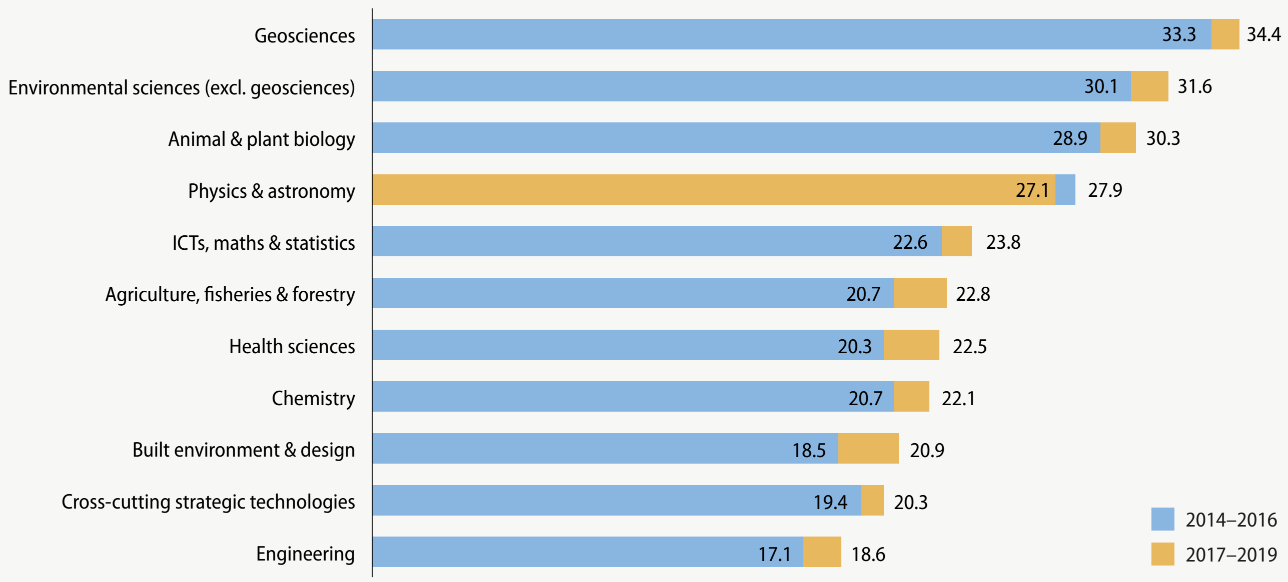
Countries are also developing their own smart specialization strategies, a *de facto* prerequisite for EU accession. The first to complete these were Montenegro in 2019 and Serbia in 2020. These strategies could provide the missing link for countries struggling to integrate their research and economic sectors; innovation systems within the region currently tend towards the outmoded linear model, with the region's limited business sector activity being reflected in low patenting levels.

There are signs that active policy instruments are reversing this trend. Serbia and Albania have both established innovation funds and Serbia opened its first tech park in 2015, followed by another two in Novi Sad and Nis in 2020.

Of the four members of the **European Free Trade Association** (chapter 11), all but Liechtenstein have participated in the EU's Horizon 2020 research programme. Norway and Iceland are expected to maintain their status of 'full association' with its successor, Horizon Europe. Switzerland's own status will depend on the outcome of ongoing negotiations with the EU on a comprehensive institutional framework agreement.

Norway, Iceland and Switzerland have bold ambitions to achieve carbon neutrality by 2030, 2040 and 2050, respectively. Norway and Iceland have high carbon taxes and are expanding the electrification of road transportation. They are also piloting groundbreaking projects in carbon capture and storage, one being the first industrial-sized

Figure 1.16: **Share of scientific publications involving international collaboration by broad field, 2014–2016 and 2017–2019 (%)**



Source: Scopus (Elsevier), excluding Arts, Humanities and Social Sciences; data treatment by Science-Metrix

project of its kind and the other having successfully stored carbon dioxide in subsurface basaltic rocks. A significant challenge for Norway will be to reconcile the goal of carbon neutrality with plans to intensify oil exploration.

Iceland's innovative *Policy and Action Plan 2017–2019* evokes Industry 4.0 and extends the concept of economic growth to 'quality growth'. It emphasizes the role that R&D can play in ensuring 'quality growth' by taking into account the potential negative impact of technologies on future users.

Swiss firms invest about 7% of their turnover in R&D, the highest ratio in the world. However, the bulk of these firms operate in the pharmaceutical and chemicals sector. Should these multinational corporations decide to take their business elsewhere, Switzerland would lose the heart of its research enterprise. This vulnerability has spawned policy efforts to nurture start-ups and SMEs, including a tax reform in favour of research-intensive companies and the opening of the Swiss Innovation Park in 2016, which extends to companies specializing in advanced manufacturing, smart buildings and robotics.

Swiss firms are increasingly conducting basic research and Switzerland has performed well in obtaining grants from the European Research Council, which is known for its pedigree in basic research. Finding a balance between basic and mission-oriented research remains a challenge for all four countries.

All seven **Countries in the Black Sea Basin** profiled (chapter 12) – Armenia, Azerbaijan, Belarus, Georgia, the Republic of Moldova, Turkey and Ukraine – consider the digital economy to be a growth engine. For instance, information technology accounts for more than 40% of Ukraine's exports of services. Ukraine's *Concept for the Development of a Digital Economy and Society* covering the years 2018–2020 has sought to create a 'digital workplace'.

Countries in the region have launched initiatives to foster innovation. Azerbaijan, for instance, created an Innovation Agency in 2018 that provides venture capital to innovative businesses, including start-ups. Belarus has been reforming the national innovation system since 2015. More than 90 legal acts directly or indirectly relating to R&D had been issued by 2018. In 2016, the government consolidated its 25 innovation funds into a single Republican Centralized Innovation Fund, which functions as a state agency.

Notwithstanding these efforts, countries are struggling to incentivize experimentation, dynamism and the creation of new knowledge in the economy. In the post-Soviet countries, restrictive oligarchic structures are limiting the rewards from innovation.

In Turkey, structural imbalances lie elsewhere. Recent firm-level evidence shows that Turkey's technology-intensive firms carry out little R&D relative to their size. This picture contrasts sharply with the state's strong emphasis on supporting innovation: tax breaks for technology-intensive firms grew three-fold in local currency between 2015 and 2018, according to the Turkish Statistical Institute. However, firms in the services and construction sectors, which accounted for 64% of GDP in 2018, remain largely shielded from competition and can, thus, afford to ignore the government's support programmes for R&D and manufacturing-focused innovation.

All but Belarus are dovetailing with European structures and networks. Armenia, Georgia and Ukraine became formally associated with the EU's Horizon 2020 programme in 2015–2016. Ukrainian and Georgian researchers submitted their first project proposals to the European Research Council in 2015 and 2017, respectively.

Turkey's geothermal industry has benefited from a favourable regulatory environment for business investment as well as the experience gained by Turkish geothermal power companies through their participation in the EU's Horizon 2020 programme via consortia. Between 2009 and 2019, the number of geothermal power plants in Turkey shot up from three to 49.

In the **Russian Federation** (chapter 13), the economy remains heavily reliant upon oil, gas, metals, chemicals and agricultural products. There also remains a mismatch between supply and demand with regard to scientific knowledge and technology.

Government intervention since 2015 has demonstrated a willingness to tackle these structural imbalances. This is epitomized by the 13 large-scale national projects to 2024, with total funding of about RUB 26 trillion (*ca* PP$ 1 trillion) over six years and a focus on science–industry collaboration.

Priority areas of the National Project for the Digital Economy include quantum technologies and AI. It is complemented by the *National Strategy for the Development of Artificial Intelligence* covering the years 2020–2030.

The National Project for Science prioritizes the development of megascience facilities and the emergence of a 'new geography' of Russian science, with world-class research and education centres to be established in selected regions. The government has also recognized the need to promote a culture of innovation in government structures, to be achieved through specialized training and strategic selection procedures.

Major energy companies have signed up for the government's National Project for Ecology by investing in green technologies. The use of renewables is being impeded, however, by the centralized management of the energy sector, higher consumer prices and the country's cold climate. Consumption of coal and petroleum products, as a share of the fuel and energy balance, nevertheless, declined slightly over 2015–2018.

Confronted with a shrinking researcher pool, the government has fulfilled its pledge to raise the renumeration of researchers by 2018. This has helped to attract more researchers under the age of 39 years to the profession.

The Arctic is a strategic focus not only for the Russian Federation but also Canada, China, the EU and USA. This makes it a hub for science diplomacy. The *Agreement on Enhancing International Arctic Scientific Cooperation* (2017), signed by the Russian Federation and seven other Arctic States, aims to promote inclusion of local and traditional knowledge, among other aims.

Chronic underinvestment in R&D in **Central Asia** (chapter 14) – no country spent more than 0.13% of GDP on R&D in 2018 – has spawned a range of systemic challenges that are holding back research and innovation. These include a vocational crisis in the research community and an exodus of skills.

The cultural divide between the business and scientific communities is another challenge. Disinterest in science among the business community has translated into a lack of demand for technology, creating a heavy burden for the state budget. Since it communicates little with the manufacturing sector, the scientific community itself remains detached from the needs of the real economy.

Poor intellectual property protection and complex tax regimes, coupled with the lack of tax rebates and loans for enterprises, are discouraging innovation and making innovative enterprises unattractive targets for investment and lending.

Central Asian governments are taking steps to overcome these obstacles. There is a desire to improve the investment climate for businesses and to use innovation to modernize industry. Uzbekistan has even placed innovation-based development at the top of its political agenda.

There are a growing number of technology parks which benefit from advantageous tax regimes. Governments are also making an effort to improve the status of researchers through measures such as pay rises, competitive research grants, modern research equipment and joint research projects with institutional partners in countries such as Belarus, China, India and the Republic of Korea.

Scientists and engineers are enjoying more international exposure than in the past. For example, the international accelerator programme, Start-up Kazakhstan, is open to participants from the Commonwealth of Independent States and Europe.

Governments are also working with international partners to access green finance. Faced with growing water scarcity and ageing energy infrastructure, they are investing in renewable energy programmes, such as through 'solar auctions' in Kazakhstan and Uzbekistan or the construction of the Rogun Dam in Tajikistan. One challenge will be to balance competing demands for innovation from the mining sector, which forms the bedrock of Central Asian economies.

Countries are embracing the digital economy and e-governance. The comprehensive Digital Kazakhstan initiative spans sectors such as energy, transportation, finance, infrastructure, mining, agriculture and education. Both the Alatau Park of Innovative Technologies and Tech Garden Innovative Cluster in Kazakhstan are embracing Industry 4.0 technologies.

Kyrgyzstan is targeting digital public services through its *Taza Koom* (Smart Nation) programme. There is growing interest among Kyrgyz youth in computer programming, as reflected in recent growth in tech-oriented start-ups and software companies.

There has been exponential growth in knowledge-based firms and start-ups in **Iran** (chapter 15). This trend is the result of heightened domestic demand, combined with the multiplication of technology incubators and accelerators since the launch of the country's first public innovation centres in 2015.

By 2020, 49 innovation accelerators had been established with private equity and 113 innovation centres had been set up in partnership with science parks and major universities. Technology incubators, meanwhile, have been providing graduate entrepreneurs with co-working spaces and mentoring on campus to help them launch their own start-up.

The government has been encouraging start-ups to diversify into knowledge-based fields. A series of laws and policies adopted since 2015 have removed barriers to competition and enhanced the financial support system for innovation.

Between 2014 and 2017, exports of knowledge-based goods grew by a factor of five, before slumping in 2018 after the USA withdrew from the *Joint Comprehensive Plan of Action* (2015), commonly referred to as the nuclear deal, and reimposed sanctions. This move has put the economy under considerable pressure.

However, the restoration of sanctions has also motivated companies to use local suppliers of knowledge-based goods and services. One targeted sector has been renewable energy but, despite attempts to boost domestic manufacturing and employment, renewables still contribute less than 1% of the energy mix.

Market incentives have not sufficed to boost business investment in R&D, which dipped from 35% to 28% of domestic research spending between 2014 and 2016.

One imperative will be to adapt academic programmes to the needs of the job market. Despite growth in the number of master's and PhD graduates, there is a high share (39%) of unemployment among university graduates.

Home to the most start-ups per capita in the world, **Israel** (chapter 16) has been dubbed the 'start-up nation'. More than 6 000 start-ups were founded between 2011 and 2019 alone.

Israel is the most research-intense country in the world. In 2017, foreign multinationals and research centres financed more than half of gross domestic expenditure on research, followed by the Israeli business sector.

One trend that should be of concern is the growing rate of transfer of Israeli intellectual property, know-how and technology to foreign research centres. Fewer than half of patents obtained by inventors from Israel are owned by Israeli companies.

Industry 4.0 is a growing priority, both in the start-up sector and in government policy more broadly. Through the Digital Israel initiative, the government is investing heavily in technologies that include AI and (big) data science, smart mobility and e-governance. The ambition is to leverage Israeli expertise in digital technologies to accelerate growth, improve inclusivity and strengthen governance.

Israeli universities have established educational programmes and research centres in cutting-edge fields, such as the Center of Knowledge in Machine Learning and Artificial Intelligence at the Hebrew University in Jerusalem.

This focus on innovation and technology has fed into industrial policy. The government's *National Strategic Plan for Advanced Manufacturing in Industry* (2018) outlines a framework for investment, skills development, infrastructure reinforcement and greater access to knowledge, with a focus on SMEs. Over the past ten years, a vibrant auto-tech sector has emerged, supported by the Fuel Choices and Smart Mobility Initiative launched in 2010. There are now 25 research centres in the automotive sector.

However, the quality and quantity of freshwater has declined in Israel, making it imperative to adopt new approaches to water management. Use of desalinated water is growing but has been associated with a magnesium deficiency in human diets and saltwater intrusion into aquifers.

The message that sustainable development is a necessity, not a luxury, has resonated with policy-makers, who mainstreamed the SDGs across government strategic planning in 2019.

Despite their socio-economic differences, **The Arab States** (chapter 17) share common priorities. With water scarcity, soil erosion and environmental degradation presenting serious challenges, more governments are embracing science-based solutions, such as indoor vertical farming, desalination and large-scale solar plants.

Countries are investing in high-tech, sustainable urban centres. Egypt, for instance, has outlined a set of sustainability principles for its new cities which include a minimum threshold for land per capita and the installation of solar panels.

Arab countries are seeking to develop their manufacturing sector, including in high-tech fields such as aeronautics, agricultural biotechnology and the space industry. They remain reliant on technology imports, however, and partnerships with leaders in space technology.

Harnessing the Fourth Industrial Revolution has become an explicit policy priority. Saudi Arabia and the United Arab Emirates have adopted national AI strategies and at least Algeria, Egypt and Tunisia have plans to do the same. Morocco has established a research programme in AI.

Gulf states were among the first in the world to launch commercial 5G networks. Saudi Arabia has opened a Centre for the Fourth Industrial Revolution and the UAE is integrating blockchain into government services and transactions.

One challenge will be to ensure that education systems can deliver an endogenous skilled workforce, including a critical mass of technicians for Industry 4.0. There are signs that secondary school systems are not delivering as effectively as in neighbouring countries.

The past five years have witnessed a significant expansion in higher education yet, despite generous public funding for universities, the proportion allocated to R&D remains low in most countries. Consequently, innovative technologies are not being developed or exported by Arab countries. Even the region's most prosperous economies rely massively upon the purchase of packaged technology inputs from abroad. There even appears to have been a regression in technology transfer in recent years. This suggests a need to prioritize building endogenous research communities whose output is determined by societal demand.

Evidence to inform policy is lacking in many countries where there is no regular data collection and analysis. Moreover, existing R&D surveys tend to exclude the business sector, creating a policy 'blind spot'. There were plans to develop an Innovation Scoreboard for Arab countries but this is yet to materialize.

Faced with increasingly capricious weather patterns that are playing havoc with food security, countries in **West Africa** (chapter 18) are developing expertise in climate science with international support. For instance, the Economic Community of West African States (ECOWAS) has partnered with the German government to create the West African Science Service Centre on Climate Change and Adapted Land Use, which encompasses a Climate Research Programme, a Graduate Studies Programme and observation networks.

With the African Continental Free Trade Area on the horizon, countries are racing to restructure their economies. The Senegalese Sovereign Fund for Strategic Investments (FONSIS, est. 2012) uses state oil and gas revenue to invest in capital funds targeting SMEs in priority sectors such as solar energy, agriculture and health. One subsidiary, SOGENAS, specializes in the production and commercialization of dairy cows genetically modified to resist hot, dry conditions.

There is a strong market potential for plant-based products. Félix Houphouët-Boigny University in Côte d'Ivoire is developing plant-based biopesticides, as well as low-cost phytomedicines for the African market.

Burkina Faso (10), Ghana (36), Côte d'Ivoire (30), Nigeria (101), Mali (11), Senegal (22) and Togo (21) host a growing number of tech hubs but the near absence of local business angels and seed capital remains a challenge for start-ups.

Through their digital agendas, countries such as Cabo Verde, The Gambia, Ghana, Nigeria and Senegal are preparing for the day when much of intra-African trade may take place on the Internet, including through the creation of locally led data centres.

With more than half the population below the age of 20 years, governments are investing in physical and virtual universities to cope with growing demand for higher education. Burkina Faso is taking inspiration from Senegal's model for its own virtual university.

Nine out of 15 countries now have explicit STI policies but only five have reported recent data on research trends.

Burkina Faso's *Sectoral Research and Innovation Policy (2018–2027)* has introduced what it terms 'federative research programmes' with other ministries to improve programme delivery. The Ministries of Health and Agriculture are each leading a programme in partnership with the Ministry of Higher Education, Scientific Research and Innovation. It also raised research expenditure to 0.61% of GDP before a spate of terrorist attacks in 2019 obliged it to re-allocate funds to national security.

Countries in **Central and East Africa** (chapter 19) are taking advantage of more widespread telecommunications infrastructure to introduce e-governance in a drive to improve public services and make it easier to do business, as part of preparations for the future African Continental Free Trade Area. This project overlaps with efforts to reduce the cost of telecommunications, improve the electricity supply and develop roads, railways, airports and ports.

Ethiopia has founded the African Railway Academy to train engineers to take over operation of the railway line built by Chinese partners linking Addis Ababa and Djibouti, once the Chinese withdraw in 2023.

Strenuous efforts are being made to develop small and large hydropower projects, solar and wind parks and geothermal plants. The Grand Ethiopian Renaissance Dam is nearing completion and, in Kenya, geothermal power now reaches 35% of households.

Climate-smart agriculture, agro-ecology, biodiversity protection, medicine and water management are the focus of centres of excellence established in Ethiopia, Kenya and Uganda in 2017 under a World Bank project. Innovative drug development is the focus of one of the centres in Ethiopia, which has hosted the Africa Centres for Disease Control and Prevention since 2016 and plans to develop a pharmaceutical industry.

For their part, the World Bank centres of excellence in Rwanda (est. 2017) are focusing on energy research, mathematics, the Internet of Things and data science. Rwanda also hosts the East African Institute for Fundamental Research, established in 2018 through a project with the UNESCO Abdus Salam International Centre for Theoretical Physics; its research and teaching focus extends to AI-related areas.

Five out of 15 countries have explicit STI policies: Burundi, Ethiopia, Kenya, Rwanda and Uganda. Many have implicit STI policies, such as for energy, education or the digital economy. Examples are Rwanda's *ICT in Education Policy* (2016), the *Digital Cameroon 2020 Strategic Plan* (2017), Uganda's *National 4IR Strategy* (2020) and Chad's *Energy Policy* (2019) stressing the country's potential for renewable energy.

In sub-Saharan Africa, it is Cameroon which has the greatest volume of publications per million inhabitants on AI and robotics, as well as on energy-related topics; its publication intensity is even four times that of South Africa in both areas.

By 2019, there were 28 active tech hubs in Cameroon. Other Central African countries have five or fewer hubs. Their economies remain overdependent on oil and other raw materials, delaying the necessary economic diversification.

In all, there were 166 active technology hubs in 12 Central and East African countries in 2020. Four out of ten (42%) were located in Kenya alone. Governments need to support this vibrant start-up ecosystem, including by making it easier and less costly for inventors to register their intellectual property in Africa.

Although services dominate the economy in **Southern Africa** (chapter 20), it is manufacturing that has been identified as a key growth engine.

Steps have been taken towards closer integration. A Regional Development Fund was operationalized in 2017 and the draft Protocol on Industry would provide the Secretariat of the Southern African Development Community (SADC) with a legal mandate to implement regional industrial programmes. Although a free trade area was established in 2008, not all member countries are participating in it.

Several countries are exploring e-governance to improve the delivery of public services and make it easier to do business, including Madagascar and Namibia. However, a lack of private-sector competition has made digital services unaffordable for many citizens and businesses, even as the geographical coverage of communication infrastructure has expanded.

South Africa is the only country with a strong patenting record. Malawi and Namibia have taken steps to strengthen their intellectual property regime. Legislation passed by Eswatini in 2018 to establish an intellectual property tribunal had not been followed by a decree of application a year later. In 2018, ministers adopted the *SADC Regional Framework and Guidelines on Intellectual Property Rights* to foster mutual co-operation on reforming national intellectual property regimes.

Half of countries[13] have published explicit STI policies since 2010. Others have plans to develop or update their own strategies, including the Democratic Republic of Congo, Malawi, Lesotho, Tanzania and Zambia.

Only Mauritius, the Seychelles and South Africa have an electrification rate above 90%. Since SADC opened a Centre for Renewable Energy and Energy Efficiency in Namibia in 2015, the share of renewables in the region's power supply has risen from 24% to 39% (2018).

Through partnerships with the African Development Bank, World Bank and others, countries are expanding the electricity grid and off-grid solutions. The Democratic Republic of Congo's plans to build the massive Grand Inga dam have raised social and environmental concerns.

Hydropower accounted for about 81% of Zambia's installed generation capacity in 2019 but insufficient rainfall has made it an unreliable resource. In 2019, the government introduced a feed-in-tariff scheme for small-scale solar and small hydropower projects. In 2020, it adopted a *National Nuclear Policy* to help curtail reliance on hydropower.

Climate-smart agricultural practices have risen on the policy agenda following severe episodes of drought or flooding. Zambia's *Climate-Smart Agriculture Investment Plan* (2019) predicts that climate change could diminish the yields of key crops by 25% but, crucially, that climate-smart agriculture could increase crop yields by 23%.

South Africa is leading the development of an African Open Science Platform to facilitate international collaboration and data-intensive research. The country also hosts the Square Kilometre Array, the world's largest telescope. It holds great potential for stimulating scientific mobility and intra-African scientific collaboration and applications in fields such as AI and big data.

Countries in **South Asia** (chapter 21) are key beneficiaries of loans awarded within China's Belt and Road Initiative to fund major upgrades to infrastructure. One flagship project is the China–Pakistan Economic corridor, which is developing roads, ports and coal- and oil-fired plants, among other infrastructure.

The push for infrastructure development and industrialization is taking place on a parallel path to research and development. Chronic underspending on R&D means that the region is largely a recipient of foreign scientific expertise and technology.

Bangladesh, Nepal, Pakistan and Sri Lanka all have explicit STI policies but a lack of adequate instruments is impeding implementation. Owing to the modest size of public research budgets and small research pool, there is also a risk of funds being spread too thinly across research centres operating in a wide range of areas.

One priority is to foster technology transfer to SMEs. In Sri Lanka, for instance, the *National Policy Framework for the Development of SMEs* (2016) is accompanied by a national technology development fund co-financed by the government and private sector.

The pharmaceutical industries of Bangladesh, Pakistan and Sri Lanka hold potential but remain reliant on imports of raw materials. In Bangladesh, the Active Pharmaceutical Ingredients Industrial Park at Munshiganj is expected to be operational by 2023. The park will enable companies to produce the main chemical components of drugs themselves, thereby lowering the cost of domestic drugs and boosting their international competitiveness.

In Sri Lanka, pharmaceutical exports had been stagnating since 2016 but, with the Covid-19 crisis having spurred demand, the government and private sector invested US$ 30 million in a new pharmaceutical manufacturing plant in 2020.

Digital economies are emerging. For instance, Bhutan now has a FabLab for developers of digital projects and Pakistan is home to several 'tech unicorns' – start-ups valued at more than US$ 1 billion. This boom has led some governments to make plans for 'smart' infrastructure such as cities and schools. One challenge will be to ensure that these plans incorporate sustainability principles.

In 2016, the rising cost of fossil fuel imports, coupled with declining rainfall that made hydropower an unsustainable option, inspired Sri Lanka to launch a community-based project (*Soorya Bala Sangramaya,* or Battle for Solar Energy) that promotes small rooftop solar power plants for households and businesses through public–private partnerships.

In **India** (chapter 22), the government launched the Digital India programme in 2015 to transform the ecosystem of public services. Blockchain is now widely integrated within central government.

In 2016, the government embarked on one of the boldest economic experiments of modern times by demonetizing two of the largest banknotes in circulation, in a push to reduce the size of the informal economy. The government then shifted its focus to creating a fully cashless economy. The share of Indians with a bank account rose from 53% to 80% between 2014 and 2017. These developments have taken place against a backdrop of sharp growth in access to Internet, which has fuelled the digital economy, including e-commerce.

The flagship Make in India programme has sought to promote investment in manufacturing and related infrastructure, among other things. Although it may have helped to improve the business environment, it has had little tangible impact on manufacturing itself. Since Covid-19, the manufacturing sector has been developing frugal (low-cost) technologies, including lung ventilators.

Since 2016, the Startup India initiative has boosted the number of start-ups but these remain concentrated in the services sector, in general, and software development, in particular.

Overall research intensity remains stagnant and the density of scientists and engineers remains one of the lowest among BRICS countries, despite having risen somewhat.

The government has reduced the tax incentive for firms conducting R&D, which is consistent with the finding of the previous *UNESCO Science Report* (2015) that the tax regime had 'not resulted in the spread of an innovation culture across firms and industries'. Pharmaceuticals and software still account for the majority of patents. Although inventive activity by Indian inventors has surged, foreign multinational corporations remain assignees for the vast majority of patents.

The phenomenon of 'jobless growth' that has plagued India since 1991 has worsened. Moreover, in 2017, the size of the workforce contracted for the first time since independence. Another concern is the low employability of graduates, including those enrolled in STEM subjects, although this indicator did improve over 2014–2019. The ambitious National Skills Development Mission aims to train about 400 million Indians over 2015–2022.

In 2018, investment in renewable sources exceeded that in fossil fuels. India's efforts are considered 2°C compatible but insufficient to meet the *Paris Agreement* target of 1.5°C.

The government is planning to add 46 GW of coal-fired capacity by 2027, even though plans for other coal plants were cancelled in 2017 after being deemed uneconomical.

Air and water pollution remain life-threatening challenges in India. The government is striving for universal electrification and the diffusion of electric and hybrid vehicles.

Made in China 2025 (2015) sets out to help ten strategic industries reduce **China's** (chapter 23) reliance on certain core foreign technologies through government subsidies, the mobilization of state-owned enterprises and pursuit of intellectual property acquisition. These cutting-edge manufacturing sectors include electric cars, aerospace engineering, biomedicine and advanced robotics and AI.

By 2030, China aims to be 'the world's primary centre for innovation in AI'. It is already the world's biggest owner of AI patents but lacks top-tier talent in this field. The government has launched megaprogrammes in science and engineering to 2030 that include quantum computing and brain science.

High technology, technology transfer and intellectual property protection are among sources of tension in the current trade dispute between China and the USA. The Foreign Investment Law (2020) sets out to make it easier to do business in China.

China's own strategic industries desire greater government protection of their intellectual property. The Anti-Unfair Competition Law was amended in April 2019 and the Patent Law in 2020 to offer better protection for trade secrets and patent-owners' rights, respectively. China has also established its first courts specializing in intellectual property.

The Law on Promoting the Transformation of Scientific and Technological Achievements (1993), also known as China's Bayh-Dole Act, was amended in 2015 to help universities and public research institutes transfer technology to industrial organizations. This may encourage both central and local governments and enterprises to invest more in basic research, which accounted for just 6% of GERD in 2018.

China is targeting carbon neutrality by 2060. In order to reach its 20% target for non-fossil energy consumption by 2030, it is developing nuclear power, hydropower, wind and solar energy. In parallel, the number of permits granted for new coal plants has risen since 2019.

Chinese companies are being encouraged to engage in scientific co-operation with countries partnering in the Belt and Road Initiative. The adoption of a series of guidelines in 2017 aims to set this initiative on a 'greener' trajectory.

Following the Covid-19 outbreak in the city of Wuhan, the National People's Congress adopted measures in February 2020 restricting wildlife trade and banning consumption of bushmeat and market sales of farmed wild animals like civets.

Japan (chapter 24) is facing a fairly unique set of structural challenges. The Japanese market is shrinking as the population ages, leading companies to purchase enterprises abroad to 'buy time and labour'. As a result, investment is leaving Japan's shores, hollowing out the country's industrial base. To compound matters, inward investment flows remain low, suggesting that the business environment might be losing its attractiveness abroad.

To address these challenges, the government adopted Society 5.0 in 2017, a blueprint for a super-smart society. It is the centrepiece of the country's new growth strategy, which envisions a transformation to a sustainable, inclusive socio-economic system enabled by digital technologies, including AI and robotics. For instance, autonomous vehicles and drones could be deployed to bring key services to depopulated areas, such as postal deliveries and care for the aged. 'Smart agriculture' is being explored to compensate for labour shortages. AI is already being used to improve disaster readiness and response.

The rising price of electrical power in industry poses an acute challenge. Following the Great East Japan Earthquake in 2011, nuclear power plants suspended operations for mandatory inspections and upgrades over 2013–2015. To compensate, imports of oil, gas and coal have risen and self-sufficiency has declined. The government has restarted nuclear reactors since 2016 to bolster energy security. Plans to build new coal power plants could compromise targets to reduce greenhouse gas emissions. The Fukushima Prefecture, itself, plans to be fully powered by renewables by 2040.

Government research expenditure has declined, reflecting the tight fiscal situation. Industry was the only sector to see a rise in research expenditure over 2014–2017, with strong growth observed in space-related expenditure as companies embraced the 'space business'.

In 2019, the government launched a 'Moonshot' programme to develop disruptive technologies, with a focus on problem-solving tied to such challenges as large-scale natural disasters, cyberterrorism and global warming. By setting ambitious targets, the programme hopes to attract researchers from around the world.

Universities have developed closer ties with the private sector, as reflected in the growing number of university start-ups over 2013–2018. This development follows efforts under way since 2004 to reform the university system which have led to the semi-privatization of national universities.

These reforms have also impinged on academic productivity by diversifying researchers' workload. Japan is one of the rare countries to have seen the volume of its scientific publications decline since 2011.

In parallel, enrolment in master's and doctoral degree programmes has dropped, suggesting that the young may have become disillusioned with an academic career.

The **Republic of Korea** (chapter 25) boasts the world's second-highest research intensity. Investment in research contributed an estimated 40% of national GDP over 2013–2017.

Since 2017, the government has been pursuing innovation-driven and income-led growth, in partial pursuit of previous government policy.[14] The *Future Vision for Science and Technology: towards 2040* (2010) has been revised to emphasize quality of life, consumption based on social values and support for SMEs.

The revised strategy contains no reference to nuclear technology, reflecting emerging doubts over the safety of nuclear power,[15] even though the Republic of Korea is a leader for the manufacture of nuclear reactors. Hydrogen and fuel cell technologies have received attention from the present government, as they are perceived as a way of compensating for the loss of nuclear energy.

The SDGs for affordable and clean energy (SDG7) and climate action (SDG13) are proving a challenge; ambitious targets to 2040 for renewable power generation will require considerable infrastructural investment. One government plan in the works is to help farmers transform degraded farming areas into solar farms.

In line with the *I-Korea 4.0* (2017) strategy for Industry 4.0, the country has begun installing a designated network for the Internet of Things and is commercializing 5G. The Personal Information Protection Act (2017) was amended in January 2020 to authorize commercial use and analysis of personal information.

One trend of some concern is the slide witnessed in scientific and technological competitiveness since 2010, even though research expenditure has increased.

Consequently, the government has striven to restructure the innovation ecosystem, including through the establishment of a National Science, Technology and Innovation Office in 2017 to improve co-ordination of the system. Other measures include merging administrative online systems for research; increasing researchers' autonomy by enabling them to design their own projects in basic science; evaluating research with a focus on process, rather than outcome; and a shift towards 'disruptive innovation' to regain competitiveness.

Establishing greater regional autonomy has been another policy priority. The government has created national innovation clusters centred on regional priorities. Public institutions and state-owned enterprises have been relocated to the provinces to support this endeavour. The Ministry for Small and Medium-sized Enterprises (est. 2017) is supporting this initiative and there are plans for SMEs, more generally, to play a greater role in national innovation.

In **Southeast Asia and Oceania** (chapter 26), the Regional Comprehensive Economic Partnership signed in November 2020 has the potential to bind more closely the economies of the Association of Southeast Asian Nations (ASEAN) with Australia, China, Japan, the Republic of Korea and New Zealand.

The recent publishing record suggests that stronger bilateral ties have been forged among ASEAN scientific communities since the ASEAN Economic Community came into force in 2015. At the multilateral level, however, there have been few effective initiatives since 2015 to close the capacity gap, as ASEAN has a limited operational budget and member states do not tend to share resources.

Research intensity has dipped in Australia and Singapore and progressed in each of Malaysia, New Zealand, Thailand and Viet Nam, creating greater convergence.

There is growing awareness that the digital transformation inherent to Industry 4.0 presents a great challenge for business, government and society at large. In the less developed countries, the priority is to raise the technical and managerial capability of the workforce and accelerate Internet penetration to make the most of this 'revolution'.

Several ASEAN countries have launched initiatives to integrate Industry 4.0 technologies into manufacturing. For instance, the *Making Indonesia 4.0* strategy aims to ramp up industrial performance by transitioning to high-tech, high value-added and specialized activities. The government introduced a 300% tax reduction on research expenditure for firms in 2019.

Another example is Singapore's Standards Mapping for for Smart Industry Readiness Index, which defines good practices with regard to reliability, interoperability, safety and cybersecurity in areas related to Industry 4.0.

Several countries are pinning their hopes on special economic zones to attract investment and foster innovation, including Cambodia, Thailand and Indonesia. Thailand's Eastern Economic Corridor of Innovation aims to establish linkages within the national innovation system, with the bio-industry being one focus area.

In striving to improve the ease of doing business, all governments will need to take care to preserve a regulatory framework that is protective of the environment and workforce.

Most countries have developed a strategic plan or performance monitoring framework for the SDGs but few have been able to provide a comprehensive report on their progress. Although policy-makers acknowledge the need to develop capacities in renewable energy, the transition from fossil fuels presents a challenge.

The Pacific Island countries are among the most committed to solar and wind energy. For them, these technologies offer the tantalizing promise of greater energy independence and a lesser reliance on costly fuel imports.

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ENDNOTES

1 See: https://tinyurl.com/covid-health-innovation-afr
2 Ultimately, ZTE avoided bankruptcy after paying a consequential fine and agreeing to allow the US government to monitor its operations.
3 In February 2021, 66 SMEs and mid-tier firms in traditional sectors such as tourism, real estate, education and health care were awarded the Smart Automation Grant as part of the government's National Economic Recovery Plan (Penjana) in response to the Covid-19 pandemic (see chapter 26).
4 Most EU member states have released national AI strategies, as have Canada, China, India, Japan, Mauritius, the Russian Federation, Saudi Arabia, United Arab Emirates, USA and Viet Nam. Others are in the process of elaborating their own AI strategy, including Bangladesh, Malaysia and Tunisia.
5 For the *Malabo Convention* to enter into force, 15 African countries must ratify it. As of May 2020, only eight had done so: Angola, Ghana, Guinea, Mauritius, Mozambique, Namibia, Rwanda and Senegal.
6 In India, the majority of robots have been installed in four industries, in descending order: automotive; chemicals, rubber and plastics; metal; and electrical and electronics.
7 Bhutan is the only carbon-negative country in the world. Its Constitution requires that 'a minimum of 60% of the country's total land be maintained under forest cover for all time'.
8 See: https://en.unesco.org/sites/default/files/usr15_tracking_trends_in_innovation_and_mobility.pdf
9 NASA is returning human spaceflight capabilities to the USA for the first time in nearly a decade with the development of the next-generation Space Launch System. The latter is now almost complete and should be far superior to the defunct Space Shuttle (see chapter 5).
10 The Querétaro Aerospace Cluster in Mexico dates from 2012, when multinational corporations that include Airbus, Delta and Bombardier joined forces with local entrepreneurs, research centres and the specialized University of Aeronautics of Querétaro to form this innovation cluster (see chapter 7).
11 Since much of this output involved international scientific collaboration, global publishing totals will add up to more than 100%.
12 The Balik (Returning) Scientist Act (2018) builds upon the Balik Science programme (1975). It covers the cost of repatriating voluntary Filipino STI personnel to the Philippines. The Department of Science and Technology hopes to woo 235 Balik Scientists over 2018–2022 (see chapter 26).
13 Angola, Botswana, Eswatini, Namibia, Seychelles, South Africa, Tanzania and Zimbabwe
14 As explored in the previous edition of the *UNESCO Science Report* (2015), the Park Guen-hye government had aimed to engender a creative economy, through a cultural shift towards greater entrepreneurship.
15 These doubts have arisen in the wake of the Fukushima Daïchi Nuclear Power Plant disaster of 2011 in Japan (see chapter 24).

Table 1.1: **Global trends in population, GDP and Internet penetration, 2015 and 2018**

	Population (millions)		Share of global population (%)		GDP (constant 2017 PPP$ billions)		Share of global GDP (%)		Internet users per 100 population	
	2015	2018	2015	2018	2015	2018	2015	2018	2015	2019
World	**7 371.65**	**7 623.14**	**100.00**	**100.00**	**111 572.24**	**123 921.67**	**100.00**	**100.00**	**41.68**	**48.40**
High-income	1 317.84	1 336.22	17.88	17.53	58 393.14	62 180.54	52.34	50.18	78.87	87.99
Upper middle-income	2 489.47	2 547.57	33.77	33.42	34 635.03	39 839.99	31.04	32.15	51.57	60.38
Lower middle-income	2 679.21	2 792.32	36.34	36.63	16 470.51	19 425.00	14.76	15.68	23.45	29.06
Low-income	885.12	947.04	12.01	12.42	2 073.55	2 476.14	1.86	2.00	12.83	17.53
Americas	**975.79**	**1 001.65**	**13.24**	**13.14**	**29 586.63**	**31 384.17**	**26.52**	**25.33**	**62.44**	**75.32**
North America	356.90	364.17	4.84	4.78	20 474.17	21 918.82	18.35	17.69	76.11	89.41
Latin America	581.05	598.77	7.88	7.85	8 841.44	9 163.95	7.92	7.39	55.69	67.91
Caribbean	37.84	38.71	0.51	0.51	271.01	301.40	0.24	0.24	37.23	57.66
Europe	**822.27**	**829.46**	**11.15**	**10.88**	**28 681.87**	**30 779.74**	**25.71**	**24.84**	**72.23**	**82.16**
European Union	508.56	511.68	6.90	6.71	21 093.72	22 607.01	18.91	18.24	77.77	85.05
Southeast Europe	17.90	17.72	0.24	0.23	231.31	254.15	0.21	0.21	63.23	74.80
European Free Trade Assoc.	13.86	14.24	0.19	0.19	886.25	939.28	0.79	0.76	91.26	95.11
Eastern Europe	281.95	285.82	3.82	3.75	6 470.59	6 979.30	5.80	5.63	61.89	76.81
Africa	**1 180.80**	**1 274.21**	**16.02**	**16.71**	**5 612.87**	**6 130.69**	**5.03**	**4.95**	**23.96**	**24.20**
Sub-Saharan Africa	953.42	1 033.08	12.93	13.55	3 555.34	3 834.12	3.19	3.09	20.52	18.21
Arab States in Africa	227.38	241.13	3.08	3.16	2 057.53	2 296.58	1.84	1.85	38.40	50.04
Asia	**4 353.78**	**4 477.14**	**59.06**	**58.73**	**46 311.07**	**54 127.88**	**41.51**	**43.68**	**35.81**	**42.94**
Central Asia	71.48	75.22	0.97	0.99	774.47	876.02	0.69	0.71	42.81	54.04
Arab States in Asia	153.42	162.22	2.08	2.13	3 400.25	3 571.97	3.05	2.88	55.69	70.07
West Asia	103.04	107.09	1.40	1.40	1 535.48	1 799.86	1.38	1.45	51.25	72.94
South Asia	1 749.36	1 814.01	23.73	23.80	8 996.76	10 979.85	8.06	8.86	16.22	20.21
East & Southeast Asia	2 276.49	2 318.60	30.88	30.42	31 604.10	36 900.18	28.33	29.78	48.74	57.31
Oceania	**39.03**	**40.72**	**0.53**	**0.53**	**1 379.94**	**1 499.34**	**1.24**	**1.21**	**65.64**	**69.41**
Other groupings										
Least developed countries	942.30	1 011.00	12.78	13.26	2 433.00	2 815.98	2.18	2.27	13.71	17.74
All Arab States	380.80	403.35	5.17	5.29	5 457.78	5 868.55	4.89	4.74	45.37	58.09
OECD	1 275.10	1 296.63	17.30	17.01	55 038.06	58 890.90	49.33	47.52	76.50	85.62
G20	4 723.61	4 826.67	64.08	63.32	91 421.33	101 355.99	81.94	81.79	47.63	54.84
Org. Islamic Co-op.	1 734.69	1 838.15	23.53	24.11	15 927.97	17 885.89	14.28	14.43	30.36	38.14
Selected countries										
Argentina	43.08	44.36	0.58	0.58	1 032.32	1 012.07	0.93	0.82	68.04	74.29^{-2}
Australia	23.93	24.90	0.32	0.33	1 143.65	1 238.54	1.03	1.00	84.56	86.55^{-2}
Brazil	204.47	209.47	2.77	2.75	3 079.19	3 057.47	2.76	2.47	58.33	70.43^{-1}
Canada	36.03	37.07	0.49	0.49	1 705.54	1 813.03	1.53	1.46	90.00	91.00^{-2}
China	1 406.85	1 427.65	19.08	18.73	17 403.45	21 229.73	15.60	17.13	50.30	54.30^{-2}
Egypt	92.44	98.42	1.25	1.29	977.16	1 118.72	0.88	0.90	37.82	57.30
France	64.45	64.99	0.87	0.85	2 898.40	3 051.03	2.60	2.46	78.01	83.30
Germany	81.79	83.12	1.11	1.09	4 183.10	4 448.72	3.75	3.59	87.59	88.10
India	1 310.15	1 352.64	17.77	17.74	7 146.03	8 787.69	6.40	7.09	17.00	20.10^{-1}
Indonesia	258.38	267.67	3.51	3.51	2 622.49	3 043.74	2.35	2.46	21.98	47.70
Iran	78.49	81.80	1.06	1.07	996.70	–	0.89	–	45.33	70.00^{-1}
Israel	7.98	8.38	0.11	0.11	315.37	351.25	0.28	0.28	77.35	86.80
Italy	60.58	60.63	0.82	0.80	2 456.24	2 549.69	2.20	2.06	58.14	74.39^{-1}
Japan	127.99	127.20	1.74	1.67	5 044.06	5 197.07	4.52	4.19	91.06	91.28^{-1}
Korea, Rep.	50.82	51.17	0.69	0.67	1 982.96	2 162.01	1.78	1.74	89.90	96.20
Malaysia	30.27	31.53	0.41	0.41	750.49	868.20	0.67	0.70	71.06	84.20
Mexico	121.86	126.19	1.65	1.66	2 350.43	2 522.84	2.11	2.04	57.43	70.10
Russian Federation	144.99	145.73	1.97	1.91	3 743.06	3 915.64	3.35	3.16	70.10	82.60
Saudi Arabia	31.72	33.70	0.43	0.44	1 551.67	1 604.01	1.39	1.29	69.62	95.70
South Africa	55.39	57.79	0.75	0.76	711.16	729.80	0.64	0.59	51.92	56.17^{-2}
Turkey	78.53	82.34	1.07	1.08	2 042.98	2 329.55	1.83	1.88	53.74	74.00
UK	65.86	67.14	0.89	0.88	2 924.55	3 077.77	2.62	2.48	92.00	92.50
USA	320.88	327.10	4.35	4.29	18 768.63	20 105.79	16.82	16.22	74.55	88.50^{-1}

Note: Eastern Europe refers to those countries that are not members of the European Union. Global and regional estimates are derived from national data without extrapolation to other countries. OECD stands for the Organisation for Economic Co-operation and Development.

Source: World Bank's World Development Indicators, August 2020

Table 1.2: **Global trends in research expenditure, 2014 and 2018**

	Gross domestic expenditure on R&D (GERD) [PPP$ billions]			Share of global GERD (%)		GERD as share of GDP (%)		GERD per capita (PPP$)			GERD per researcher (FTE) [PPP$ thousands]		
	2014	**2018**	**Change (%)**	**2014**	**2018**	**2014**	**2018**	**2014**	**2018**	**Change (%)**	**2014**	**2018**	**Change (%)**
World	**1 482.68**	**1 767.27**	**19.19**	**100.00**	**100.00**	**1.73**	**1.79**	**236.16**	**269.52**	**14.13**	**164.40**	**166.96**	**1.56**
High-income	1 011.23	1 137.40	12.48	68.20	64.36	2.31	2.40	805.72	890.75	10.55	194.28	195.71	0.74
Upper middle-income	407.70	551.59	35.29	27.50	31.21	1.39	1.57	170.74	223.81	31.08	187.48	199.15	6.22
Lower middle-income	62.20	76.56	23.09	4.20	4.33	0.48	0.49	27.94	32.40	15.96	126.63	123.21	-2.70
Low-income	1.55	1.72	10.97	0.10	0.10	0.22	0.22	3.66	3.81	4.10	145.21	138.34	-4.73
Americas	**476.69**	**531.35**	**11.47**	**32.15**	**30.07**	**2.05**	**2.12**	**536.66**	**576.51**	**7.43**	**245.02**	**230.33**	**-6.00**
North America	425.21	483.43	13.69	28.68	27.35	2.63	2.73	1 200.02	1 327.48	10.62	284.19	295.60	4.01
Latin America	51.44	47.89	-6.90	3.47	2.71	0.73	0.66	96.60	86.72	-10.23	217.39	184.61	-15.08
Caribbean	0.03	0.03	0.00	0.00	0.00	0.08	0.09	22.75	23.52	3.38	44.57	45.47	2.02
Europe	**345.51**	**390.28**	**12.96**	**23.30**	**22.08**	**1.72**	**1.78**	**423.13**	**472.56**	**11.68**	**125.38**	**124.80**	**-0.46**
European Union	290.35	330.83	13.94	19.58	18.72	1.94	2.02	572.19	646.65	13.01	153.86	150.40	-2.25
Southeast Europe	0.82	1.05	28.05	0.06	0.06	0.57	0.65	64.57	86.45	33.89	55.69	54.72	-1.74
European Free Trade Assoc.	16.63	18.82	13.17	1.12	1.07	2.65	2.87	1 208.43	1 317.70	9.04	225.11	230.21	2.27
Eastern Europe	37.70	39.57	4.96	2.54	2.24	0.97	0.95	134.43	138.96	3.37	70.91	73.66	3.88
Africa	**14.90**	**17.85**	**19.80**	**1.01**	**1.01**	**0.54**	**0.59**	**24.93**	**26.82**	**7.58**	**137.19**	**141.05**	**2.81**
Sub-Saharan Africa	6.51	7.34	12.75	0.44	0.42	0.49	0.51	14.36	14.49	0.91	156.79	147.32	-6.04
Arab States in Africa	8.39	10.51	25.27	0.57	0.59	0.59	0.65	57.51	67.48	17.34	78.35	92.60	18.19
Asia	**627.58**	**808.05**	**28.76**	**42.33**	**45.72**	**1.62**	**1.70**	**159.01**	**196.99**	**23.89**	**159.28**	**167.32**	**5.05**
Central Asia	0.95	0.81	-14.74	0.06	0.05	0.17	0.12	14.72	11.72	-20.38	25.83	24.44	-5.38
Arab States in Asia	6.94	10.17	46.54	0.47	0.58	0.40	0.53	106.66	143.09	34.16	176.41	144.28	-18.21
West Asia	15.54	26.05	67.63	1.05	1.47	0.94	1.37	150.77	242.22	60.66	71.18	93.41	31.23
South Asia	45.61	56.49	23.85	3.08	3.20	0.64	0.60	30.18	35.59	17.93	144.92	140.30	-3.19
East & Southeast Asia	558.54	714.52	27.93	37.67	40.43	2.03	2.13	253.47	315.45	24.45	174.77	193.03	10.45
Oceania	**18.01**	**19.75**	**9.66**	**1.21**	**1.12**	**1.74**	**1.81**	**496.95**	**514.61**	**3.55**	**42.05**	**46.90**	**11.53**
Other groupings													
Least developed	1.80	2.03	12.78	0.12	0.11	0.19	0.21	3.89	4.08	4.88	137.35	132.04	-3.87
All Arab States	15.33	20.69	34.96	1.03	1.17	0.48	0.59	72.61	91.15	25.53	109.07	109.09	0.02
OECD	988.49	1 114.38	12.74	66.67	63.06	2.36	2.43	779.71	859.34	10.21	206.90	204.27	-1.27
G20	1 393.89	1 647.65	18.21	94.01	93.23	1.93	1.99	299.38	343.87	14.86	182.53	188.45	3.24
Org. Islamic Co-op .	48.73	69.04	41.68	3.29	3.91	0.45	0.60	45.96	59.20	28.81	92.17	89.86	-2.51
Selected countries													
Argentina	4.28	4.03^{-1}	-5.84	0.29	0.23^{-1}	0.59	0.54^{-1}	100.28	91.63^{-1}	-8.63	83.09	76.86^{-1}	-7.50
Australia	–	17.30	–	–	0.98^{-1}	–	1.87^{-1}	–	703.57^{-1}	–	–	–	–
Brazil	35.56	33.30	-6.36	2.40	1.88^{-1}	1.27	1.26^{-1}	175.35	160.23^{-1}	-8.62	197.54	–	–
Canada	23.47	22.85^{-1}	-2.64	1.58	1.29	1.72	1.57	658.16	616.40	-6.34	144.91	150.68^{-1}	3.98
China	313.94	439.02	39.84	21.18	24.84	2.03	2.19	224.33	307.51	37.08	205.96	235.26	14.23
Egypt	5.14	6.99	35.99	0.35	0.40	0.64	0.72	56.89	71.03	24.85	84.26	103.44	22.76
France	47.55	48.88	2.80	3.21	2.77	2.28	2.20	740.75	752.06	1.53	174.97	159.49	-8.85
Germany	85.96	99.99	16.32	5.80	5.66	2.87	3.09	1 055.35	1 202.88	13.98	244.26	230.80	-5.51
India	43.55	54.04	24.09	2.94	3.06	0.70	0.65	33.62	39.95	18.83	–	158.11	–
Indonesia	–	6.26		–	0.35	–	0.23	–	23.40	–	–	108.36	–
Iran	–	11.40^{-1}		–	0.64^{-1}	–	0.83^{-1}	–	141.28^{-1}	–	–	95.79^{-1}	–
Israel	10.19	13.81	35.53	0.69	0.78	4.17	4.95	1 297.90	1 647.67	26.95	–	–	–
Italy	22.15	24.15	9.03	1.49	1.37	1.34	1.40	366.62	398.30	8.64	187.40	172.67	-7.86
Japan	143.48	144.12	0.45	9.68	8.16	3.40	3.26	1 119.47	1 133.01	1.21	210.10	212.53	1.16
Korea, Rep.	68.98	86.62	25.57	4.65	4.90	4.29	4.53	1 363.09	1 692.64	24.18	199.68	212.10	6.22
Malaysia	8.23	–		0.56	–	1.26	–	275.50	–	–	134.12	–	–
Mexico	7.04	5.59	-20.60	0.47	0.32	0.44	0.31	58.50	44.27	-24.32	224.85	–	–
Russian Fed.	24.00	22.57	-5.96	1.62	1.28	1.07	0.99	165.89	154.88	-6.64	53.94	55.62	3.11
South Africa	4.64	5.16^{-1}	11.21	0.31	0.29^{-1}	0.77	0.83^{-1}	85.12	90.55^{-1}	6.38	196.96	174.89^{-1}	-11.21
Turkey	10.83	14.22^{-1}	31.30	0.73	0.80^{-1}	0.86	0.96^{-1}	140.19	175.26^{-1}	25.02	120.76	127.05^{-1}	5.21
UK	36.00	40.24	11.78	2.43	2.28	1.66	1.72	550.28	599.32	8.91	130.16	130.19	0.02
USA	401.74	460.58^{-1}	14.65	27.10	26.06^{-1}	2.72	2.84^{-1}	1 260.66	1408.08^{-1}	11.69	299.78	309.94^{-1}	3.39

Note: GERD figures are in PPP$ (constant 2005 prices). Many of the underlying data are estimated by the UNESCO Institute for Statistics for developing countries, in particular. Furthermore, in a substantial number of developing countries data do not cover all sectors of the economy.

Source: global and regional estimates based on country-level data from the UNESCO Institute for Statistics, August 2020, without extrapolation

Table 1.3: **Global trends in research personnel, 2014 and 2018**

	Researchers (FTE, thousands)			Share of global researchers (%)		Females, in head counts (%)	Researchers per million inhabitants (FTE)			Technicians per million inhabitants (FTE)		
	2014	2018	Change (%)	2014	2018	2018	2014	2018	Change (%)	2014	2018	Change (%)
World	**7 789.79**	**8 854.29**	**13.67**	**100.00**	**100.00**	**33.25**	**1 245.3**	**1368.0**	**9.86**	**301.7**	**311.3**	**3.18**
High-income	4 885.91	5 333.83	9.17	62.72	60.24	29.59	3 994.7	4301.1	7.67	1 021.7	1 047.1	2.49
Upper middle-income	2 256.87	2 762.41	22.40	28.97	31.20	42.65	955.0	1141.1	19.49	358.1	425.3	18.77
Lower middle-income	633.92	739.42	16.64	8.14	8.35	42.79	275.8	312.2	13.20	83.5	73.8	-11.62
Low-income	13.09	18.64	42.37	0.17	0.21	19.54	33.1	45.1	36.13	20.1	22.7	12.94
Americas	**1 797.28**	**1 918.33**	**6.74**	**23.07**	**21.67**	**49.80**	**2 046.7**	**2131.6**	**4.15**	**33.1**	**45.1**	**36.25**
North America	1 502.09	1 603.66	6.76	19.28	18.11	–	4 239.1	4 432.2	107.72	1 353.0	1 280.2	-5.38
Latin America	294.49	313.95	6.61	3.78	3.55	49.77	563.7	592.9	5.19	531.2	556.6	4.78
Caribbean	0.70	0.72	2.02	0.01	0.01	50.24	509.2	519.5	2.02	273.8	268.4	-1.97
Europe	**2 446.37**	**2 746.56**	**12.27**	**31.40**	**31.02**	**34.85**	**3 034.4**	**3372.0**	**11.12**	**930.4**	**977.0**	**5.01**
European Union	1 772.36	2 081.75	17.46	22.75	23.51	33.78	3 492.9	4069.2	16.50	1 336.2	1 413.6	5.79
Southeast Europe	16.21	18.23	12.47	0.21	0.21	51.21	1 290.8	1487.2	15.21	236.7	275.3	16.31
European Free Trade Assoc.	74.43	83.05	11.58	0.96	0.94	36.59	5 406.9	5876.6	8.69	2 525.0	2 631.7	4.23
Eastern Europe	583.37	563.53	-3.40	7.49	6.36	39.04	2 153.5	2053.8	-4.63	357.1	362.8	1.60
Africa	**194.59**	**221.28**	**13.72**	**2.50**	**2.50**	**41.82**	**307.9**	**326.4**	**6.01**	**86.0**	**93.3**	**8.49**
Sub-Saharan Africa	46.54	59.93	28.77	0.60	0.68	33.48	102.3	123.8	20.97	36.4	38.5	5.77
Arab States in Africa	148.05	161.36	8.99	1.90	1.82	44.87	837.0	866.2	3.49	202.7	214.5	5.82
Asia	**3 326.52**	**3 941.58**	**18.49**	**42.70**	**44.52**	**28.43**	**845.0**	**969.9**	**14.79**	**130.2**	**133.6**	**2.61**
Central Asia	29.07	27.68	-4.77	0.37	0.31	44.90	609.1	545.0	-10.52	104.0	75.4	-27.50
Arab States in Asia	29.53	40.33	36.58	0.38	0.46	34.17	354.7	458.2	29.18	148.8	149.3	0.34
West Asia	68.21	126.51	85.48	0.88	1.43	33.95	826.6	1494.0	80.74	160.1	491.5	207.00
South Asia	336.37	415.29	23.46	4.32	4.69	39.14	219.7	262.8	19.61	86.0	67.7	-21.28
East & Southeast Asia	2 863.35	3 331.77	16.36	36.76	37.63	26.31	1 297.9	1475.6	13.70	209.8	224.1	6.82
Oceania	**25.03**	**26.53**	**6.01**	**0.32**	**0.30**	**33.25**	**1 978.9**	**2005.6**	**1.35**	**382.4**	**464.6**	**21.50**
Other groupings												
Least developed	21.65	28.21	30.35	0.28	0.32	21.98	49.1	62	26.27	20.6	23.3	13.11
All Arab States	177.58	201.69	13.58	2.28	2.28	42.60	681.9	736	7.93	185.4	193.7	4.48
OECD	4 478.64	4 987.73	11.37	57.49	56.33	28.96	3 622.6	3959	9.29	926.9	976.2	5.32
G20	6 973.47	7 865.54	12.79	89.52	88.83	30.82	1 504.3	1654	9.95	405.0	406.8	0.44
Org. Islamic Co-op .	533.53	681.62	27.76	6.85	7.70	40.17	499.5	609	21.93	94.1	140.9	49.73
Selected countries												
Argentina	51.46	52.4^{-1}	1.79	0.66	0.59^{-1}	54.07^{-1}	1 206.9	1 192.23^{-1}	-1.22	318.8	398.1	24.87
Brazil	179.99	–	-	2.31	–		887.7		–	969.9	–	–
Canada	161.98	158.89^{-1}	-1.91	2.08	1.80^{-1}	–	4 541.9	4 325.64^{-1}	-4.76	1 353.0	1 268.4^{-1}	-6.25
China	1 524.28	1 866.11	22.43	19.55	21.12	–	1 089.2	1 307.12	20.01	–	–	–
Egypt	61.06	67.59	10.70	0.78	0.76	45.6	675.2	686.72	1.70	351.6	369.6	5.12
France	271.77	306.45	12.76	3.49	3.47	28.3^{-1}	4 233.6	4 715.32	11.38	1 809.3	1 805.5^{-1}	-0.21
Germany	351.92	433.23	23.10	4.51	4.90	27.9^{-1}	4 320.7	5 211.87	20.63	1 883.2	2 018.0	7.16
India	–	341.82	–	–	3.87	–	–	252.70	–	95.5	73.1	-23.46
Indonesia	–	57.82	–	–	0.65	45.8	–	215.99	–	16.3^{+2}	34.7	112.88
Iran	–	118.99^{-1}	–	–	1.35^{-1}	31.2^{-1}	–	1 474.91^{-1}	–	160.6^{+1}	496.8^{-1}	209.34
Italy	118.18	139.85	18.34	1.52	1.58	34.3^{-1}	1 956.4	2 306.77	17.91	–	–	–
Japan	682.94	678.13	-0.70	8.76	7.67	16.6	5 328.4	5 331.15	0.05	537.0	524.3	-2.36
Korea, Rep.	345.46	408.37	18.21	4.43	4.62	20.4	6 826.3	7 980.40	16.91	1 228.2	1 251.1	1.86
Malaysia	61.35	–	–	0.79	–	48.2^{-2}	2 054.2	–	–	212.2	233.4	9.99
Mexico	31.32	–	–	0.40	–	–	260.2	–	–	115.6	140.3^{-2}	21.37
Russian Fed.	444.87	405.77	-8.79	5.71	4.59	39.2	3 075.1	2 784.33	-9.46	496.6	437.8	-11.84
South Africa	23.57	29.52^{-1}	25.21	0.30	0.33^{-1}	44.9^{-1}	432.2	517.72^{-1}	19.80	141.7	129.5^{-1}	-8.61
Turkey	89.66	111.89^{-1}	24.80	1.15	1.27^{-1}	37.0^{-1}	1 160.9	1 379.41^{-1}	18.82	208.3	353.7^{-1}	69.80
UK	276.58	309.07	11.75	3.55	3.50	38.7^{-2}	4 227.6	4 603.31	8.89	1 255.5	1 305.4^{-2}	3.97
USA	1 340.10	1 434.42^{-1}	7.04	17.19	16.23^{-1}	–	4 205.3	4 412.44^{-1}	4.93	–	–	–

Note: Researchers are counted in full-time equivalents (FTE). Global and regional estimates are based on the available FTE data for the countries. The share of female researchers is based on available head count data for the most recent year between 2015 and 2018. See Table 1.1 for regional terms.

Source: global and regional estimates based on country-level data from the UNESCO Institute for Statistics, August 2020, without extrapolation

Table 1.4: **Global trends in scientific publications, 2015 and 2019**

	Volume		Change (%)	Global share (%)		Publications per million inhabitants		Publications with international co-authors (%)		Cross-cutting strategic technologies: Volume		Cross-cutting strategic technologies: Change (%)	Cross-cutting strategic technologies: Global share (%)	
	2015	2019	2015–2019	2015	2019	2015	2019	2015	2019	2015	2019	2015–2019	2015	2019
World	**2 178 625**	**2 629 248**	**20.68**	**100.00**	**100.00**	**295.24**	**340.90**	**21.69**	**23.48**	**351 447**	**467 883**	**33.13**	**100.00**	**100.00**
High-income	1 509 655	1 654 704	9.61	69.29	62.93	1 139.12	1 226.93	30.40	35.46	212 582	244 026	14.79	60.49	52.16
Upper middle-income	702 587	1 000 301	42.37	32.25	38.05	282.22	389.91	24.89	27.41	140 207	208 580	48.77	39.89	44.58
Lower middle-income	174 394	299 319	71.63	8.00	11.38	65.09	105.76	29.11	29.63	33 977	75 894	123.37	9.67	16.22
Low-income	13 923	23 799	70.93	0.64	0.91	15.73	24.58	72.13	69.96	1 014	2 739	170.12	0.29	0.59
Americas	**658 936**	**724 263**	**9.91**	**30.25**	**27.55**	**672.69**	**714.78**	**34.99**	**39.44**	**77 773**	**87 323**	**12.28**	**22.13**	**18.66**
North America	565 726	609 538	7.74	25.97	23.18	1 568.56	1 648.32	36.52	41.29	66 316	71 063	7.16	18.87	15.19
Latin America	107 634	135 039	25.46	4.94	5.14	185.24	223.39	36.75	40.82	12 516	17 534	40.09	3.56	3.75
Caribbean	2 833	3 110	9.78	0.13	0.12	74.87	79.78	59.20	71.16	237	301	27.00	0.07	0.06
Europe	**822 170**	**918 168**	**11.68**	**37.74**	**34.92**	**995.42**	**1 099.43**	**37.35**	**41.14**	**117 410**	**140 646**	**19.79**	**33.41**	**30.06**
European Union	700 849	752 472	7.37	32.17	28.62	1 368.20	1 457.36	41.01	46.54	99 892	108 910	9.03	28.42	23.28
Southeast Europe	8 125	8 967	10.36	0.37	0.34	453.84	507.60	43.47	52.68	1 160	1 156	-0.34	0.33	0.25
European Free Trade Assoc.	54 041	61 685	14.14	2.48	2.35	3 897.85	4 299.42	66.28	69.91	6 055	6 811	12.49	1.72	1.46
Eastern Europe	105 579	152 895	44.82	4.85	5.82	374.47	533.12	25.33	24.54	15 432	30 547	97.95	4.39	6.53
Africa	**61 236**	**92 133**	**50.46**	**2.81**	**3.50**	**51.86**	**70.53**	**53.95**	**55.40**	**8 966**	**14 537**	**62.13**	**2.55**	**3.11**
Sub-Saharan Africa	30 805	47 374	53.79	1.41	1.80	32.31	44.67	58.89	60.52	3 112	5 916	90.10	0.89	1.26
Arab States in Africa	30 951	45 665	47.54	1.42	1.74	136.12	185.84	49.81	50.98	5 910	8 704	47.28	1.68	1.86
Asia	**900 254**	**1 262 260**	**40.21**	**41.32**	**48.01**	**206.78**	**279.46**	**22.61**	**24.43**	**184 247**	**281 245**	**52.65**	**52.43**	**60.11**
Central Asia	2 528	5 780	128.64	0.12	0.22	35.37	75.62	60.96	61.28	536	1 456	171.64	0.15	0.31
Arab States in Asia	32 414	58 153	79.41	1.49	2.21	211.28	352.07	70.77	62.15	6 923	12 443	79.73	1.97	2.66
East & Southeast Asia	699 375	964 627	37.93	32.10	36.69	307.22	413.75	22.03	24.17	147 103	211 303	43.64	41.86	45.16
South Asia	126 301	191 638	51.73	5.80	7.29	72.20	104.42	21.45	24.46	24 939	52 818	111.79	7.10	11.29
West Asia	59 727	82 087	37.44	2.74	3.12	579.63	757.01	30.15	34.89	8 687	11 431	31.59	2.47	2.44
Oceania	**80 984**	**98 304**	**21.39**	**3.72**	**3.74**	**2 074.98**	**2 381.70**	**53.55**	**61.61**	**9 298**	**11 924**	**28.24**	**2.65**	**2.55**
Other groupings														
Least developed	13 826	23 572	70.49	0.63	0.90	14.67	22.78	72.90	71.30	1 081	2 881	166.51	0.31	0.62
Arab States	58 447	95 817	63.94	2.68	3.64	153.49	233.19	57.21	53.66	11 944	19 840	66.11	3.40	4.24
OECD	1 439 908	1 549 257	7.59	66.09	58.92	1 122.70	1 182.48	30.49	35.72	195 786	215 660	10.15	55.71	46.09
G20	1 989 718	2 381 962	19.71	91.33	90.59	420.57	489.53	23.33	25.31	316 697	419 013	32.31	90.11	89.56
Org. Islamic Co-op .	183 243	300 234	63.84	8.41	11.42	105.63	160.31	36.35	36.80	33 640	59 098	75.68	9.57	12.63
Selected countries														
Argentina	10 982	12 280	11.82	0.50	0.47	254.95	274.23	46.60	50.47	897	1 071	19.40	0.26	0.23
Australia	71 691	87 187	21.61	3.29	3.32	2 995.55	3 459.36	53.94	62.23	8 366	10 736	28.33	2.38	2.29
Brazil	61 006	74 270	21.74	2.80	2.82	298.36	351.91	30.75	35.21	6 699	8 596	28.32	1.91	1.84
Canada	82 595	94 578	14.51	3.79	3.60	2 292.61	2 528.08	51.84	57.94	9 533	10 699	12.23	2.71	2.29
China	431 654	644 655	49.35	19.81	24.52	306.82	449.62	20.23	22.98	98 669	149 832	51.85	28.08	32.02
Egypt	14 728	23 224	57.69	0.68	0.88	159.32	231.34	52.17	53.33	2 402	3 787	57.66	0.68	0.81
France	101 491	101 081	-0.40	4.66	3.84	1 510.19	1 486.96	54.50	60.34	14 016	12 788	-8.76	3.99	2.73
Germany	144 201	152 348	5.65	6.62	5.79	1 763.12	1 824.15	50.56	54.79	19 974	20 814	4.21	5.68	4.45
India	110 282	161 066	46.05	5.06	6.13	84.17	117.87	17.67	18.88	22 725	47 333	108.29	6.47	10.12
Indonesia	6 080	37 513	516.99	0.28	1.43	23.53	138.62	40.10	17.03	1 811	9 195	407.73	0.52	1.97
Iran	41 292	60 562	46.67	1.90	2.30	526.06	730.42	20.60	28.17	6 629	9 091	37.14	1.89	1.94
Israel	16 393	18 671	13.90	0.75	0.71	2 054.65	2 191.59	51.96	54.26	1 852	1 949	5.24	0.53	0.42
Italy	91 895	103 577	12.71	4.22	3.94	1 516.96	1 710.60	46.34	50.27	12 500	13 718	9.74	3.56	2.93
Japan	117 020	119 347	1.99	5.37	4.54	914.32	940.78	26.27	31.24	17 564	18 129	3.22	5.00	3.87
Korea, Rep.	71 719	81 327	13.40	3.29	3.09	1 411.15	1 587.63	26.89	29.33	12 992	15 793	21.56	3.70	3.38
Malaysia	22 405	30 172	34.67	1.03	1.15	740.15	944.36	39.01	43.84	7 428	9 912	33.44	2.11	2.12
Mexico	18 321	23 508	28.31	0.84	0.89	150.35	184.27	40.28	44.95	2 662	3 414	28.25	0.76	0.73
Russian Fed.	60 156	96 394	60.24	2.76	3.67	414.91	660.81	27.17	23.73	9 558	20 666	116.22	2.72	4.42
Saudi Arabia	17 681	25 205	42.55	0.81	0.96	557.45	735.51	76.22	75.84	3 672	4 994	36.00	1.04	1.07
South Africa	14 706	21 062	43.22	0.68	0.80	265.52	359.68	54.13	57.42	1 622	2 623	61.71	0.46	0.56
Turkey	36 308	43 245	19.11	1.67	1.64	462.35	518.34	21.16	25.12	3 876	5 927	52.92	1.10	1.27
UK	141 834	160 174	12.93	6.51	6.09	2 137.31	2 353.92	57.58	64.49	16 960	19 316	13.89	4.83	4.13
USA	502 105	538 259	7.20	23.05	20.47	1 546.66	1 619.40	36.40	40.91	58 082	61 890	6.56	16.53	13.23

Note: The sum of the regional values exceeds the world number because papers with multiple authors from different regions are counted for each of these regions.

Source: Scopus (Elsevier), excluding Arts, Humanities and Social sciences; data treatment by Science-Metrix

Table 1.5: **Global trends in scientific publications on selected cross-cutting strategic technologies, 2015 and 2019**

	Volume											
	AI & robotics		Biotechnology		Energy		Materials		Nanoscience & nanotech		Opto-electronics	
	2015	2019	2015	2019	2015	2019	2015	2019	2015	2019	2015	2019
World	**102 347**	**147 806**	**16 707**	**18 714**	**86 771**	**108 129**	**63 705**	**93 033**	**31 226**	**46 121**	**29 517**	**26 651**
High-income	65 365	74 661	9 869	9 394	49 997	57 245	31 625	40 729	21 104	27 979	18 560	15 330
Upper middle-income	33 075	50 340	6 531	9 333	36 903	53 560	32 529	48 484	13 290	24 657	11 813	11 872
Lower middle-income	13 052	37 389	2 283	2 937	7 890	12 701	6 097	15 194	2 035	3 588	1 293	1 816
Low-income	280	1 037	79	120	249	607	89	284	33	103	31	67
Americas	**20 633**	**24 969**	**3 934**	**4 161**	**19 674**	**21 445**	**9 471**	**10 588**	**8 457**	**11 053**	**7 623**	**5 964**
North America	16 628	18 727	2 876	2 603	16 859	17 434	7 623	8 088	8 075	10 514	6 901	5 354
Latin America	4 211	6 524	1 122	1 651	3 152	4 394	1 974	2 661	478	670	800	655
Caribbean	92	144	36	20	53	60	26	44	6	6	4	5
Europe	**40 993**	**47 402**	**4 883**	**4 984**	**26 524**	**31 950**	**19 124**	**28 125**	**8 181**	**11 040**	**9 781**	**8 299**
European Union	36 554	37 207	4 284	4 246	21 637	25 662	14 797	17 913	7 355	9 717	8 244	6 178
Southeast Europe	382	336	79	86	325	313	201	302	41	37	37	30
European Free Trade Assoc.	1 851	2 034	191	215	1 635	1 837	680	804	589	861	382	334
Eastern Europe	3 624	9 658	528	666	4 004	5 586	4 423	10 466	767	1 280	1 580	2 283
Africa	**3 207**	**4 752**	**551**	**844**	**2 710**	**4 443**	**1 185**	**2 451**	**400**	**604**	**310**	**445**
Sub-Saharan Africa	823	1 539	221	383	1 169	2 018	334	965	91	168	61	125
Arab States in Africa	2 389	3 225	334	467	1 563	2 450	862	1 505	311	441	254	330
Asia	**46 913**	**84 072**	**9 285**	**11 355**	**45 754**	**64 150**	**39 692**	**60 953**	**19 968**	**32 818**	**14 800**	**14 896**
Central Asia	142	569	15	11	194	317	102	304	6	80	62	149
Arab States in Asia	1 908	3 936	286	458	2 466	4 125	883	2 050	719	1 008	283	294
Southeast Asia	33 662	50 330	6 854	8 491	36 498	50 194	33 248	49 993	17 598	28 957	13 139	13 030
South Asia	9 956	29 049	1 896	2 179	5 045	7 976	4 599	7 961	1 566	2 875	837	1 118
West Asia	2 173	2 402	473	657	2 579	3 744	1 667	2 250	612	927	648	565
Oceania	**2 918**	**3 469**	**368**	**412**	**2 198**	**3 066**	**1 328**	**1 671**	**1 078**	**1 809**	**466**	**308**
Other groupings												
Least developed countries	325	1 126	82	132	289	630	95	295	32	111	33	67
All Arab States	4 091	6 868	558	833	3 785	6 187	1 581	3 219	886	1 340	498	577
OECD	60 878	66 911	9 396	9 105	45 852	51 576	28 260	32 085	18 834	24 861	16 979	13 274
G20	91 303	128 003	15 220	16 808	76 010	96 361	58 375	84 400	28 953	43 399	27 521	25 161
Org. Islamic Co-op.	9 685	20 149	1 759	2 604	11 790	15 537	5 659	13 942	1 740	2 767	1 426	1 585
Selected countries												
Argentina	218	250	116	120	205	336	162	179	59	64	32	20
Australia	2 520	3 003	325	342	2 077	2 840	1 202	1 541	1 045	1 743	432	286
Brazil	2 037	2 640	684	1 032	1 641	2 181	1 331	1 654	256	293	405	341
Canada	2 792	3 217	413	431	2 752	2 937	1 111	1 227	794	1 143	780	630
China	20 414	29 766	3 891	5 608	24 352	38 521	24 863	35 942	11 554	22 270	9 559	10 010
Egypt	610	837	166	302	760	1 247	404	784	236	279	132	201
France	5 215	4 536	512	461	2 755	2 667	2 031	1 900	1 170	1 350	1 374	945
Germany	6 712	6 726	827	776	3 950	4 305	3 262	3 441	1 949	2 684	1 995	1 507
India	9 276	26 779	1 770	1 918	4 562	6 609	4 152	7 257	1 433	2 550	717	969
Indonesia	822	3 229	57	138	670	1 098	166	4 264	16	86	42	182
Iran	1 357	1 613	406	590	2 366	3 463	1 514	1 952	369	548	312	314
Israel	745	638	59	56	165	196	122	216	236	361	308	215
Italy	4 380	4 773	496	436	3 429	3 683	1 242	1 651	953	1 128	959	664
Japan	4 891	5 917	973	953	3 778	3 293	3 481	3 295	1 841	2 225	1 847	1 603
Korea, Rep.	2 426	3 029	1 304	1 108	2 900	3 786	2 510	3 009	2 630	3 452	645	592
Malaysia	1 685	4 404	357	446	3 550	1 821	1 137	2 598	258	307	236	138
Mexico	969	1 228	204	324	605	761	362	505	120	218	234	213
Russian Fed.	1 986	5 704	254	273	2 527	3 259	2 949	8 357	455	903	1 161	1 898
Saudi Arabia	927	1 265	192	195	1 075	1 662	519	849	584	639	159	146
South Africa	511	701	85	145	529	959	214	441	72	84	40	93
Turkey	1 094	2 073	247	355	943	1 544	929	1 242	181	240	224	159
UK	5 700	6 192	472	578	3 903	4 947	2 166	2 458	1 488	2 072	1 410	950
USA	14 149	15 893	2 526	2 231	14 435	14 862	6 636	7 001	7 419	9 614	6 251	4 841

Note: The sum of the numbers for the various regions exceeds the total number because papers with multiple authors from different regions are counted for each of these regions.The six cross-cutting technologies featured here were followed by bioinformatics, Internet of Things, strategic, defence and security studies and blockchain technology. See Table 1.1 for regional terms.

	Global share (%)											
	AI & robotics		**Biotechnology**		**Energy**		**Materials**		**Nanoscience & nanotech**		**Opto-electronics**	
	2015	**2019**	**2015**	**2019**	**2015**	**2019**	**2015**	**2019**	**2015**	**2019**	**2015**	**2019**
World	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
High-income	63.87	50.51	59.07	50.20	57.62	52.94	49.64	43.78	67.58	60.66	62.88	57.52
Upper middle-income	32.32	34.06	39.09	49.87	42.53	49.53	51.06	52.11	42.56	53.46	40.02	44.55
Lower middle-income	12.75	25.30	13.66	15.69	9.09	11.75	9.57	16.33	6.52	7.78	4.38	6.81
Low-income	0.27	0.70	0.47	0.64	0.29	0.56	0.14	0.31	0.11	0.22	0.11	0.25
Americas	**20.16**	**16.89**	**23.55**	**22.23**	**22.67**	**19.83**	**14.87**	**11.38**	**27.08**	**23.97**	**25.83**	**22.38**
North America	16.25	12.67	17.21	13.91	19.43	16.12	11.97	8.69	25.86	22.80	23.38	20.09
Latin America	4.11	4.41	6.72	8.82	3.63	4.06	3.10	2.86	1.53	1.45	2.71	2.46
Caribbean	0.09	0.10	0.22	0.11	0.06	0.06	0.04	0.05	0.02	0.01	0.01	0.02
Europe	**40.05**	**32.07**	**29.23**	**26.63**	**30.57**	**29.55**	**30.02**	**30.23**	**26.20**	**23.94**	**33.14**	**31.14**
European Union	35.72	25.17	25.64	22.69	24.94	23.73	23.23	19.25	23.55	21.07	27.93	23.18
Southeast Europe	0.37	0.23	0.47	0.46	0.37	0.29	0.32	0.32	0.13	0.08	0.13	0.11
European Free Trade Assoc.	1.81	1.38	1.14	1.15	1.88	1.70	1.07	0.86	1.89	1.87	1.29	1.25
Eastern Europe	3.54	6.53	3.16	3.56	4.61	5.17	6.94	11.25	2.46	2.78	5.35	8.57
Africa	**3.13**	**3.22**	**3.30**	**4.51**	**3.12**	**4.11**	**1.86**	**2.63**	**1.28**	**1.31**	**1.05**	**1.67**
Sub-Saharan Africa	0.80	1.04	1.32	2.05	1.35	1.87	0.52	1.04	0.29	0.36	0.21	0.47
Arab States in Africa	2.33	2.18	2.00	2.50	1.80	2.27	1.35	1.62	1.00	0.96	0.86	1.24
Asia	**45.84**	**56.88**	**55.58**	**60.68**	**52.73**	**59.33**	**62.31**	**65.52**	**63.95**	**71.16**	**50.14**	**55.89**
Central Asia	0.14	0.38	0.09	0.06	0.22	0.29	0.16	0.33	0.02	0.17	0.21	0.56
Arab States in Asia	1.86	2.66	1.71	2.45	2.84	3.81	1.39	2.20	2.30	2.19	0.96	1.10
Southeast Asia	32.89	34.05	41.02	45.37	42.06	46.42	52.19	53.74	56.36	62.78	44.51	48.89
South Asia	9.73	19.65	11.35	11.64	5.81	7.38	7.22	8.56	5.02	6.23	2.84	4.19
West Asia	2.12	1.63	2.83	3.51	2.97	3.46	2.62	2.42	1.96	2.01	2.20	2.12
Oceania	**2.85**	**2.35**	**2.20**	**2.20**	**2.53**	**2.84**	**2.08**	**1.80**	**3.45**	**3.92**	**1.58**	**1.16**
Other groupings												
Least developed countries	0.32	0.76	0.49	0.71	0.33	0.58	0.15	0.32	0.10	0.24	0.11	0.25
All Arab States	4.00	4.65	3.34	4.45	4.36	5.72	2.48	3.46	2.84	2.91	1.69	2.17
OECD	59.48	45.27	56.24	48.65	52.84	47.70	44.36	34.49	60.32	53.90	57.52	49.81
G20	89.21	86.60	91.10	89.82	87.60	89.12	91.63	90.72	92.72	94.10	93.24	94.41
Org. Islamic Co-op.	9.46	13.63	10.53	13.91	13.59	14.37	8.88	14.99	5.57	6.00	4.83	5.95
Selected countries												
Argentina	0.21	0.17	0.69	0.64	0.24	0.31	0.25	0.19	0.19	0.14	0.11	0.08
Australia	2.46	2.03	1.95	1.83	2.39	2.63	1.89	1.66	3.35	3.78	1.46	1.07
Brazil	1.99	1.79	4.09	5.51	1.89	2.02	2.09	1.78	0.82	0.64	1.37	1.28
Canada	2.73	2.18	2.47	2.30	3.17	2.72	1.74	1.32	2.54	2.48	2.64	2.36
China	19.95	20.14	23.29	29.97	28.06	35.63	39.03	38.63	37.00	48.29	32.38	37.56
Egypt	0.60	0.57	0.99	1.61	0.88	1.15	0.63	0.84	0.76	0.60	0.45	0.75
France	5.10	3.07	3.06	2.46	3.18	2.47	3.19	2.04	3.75	2.93	4.65	3.55
Germany	6.56	4.55	4.95	4.15	4.55	3.98	5.12	3.70	6.24	5.82	6.76	5.65
India	9.06	18.12	10.59	10.25	5.26	6.11	6.52	7.80	4.59	5.53	2.43	3.64
Indonesia	0.80	2.18	0.34	0.74	0.77	1.02	0.26	4.58	0.05	0.19	0.14	0.68
Iran	1.33	1.09	2.43	3.15	2.73	3.20	2.38	2.10	1.18	1.19	1.06	1.18
Israel	0.73	0.43	0.35	0.30	0.19	0.18	0.19	0.23	0.76	0.78	1.04	0.81
Italy	4.28	3.23	2.97	2.33	3.95	3.41	1.95	1.77	3.05	2.45	3.25	2.49
Japan	4.78	4.00	5.82	5.09	4.35	3.05	5.46	3.54	5.90	4.82	6.26	6.01
Korea, Rep.	2.37	2.05	7.81	5.92	3.34	3.50	3.94	3.23	8.42	7.48	2.19	2.22
Malaysia	1.65	2.98	2.14	2.38	4.09	1.68	1.78	2.79	0.83	0.67	0.80	0.52
Mexico	0.95	0.83	1.22	1.73	0.70	0.70	0.57	0.54	0.38	0.47	0.79	0.80
Russian Fed.	1.94	3.86	1.52	1.46	2.91	3.01	4.63	8.98	1.46	1.96	3.93	7.12
Saudi Arabia	0.91	0.86	1.15	1.04	1.24	1.54	0.81	0.91	1.87	1.39	0.54	0.55
South Africa	0.50	0.47	0.51	0.77	0.61	0.89	0.34	0.47	0.23	0.18	0.14	0.35
Turkey	1.07	1.40	1.48	1.90	1.09	1.43	1.46	1.34	0.58	0.52	0.76	0.60
UK	5.57	4.19	2.83	3.09	4.50	4.58	3.40	2.64	4.77	4.49	4.78	3.56
USA	13.82	10.75	15.12	11.92	16.64	13.74	10.42	7.53	23.76	20.85	21.18	18.16

Source: Scopus (Elsevier), excluding Arts, Humanities and Social sciences; data treatment by Science-Metrix

The Rwanda E-Waste Recycling Facility opened in 2017, the second-largest in Africa. The Rwanda Green Fund (FONERWA) has invested close to US$ 1 million in the facility, which can process more than 7 000 tonnes of electrical and electronic waste each year. Three million tonnes of e-waste were generated in Africa in 2019 but only 0.9% was collected and recycled.

AT A GLANCE

- UNESCO analysed 56 research topics of relevance to the Sustainable Development Goals to identify national research priorities and track change since 2011.
- The study found that developing countries showed strong specialization in research related to the Sustainable Development Goals.
- Consumer pressure and policy changes over the past decade have been informed by a growing body of research on floating plastic debris in the ocean, the fastest-growing topic among the 56 analysed.
- Sustainability research has often been reactive, rather than pro-active. For example, national trends in research on new or re-emerging viruses closely track viral disease outbreaks.
- Climate resilience and sustainable environmental management continue to account for the smallest shares of research by volume.
- Innovation in electricity distribution and storage is growing faster than research on alternative forms of non-fossil energy generation.

2 · Are we using science for smarter development?

Tiffany Straza and Susan Schneegans

INTRODUCTION

Tracking research related to the SDGs

In 2015, Brazilian health care workers began noticing a growing number of babies born with abnormally small heads, or microcephaly, a condition that would affect their brain development. Scientists at the Federal University of Pernambuco in Recife were the first to link a rise in the incidence of newborns displaying microcephaly with an outbreak of Zika, transmitted to their mothers by mosquitoes.

This discovery has transformed our understanding of the Zika virus, which had previously been considered relatively benign. The virus has been recorded in Asia, Africa, the Pacific and the Americas, where it has travelled as far north as the USA.

The outbreak in Brazil became an epidemic. By the time it ended in 2018, largely thanks to the control of mosquito populations and human behavioural changes,[1] Zika had spread to over 50 countries and territories in the Americas. It is expected to circulate among mosquitoes and humans for the foreseeable future (Lowe *et al*., 2018).

A study conducted by the São Paulo Research Foundation (FAPESP) found that, as of April 2018, Brazil was second only to the USA for the volume of scientific publications on Zika, accounting for 15% of the global total (see Box 8.6). This means that Brazil had fresh experience of tackling a viral disease epidemic when the Covid-19 crisis struck in 2020.

Brazil's response to the Zika outbreak was not dictated by scientific advice and experience alone, of course. As with any country, it was also influenced by socio-economic, cultural and political factors that direct our human response to any challenge.

In 2015, Brazilian scientists authored 144 publications on the broader topic of new or re-emerging viruses than can infect humans.[2] By 2019, the Zika outbreak had pushed this number up to 479 and Brazilian researchers were contributing to 4% of global output in this broad field. Other countries had also seen a surge in scientific publishing on this topic during outbreaks of the Influenza A subtype H1N1 and Ebola viruses (Box 2.1 and Figure 2.1).

This broad research topic is one of 56 studied in the present report that have been chosen by UNESCO for their linkages to eight of the United Nations' Sustainable Development Goals (SDGs) to 2030, namely zero hunger (SDG2), good health and well-being (SDG3), clean water and sanitation (SDG6), affordable and clean energy (SDG7), industry, innovation and infrastructure (SDG9), climate action (SDG13), life below water (SDG14) and life on land (SDG15). Between six and nine research topics were analysed for each of these eight goals.

The UNESCO study analysed scientific publishing trends in almost 200 countries between 2011 and 2019, to see which topics were being prioritized and to track change over this period (for details, see Annex 4). The aim of the study was three-fold:

- **to assess the volume of scientific articles published** by each country in the world between 2011 and 2019 on 56 key topics of relevance to the SDGs;
- **to identify the degree of specialization in each topic**, by assessing the number of publications produced in a given country over the 2011–2019 period as a proportion of that country's total scientific output, in comparison with the global average for the given topic; and
- **to identify the growth rate of each topic**, in order to monitor change at the national level in the priority accorded to each of these topics since the adoption of *The 2030 Agenda for Sustainable Development* by the 193 member states of the United Nations in 2015. To avoid annual fluctuations, the study compared scientific output between two periods: 2012–2015 and 2016–2019.

To our knowledge, the present study is the first global assessment of scientific publishing across topics related to the SDGs reported for each country. In the following pages, we describe the most striking trends. The complete datasets, country factsheets and related data visualization for each topic and the linkages between them are freely available from the *UNESCO Science Report* web portal.

The volume of output varies among fields

Worldwide, the great majority of scientific publications tend to focus on health research. This is the case for developing countries like Ghana (49%) but also for some of the most developed ones like the USA (48%). Notable exceptions are China (19%) and the Russian Federation (17%), which have specialized up to now in physical sciences. The health-related topics selected for the present study follow this broader pattern, topping the chart by volume (Figure 2.2).

The study of selected SDG-related research topics blended well-established topics and comparably newer ones characterized, logically, by lower output. For instance, in health research (SDG3), the study analysed the traditional topics of reproductive health and neonatology, tuberculosis and the human immunodeficiency virus (HIV) but also relatively new topics like precision medicine and human resistance to antibiotics. In the field of ocean research (SDG14), it analysed trends in the comparably new fields of ocean acidification and floating plastic debris in the ocean, as well as the more traditional topic of coastal eutrophication.

Owing to differences in the scope and history of the selected topics, it is more meaningful to look for signs of investment in a given topic by focusing on growth and

Box 2.1: **Research on new or re-emerging viruses has surged during epidemics**

With the year 2020 having been dominated by the Covid-19 pandemic, one might expect there to be a voluminous research record on new or re-emerging viruses that can infect humans. There is not. There were just 7 471 publications on this topic in 2019, 35% of which were produced by scientists in the USA alone (Figure 2.1). Global output on this broad topic progressed by just 2% per year between 2011 and 2019, slower than global scientific publications overall: 3.8% per year.

Growth was much faster in individual countries which had to marshal science to cope with other viral outbreaks over this period (Figure 2.1). The 2014–2015 Ebola outbreak in Liberia and neighbouring Guinea and Sierra Leone stamped its mark on these countries' scientific output, as did repeated Ebola outbreaks in the Democratic Republic of Congo. For instance, Liberia's publications on new or re-emerging viruses that can infect humans quadrupled from 33 (2012–2015) to 133 (2016–2019), an intensity 144 times the global average (see chapter 18). Liberia, Sierra Leone and Guinea all had the strongest specialization in the world on emerging viruses over the 2011–2019 period. Much of this output involved international collaboration, which accounted for 70% of scientific publications in low-income countries.

USA, Brazil and France have the highest specialization

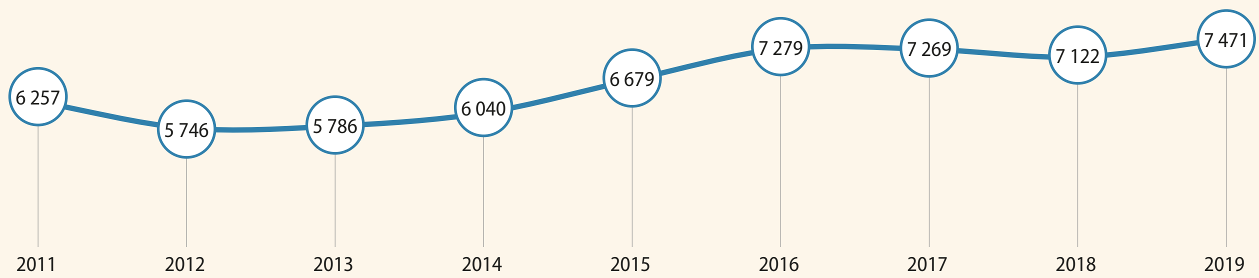
Among the top 10 countries for the volume of output on new or re-emerging viruses that can infect humans, the strongest specialization was found in the USA, Brazil and France. In January 2021, the French government announced the launch of the world's first research institution specializing in this field (see essay, p. 9).

Those countries which showed the fastest growth rates were Brazil and India (Figure 2.1). Brazilian output on viral research surged from 643 (2012–2015) to 1 605 (2016–2019) publications, 1.4 times the global average intensity. It was able to draw on its existing specialization in tropical communicable diseases (four times the global average intensity) in tackling the Zika outbreak in Brazil between 2015 and 2018, which also affected Colombia and the USA, among other countries.

The strong growth in research on this topic in low- and middle-income countries shows the value of

Figure 2.1: **Scientific publications on new or re-emerging viruses that can infect humans**

Global trend in volume of publications on new or re-emerging viruses that can infect humans, 2011–2019



Top 10 countries for volume of scientific publications on new or re-emerging viruses that can infect humans, 2011–2019

	Volume 2011–2019	Growth rate 2012–2019	Specialization index 2011–2019	World share (%) 2011–2019
USA	20 965	1.24	1.46	35.1
China	7 776	1.23	0.59	13.0
UK	4 807	1.28	1.08	8.1
France	3 813	1.24	1.30	6.4
Germany	3 796	1.24	0.88	6.4
Japan	3 635	0.92	1.05	6.1
Canada	2 614	1.15	1.06	4.4
Australia	2 454	1.13	1.22	4.1
Brazil	2 381	2.50	1.37	4.0
India	2 210	1.35	0.66	3.7

international scientific collaboration in tackling pandemics (Figure 2.5). This high level of scientific collaboration augurs well for the fight against Covid-19.

Prevention is better than a cure

The current focus in tackling new or re-emerging viruses tends to be reactive, rather than proactive. A workshop report published in October 2020 by the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services (IPBES), which is co-sponsored by UNESCO and three other United Nations agencies,* observes that the majority (70%) of emerging diseases such as Ebola and Zika and almost all known pandemics (e.g. influenza, HIV/AIDS and Covid-19), are zoonoses, meaning that they are caused by microbes of animal origin.

These microbes 'spill over' when humans, wildlife and livestock come into contact with one another, such as through agricultural expansion, deforestation or wildlife trade.

The IPBES report estimates that there are another 1.7 million currently 'undiscovered' viruses in mammals and birds, up to half of which could have the ability to infect people. It predicts that future pandemics will emerge more often, spread more rapidly, do more damage to the global economy and kill more people than Covid-19, unless there is a transformative change in the global approach to dealing with infectious diseases.

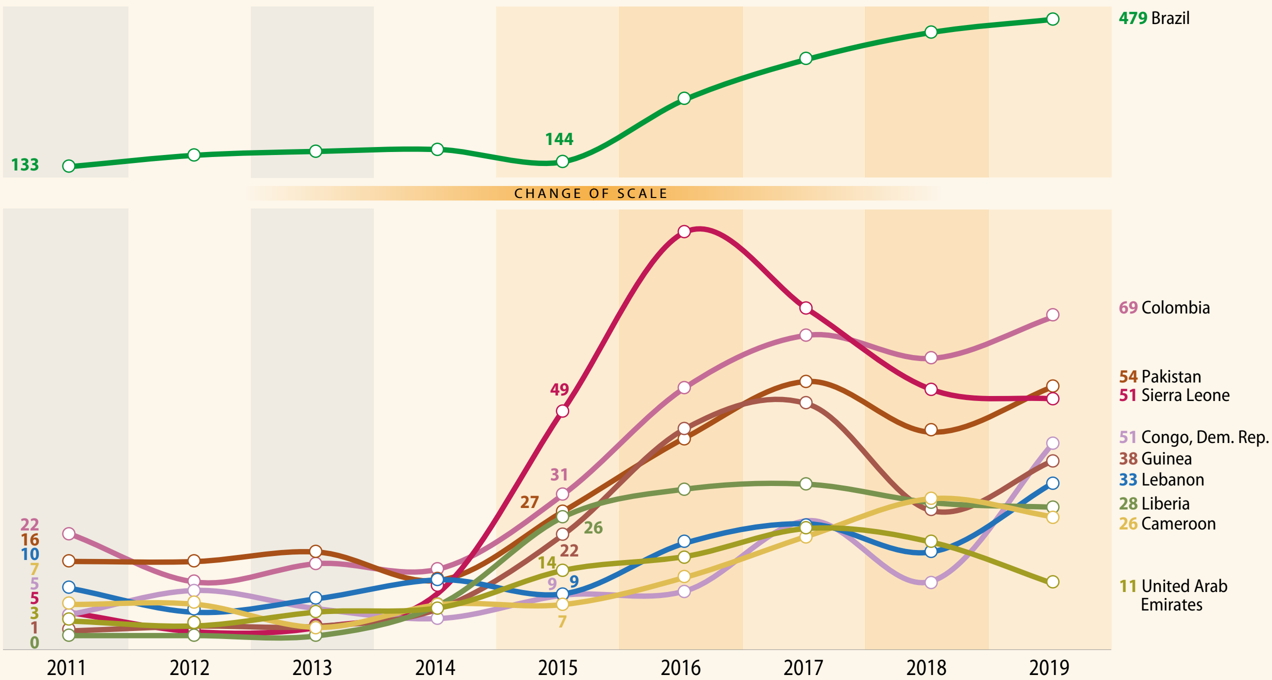
For Dr Peter Daszak, President of the EcoHealth Alliance and IPBES workshop chair, 'we still rely on attempts to contain and control diseases after they emerge, through vaccines and therapeutics. We can escape the era of pandemics but this requires a much greater focus on prevention, in addition to reaction.'

As the report recalls, the risk of a pandemic can be significantly lowered by reducing the human activities that drive the loss of biodiversity, such as agricultural expansion and intensification, the unsustainable exploitation of biodiversity-rich regions and unsustainable production and consumption patterns.

Source: compiled by Susan Schneegans and Tiffany Straza; IPBES (2020) Workshop Report on Biodiversity and Pandemics, October, see: https://ipbes.net/sites/default/files/2020-12/IPBES%20Workshop%20on%20Biodiversity%20and%20Pandemics%20Report_0.pdf

*United Nations Development Programme, United Nations Environment Programme and United Nations' Food and Agricultural Organization

Top 10 countries for growth in scientific publishing on new or re-emerging viruses, 2011–2019
For countries with at least 100 publications

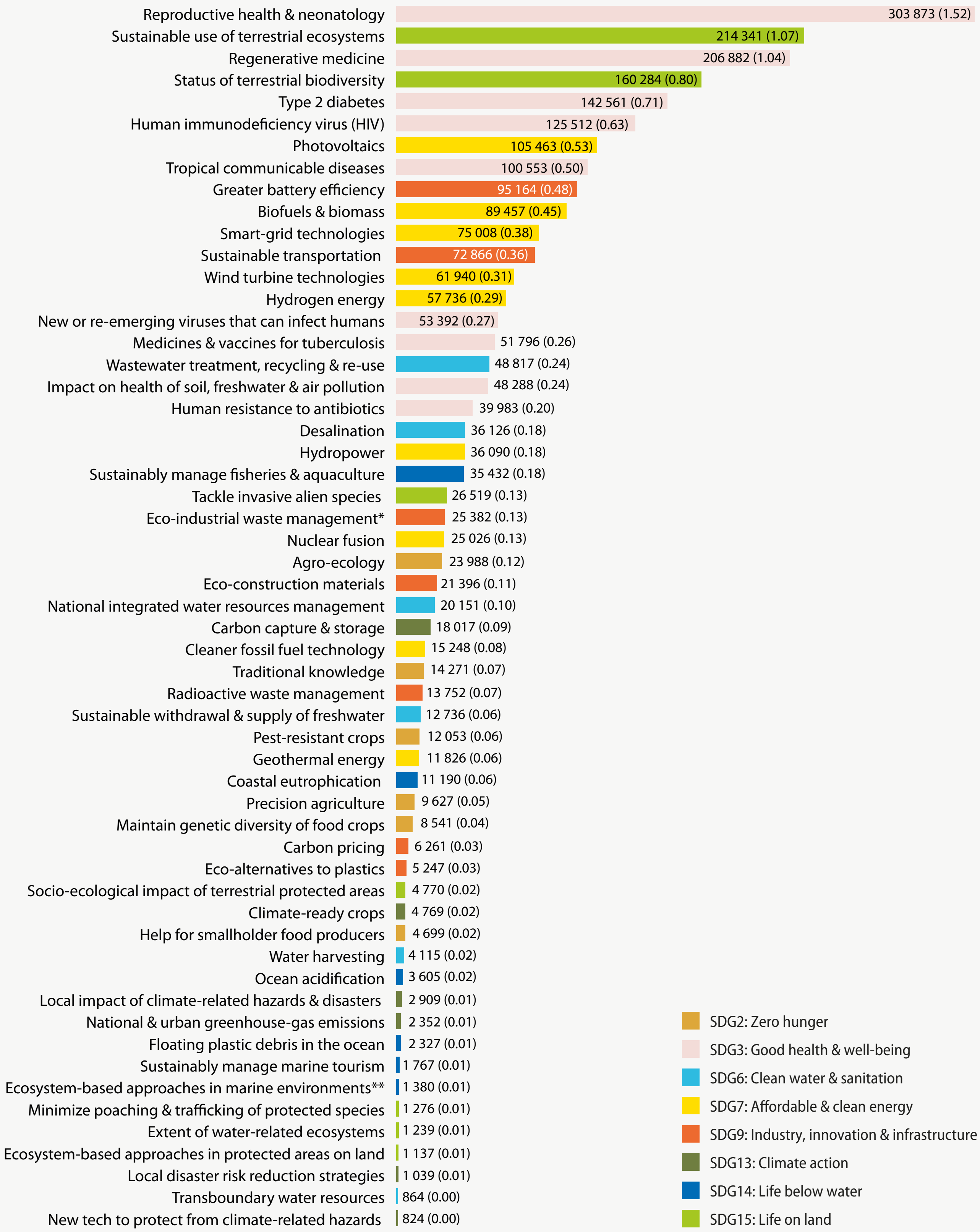


Note: These data exclude HIV, the subject of a separate research topic, and SARS-CoV-2 (Covid-19) which was unknown in 2019. The growth rate is calculated as the number of publications from 2016–2019 divided by the number of publications from 2012–2015. The degree of specialization is calculated by assessing the number of publications produced by a given country over the 2011–2019 period as a proportion of that country's total scientific output. This level of specialization is then compared with the global average to give the specialization index. For details, see Annex 4.

Source: Scopus (Elsevier), including Arts, Humanities and Social Sciences; data treatment by Science-Metrix

Figure 2.2: **Volume of global publications on selected topics related to the SDGs, 2012–2019**

Share of total publications is given within brackets (%)



* Eco-industrial waste management excludes radioactive nuclear waste.
**The topic of ecosystem-based approaches in marine environments covers environments within national exclusive economic zones.

Note: Topics are assigned a colour according to the most closely related Sustainable Development Goal (SDG), even though most of these research topics are relevant to more than one SDG.

Source: Scopus (Elsevier), including Arts, Humanities and Social Sciences; data treatment by Science-Metrix

specialization, or intensity of output on a given topic as a share of overall publishing (Figures 2.2 and 2.3). For instance, the study revealed little growth in research related to tuberculosis and HIV, even though HIV infection rates remain high[3] and the world is not on track to reach the SDG target of ending tuberculosis by 2035 (Merk *et al.*, 2019). HIV research declined as a share of global output between 2012–2015 and 2016–2019 (Figure 2.4).

A country's level of specialization in a given topic is a meaningful indicator, even when the overall volume of output may be low. In fact, it could be argued that it is more striking for a country with low research output to focus on an emerging topic of sustainability research. For example, Rwandan scientists produced 48 publications on the topic of help for smallholder food producers between 2011 and 2019, 56 times the global average publication intensity for this topic.

In general, high-output countries have lower absolute values for the specialization index on a given topic. Even topics that are defined as national priorities, and which make up a substantial body of work, form only a small share of the country's much larger overall output. For lower-output countries, fewer publications are needed to show a trend of specialization on a given topic. For this reason, the USA's specialization in HIV research – 1.9 times the global average intensity – can still be interpreted as meaningful, since the USA contributed 44% of global output on this topic in 2019. For comparison, Uganda contributed 2.4% of publications on HIV research in 2019 but its specialization index value is 37 times the global average intensity for this topic, owing to its overall lower volume of total output.

The path from data to societal change is indirect

In examining growth trends, we have sought to identify those countries that are investing in topics considered vital for sustainable development. That said, the relationship between publication output and development pathway is neither direct, nor a one-way street. Although trends in publication output can reflect government prioritization trickling down through research funding, scientific publications alone are not causative of societal change. Whenever there is an observed decline in research output, this may be because government funding has been diverted to other areas or because the field has moved on. For example, a substantial body of work has been done on the selected topics related to renewable energy (SDG7) but this trend is now showing signs of tapering off, even though the adoption of renewable energy technologies is still limited at the global level (IEA, 2020). In other words, the production of knowledge alone is insufficient to bring about societal change; it must be accompanied by political will (see chapter 1).

Science communication experts have largely discredited the 'information deficit' model, namely, the idea that science can fill knowledge gaps and automatically effect societal change, recommending instead that scientists dialogue with policy-makers (Reincke *et al.*, 2020). Although domestic investment in priority areas of scientific research does bear fruit in the form of publications, the reverse flow of scientific information to policy is neither as direct, nor as assured. There is a need to institutionalize scientific policy advice, in order to foster coherent, stable policies capable of making a sustainable impact. Policies take time to produce results. Institutionalized mechanisms for providing scientific advice have advantages over ad hoc arrangements like those observed during the Covid-19 pandemic, in that they take the long view (see What the Covid-19 pandemic reveals about the evolving landscape of scientific advice, p. 3).

The dominance of high-income economies is waning

Perhaps a more surprising trend is the limited growth observed in high-income economies for the 56 topics selected for the present study. This slow pace of change has been observed by other measures of sustainability science (Elsevier and SciDev, 2015).

High-income economies are losing their monopoly on the majority of these 56 topics, with notable declines in the share of global output on topics related to clean energy and innovation, particularly with regard to battery efficiency and carbon capture and storage (Figures 2.5 and 2.6). By 2019, China was contributing to 53.2% of global publications on greater battery efficiency with 9 944 articles in that year alone.

To take another example, scientists from high-income economies (co-)authored 74.8% of the world's publications on photovoltaics in 2011 but only 50.5% in 2019. Such declines occurred for nearly all of the 56 topics (Figure 2.6). Notwithstanding this, high-income economies still dominate scientific publishing by volume. This demonstrates the need for developing economies to invest more in research infrastructure.

In some cases, national priorities align neatly with trends in research output. For example, Central Asian countries specialize in transboundary water management. Although their total output is small, the expertise of authors from countries such as Kazakhstan and Uzbekistan which border the Aral Sea is essential for managers looking to address the socio-ecological challenges of water rights (see chapter 14). By contrast, Ethiopian-affiliated researchers were involved in only three publications on transboundary water management from 2011 to 2019, compared with 13 for Egypt and five for Sudan, despite Ethiopia's ongoing negotiations with these two downstream users of the Blue Nile on sharing the benefits of the Grand Ethiopian Renaissance Dam (see chapter 19).

Other relationships are less clear-cut, be it due to a gap in research or, alternatively, to an abundance of research but a conflicting national pathway. For example, the absence of authors from small island developing states (SIDS) from the body of research on the impact of climate change may be indicative of both a research gap and the practice of on-site research being driven by an external research agenda. To take another example, despite the sizeable contribution by US (25%) and Australian (14%) scientists to global research on local disaster risk reduction strategies to mitigate climate change, their respective governments have not prioritized climate-mitigation policies in recent years (see chapters 5 and 26).

Figure 2.3: **Growth rate for publications on selected topics related to the SDGs, 2012–2019 (%)**

* Eco-industrial waste management excludes radioactive nuclear waste. The topic of ecosystem-based approaches in marine environments covers environments within national exclusive economic zones.

Note: Topics are assigned a colour according to the most closely related Sustainable Development Goal (SDG), even though most topics examined here are relevant to more than one SDG goal. The growth rate is calculated as the number of publications from 2016–2019 divided by the number of publications from 2012–2015; a growth rate of 1.16 indicates a 16% increase in publication output, the global average for scientific publications overall. For details, see Annex 4 of the *UNESCO Science Report* (2021).

Source: Scopus (Elsevier), including Arts, Humanities and Social Sciences; data treatment by Science-Metrix

It is rare to see strong growth in output on the majority of the 56 SDG-related topics. In this regard, Iraq and Indonesia stand out. Iraqi research is emerging on many of these topics, building on an existing specialization in health, desalination, wastewater treatment and solar photovoltaics. For its part, Indonesia's output at least tripled between 2011 and 2019 for 40 topics. By 2019, Indonesian researchers had published on each of the 56 topics analysed, including the country's first footprint in the international literature on climate action. Contributing to this surge has been the decision by Indonesia, in 2017, to link the publication of research in international, indexed journals to the review of scientists' career performance (see chapters 1 and 26).

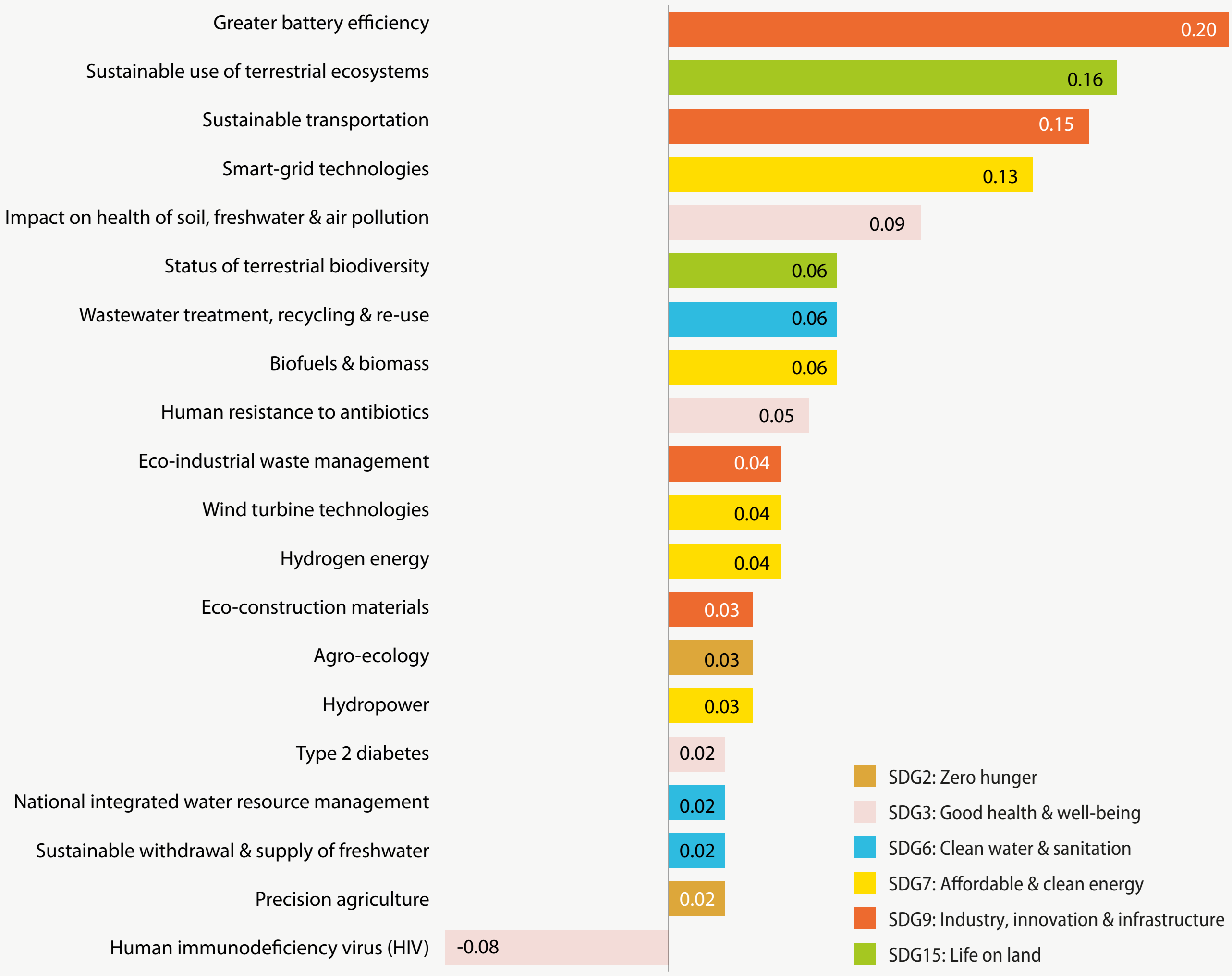
How can we distinguish volatile from flexible research?

Volatile research systems and flexible research systems may leave the same footprint in terms of rapid swings in the number of publications on each subject over time.

When countries with a modest output show strong growth in a particular research topic, this may be because their research is enmeshed with their country's development agenda. For example, Ecuador's output on sustainable transportation has soared from 12 (2012–2015) to 92 papers (2016–2019), that on solar photovoltaics from 3 to 36 papers and that on smart-grid technologies from 35 to 143 papers. Ecuador's rapid specialization in these fields can be traced back to a series of rolling blackouts in 2009 which

Figure 2.4: **Change in the share of 56 SDG-related topics among global publications, 2012–2015 to 2016–2019 (%)**

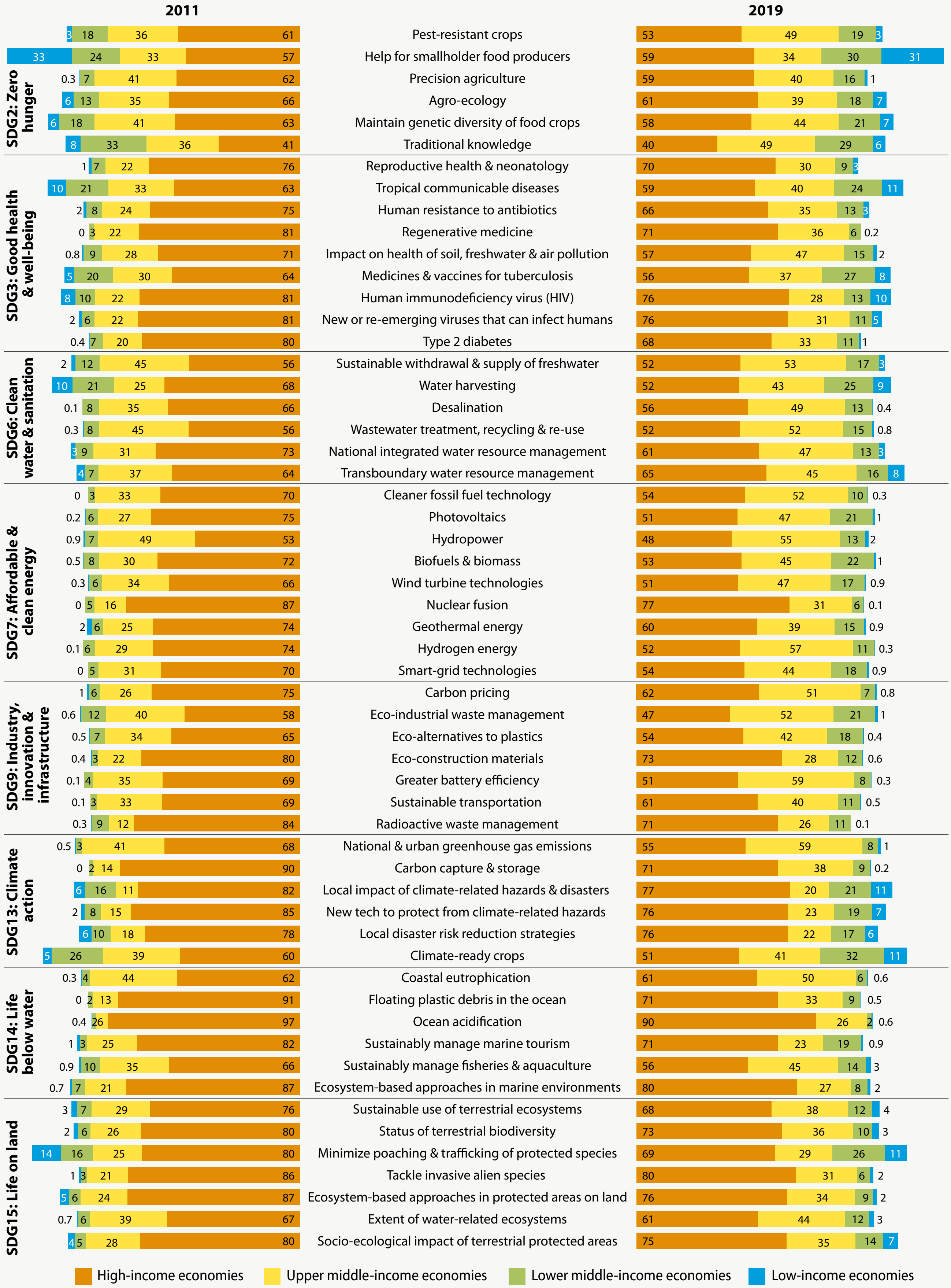
Excluding topics demonstrating change of less than ±0.02%



Note: The topic of floating plastic debris in the ocean has been excluded from this figure, owing to the low volume of publications on this topic.

Source: Scopus (Elsevier), including Arts, Humanities and Social Sciences; data treatment by Science-Metrix

Figure 2.5: **Contribution by income group to global publishing on 56 research topics related to the SDGs, 2011 and 2019 (%)**



Note: See Annex 1 of the *UNESCO Science Report* (2021) for a list of countries by income group. These values reflect the participation of authors from countries in the selected groups. Owing to co-authorship, the sum of the shares may exceed 100%, with larger cumulative totals indicating greater collaboration among income groups.

Source: Scopus (Elsevier), including Arts, Humanities and Social Sciences; data treatment by Science-Metrix

prompted the government to prioritize investment in energy infrastructure and the transition from thermal to hydropower and other renewable sources of energy (see chapter 7).

Alternatively, strong growth in a particular topic may reflect a research agenda dominated by short-term projects and short-term funding or a development agenda determined by international donors – or a combination of two or more of these factors. Not all of these factors are synonymous with the type of stable, predictable ecosystem that is supportive of the scientific enterprise (see Global standards now exist for a healthy ecosystem of research and innovation, p. 24).

In high-output countries, strong growth in a given topic may be explained by the fact that they are the ones driving the development agenda, are more flexible and quicker at producing topical research, or have rapid access to funding and expertise that allows them to react to new trends. Conversely, a slow response may not be a sign of indifference to sustainability topics but, rather, may simply be masked by the sustained high volume of output in established fields. Large research ecosystems may require more time for changes to become visible (see chapter 1).

We shall see these complex interactions in each subject area.

SCIENCE UNDERPINNING DEVELOPMENT

Today, youth the world over are looking to science to solve the multifaceted crises that could compromise their future: the climate emergency, growing demand for energy, the shattering of the Earth's ecological balance and pollution levels that threaten the health and well-being of billions of people. The anxieties of youth are encapsulated in the catchphrase brandished by young demonstrators around the world: 'You'll die of old age; I'll die of climate change'.

Should there remain any subsisting doubt as to the urgency of taking an integrated approach to development, one need only consider the ravages of the Covid-19 pandemic, a prime example of the interconnectedness between ecology, human health and economic prosperity.

As Dr Peter Daszak, one of the authors of an expert report co-sponsored by UNESCO (IPBES, 2020), put it, 'there is no great mystery about the cause of the Covid-19 pandemic, or of any modern pandemic. The same human activities that drive climate change and biodiversity loss also drive pandemic risk through their impact on our environment. Changes in the way we use land, the expansion and intensification of agriculture and unsustainable trade, production and consumption disrupt nature and increase contact between wildlife, livestock, pathogens and people. This is the path to pandemics' (Box 2.1).

Science, technology and innovation will be fundamental to achieving the SDGs. Coupled with strong political will, this should make for a potent combination, as long as there is sustained investment in research and development.

The good news is that global research spending (in PPP$ billions) progressed almost everywhere between 2014 and 2018, with growth being especially strong in upper middle-income countries, in a trend driven largely by China (see chapter 1). At the global level, research expenditure

Young demonstrators in Toronto, September 2019. © K6ka CC BY-SA 3.0

surged by 19%. Progress was visible in all but two regions: Central Asia and Latin America and the Caribbean. However, the proportion of GDP devoted to research expenditure (target SDG9.5.1) progressed only from 1.73% to 1.79%.

Researcher density rose in all but Central Asia and Eastern Europe over the same period (see chapter 1).[4] The global density progressed from 1 245 to 1 368 researchers (in full-time equivalents) per million inhabitants (see chapter 1).

One key development is the growing scientific collaboration between developing countries. This trend tends to be most visible within regions but a large diaspora is also boosting co-authorship farther afield, as in the case of Pakistani scientists based in Saudi Arabia (see chapter 21).

In the following pages, we examine publishing trends with regard to research topics that are considered essential for achieving eight of the 17 SDGs.

SELECTED RESEARCH THEMES

Plastic debris research shows fastest growth

Among the 56 topics examined, that of **floating plastic debris in the ocean** showed the fastest growth, albeit from a low starting point (Figure 2.3). Over nine years, global research documenting this phenomenon ballooned from 46 (2011) to 853 (2019) publications (Figure 2.7).

As a result, we know that plastics have penetrated the deepest ocean trenches (Peng *et al*., 2018). Jamieson *et al*. (2019) found ingested microplastics in the hindguts of crustaceans in six deep ocean trenches around the Pacific Rim,[5] at depths ranging from 7 000 to 10 890 m. Over 72% of the 90 individuals examined contained at least one microparticle. Human beings are not exempt: researchers have found microplastics in human placentas (Ragusa *et al*., 2021).

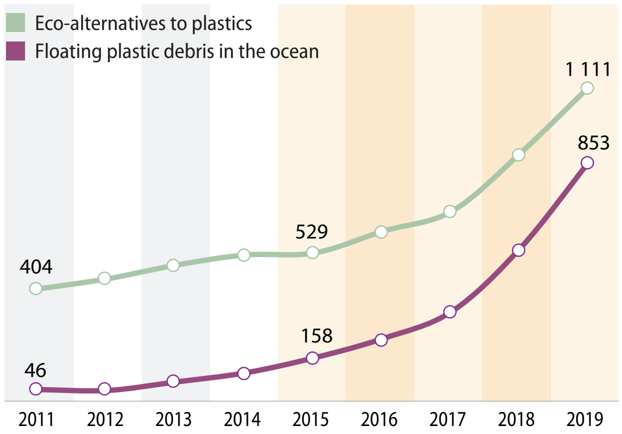
Plastics have been found not only in animals but also in fruit and vegetables, such as apples and carrots (Conti *et al*., 2020). At the present rate, plastic particles could outweigh fish in the ocean by 2050 (WEF, 2016); experts estimate that plastic pollution will triple by 2040 (Lau *et al.*, 2020). According to British Petroleum, single-use plastics made up just over one-third of all plastics produced in 2017.

Plastics are derived from oil. In the short term, demand for oil has been eroded in 2020 by the vertiginous drop in global travel during the Covid-19 pandemic. However, the long-term prospects for oil production are threatened by the growing affordability of renewables, which is motivating oil companies to step up the production of synthetics. Plastics now make up two-thirds of demand for oil in the petrochemical sector and all of the growth in demand for oil (Bond *et al.,* 2020). At current growth rates, plastic production could account for 20% of global oil consumption by 2050 (UNEP, 2018).

Asia is considered a dominant source of plastic pollution, in part because it is a manufacturing and recycling hub for plastics (WEF, 2016). China's decision in 2017 to stop importing low-quality plastic waste has fundamentally changed global recycling streams, as China had previously accepted 45% of all global plastic that was recycled between 1992 and 2017, according to United Nations Comtrade data. China's publications on floating plastic debris jumped from 7 (2012–2015) to 286 (2016–2019), ranking it third in the world by volume after the USA and UK over this dual period.

For plastics, and consumer goods more generally, the cost of safe disposal during the product's lifecycle is not incorporated in the sales price. This is making it uneconomical to produce rapidly biodegradable alternatives to plastic and placing a burden on public authorities to finance recycling. Were the manufacturer to pay for the cost of recycling, such as through an ecotax, they would be less inclined to produce single-use plastics or to endorse programmed obsolescence (Box 2.2).

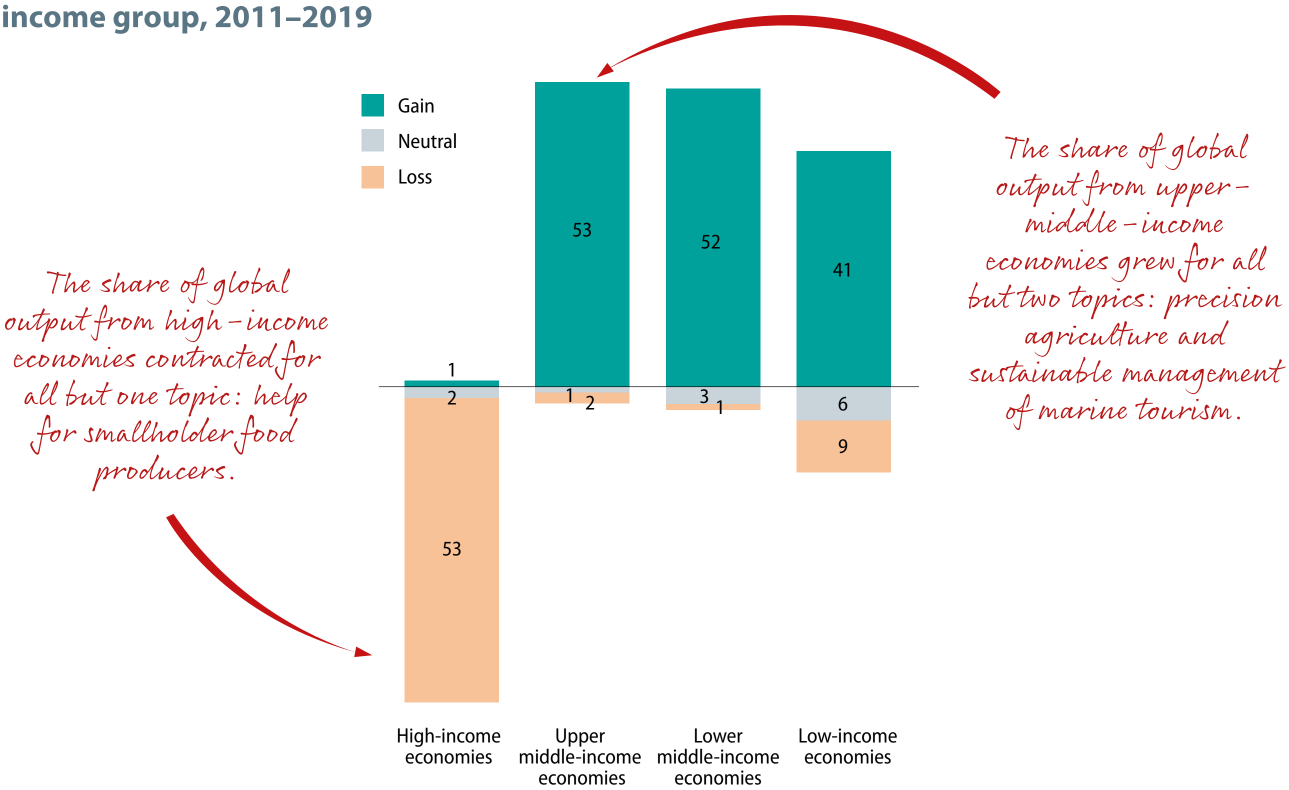
Figure 2.7: **Volume of global publications on plastics, 2011–2019**



Source: Scopus (Elsevier), including Arts, Humanities and Social Sciences; data treatment by Science-Metrix

A growing number of countries are banning or phasing out single-use plastics. In 2019, Panama became the first Central American country to do so. Costa Rica has adopted a five-year *National Strategy for the Substitution of Single-use Plastics by Renewable and Compostable Alternatives 2017–2021*. In other countries, single-use plastics are being banned by local bodies, such as by municipalities in Guatemala (see chapter 7). To date, 11 of the 14 Pacific Island countries have introduced legislation to slow the sale or import of single-use

Figure 2.6: **Number of SDG-related topics with a gain or loss in share of global output, by income group, 2011–2019**



Note: A change of 1% or more was defined as a loss or gain with the exception of low-income economies, for which a threshold of 0.2% was used to account for the proportionately smaller share of global output.

Source: Scopus (Elsevier), including Arts, Humanities and Social Sciences; data treatment by Science-Metrix

plastics or Styrofoam (see chapter 26). China plans to eliminate the use of single-use plastic bags by 2022 and to reduce single-use plastics in the restaurant business by 30% by 2025.

In June 2019, the European Parliament and Council of the European Union adopted a Directive on the Reduction of the Impact of Certain Plastic Products on the Environment (#904).[6] The intention is to eliminate ten single-use pollutants (straws, takeaway food containers, etc.) and to incite producers of others, such as single-use plastic bags, to cover the costs of waste collection and treatment (see chapter 9).

Banning single-use plastics will not suffice on its own (UNEP and WRI, 2019). Given the low recycling rate of plastic (less than 10%), it will be essential to transition to lightweight alternatives (Bond *et al.,* 2020). Rwanda, for instance, has been developing bags made of bamboo, banana and other products since it banned plastic bags in 2008. **Sustainable alternatives to plastics** was the second-fastest growing research topic for sub-Saharan Africa between 2012 and 2019, even though total output did not exceed 100 papers by 2019.

Indonesia, Malaysia and Thailand are boosting their own research output on sustainable alternatives to plastics, which amounted to over five times the global average intensity in 2019. Indonesia went from producing six publications on this topic between 2012 and 2015 to 155 over the next four years. Other countries with greater output that show strong growth include Brazil, China, Germany, India, Iran, Italy, Nigeria and the United Kingdom (UK).

Health topics dominate by volume but little change

At the other end of the scale, **HIV** research had the lowest growth rate of all 56 topics under study. Although the volume of publications on the nine health-related topics examined topped the scale for the volume of output (Figure 2.2), growth rates were either below or on par with the global average of 1.2% per year for all scientific publications. Only the topics on **human resistance to antibiotics** and the **impact on health of soil, freshwater and air pollution** showed strong growth (Figures 2.3 and 2.4).

All of the top countries for the growth rate in research on **new or re-emerging viruses that can infect humans** have been affected by a viral outbreak in the past decade (Box 2.1).

Health remains a strong suit for African researchers, with **tropical communicable diseases**[7] and HIV research among the top five topics for the majority of sub-Saharan countries. However, output on these topics is not growing, which may be a sign that research investment is waning or that other subjects are competing for precedence in Africa's research pathway (Figure 2.10).

Health concerns are evolving as lifestyles and surrounding environments change. **Type 2 diabetes** (also called adult-onset diabetes) is becoming more prevalent. Africa, the Arab States, Asia and Europe are leading the growth in related research. As an identified co-morbidity factor for other illnesses, including Covid-19 (Guo *et al*., 2020), diabetes is likely to receive greater attention in the coming decade. Treatment of diabetes has already benefited from advances in precision medicine, notably in the USA (see chapter 5).

The impact of soil, freshwater and air pollution on human health is gaining in international priority. It enjoyed the highest global growth rate among the examined health topics. The Russian Federation has boosted its own output on this topic from 157 (2012–2015) to 609 (2016–2019) publications. The government has set a target of lowering air pollution by 22%, as part of its national research projects endeavour covering the period from 2013 to 2024 (see chapter 13). Sub-Saharan Africa is also taking up this research, with output having doubled from 523 (2012–2015) to 1 085 (2016–2019) publications, comparable to the pattern observed in the Arab States and Asia.

The intersection of environmental and human health is increasingly obvious. In 2020, this link was most commonly illustrated by the global call for frequent handwashing during the Covid-19 pandemic, which presupposes that freshwater is easily available and pathogen-free.

Freshwater management a growing research focus in Asia

Globally, an estimated 80% of all industrial and municipal wastewater is released into the environment without any prior treatment, placing human health and ecosystems at risk (WWAP, 2017). This ratio is much higher in low-income countries, where sanitation and wastewater treatment facilities are a rare commodity. Countries in this income bracket contributed to 0.8% of global publications on wastewater management in 2019, up from 0.3% in 2011 (Figure 2.5).

In the Arab States, growth in research on **wastewater treatment, recycling and re-use** was surpassed only by that on photovoltaics and smart-grid technology.

In the Philippines, a wastewater management system has been deemed indispensable for making the New Clark City development both smart and green (see chapter 26). Following the announcement of this new smart city, output on this topic by Filipino researchers doubled to more than 30 publications per year in 2018.

Growth in scientific publications on this topic has been strong elsewhere in East and Southeast Asia. For example, Viet Nam's output has quadrupled from 51 (2012–2015) to 206 (2016–2019) publications.

Between 2011 and 2019, global research on the **sustainable withdrawal and supply of freshwater resources** surged by 150% to 13 863 publications. The strongest growth was observed in the Arab States and Central Asia, both of which are experiencing water insecurity.

Nearly 86% of the Arab population, or close to 362 million people, lives under conditions of chronic water scarcity (UNESCWA, 2019). This scarcity has increased dependency on transboundary, non-renewable groundwater resources (fossil water), which is unsustainable. In the past eight years, the region has doubled its research output on **transboundary water management** from 14 (2012–2015) to 31 (2016–2019) publications. Although the numbers are modest, this nevertheless represents 5% of global output on this topic.

The Arab region's research output on **desalination** is much larger. Moreover, it grew by 50% between 2012 and 2019, from 1 468 to 2 218 publications, accounting for 10% of the global total (see chapter 17).

Greater research focus on impact of climate hazards than mitigation

The threats to freshwater supply and the spread of many communicable diseases cannot be separated from the defining crisis of our time: climate change.

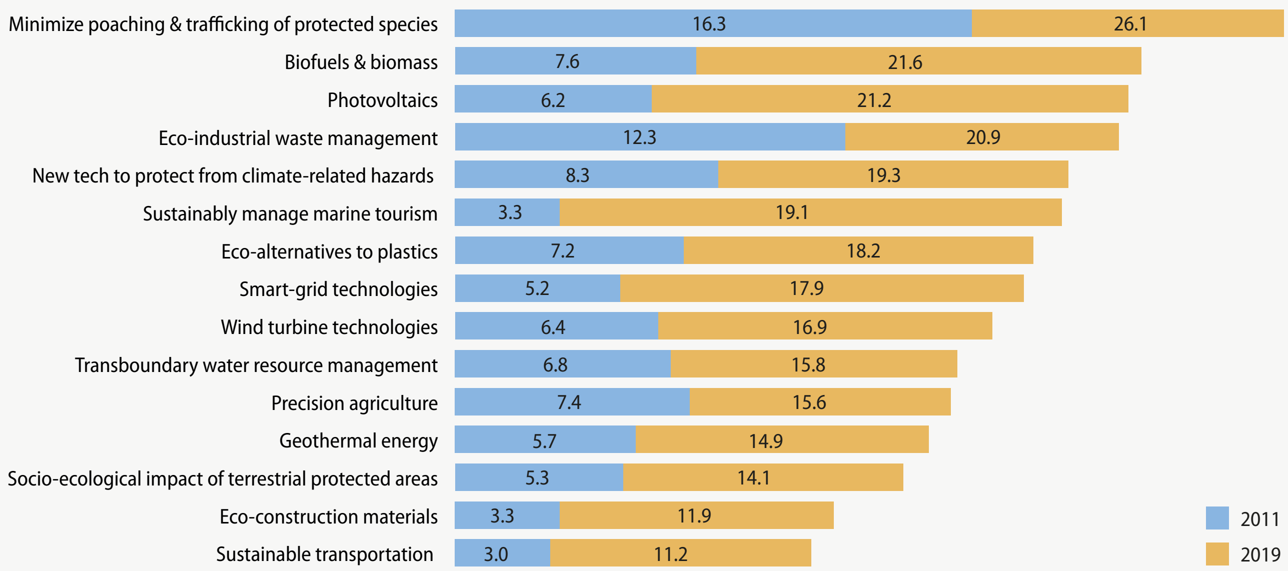
The side-effects of our reliance on fossil fuels are severe, as we shall see in the following pages. Direct economic losses from climate-related disasters rose by 151% between 1998 and 2017 (UNISDR and CRED, 2019). Single events can decimate an economy, as demonstrated in 2015 when Cyclone Pam cost Vanuatu 61% of its national GDP (see chapter 26). In the Caribbean, the particularly destructive Hurricane Maria in 2017 led Ross University's School of Medicine to depart Dominica after 40 years, amputating about 19% of the country's GDP in the process (see chapter 6).

Globally, research still focuses more on understanding the **local impact of climate-related hazards and disasters** than on mitigating such hazards (Figure 2.9).

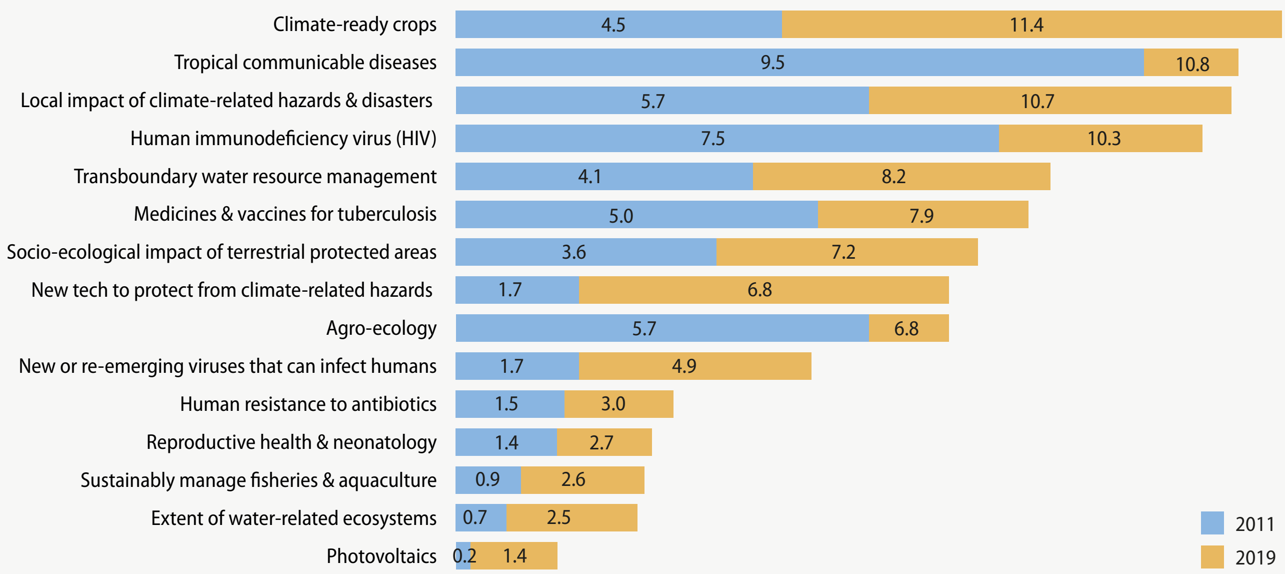
Climate-related disasters have focused attention on rebuilding more resilient infrastructure capable of

Figure 2.8: Top 15 research topics for lower middle-income and low-income countries by increase in their share of global output, 2011–2019

Top 15 topics by increase in the share of global output from lower middle-income economies, 2011 and 2019 (%)



Top 15 topics by increase in the share of global output from low-income economies (%)



Note: See Annex 1 for a list of countries by income group.

Source: Scopus (Elsevier), including Arts, Humanities and Social Sciences; data treatment by Science-Metrix

withstanding the growing intensity and frequency of extreme events (IPCC, 2018). Research on **new technologies to protect from climate-related hazards** is growing in several developed countries (Figure 2.10) but research output is noticeably absent, or static, in the most vulnerable regions like the Caribbean (see chapter 6).

This research topic showed the tenth-fastest growth rate in sub-Saharan Africa. Studies of the local impact of climate-related hazards and disasters was even the eighth-highest priority. These efforts are also being supported at the regional level, such as through the Southern African Development Community's Regional Climate Change Programme (see chapter 20) and the West African Science Service Centre on Climate Change and Adapted Land Use (see chapter 18).

Little growth in research on carbon capture

All of the pathways defined by the Intergovernmental Panel on Climate Change for limiting global warming to 1.5°C rely on technological advances in carbon dioxide (CO_2) removal from the atmosphere to augment the natural process of carbon sequestration (IPCC, 2018). Companies such as Equinor (formerly Statoil), Total and Shell are all developing projects in this area. In Norway, Equinor is developing what may become the first industrial-scale project for **carbon capture and storage** in Europe (see chapter 11).

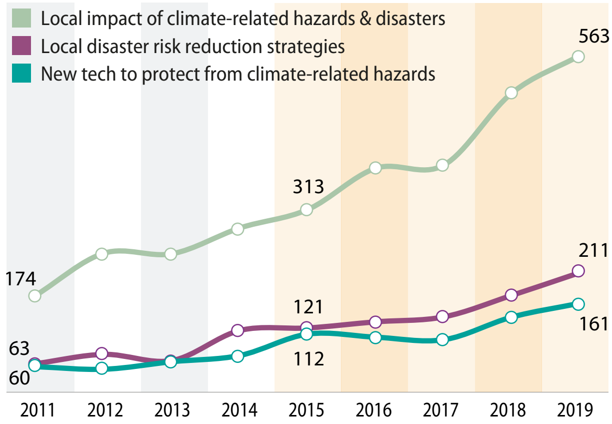
This new industrial sector is still in its infancy. Only a minute quantity of CO_2 is being stored artificially at the global level: 35 million tonnes in 2019, a drop in the ocean compared to global carbon emissions of 40 gigatonnes. The International Energy Agency's clean technology scenario forecasts a cumulative storage capacity of 107 gigatonnes of CO_2 by 2060 (IEA, 2019).

Global scientific output does not match the urgency of finding technical solutions to sequester carbon. The topic of carbon capture and storage has one of the lowest growth rates, with a mere 2 501 publications on this topic produced around the world in 2019. This compares with 12 975 publications on smart-grid technology, up from 4 737 in 2011.

The USA leads the field for the volume of output on carbon capture and storage but its own publications have declined from 2 507 (2012–2015) to 2 098 (2016–2019). In fact, output has been declining in six of the top ten countries for this topic, namely Canada, France, Germany, the Netherlands, Norway and USA. Here, again, China is poised to take the lead, with its publications having surged from 1 300 (2012–2015) to 2 049 (2016–2019).

Both the severity of the impact of climate change and countries' capacity to respond vary around the world, increasing the need for geographical and epistemological diversity in climate-related research. Among small island developing states (SIDS), Fiji dominated output in this area between 2012 and 2019, both in terms of volume and specialization. Fiji hosts the regional University of the South Pacific, which serves 12 countries (see chapter 26). However, even on this existential topic for SIDS, local researchers are not visible in global publishing.

Figure 2.9: **Volume of global publications on climate hazards, 2011–2019**



Source: Scopus (Elsevier), including Arts, Humanities and Social Sciences; data treatment by Science-Metrix

Surge in research on climate-ready crops in developing world

On the topic of **climate-ready crops**, developing regions specializing in agriculture come into their own. By 2019, low-income economies were contributing to 11% of global output on climate-ready crops, up from 4.5% in 2011 (Figure 2.8). Lower middle-income countries contributed another 32% (up from 26%). Mexico doubled its own output and there are encouraging signs from other vulnerable countries, such as Ethiopia, Ghana, India, Kenya, Mali, Mozambique and Senegal.

Climate-ready crops make up one of the fastest-growing research topics for sub-Saharan Africa and take the lead among topics with at least 100 publications (Figure 2.10). This trend is in line with the Comprehensive Africa Agriculture Development Programme and the *Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods* (see chapters 18, 19 and 20).

The rise in climate-related research in West Africa can also be linked to regional initiatives. Since 2014, the World Bank has supported the Africa Higher Education Centers of Excellence programme, including the West Africa Centre for Crop Improvement at the University of Ghana, which is developing climate-resilient strains of food crops. For its part, Germany has invested over € 50 million (US$ 56 million) in the West African Science Service Centre on Climate Change and Adapted Land Use, including with regard to related doctoral programmes at universities in the region (see chapter 18).

More recently, the World Bank has extended the Centres of Excellence Programme to East Africa. Since 2017, there has been a centre specializing in climate-smart agriculture at Haramaya University in Kenya, for instance, and another in agro-ecology and livelihood systems at the Uganda Martyrs University (see chapter 19).

With the Covid-19 pandemic having altered global flows of food and agricultural workers, the topic of climate-ready crops may become a priority investment for countries wishing to maintain healthy domestic food supplies.

Figure 2.10: **Top SDG-related topics based on specialization and growth in selected regions and countries, 2011–2019**

For topics with at least 100 publications over 2011–2019
The growth rate and specialization index are given within brackets

USA

Top five topics by growth rate
- Floating plastic debris in the ocean (3.62)
- Help for smallholder food producers (2.12)
- Sustainably manage marine tourism (1.84)
- Local impact of climate-related hazards & disasters (1.71)
- Local disaster risk reduction strategies (1.67)

Top five topics by specialization
- Human immunodeficiency virus (HIV) [1.92]
- Tackle invasive alien species (1.61)
- Ocean acidification (1.50)
- New or re-emerging viruses that can infect humans (1.46)
- Extent of water-related ecosystems (1.39)

EUROPEAN UNION

Top five topics by growth rate
- Floating plastic debris in the ocean (5.29)
- New tech to protect from climate-related hazards (1.90)
- Greater battery efficiency (1.76)
- Minimize poaching & trafficking of protected species (1.75)
- Local impact of climate-related hazards & disasters (1.75)

Top five topics by specialization
- Floating plastic debris in the ocean (1.74)
- Ecosystem-based approaches in marine environments* (1.58)
- Eco-construction materials (1.56)
- Nuclear fusion (1.41)
- New tech to protect from climate-related hazards (1.30)

EUROPEAN FREE TRADE ASSOC.

Top five topics by growth rate
- Climate-ready crops (2.19)
- Precision agriculture (1.93)
- Greater battery efficiency (1.87)
- Local impact of climate-related hazards & disasters (1.86)
- Eco-construction materials (1.72)

Top five topics by specialization
- Carbon capture & storage (3.70)
- Sustainably manage fisheries & aquaculture (3.25)
- Geothermal energy (2.72)
- Hydropower (2.10)
- Cleaner fossil fuel technology (1.98)

BRAZIL

Top five topics by growth rate
- Floating plastic debris in the ocean (3.21)
- New or re-emerging viruses that can infect humans (2.50)
- Eco-construction materials (2.02)
- Carbon capture & storage (2.01)
- Sustainable withdrawal & supply of freshwater (2.00)

Top five topics by specialization
- Agro-ecology (4.48)
- Tropical communicable diseases (4.16)
- Traditional knowledge (3.52)
- Help for smallholder food producers (3.08)
- Sustainable use of terrestrial ecosystems (2.60)

SUB-SAHARAN AFRICA

Top five topics by growth rate
- Climate-ready crops (2.85)
- Greater battery efficiency (2.85)
- Eco-construction materials (2.85)
- Smart-grid technologies (2.61)
- Carbon capture & storage (2.48)

Top five topics by specialization
- Help for smallholder food producers (27.35)
- Traditional knowledge (11.75)
- Minimize poaching & trafficking of protected species (11.66)
- Human immunodeficiency virus (HIV) [11.46]
- Tropical communicable diseases (9.04)

ARAB STATES

Top five topics by growth rate
- Sustainable transportation (2.80)
- Climate-ready crops (2.76)
- Smart-grid technologies (2.73)
- Precision agriculture (2.57)
- Eco-construction materials (2.41)

Top five topics by specialization
- Desalination (3.75)
- Wind turbine technologies (2.63)
- Water harvesting (2.36)
- Photovoltaics (2.22)
- Wastewater treatment, recycling & re-use (2.00)

LATIN AMERICA

Top five topics by growth rate
- Floating plastic debris in the ocean (3.62)
- National & urban greenhouse gas emissions (2.58)
- New tech to protect from climate-related hazards (2.45)
- Extent of water-related ecosystems (2.28)
- Eco-construction materials (2.20)

Top five topics by specialization
- Agro-ecology (3.95)
- Tropical communicable diseases (3.77)
- Traditional knowledge (3.34)
- Help for smallholder food producers (2.86)
- Sustainable use of terrestrial ecosystems (2.78)

CARIBBEAN

Top five topics by growth rate
- Human resistance to antibiotics (2.16)
- New or re-emerging viruses that can infect humans (1.78)
- Wastewater treatment, recycling & re-use (1.56)
- Traditional knowledge (1.45)
- Impact on health of soil, freshwater & air pollution (1.38)

Top five topics by specialization
- Tropical communicable diseases (5.40)
- Human immunodeficiency virus (HIV) (3.66)
- Medicines & vaccines for tuberculosis (3.01)
- Reproductive health & neonatology (2.92)
- Traditional knowledge (2.89)

SOUTH AFRICA

Top five topics by growth rate
- Local impact of climate-related hazards & disasters (4.75)
- Climate-ready crops (4.19)
- Human resistance to antibiotics (2.93)
- Eco-industrial waste management (2.77)
- Photovoltaics (2.73)

Top five topics by specialization
- Help for smallholder food producers (10.78)
- Minimize poaching & trafficking of protected species (10.45)
- Human immunodeficiency virus (HIV) [10.23]
- Medicines & vaccines for tuberculosis (9.13)
- Traditional knowledge (8.18)

RUSSIAN FEDERATION

Top five topics by growth rate
- Sustainable transportation (7.31)
- Eco-construction materials (6.95)
- Precision agriculture (6.11)
- Wind turbine technologies (4.95)
- Wastewater treatment, recycling & re-use (4.92)

Top five topics by specialization
- Radioactive waste management (2.58)
- Nuclear fusion (2.11)
- Geothermal energy (1.04)
- Medicines & vaccines for tuberculosis (0.87)
- Hydropower (0.80)

REPUBLIC OF KOREA

Top five topics by growth rate
- Impact on health of soil, freshwater & air pollution (2.02)
- Agro-ecology (1.84)
- Tackle invasive alien species (1.77)
- National integrated water resource management (1.67)
- Eco-industrial waste management (1.65)

Top five topics by specialization
- Photovoltaics (2.50)
- Greater battery efficiency (2.34)
- Hydrogen energy (1.91)
- Sustainable transportation (1.63)
- Radioactive waste management (1.59)

CHINA

Top five topics by growth rate
- Floating plastic debris in the ocean (40.86)
- Transboundary water resource management (2.85)
- Help for smallholder food producers (2.78)
- Water harvesting (2.74)
- Ocean acidification (2.69)

Top five topics by specialization
- Greater battery efficiency (2.12)
- National & urban greenhouse gas emissions (1.73)
- Coastal eutrophication (1.72)
- Hydropower (1.53)
- Cleaner fossil fuel technology (1.52)

THAILAND

Top five topics by growth rate
- Eco-construction materials (3.86)
- Eco-industrial waste management (2.51)
- Sustainable transportation (2.44)
- Greater battery efficiency (2.44)
- Help for smallholder food producers (2.39)

Top five topics by specialization
- Eco-alternatives to plastics (9.12)
- Sustainably manage fisheries & aquaculture (4.00)
- Tropical communicable diseases (3.96)
- Biofuels & biomass (3.67)
- Help for smallholder food producers (3.10)

VIET NAM

Top five topics by growth rate
- Eco-construction materials (12.00)
- Hydrogen energy (7.09)
- Smart-grid technologies (5.54)
- Biofuels & biomass (5.22)
- Eco-industrial waste management (5.17)

Top five topics by specialization
- Sustainably manage fisheries & aquaculture (4.42)
- Help for smallholder food producers (3.60)
- New or re-emerging viruses that can infect humans (2.17)
- Maintain genetic diversity of food crops (1.93)
- Hydropower (1.91)

JAPAN

Top five topics by growth rate
- Impact on health of soil, freshwater & air pollution (1.63)
- Eco-industrial waste management (1.60)
- Geothermal energy (1.48)
- National & urban greenhouse gas emissions (1.46)
- Eco-construction materials (1.43)

Top five topics by specialization
- Nuclear fusion (1.88)
- Radioactive waste management (1.60)
- Regenerative medicine (1.31)
- Hydrogen energy (1.21)
- Photovoltaics (1.21)

INDIA

Top five topics by growth rate
- Sustainable transportation (3.96)
- Smart-grid technologies (3.19)
- Greater battery efficiency (2.92)
- Eco-construction materials (2.70)
- Geothermal energy (2.47)

Top five topics by specialization
- Climate-ready crops (3.07)
- Medicines & vaccines for tuberculosis (2.95)
- Traditional knowledge (2.83)
- Water harvesting (2.74)
- Pest-resistant crops (2.12)

MALAYSIA

Top five topics by growth rate
- Carbon pricing (2.65)
- Sustainable withdrawal & supply of freshwater (2.52)
- Hydropower (2.27)
- Greater battery efficiency (2.24)
- Carbon capture & storage (2.21)

Top five topics by specialization
- Eco-alternatives to plastics (6.11)
- Eco-industrial waste management (3.99)
- Biofuels & biomass (3.71)
- Eco-construction materials (3.24)
- Traditional knowledge (2.99)

AUSTRALIA

Top five topics by growth rate
- Floating plastic debris in the ocean (3.94)
- Minimize poaching & trafficking of protected species (2.18)
- Greater battery efficiency (2.09)
- Help for smallholder food producers (1.98)
- Climate-ready crops (1.94)

Top five topics by specialization
- Ocean acidification (5.63)
- Local disaster risk reduction strategies (5.45)
- Sustainably manage marine tourism (5.38)
- Local impact of climate-related hazards & disasters (4.62)
- Socio-ecological impact of terrestrial protected areas (3.93)

INDONESIA

Top five topics by growth rate
- Eco-alternatives to plastics (25.83)
- Sustainably manage marine tourism (16.83)
- Eco-construction materials (8.52)
- Water harvesting (8.00)
- Traditional knowledge (6.73)

Top five topics by specialization
- Sustainably manage marine tourism (10.50)
- Geothermal energy (6.34)
- Help for smallholder food producers (6.25)
- Eco-alternatives to plastics (5.44)
- Minimize poaching & trafficking of protected species (4.73)

NEW ZEALAND

Top five topics by growth rate
- Greater battery efficiency (3.26)
- Local impact of climate-related hazards & disasters (2.29)
- Hydrogen energy (1.77)
- Human resistance to antibiotics (1.65)
- Agro-ecology (1.63)

Top five topics by specialization
- Tackle invasive alien species (6.52)
- Geothermal energy (6.44)
- Ocean acidification (6.41)
- Status of terrestrial biodiversity (3.04)
- Sustainable use of terrestrial ecosystems (2.78)

* The topic of ecosystem-based approaches in marine environments covers environments within national exclusive economic zones.

Note: Topics with at least 100 publications were considered, with exceptions for the Caribbean, Indonesia, Malaysia, New Zealand, the Russian Federation, Singapore, Thailand and Viet Nam (50 publications).

Source: Scopus (Elsevier), including Arts, Humanities and Social Sciences; data treatment by Science-Metrix

Resilient food systems rely on smart use of land and sea

The world is not on track to achieve SDG2 for zero hunger, according to the UN Food and Agriculture Organization (FAO, 2020a). Innovation in sustainable food systems, such as climate-ready crops, agro-ecology and **precision agriculture**,[8] can make agriculture more productive without depleting soils.

These three approaches were among the fastest-growing research topics in the Russian Federation over the 2012–2019 period (Figure 2.10). Sustainable agriculture features among the seven mission-oriented priorities of the government's *Strategy for the Development of Science and Technology* to 2035 (see chapter 13).

Along with China, India, Israel and the UK, the Russian Federation boosted its output on precision agriculture by 70% or more between 2011 and 2019. On this topic, high-income economies maintained their share (*ca* 60%) of global publications over the period under study, whereas the contribution by lower middle-income economies grew from 10% to 14% of total output over the dual periods 2012–2015 and 2016–2019 (Figure 2.5).

In considering efforts to achieve zero hunger, it would be misguided to consider only advanced technologies. Sub-Saharan African researchers specialize in **helping smallholder food producers**. This topic is a small field globally, with sub-Saharan authors contributing to 361 of the world's 885 publications and the EU 294 articles in 2019.

There are signs that other regions are taking up this research. Between 2011 and 2019, East and Southeast Asia's global share of output increased from 15% to 23% for instance. Sub-Saharan Africa's own share decreased from

Box 2.2: **How sustainable is advanced technology?**

As you read this, most of you could reach out and touch at least one device containing cobalt that may have been extracted from the Democratic Republic of the Congo, or lithium that may have come from Australia, among scores of other metals and rare earth metals. Over half of the 30 elements in the average smartphone are increasingly scarce and many are being obtained through unsustainable and unjust mining practices.

Mining is having a widespread impact on people and ecosystems. The first study of the effects of mining-related pollution on newborns in sub-Saharan Africa demonstrated a link between birth defects and paternal mining-related work in the Democratic Republic of the Congo (Van Brusselen *et al.*, 2020). The health of miners has grown into a national policy issue but the drivers of resource extraction, namely consumer demand and industry pressure, are international in scope.

Demand for technology is often used as a reason to push for mining, including deep-sea mineral exploration. The transition towards efficient electrification will increase our demand for batteries and, therefore, for rare earth metals. At the same time, technology is transforming mining through automation, reducing the risk to miners and improving efficiency (McKinsey & Company, 2018).

The benefits of the circular economy

To enjoy the benefits of advanced technology, products must be produced more sustainably, last longer and be recycled at their end of life. Our track record in these areas is weak.

Manufacturing waste exceeds post-consumer waste by an order of magnitude (Lepawsky, 2019). E-waste is the fastest-growing waste stream. In 2019, each person produced 7.3 kg, on average, but only 1.3 kg underwent environmentally sound recycling (Forti *et al.*, 2020). In other words, 83% of e-waste is undocumented. Globally, 54 million metric tonnes of e-waste were discarded in 2019 and we shall most likely throw away more than 75 million metric tonnes each year by 2030 (Forti *et al.*, 2020).

The term 'planned obsolescence' refers to the design of a product to ensure that it becomes rapidly outdated, either because it cannot be repaired or is intentionally subject to early failure, obliging the customer to replace the product. The combination of planned obsolescence and repair monopolies has contributed to shorter product lifespans and undermined our ability to understand and fix our own belongings, particularly when they involve advanced technologies.

Although proponents argue that early obsolescence drives rapid innovation and economic growth, consumers and sustainability experts wish products to last longer. Today's buyers pay for products with ever-shorter lifespans: in 2013, 8.3% of appliances were replaced within five years due to a defect, compared to 3.5% in 2004 (Prakash *et al.*, 2016).

In 2015, France made history by passing Hamon's Law, which made planned obsolescence illegal and obliged French manufacturers to identify if, and for how long, replacement parts would be available for a given product.

Recycling is hindered by repair monopolies and the transition away from standardized modular construction that would enable the sale and re-use of parts. Consumers are beginning to demand the 'right to repair' the technology they purchase.

In the USA, right-to-repair legislation is being considered at the federal level for the first time, thanks to the Covid-19 pandemic. The Critical Medical Infrastructure Right-to-Repair Act* of 2020 would permit technicians to perform critical repairs of hospital equipment without fear of a lawsuit if they break a digital lock. In advance of federal legislation, 20 of the 50 US states have considered right to repair bills for specific sectors. However, major corporations have successfully lobbied against several state proposals.

Such lobbying has also stymied repair bills in Canada, despite a 2019 poll by the Innovative Research

46% to 41%, despite a growth rate of 2.0%. Global interest in this topic among all income groups may reflect high levels of international collaboration (Figure 2.5).

Asia and Africa have the most smallholdings in agriculture but large-scale farming is gaining ground around the world, which often involves foreign ownership of arable land. This has consequences for long-term land management. The International Land Coalition estimates that 1% of the world's largest farms manage over 70% of the world's farmland (ILC, 2020).

Less research on sustainably managing fisheries

More than half of the global ocean is harvested on an industrial scale, an area four times greater than land used for intensive agriculture (Kroodsma *et al*., 2018). Despite this, the volume of scientific research on the **sustainable management of fisheries and aquaculture** declined by 2% annually worldwide, from 3 754 publications in 2011 to 3 135 in 2019.

Fish supply up to 90% of protein in the diets of coastal populations and assure a livelihood for one in ten human beings (Gaines *et al*., 2018). However, the Food and Agriculture Organization (FAO) has demonstrated that 90% of commercially exploited marine fish stocks are either overfished or fished to their maximum sustainable limits (FAO, 2020b). Researchers have estimated that proactive and adaptive fishery management could boost profits and result in 60% more fish biomass (Gaines *et al*., 2018).

In this context, the missing research by scientists from the Caribbean, Southeast Asia, sub-Saharan Africa and the islands

Group showing that 75% of Canadians support right-to-repair legislation. Similarly, according to a 2014 Eurobarometer survey, 77% of European Union citizens would rather repair their goods, even though the current cost of repairs and service options leads most to replace or discard their belongings (EU, 2014).

The European Commission is working towards a right to repair for consumers, including a right to update obsolete software (see chapter 9). In 2019, it adopted eco-design measures to increase the energy efficiency and reparability of household appliances.** From 2021, manufacturers will have to make appliances last longer and supply spare parts for machines for up to 10 years.

In Bangladesh in 2020, the Department of the Environment published the draft *Hazardous Waste (E-Waste) Management Rules*, restricting the use of 15 chemical substances in certain electrical products and outlining procedures for company recycling of e-waste. Since 2019, entities seeking to import machinery and other accessories for initiatives with an environmental focus like waste management can access the Green Transformation Fund managed by the national central bank (see chapter 21).

Our choices will define our legacy

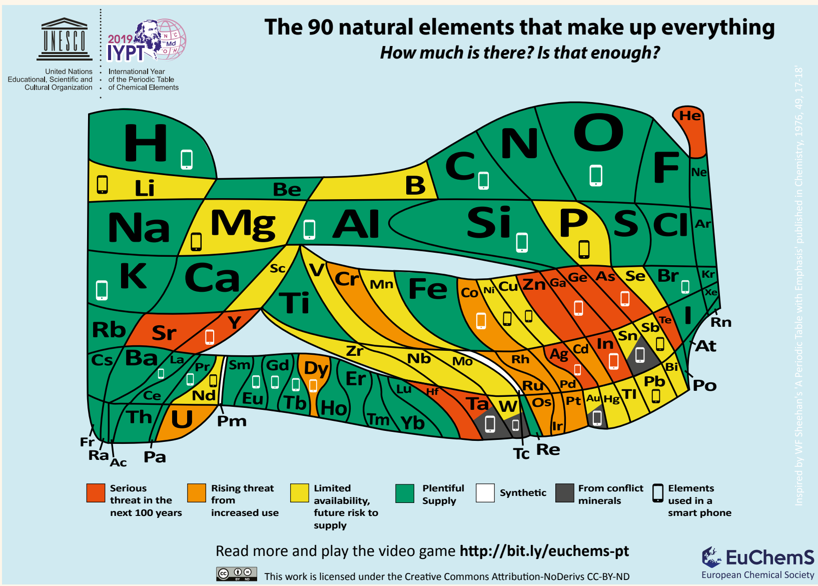
Our choices about technology consumption and production will define our legacy. For example, the process of modern steel production is contaminated with radionuclides carried in the air, as background radiation in the atmosphere has increased since the start of the nuclear era in the 1940s. To meet the demand for uncontaminated, low-background steel, pillagers are seeking to retrieve metals from shipwrecks that predate the nuclear era.

UNESCO is supporting the efforts of countries to identify and manage such sites through the Convention on Underwater Cultural Heritage but pressure is mounting for unregulated retrieval of non-irradiated metals. This begs the age-old question of preservation versus re-use: what are we prepared to give up of our past to create the future we want?

Source: compiled by Tiffany Straza

* See: https://tinyurl.com/congress-USgov-right-to-repair

** See: https://tinyurl.com/EC-rules-sustainableappliances



Graphic produced in 2019 for the International Year of the Periodic Table of Chemical Elements designated by UNESCO to mark the 150th anniversary of the Mendeleev periodic table

Source: European Chemical Society and UNESCO of Oceania is striking. Indonesia is a notable exception. Its output quadrupled from 115 to 479 publications between 2012–2015 and 2016–2019.

With over 40% of the world's population living within 100 km of the coast and excess nutrients from human activities a known contributor to the loss of oxygen from the global ocean, the 12 231 global publications on **coastal eutrophication** from 2011 to 2019 might seem paltry.

Among major economies, Canada's 37% growth stands out: from 206 to 336 publications. Among least developed countries, output rose by 30% over this nine-year period to a total of 58 publications.

Ocean-dependent countries with traditional connections to the sea are assuming global leadership roles in the sustainable management of oceanic systems. Kenya hosted the first global Sustainable Blue Economy Conference in 2018 and co-hosted the second United Nations Ocean Conference in 2019, following the first such event in 2017 co-hosted by Fiji and Sweden to address SDG14 on oceans. Kenyan scientists published at least three times the global average intensity on sustainable management of fisheries and aquaculture between 2011 and 2019.

In 2018, Kenya joined others[9] in establishing the High-Level Panel for a Sustainable Ocean Economy. This Ocean Panel committed to an ocean action agenda in December 2020 with knowledge forming one of the five priority areas of transformation, leveraging the UN Decade of Ocean Science.

We can expect growth in publishing in ocean science during the United Nations Decade of Ocean Science for Sustainable Development, which got under way in January 2021 under the stewardship of the UNESCO Intergovernmental Oceanographic Commission.[10] With inclusivity being a key principle for the Decade, research is expected to be internationally collaborative and representative of ocean users. The multifarious connections between marine resources and planetary health make this research area a rich source of scientific discovery but also reliant upon technology transfer.

One growth area is the study of **ocean acidification**. The acidity of seawater is increasing, effectively depleting the calcium carbonate which serves to form the skeletons and shells of corals and shellfish. This is imperilling ocean ecosystems, the marine food web and, indirectly, a major source of protein for human populations. The acidification of the ocean stems from the same cause as the climate crisis, namely greenhouse gas emissions driven primarily by fossil fuel-based energy systems.

Will the energy transition keep pace with research?

In 2018, over 80% of world energy production remained based on coal, oil and gas (Figure 2.11) [IEA, 2020]. Nuclear power (5%) and renewable energy (14%) made up the remainder. Among renewables, biofuels and waste (9.3%) dominated; solar photovoltaic and wind power represented less than 2% of total energy production and geothermal plants less than 0.5%.

Even if global coal use were to end immediately, assuming cement emissions remain constant, existing developed oil and gas fields would push the world beyond the target of 1.5°C warming (OCI, 2020). Despite the growing impact of climate change, action by governments and businesses in support of the necessary energy transition is lagging behind. In the four years (2016–2019) following adoption of the *Paris Agreement*, 35 banks from Canada, China, Europe, Japan and the USA together invested US$ 2.7 trillion in fossil fuels (RAN *et al.*, 2020). India's *National Electricity Plan* (2018) foresees adding 46 GW of coal-fired capacity by 2027, even though plans to build nearly 14 GW of coal-fired power plants were cancelled in May 2017 after being deemed uneconomical (see chapter 22). In the USA, factors such as falling costs and federal tax credits have driven growth in renewable energy but the huge legacy investments of large US energy companies have been hindering the deployment of clean energy (see chapter 5).

In 2017, Ireland became the world's first country to commit to divesting public money fully from fossil fuels, when parliament passed legislation to remove investment in coal, oil and gas from the € 8 billion (*ca* US$ 9.5 billion) Ireland Strategic Investment Fund (ECEEE, 2017). In 2019, the Norwegian parliament passed a law requiring the Norwegian Sovereign Wealth Fund, the world's largest with a worth of over US$ 1 trillion, to drop investments of US$ 13 billion in eight coal companies and about 150 oil producers (Ambrose, 2019).

Renewable energy systems have become cheaper to build than fossil fuel power plants across much of the world (IRENA, 2020), thanks to advances in wind and solar energy technology, in particular. Renewable energy was the only energy sector to see growth at the height of the Covid-19 pandemic and demand is projected to grow further (IEA, 2020).

Many countries have set renewable energy targets and some have formalized commitments to a sustainable transition, through instruments such as the *Sustainability Charter* (2016) signed by Albania, Bosnia and Herzegovina, Kosovo, Montenegro, North Macedonia and Serbia under the *Energy Community Treaty* (2006) [see chapter 10]. Papua New Guinea was the first country to submit its Nationally Determined Contribution (2016) under the *Paris Agreement*, setting out a plan to transition to 100% renewable energy by 2030 and attain carbon neutrality by 2050. At the time of writing in February 2021, at least 110 countries had set themselves the objective of achieving carbon neutrality by 2050. To this end, Costa Rica has developed a *National Decarbonization Plan 2018–2050* (see chapter 7). In March 2020, the European Commission enshrined the target of climate neutrality by 2050 in the European Climate Law. In December 2020, the Commission adopted the target of a 55% reduction in carbon emissions by 2030 over 1990 levels (see chapter 9). China has committed to carbon neutrality by 2060 (see chapter 23).

Smart-grid tech and battery efficiency dominate energy research topics

The UNESCO study assessed scientific publications in relation to energy production via photovoltaics, hydropower, biofuels and biomass, wind-turbine technologies, geothermal energy, hydrogen energy and nuclear fusion. The study also assessed the extent to which scientific output prioritized cleaner fossil fuel technology, radioactive waste management and smart-grid technology.

Innovation in electricity distribution and storage is growing. Globally, publications on smart-grid technologies grew by nearly 12% per year from 4 737 in 2011 to 12 975 in 2019 (Figure 2.11). This impressive trend was surpassed only by output on **greater battery efficiency**, growing by 16% per year from 4 829 publications in 2011 to 18 692 in 2019. Batteries are expected to support an electrified future free from fossil-fuel consumption. Despite the expected reliance on efficient electrification and government targets for electricity production from renewable energy sources, only one in ten electric utility companies around the world is prioritizing investment in renewable energy over fossil fuels (Alova, 2020). In fact, 60% of the utilities prioritizing renewable energy are simultaneously expanding their investment in fossil fuels (Alova, 2020).

At the global level, output is stabilizing or even showing signs of decline for three of the nine selected clean energy topics, namely **cleaner fossil fuel technology, nuclear fusion** and **radioactive waste management**. Scientific output on renewable energy sources appears to have outpaced political or industrial will to transform energy supplies. Research attention is even levelling off in high-output economies: their share of global output declined by 5% or more for all of the selected energy topics. For example, high-income economies produced 6 805 (74.8% of the world's publications) on photovoltaics in 2011 and 7 928 (50.5%) in 2019.

Some of the strongest growth in research on sources of renewable energy is taking place in lower middle-income countries. For instance, their share of **photovoltaic** research surged from 6.2% to 21.2% between 2011 and 2019, that on **wind turbine technologies** from 6.4% to 16.9% and that on **biofuels and biomass** from 7.6% to 21.6% (Figures 2.5 and 2.8).

Vietnamese research output on biofuels and biomass has increased five-fold from 67 (2012–2015) to 350 publications (2016–2019) following the establishment of a 25% target for the share of biofuels in total vehicle fuel consumption by 2050 in Viet Nam's *Renewable Energy Development Strategy 2016–2030* (2015). The government banned the sale of standard gasoline in late 2017 to spur progress. Simultaneously, to avoid a repeat of price distortions for staple crops following a boom in biofuels, as had occurred in the 2000s, Viet Nam directed its ministries to control the price of biofuel and to define a price floor for cassava, the main raw material in ethanol production.

Photovoltaics formed the largest body of energy research among the topics examined, despite accounting for less than 2% of global energy supply in 2018. Electricity generation from solar photovoltaic systems has grown exponentially, with 32 038 GWh produced globally in 2010, compared to 554 283 GWh in 2018 (IEA, 2020).

Hydropower accounted for two-thirds of Brazil's installed capacity for electricity generation in 2020. Following a report by the Brazilian Agency for Water and Basic Sanitation in 2018 warning that 45 Brazilian dams were at a high risk of failure, the government announced the end of megahydropower projects in the Amazon (see chapter 8.) Research into the sustainable withdrawal and supply of freshwater is Brazil's fifth-fastest-growing topic (Figure 2.10).

The world's largest energy infrastructure project is planned for the Democratic Republic of the Congo, the Grand Inga hydropower dam (see chapter 20). Other African countries are multiplying projects to develop hydropower, wind and solar energy but African researchers are strikingly absent from this body of scientific research, despite the high priority accorded to renewable energy by the African Union's *Agenda 2063: the Africa We Want* (2015). Researchers from the Democratic Republic of Congo contributed to just seven publications on hydropower from 2011 to 2019.

Taken together, Kenya, Ethiopia and Tanzania account for half of the 20 million Africans who gained access each year to electricity between 2014 and 2018. By 2018, geothermal power generated in the Rift Valley had overtaken hydropower as the lead source of electricity in Kenya, powering 35% of households (see chapter 19). Research output has been erratic, however. Kenyan scientists produced 27 publications on **geothermal energy** in 2017 but only seven the following year and one in 2019.

Sub-Saharan researchers contributed to a total of just 829 publications from 2011 to 2019 on smart-grid technologies and 935 publications on solar photovoltaics. This translates into 1.4% and 1.5% of global output, respectively. Although the region showed the strongest specialization in hydropower among the energy topics examined, this research is being driven by only a handful of countries, led by South Africa.

With the opening of its Centre for Renewable Energy and Energy Efficiency in Namibia in 2015 (see chapter 20), the Southern African Development Community may see renewed growth in research on battery efficiency. Sub-Saharan output has already surged from 377 (2012–2015) to 983 (2016–2019) publications, driven by Ethiopia, Nigeria and South Africa.

Meanwhile, countries belonging to the Caribbean Community (Caricom) are striving to transition to clean energy, in a move led by the Caribbean Centre for Renewable Energy and Energy Efficiency established in 2017 (see chapter 6).

Such gains are fragile. Despite calls for green recovery plans, the post-Covid-19 strategies of many governments combine protection for jobs with investment in new high-carbon infrastructure, according to a recent analysis (Vivid Economics and F4B, 2020). One notable exception is the European Union (EU). With 30% of its Next Generation Recovery Fund devoted to green investment (see chapter 9), the EU leads the table for the net Greenness of Stimulus Index. The authors of the chapter on the EU in the present report argue that, 'to maintain its lead in green innovation, the EU will need to translate its vision into higher levels of investment, since the new US administration has pledged to invest massively, itself, in clean tech' (see chapter 9).

The future geoscience and engineering industry is expected to depend significantly less on oil and gas specialists than it does today. This means that both educational institutions and industry will need to begin adapting their training and hiring practices, in order to tailor the supply of specialists to anticipated demand. To some extent, this process is already under way at the institutional level (OCI, 2020).

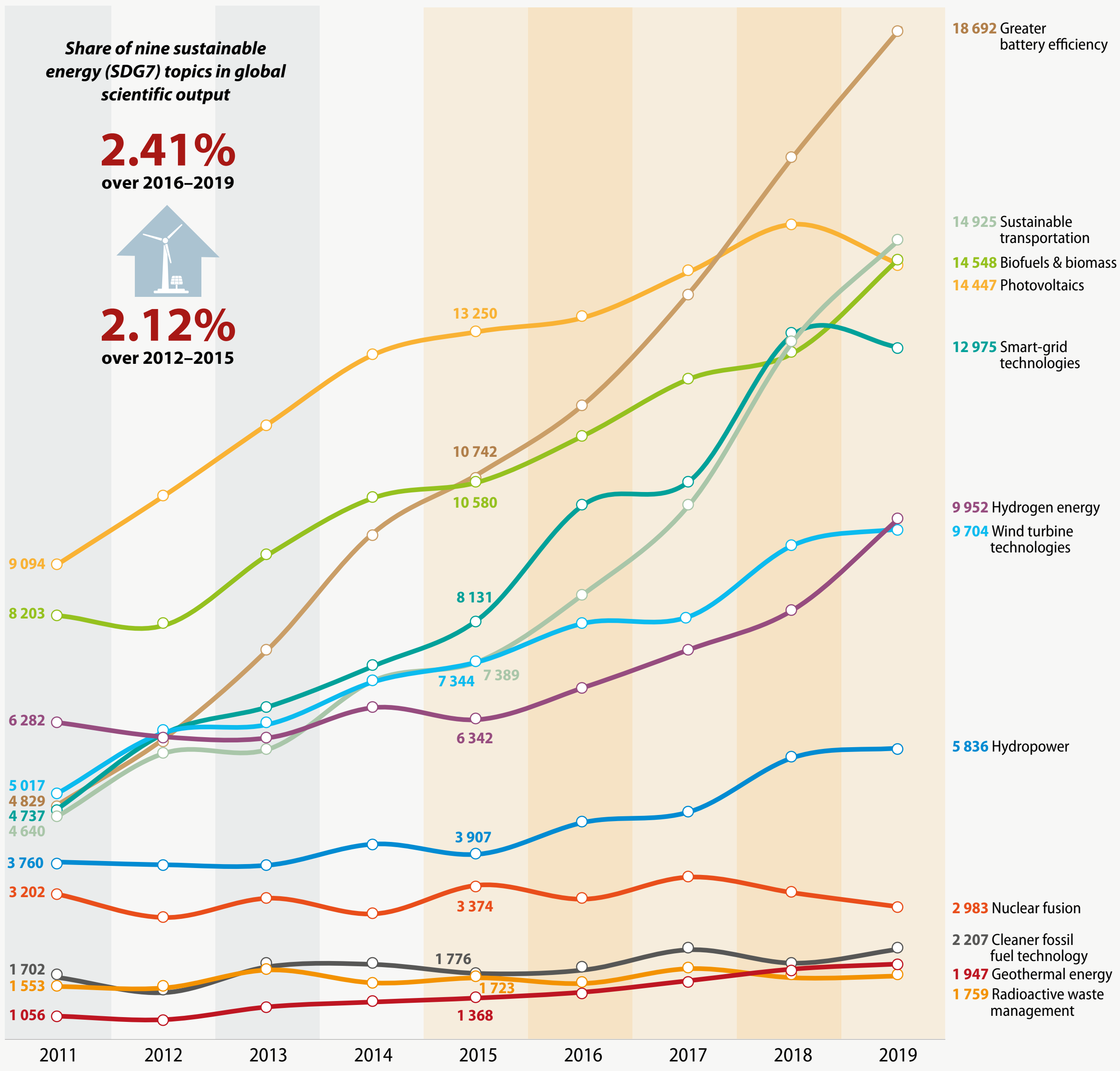
Nuclear energy currently provides 10% of the world's electricity and is the largest source of low-carbon energy (IEA, 2020). Although nuclear power features prominently in low-emission scenarios, uranium is not a renewable resource and nuclear reactors are ageing; by 2025, 25% of existing nuclear capacity in advanced economies will most likely have to be shut down.

Sustainable innovation goes beyond new technology

There are concerns that technological solutionism may become an excuse not to address the climate crisis, such as by investing in geo-engineering techniques to the detriment of transitioning to sustainable forms of energy, or by assuming that problems caused by new technology will be solved by technologies that do not yet exist. Fifty years ago, nuclear power was touted as the solution to the world's energy problems; today, we are still wrestling with the problem of radioactive waste disposal. Despite this, research output on radioactive waste

Figure 2.11: **Trends in energy production and publishing**

Global publications on selected energy and innovation topics, 2011–2019



Note: The line graph presents all topics assigned in this study to SDG7 as well as greater battery efficiency, radioactive waste management and sustainable transportation (SDG9).

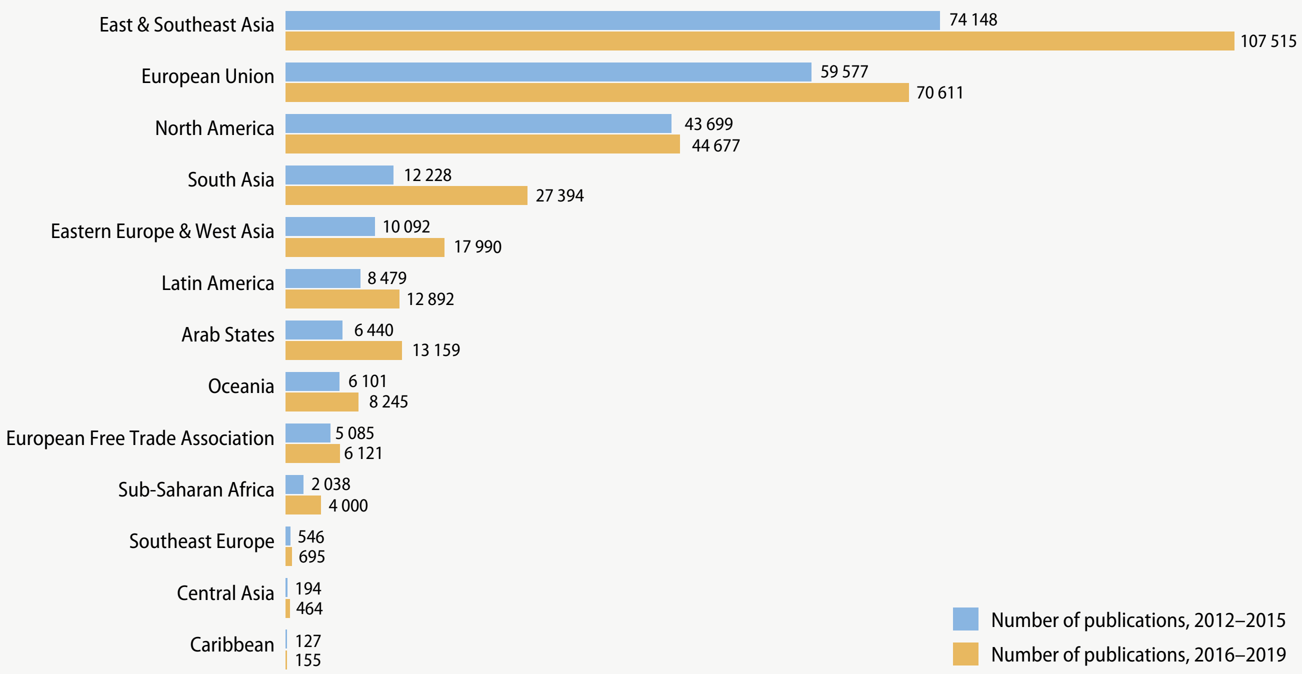
Source: Scopus (Elsevier), including Arts, Humanities and Social Sciences; data treatment by Science-Metrix; for energy and electricity by source: International Energy Agency (2020) All rights reserved management remains small and is stagnating, even within the European Union where nuclear reactors supply nearly 20% of electricity. Germany is preparing to close down its last nuclear reactor in 2022.

More generally, the management of waste generated by technology poses a major challenge for sustainability. Some solutions will be technological but just as important will be our capacity to adopt sustainable production and consumption patterns. Governments are increasingly adopting policies to reduce waste and encourage the re-use and recycling of industrial products, to foster what is known as the circular economy (Box 2.2).

Mass investment in digital technology such as computers and mobile phones has created a heavy waste burden. Bangladesh generates some of the highest volumes of electronic waste: 2.7 million metric tonnes each year, according to the Environment and Social Development Organization Dhaka (see chapter 21).

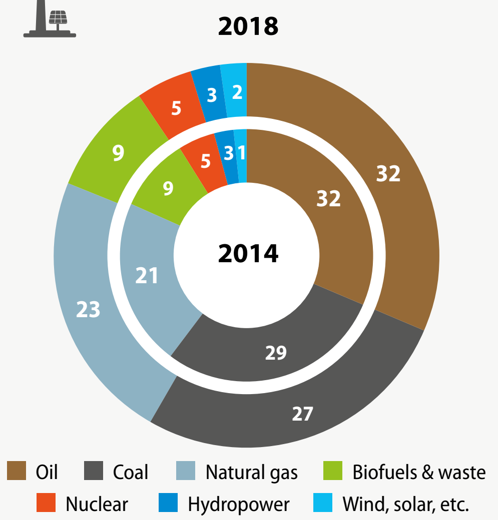
Global output on this topic is modest. For instance, scientists from Bangladesh produced 31 publications on

Volume of scientific publications on nine SDG7 renewable energy topics by selected region, 2012–2015 and 2016–2019

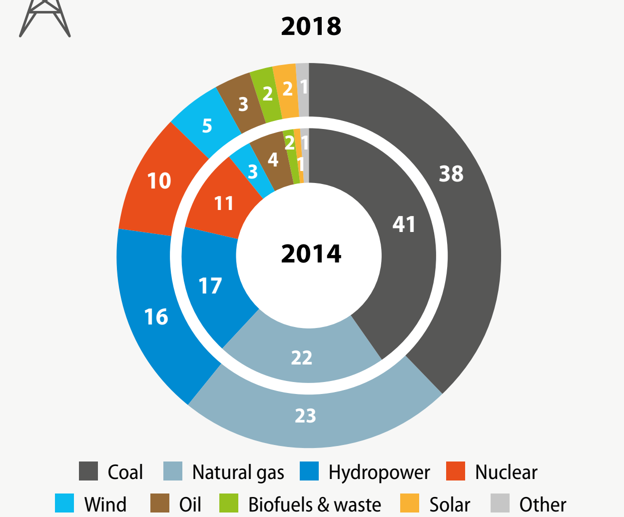


Note: The values for the regions are the number of unique publications and may differ from the sum of the sub-regions owing to potential co-authorship.

Global energy supply by source, 2014 and 2018 (%)



Global electricity generation by source, 2014 and 2018 (%)



Note: Other sources include waste, geothermal, solar thermal and energy derived from the tide..

eco-industrial waste management between 2012–2015 and 53 over 2016–2019 but this corresponded to 1.8 times the average global intensity for this topic.

In 2019, the African continent produced three million tonnes of electronic waste and continued to import it, yet only 13 African countries[11] had national e-waste legislation (Forti *et al.*, 2020). Rwanda approved an e-waste policy in 2016 and the next year launched the second-largest e-waste recycling facility in Africa (see photo, page 78). The facility creates a circular economy, with refurbished computers being sold or donated to schools, steel turned into steel bars for construction purposes and plastic crushed into pellets for re-use. The facility is undertaking a feasibility study with support from the Ministry of Trade and Industry and the EU in the hope of expanding to become the first lithium battery recycling facility in Africa (Kovacevic, 2020).

The Rwandan facility should reduce the widespread practice of informal recycling and burning of e-waste, which place people at great risk. Africans are disproportionately affected by the world's e-waste and mining residues (Forti *et al.*, 2020). Growth in research on the impact on health of air, soil and water pollution is fairly evenly distributed across the continent but sub-Saharan Africa still contributed less than 4% of global output on this topic in 2019.

Maphosa and Maphosa (2020) have demonstrated that e-waste research is gaining traction in Africa, a field they found to be dominated by Ghana, Nigeria and South Africa. This type of research is essential for problem-solving, to complement tracing the record of harm.

The UNESCO study shows a similar trend, with one notable difference. Although the bulk of research in sub-Saharan Africa stems from Nigeria (85/209 publications) and South Africa (77/213), Ethiopia's output on this topic has surged from 4 (2012–2015) to 37 (2016–2019) publications, overtaking Ghana (13/25). Ethiopia shows the subcontinent's fastest growth rate for this topic (9.3%), followed by Mauritius (3.5%), Cameroon and Mozambique (3.0%), South Africa (2.8%), Nigeria, Uganda and Zimbabwe (2.5%). Output has grown by 1.9% in Ghana and remained stable in Rwanda, which has produced four publications on this topic since 2012.

The management of industrial waste remains underrepresented in the world's largest economies. As in the case of viral disease outbreaks, the research effort could be described as being reactive rather than proactive, with output tending to surge after a disaster. For example, Brazil boosted its output on eco-industrial waste management from 332 (2012–2015) to 606 (2016–2019) publications, perhaps in response to the 2015 collapse of the Fundão dam (see chapter 8). Other economies with a strong industrial base witnessed a doubling of output on this topic over the same period, including China, Egypt, India, Iran, the Russian Federation and Saudi Arabia.

A pairing between countries' digital and green agendas

In a world first, sales of electric cars in Norway exceeded those of petrol, diesel and hybrid engines in 2020. Norwegian researchers have doubled their output on **sustainable transportation** from 133 (2012–2015) to 286 (2016–2019) publications with similar gains recorded on the topic of battery efficiency (92/219).

China's global share of publications on sustainable transportation even shot up from 37% in 2011 to 49% in 2019. In the USA, meanwhile, publications on this topic coasted with a growth rate of 1.6, resulting in a contraction from 32% to 26% of global output.

Electric vehicles are a good illustration of efforts by countries to advance their green and digital agendas in tandem. This is the case for India, for instance, which is investing simultaneously in smart cities, electric vehicles and renewable energy. The *National Electric Mobility Mission Plan 2020* (2013) has sought to populate India with a fleet of 6–7 million electric and hybrid vehicles by 2020 (see chapter 22). Sustainable transportation and greater battery efficiency are two of the country's fastest-growing research topics (Figure 2.10).

Achieving a dual green and digital transition is also a policy focus for the European Union, through its new *European Green Deal* (2020) following on the heels of its digital policy, *A Europe fit for the Digital Age* (2019). The top innovators for technologies that combine green and digital elements tend to be European (see chapter 9).

Many countries are developing or planning smart cities which they intend to make sustainable, including Costa Rica, El Salvador, India, Morocco, Saudi Arabia and the United Arab Emirates.

There are concerns that 'smart' development like automation may threaten existing jobs. Whether this change is good or bad depends greatly upon the availability of training and alternative opportunities for those who are replaced by machines. For example, Mani (see chapter 22) notes the benefits of automation in India's automotive sector, where the introduction of robots has made the workplace safer, with fewer repetitive stress injuries and accidents. In the USA (see chapter 5), on the other hand, automation is considered as having contributed to the loss of 5.5 million manufacturing jobs between 2000 and 2017, where a skills mismatch for a more advanced manufacturing sector was not addressed in time through mechanisms such as worker retraining.

Whether our cities are 'smart' (see chapter 1) or not, galloping urbanization and infrastructure development presents a real challenge for sustainability. Every year, new constructions consume 40–50 billion tonnes of sand and gravel. Sand and gravel is now the second-most traded resource after water. About three-quarters of concrete is sand. Sand mining from rivers causes pollution, flooding and aquifer depletion and can exacerbate drought. Sand mining can also destroy beaches, jeopardizing tourism, and disrupt the habitat of marine life (UNEP, 2019a).

Fuelled by a booming cement industry, the floor area of buildings is expanding at nearly 3% per year, offsetting energy efficiency gains from reducing the emissions footprint of buildings (UNEP and IEA, 2017). In 2015, cement accounted for 8% of anthropogenic CO_2 emissions, double the proportion of the airline industry and more than any individual country. Cement demand could grow by 25% by 2030 to meet urban trends.

Eco-construction materials should, thus, be a priority research topic for sustainability. Floor area in India is expected to double by 2035, placing demands on the country's plans for sustainable transportation and green smart cities (see chapter 22). Scientific output from India on eco-construction materials has surged from 205 (2012–2015) to 554 (2016–2019) publications. However, Europe alone accounts for half of global output on this topic.

Environmental protection still the poor relation

Of all the goals related to economic growth, it is those of industry, innovation and infrastructure (SDG9) and sustainable cities and communities (SDG11) which received the most official development assistance between 2000 and 2013, with donors contributing US$ 130 billion and US$ 147 billion, respectively (Sethi *et al.,* 2017).

At the other end of the scale, topics of environmental sustainability, aligned with the SDGs for responsible consumption and production (SDG12), climate action (SDG13), life below water (SDG14) and life on land (SDG15), received the least attention, attracting a cumulative total of less than US$ 25 billion in donor funding over this period.

This funding pattern is reflected in outcomes. On average, national progress around the world has been weakest for the core environmental SDGs for climate action (SDG13), life below water (SDG14) and life on land (SDG15) [Sachs *et al.*, 2019; see Table A1 in the statistical annex of the present report].[12]

This problem persists, according to the platform Aid Atlas, launched in 2019 to monitor global development finance flows. From 2013 to 2017, US$ 28 billion total in aid was directed towards environmental protection, corresponding to only 2% of the total development finance dispersed during that period and less than the amount spent on the administrative costs of donors (Atteridge and Savvidou, 2020).

In a sample of 30 voluntary national reviews submitted by governments to the High-level Political Forum on Sustainable Development as part of country-level monitoring of progress towards the SDGs, only 20% mentioned biodiversity as a national priority for sustainable development (Pesce *et al.*, 2020). The world has failed to fully meet any of the global biodiversity targets that have defined much of conservation and environmental management over the past decade (CBD, 2020).

The United Nations Environment Programme (UNEP, 2020) predicts that embracing a greener economic model would boost global economic growth by 8% by 2060.[13] The test for the coming years will be whether countries succumb to the temptation to trade long-term benefits for short-term economic relief. Some countries are loosening, at least temporarily, environmental and labour protection laws to compensate for the economic hardship associated with Covid-19. One example of this is Indonesia's 'omnibus law' (see chapter 26).

Publication output gives some indication of interest, funding and workforce expertise. The **sustainable use of terrestrial ecosystems** is a topic with broad scope and one of the most evenly spread in terms of global representation. Largely stable elsewhere, output on this topic is growing in sub-Saharan Africa, the Arab States and Asia. That said, several of the dominant threats to terrestrial ecosystems continue unabated.

Research on the use of biodiversity and ecosystems outstrips research on their status, in much the same way that research on extraction outstrips that on conservation (Figure 2.12).

For Dasgupta (2021), 'almost all governments have been exacerbating the biodiversity crisis by paying people more to exploit nature than to protect it. A conservative estimate of the global cost of subsidies that damage nature is US$ 4–6 trillion per year'.

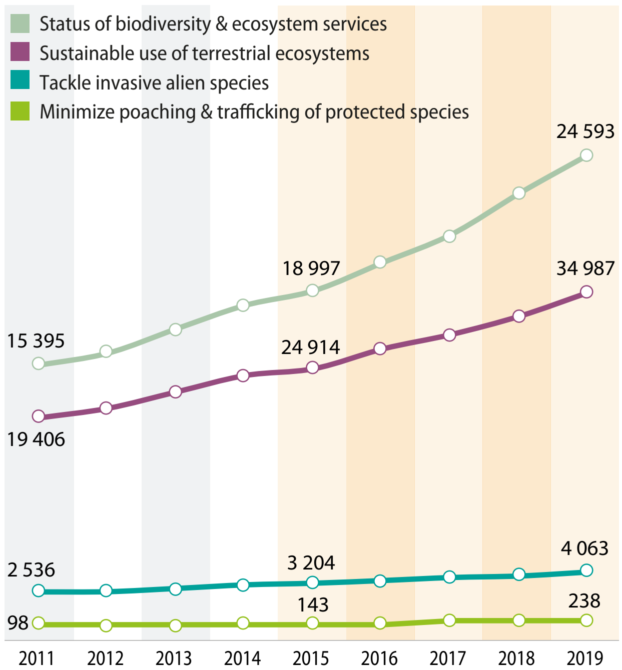
Poaching, trafficking and invasive species growing research fields

The **poaching and trafficking of endangered species** is a lucrative enterprise and now also a small but growing research field (Figure 2.12). Countries with high biodiversity and known vulnerability to the illegal wildlife trade stand out: scientific output has at least doubled in most countries in Southeast Asia, including Indonesia and Viet Nam, in addition to Colombia, Cyprus, Ghana, Mongolia and Saudi Arabia.

Uncontrolled wildlife trade not only threatens the populations of exotic species in their natural habitat but also introduces risks to the destination. Invasive species are considered a leading driver of biodiversity loss alongside climate change, having contributed to 60% of historical species extinctions. Global research on **tackling invasive species** is growing but this field of study remains small compared to the impact of the problem (Figure 2.12).

There are growing efforts to understand and slow the spread of invasive species, such as in Bangladesh, Bosnia and Herzegovina and Viet Nam. Growth has been most notable in sub-Saharan Africa, with surges of 500% or more in publications observed in Botswana, Ghana and Nigeria since 2013.

Figure 2.12: **Volume of global publications on selected biodiversity-related topics, 2011–2019**



Source: Scopus (Elsevier), including Arts, Humanities and Social Sciences; data treatment by Science-Metrix

Botswana's research tackling invasive species has risen from 1 (2012–2015) to 15 (2016–2019) publications. A single invasive water fern, *Salvinia molesta*, was threatening the Okavango Delta, a UNESCO World Heritage site and Africa's largest wetland. By introducing a *Salvinia*-munching weevil in 2002 as an alternative to chemical pesticides, Botswanan scientists managed to bring the invasion under control by 2016 after three decades of effort (see chapter 20). Invasive species threaten livelihoods in 70% of African countries (Makoni, 2020).

In the face of growing transboundary challenges, such as invasive species, air pollution, freshwater management and climate change, countries are taking steps to ensure the survival of natural systems by reducing those pressures under their control.

Little research on ecosystem-based approaches in protected areas

The Convention on Biological Diversity has proposed a target of conserving 30% of the Earth's surface area as natural space by 2030 in its zero draft of the Post-2020 Global Biodiversity Framework, to be finalized in May 2021. The extent of protected areas increased slightly between 2016 and 2020 from 14.7% to 15.0% of the total land area and, at sea, from 10.2% to 17.5% of national waters (UNEP-WCMC *et al.*, 2020).

Globally, there were 5 245 publications between 2011 and 2019 on the **socio-ecological impact of terrestrial protected areas**. The European Union and Latin America each accounted for about 40% of the total. Researchers from sub-Saharan Africa published six times and Oceania four times[14] the global average intensity.

More than half (52%) of Costa Rica's national territory is covered by biosphere reserves; these are designated territories within the UNESCO global network of the same name where communities experiment with novel approaches to sustainable development such as ecotourism and agro-ecology (see chapter 7). Costa Rica's scientific output on the sustainable use of terrestrial ecosystems (760 publications over 2011–2019) and the **status of terrestrial biodiversity** (543) is more than eight times the global average intensity.

Protection of a defined space lends itself to a whole-of-system approach, yet this method is not a common subject of experimentation. The scientific literature on **ecosystem-based approaches in protected areas on land** is small overall, with only 1 243 publications in English at the global level from 2011 to 2019, two of which came from Costa Rica. Canada's intensity of output on this topic was five times the global average, despite modest numbers: 94 (2012–2015) and 88 (2016–2019) publications.

Madagascar is an interesting case study. Scientists published 32 times the average global intensity on the socio-ecological impact of terrestrial protected areas. Madagascar is reliant on revenue from tourism to support conservation efforts. By May 2020, it had lost about US$ 500 million in tourism revenue, as a consequence of travel restrictions linked to the Covid-19 pandemic. One of the founders of Ranomafana National Park lamented that, 'without the US$ 4 million that usually flows into the region from tourism and research, the community will be forced to return to cutting the forest and farming' (see chapter 20).

Monitoring such spaces brings its own challenges. A 2019 agreement between the US National Aeronautics and Space Administration (NASA) and the Central American Integration System (SICA) of eight Central American countries[15] supports the use of remote sensing information from satellites for a range of applications, with a focus on environmental management and mitigation of environmental and disaster risks and with a specific effort to promote open data polices in SICA member countries (see chapter 7).

The world is on track to meet only 23% of the environment-related SDG indicators by 2030. The status of another 68% cannot even be measured for lack of data (UNEP, 2019b).

Research low on local disaster risk reduction strategies

Worldwide, only 1 102 publications between 2011 and 2019 were retrieved from the global literature that pertained to the topic of **local disaster risk reduction strategies**. Given the growing investment in local resilience through the Green Climate Fund, which has gathered pledges worth US$ 10.3 billion since its initial resource mobilization in 2014, the test for related projects will be whether they build local capacity, including in terms of local co-authorship of related research.

Indigenous and local knowledge are now included in a growing number of Latin American policies, in particular. Bolivia and Ecuador have introduced programmes at the national level to facilitate the recovery, safe-keeping and use of local and ancestral knowledge (see chapter 7). Traditional leaders in Pacific island countries such as Niue, Samoa, the Solomon Islands, Tonga and Vanuatu are creating restricted-access digital repositories of local and traditional knowledge pertaining to the climate (see chapter 26).

The top 10 countries ranked by specialization in research on **traditional knowledge** are all situated south of the Sahara. Researchers from high-income economies contributed less than half (40%) of global publications on this topic, the lowest proportion observed for this income group for any of the 56 topics analysed. Even countries with close ties to former colonies, such as France and the UK, produced less than half of the global average intensity on this topic.

CONCLUSION

Sustainability research not yet mainstream

The 56 research topics analysed in the preceding pages are but a subset of broader sustainability research. We can, nevertheless, draw some conclusions from this sample of current trends.

The first conclusion is that sustainability research is not yet mainstream in academic publishing at the global level. Sixteen of the 56 chosen topics accounted for less than 0.03% each of global scientific production between 2011 and 2019. These 'orphan' topics include ecosystem-based approaches in protected areas on land, help for smallholder food producers and climate-ready crops.

Even the largest topics form a small portion of scientific research. Global publications on sustainable energy (SDG7)[16] accounted for 2.1% of global scientific output over 2012–2015 and 2.4% over 2016–2019. Publications on the health-related (SDG3)[17] topics studied here stagnated at 4.4% of overall scientific output over 2011–2019 (see chapter 1).

The growth rate for some topics tells a more positive story. Research on help for smallholder food producers and on climate-ready crops showed some of the fastest growth rates among these 56 topics: 80–90% over the dual periods of 2012–2015 and 2016–2019.

There are other bright spots. Almost one-third (59) of the 193 countries studied at least doubled their output on battery efficiency between 2011 and 2019. This topic was followed by smart-grid technologies (55 countries), the impact on health of soil, freshwater and air pollution (54) and sustainable transportation (50).

Different levels of engagement

Countries on the frontlines of climate change and those most reliant on natural resources are investing heavily, proportionately, in research on topics such as agro-ecology, climate-ready crops, technologies to reduce the impact of climate hazards and the sustainable management of terrestrial and marine environments. Most are developing countries.

Sustainability topics form far greater shares of national output in small and developing science systems. There are predictable patterns, such as the Caribbean focus on health research and the specialization in agricultural research in Latin America and sub-Saharan Africa. More intriguing is that these regions are branching out from their traditional speciality areas: Latin America is taking up the baton of ocean research and at least doubled its output on topics such as eco-construction materials and new technologies to protect from climate-related hazards. Caribbean scientists are publishing on topics related to energy and freshwater resources. In sub-Saharan Africa, governments are investing in wind and solar energy systems to complement efforts to expand the traditional electrical grid. This investment is reflected in the doubling of research output on smart-grid technologies, photovoltaics and wind turbine technologies.

A decade ago, developing countries were able to leapfrog over costly investment in landlines to develop mobile communication networks. Today, the need to ensure universal access to energy is driving a similar phenomenon.

High-income countries ceding ground

High-income economies are ceding ground to other income groups for most of the 56 topics under study, with the decline in global share of output being most noticeable for battery efficiency and carbon capture and storage. High-income economies still dominate scientific publishing by volume, though. This demonstrates the need for developing countries to invest more in research infrastructure.

Low-income countries are least visible for topics related to SDGs 7 (affordable and clean energy), 9 (industry, innovation and infrastructure) and 14 (life below water). This income group is publishing more than previously on biofuels and biomass, solar and wind energy, in particular, but publications on each topic still amount to less than 1% of global output.

Low-income countries are contributing most to the topic of help for smallholder food producers: 31% of the global total. This is also one of the topics with the highest share of international scientific collaboration, as identified by the sum of contributions from individual income groups exceeding 100% by a wider margin. Other topics that involve a high level of international scientific collaboration concern climate-related hazards and climate-ready crops, the health-related topics on tropical communicable diseases, tuberculosis and HIV, as well as environmental topics relating to transboundary water resource management, the socio-ecological impact of terrestrial protected areas and minimizing the poaching and trafficking of protected species. Future studies tracking the national affiliations of authors for specific topics could identify trends and gaps in collaborative publishing (see chapter 1).

Among **lower middle-income countries**, progress has been most spectacular on problem-solving for development. For instance, their share of publications on the sustainable management of marine tourism has surged from 3% to 19% since 2011. They now account for one-quarter of global publications on minimizing poaching and trafficking of protected species and one-fifth of global output on eco-industrial waste management, photovoltaics, biofuels and biomass. They also show strong growth on smart-grid technologies, precision agriculture, geothermal energy, wind turbine technologies, sustainable alternatives to plastics and transboundary water resource management.

With the notable exception of China, progress among **upper middle-income countries** has been relatively modest. Countries in this income group made their greatest gains in national integrated water management and photovoltaics, where their share of global output grew by 8%.

China boosted its global share of research by more than 10% for a range of topics and even by more than 20% for battery efficiency (to 53%), research on national and urban greenhouse gas emissions (to 47%), hydrogen energy (to 43%) and carbon pricing (to 41%). China also accounted for almost all growth within this income group on geothermal energy, radioactive waste management and floating plastic debris in the ocean.

As a group, other upper middle-income countries contributed a greater share than China only on new or re-emerging viruses that can infect humans, human resistance to antibiotics, the status of terrestrial biodiversity, tackling invasive species and, above all, on traditional knowledge: 32% of global scientific publications.

Scientific collaboration and donor funding: a disconnect

International partnerships are considered fundamental to reaching the SDGs. In broad terms, international collaboration among the major income groups has been rising. This trend is in line with growing international co-authorship in scientific research more generally (see chapter 1). Since 2011, the level of collaboration has been particularly high on environmental management and climate research. This has not prevented climate resilience and sustainable environmental management from accounting for the smallest shares of research by volume.

This finding tallies with trends in official development assistance, where topics related to environmental sustainability attracted a cumulative total of less than US$ 25 billion in donor funding between 2000 and 2013. This funding pattern is reflected in outcomes. On average, national progress around the world has been weakest for the core environmental SDGs for climate action (SDG13), life below water (SDG14) and life on land (SDG15) [Sachs *et al*., 2019].

The present study's findings echo the observation by Atteridge and Savvidou (2020) that research topics related to climate and ecology have received less attention than advanced technology. As we have seen in the preceding pages, innovation in electricity distribution and storage is growing faster than research on alternative forms of non-fossil energy generation.

One exception to the rule is carbon capture and storage. This high-tech industry is still in its infancy. All of the pathways defined by the Intergovernmental Panel on Climate Change for limiting global warming to 1.5°C rely on technological advances in CO_2 removal from the atmosphere to augment the natural process of carbon sequestration. However, carbon capture and storage has one of the lowest growth rates (6%) among the 56 topics studied, with a mere 2 501 publications on this topic produced around the world in 2019. This compares with 12 975 publications on smart-grid technology, where growth has been driven largely by China and India.

Scientific publishing often reactive

There is evidence that much of scientific publishing over the past decade has been reactive, rather than proactive. For example, the volume of output documenting the local impact of climate-related hazards and disasters is larger and growing faster than research output on solutions such as disaster risk reduction strategies and new technologies to mitigate such hazards.

This trend stands out clearly for the topic of new or re-emerging viruses that can infect humans: countries boosted research in this field after being directly affected by an outbreak. We can anticipate a spike in research effort on viral diseases in the years to come. We can also expect governments to augment their stocks of personal protective equipment and medical treatments. What is not yet clear is whether governments will invest in prevention by tackling the root causes of zoonotic epidemics that include unfettered agricultural expansion and urbanization, deforestation and illegal wildlife trade.

To take another example, scientific publications documenting floating plastic in the ocean are growing faster than research into ecological alternatives to plastic, even though less than 10% of plastic is recycled. With the long-term prospects for oil production being threatened by the growing affordability of renewables, oil companies are stepping up the production of synthetics like plastic. At current growth rates, plastic production could account for 20% of global oil consumption by 2050 (UNEP, 2018).

This example highlights a paradox. Even as transitioning to a green economy is gaining in national priority, anxiety over potential job losses from declining industries is leading governments to prop up these very industries. This is reflected, for example, in decisions by public authorities to invest in new coal plants in full knowledge that the expansion of renewables is making coal production uneconomical.

Technological solutionism and the orientation of innovation towards fuelling economic development are, at times, proving incoherent with the demands of sustainable development. This incoherence is making it harder for countries to link existing science systems and strategies with their own sustainable development agenda.

As Dasgupta (2021) has observed, most governments tend to pay people more to exploit nature than to protect it. He has estimated the global cost of subsidies that damage nature at US$ 4–6 trillion per year. One example is plastic goods. These tend to be cheaper than ecological alternatives, as the manufacturer is not held accountable for the full life-cycle of the product; this means that the cost of collection and recycling of waste products tends to fall to public authorities. This disguised subsidy is not only costly for the public purse. It is also holding back the development of more sustainable alternatives.

Scientists and policy-makers may take diverging paths

Scientists and policy-makers are not always taking the same pathway. Some of the biggest academic output on climate change mitigation and adaptation is coming from countries where it is still government policy to minimize the importance of climate change.

This is problematic, since scientific knowledge can only be transformational if backed by political will. Without action at the policy level to embrace problem-solving, there is a risk of research simply documenting environmental decline.

The European Union has taken a decisive step in the direction of transformational change with its *European Green Deal* (2020). This new growth strategy seeks to accelerate the bloc's 'green' transition in all five socio-economic systems simultaneously (energy; agrifood; manufacturing; transportation; and buildings/housing) for greater coherence and credibility, while making sure that jobs lost in one industry can be recreated elsewhere (see chapter 9).

Adopting a 30-year target for carbon neutrality must not become a pretext for putting off until tomorrow what must be done today. Governments need to focus on reaching their 2030 targets. Measures taken today will, in turn, make it easier to reach countries' longer-term carbon neutrality targets. Strategic planning to develop infrastructure or create jobs should be approached through the lens of sustainable development, rather than as a parallel agenda.

The next *UNESCO Science Report* in 2025 should be able to confirm whether the trends observed in the preceding pages are indicative of a time lag between a change in research focus and its impact on the scientific publishing record, or whether national policy frameworks are struggling to adopt a coherent approach to sustainable development.

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ENDNOTES

1 For example, the population was advised to remove sources of stagnant water in residential areas and to use mosquito repellants like lemongrass.
2 These data stem from a global bibliometric study commissioned by UNESCO covering the period 2011–2019. The topic of new or re-emerging viruses that can infect humans covers research papers on Zika, the first Severe Acute Respiratory Syndrome (SARS) and Ebola but not HIV, which is the subject of a separate topic. The study does not cover SARS-CoV-2 (Covid-19), as this outbreak began at the end of 2019. For details of this study, see Annex 4.
3 According to the Joint United Nations Programme on HIV/AIDS (UNAIDS), 1.7 million people worldwide became infected with HIV in 2019 and 38 million are living with the disease.
4 In the present report, the Eastern Europe grouping excludes member states of the European Union.
5 The six deep ocean trenches are the Japan, Izu-Bonin, Mariana, Kermadec, New Hebrides and Peru–Chile trenches.
6 See: https://tinyurl.com/EU-single-use-plastics-2019
7 This dataset covers diseases that figure in the list of neglected tropical diseases established by the World Health Organization, namely: Buruli ulcer, Chagas disease, Dengue and Chikungunya, Dracunculiasis (guinea-worm disease), Echinococcosis, food-borne trematodiases, Human African Trypanosomiasis (sleeping sickness), Leishmaniasis, Leprosy (Hansen's disease), Lymphatic filariasis, Mycetoma, chromoblastomycosis and other deep mycoses, Onchocerciasis (river blindness), Rabies, Scabies and other ectoparasites, Schistosomiasis, soil-transmitted helminthiases, snakebite envenoming, Taeniasis/Cysticercosis, Trachoma and Yaws (endemic treponematoses). Malaria and water-borne diseases such as coliform, giardia, cholera and norovirus are also included in this topic.
8 Precision agriculture uses advanced technologies like remote sensing to monitor soil temperature and humidity, weather patterns, plant growth, irrigation rates and other factors. Crops are also rotated to preserve soils and improve biodiversity.
9 The other members of the High-level Panel for a Sustainable Ocean Economy are Australia, Canada, Chile, Fiji, Ghana, Indonesia, Jamaica, Japan, Mexico, Namibia, Norway, Palau and Portugal, representing 40% of the world's coastlines and 20% of the world's fisheries.
10 See: https://oceandecade.org/
11 These are Cameroon, Côte d'Ivoire, Egypt, Ghana, Kenya, Madagascar, Nigeria, Rwanda, Sao Tome and Principe, South Africa, Tanzania, Uganda and Zambia.
12 There is a slight tendency for countries with high scientific output on the 56 topics under study to rank higher in the *Sustainable Development Report 2020* (Sachs *et al.*, 2020) but there is no statistically significant relationship (data not shown).
13 Resource extraction was responsible for 90% of species loss and water stress in 2017, as well as half of greenhouse gas emissions (UNEP, 2020).
14 Oceania's output was dominated by Australia.
15 These are Belize, Costa Rica, the Dominican Republic, El Salvador, Guatemala, Honduras, Nicaragua and Panama.
16 These topics are cleaner fossil fuel technology, photovoltaics, hydropower, biofuels and biomass, wind turbine technologies, nuclear fusion, geothermal energy, hydrogen energy and smart-grid technologies.
17 These topics are reproductive health and neonatology, tropical communicable diseases, type 2 diabetes, human resistance to antibiotics, regenerative medicine, impact on health of soil, freshwater and air pollution, medicines and vaccines for tuberculosis, human immunodeficiency virus (HIV) and new or re-emerging viruses that can infect humans.

AT A GLANCE

Drawing by Alexia Leibbrandt for the *UNESCO Science Report: the Race Against Time for Smarter Development* (2021)

- Globally, women have achieved parity (45–55%) at the bachelor's and master's levels of study and are on the cusp at PhD level (44%) but the gender gap tends to widen as they pursue their career.
- Women represented 33.3% of all researchers in 2018, up from 28.4% in 2013, with the caveat that data are only available for 107 countries.
- There is a risk that the Fourth Industrial Revolution could perpetuate the gender imbalance, since women remain a minority in digital information technology, computing, physics, mathematics and engineering.
- In academia, female researchers tend to have shorter, less well-paid careers. Their work is underrepresented in high-profile journals. An analysis of nearly 3 million computer science papers published in the USA between 1970 and 2018 concluded that gender parity would not be reached in this field until the year 2100.
- Women also remain underrepresented in company leadership and technical roles. Corporate attitudes are evolving, however, as studies link investor confidence and greater profit margins to having a diverse workforce.

3 · To be smart, the digital revolution will need to be inclusive

Alessandro Bello, Tonya Blowers, Susan Schneegans and Tiffany Straza

INTRODUCTION

Women risk missing out on the jobs of the future

The world is undergoing a fundamental transformation that is changing the way we live, work and think. This has far-reaching implications for the role of women in society, in general, and in science, technology, engineering and mathematics (STEM[1]), in particular.

Climate change is heightening the frequency and intensity of environmental disasters, causing devastating economic losses and forcing us to rethink our approach to development, especially with regard to food, water and energy security, health care, construction and environmental management. There is evidence that the current decline in wildlife populations, such as through the conversion of forest to agriculture, urbanization, hunting and wildlife trade, has facilitated the transmission of zoonotic (animal) viruses to humans. Pandemics like Covid-19 present a major challenge for global health (Johnson *et al.*, 2020) [Box 3.1 provides an account of how Covid-19 has affected female scientists].

In parallel, what has been termed the Fourth Industrial Revolution (or Industry 4.0) is disrupting governance systems, industries and the labour market, as cyberphysical systems proliferate and become more sophisticated. Artificial intelligence (AI), robotics, nanotechnology, three-dimensional (3D) printing, genomics, biotechnology and cognitive sciences are becoming increasingly imbricated, building on and amplifying one another.

As more low-skilled jobs become automated, having a higher level of education and skills will become increasingly sought-after in the job market. A study of employment trends in England between 2011 and 2017 by the UK Office for National Statistics found that sectors dependent on highly skilled occupations were less likely to become automated (Figure 3.1). Women accounted for 70% of employees in jobs with a high risk of automation but only 43% of employees in jobs with a low risk of automation. For instance, the widespread installation of automatic checkouts in English retail outlets between 2011 and 2017 resulted in the loss of one in four cashier jobs, most of them held by women (UNESCO, 2019).

Women must not miss out on the jobs of the future. The United Nations anticipates that women will lose five jobs for every one gained through Industry 4.0, compared to the loss of three jobs by men for every one gained (UNESCO, 2018). According to a collaborative study by 29 United Nations programmes, more than 7.1 million jobs will have been displaced by 2020 and half of current jobs will have disappeared by 2050. In other words, more than 60% of children entering primary school today could end up working in jobs that do not yet exist (ITU, 2017). A fundamental transformation is under way in the workforce. This will call for institutional policies to ensure that today's teenagers understand their career options in the new world of work and can access appropriate skills training.

For women to seize upon the opportunities offered by the Fourth Industrial Revolution, there will need to be a level playing field in terms of access to enablers such as education and information. In 2016, the United Nations' Human Rights Council affirmed 'the importance of applying a comprehensive human rights-based approach in providing and expanding access to Internet'[2] and adopted a resolution stating that Internet access was a fundamental right. In developing countries, women were less likely (37%) than men (43%) in 2017 to have access to both a mobile phone and Internet, according to the Global Findex Database. In some countries, men are even twice as likely to have access to these technologies. This is the case in Bangladesh, Ethiopia, India and Pakistan, for instance. In other countries, including some of the most populous, there is no appreciable gender gap, such as in Brazil, China, Colombia, Indonesia, South Africa or Turkey.[3]

Teenagers envisaging jobs at high risk of automation

An analysis of the results of the 2018 edition of the Programme for International Student Assessment (PISA) run by the Organisation for Economic Co-operation and Development (OECD) found that many 15-year-olds anticipated pursuing jobs that were at a high risk of being automated. The ratio was particularly high among those from the most disadvantaged backgrounds. Even among high-achievers, the PISA study revealed a yawning gender gap when it came to career expectations, with more boys than girls leaning towards careers in science and engineering in 34 out of 63 countries. Less than 2% of girls had plans to become engineers or computer scientists, compared to about 16% of girls who intended to become doctors. Interestingly, fewer boys and girls expressed interest in working in computer science in 2018 than in 2000 (Mann *et al.*, 2020).

A shortage of skills for Industry 4.0

Demand in the European labour market for STEM skills is expected to almost triple from 8% to 23% of the workforce between 2015 and 2025, whereas it is anticipated that employment in STEM-related sectors will rise by only about 6.5%. This compares with anticipated growth of 3% in the number of jobs across the board over the same period (EC, 2019a). Experts predict a growing divide between supply and demand for professionals with STEM skills in the European Union (EU) [Reingarde, 2017].

Box 3.1: **Covid-19 pandemic disproportionately affecting women in science and engineering**

Initial studies show that the pandemic is disproportionately affecting female researchers, even if some have been at the vanguard of responding to the crisis.

Less job security, less research time

A report released in May by the Australian Academy of Science (AAS, 2020) found that job insecurity was more of an issue for women than for men, as a higher proportion of women were employed on short-term contracts.

Myers *et al.* (2020) surveyed 4 535 faculty or principal investigators in the USA and Europe, primarily. All else being equal, female scientists reported a 5% larger decline in research time than their male peers during the Covid-19 pandemic. For scientists with at least one child five years old or younger, the decline in research time was even 17%. The authors recalled that women tended to be the primary care-givers of young children.

Initial analyses also suggest that women's publishing rate has fallen relative to men's amid the pandemic and that women are posting fewer preprints and starting fewer research projects than their male peers (Viglione, 2020).

In the media, male voices have dominated scientific commentary on the pandemic in many countries. In the UK, there was an imbalance of 2.7 men for every female expert featured on the UK's flagship television and radio news programmes on the political handling of the coronavirus outbreak across the country, according to data gathered by the Expert Women Project from the University of London.

Survey finds widespread disruption to research

In the developing world, the closure of universities and other institutions, along with the redirecting of funding in those remaining open, has brought ongoing research projects to an abrupt halt.

This was one of the findings of a survey conducted by the Organization for Women in Science for the Developing World (OWSD), a UNESCO programme unit, of its more than 5 000 members between March and June 2020.

Among OWSD members, the most commonly cited negative impact of the pandemic on work was the inability to travel to conferences or other important events (67% of respondents). This was followed by interruptions to experiments or field work (56%), teaching duties (31%) and course attendance (22%), as well as publishing delays (20%).

Members also regretted delays in, or the suspension of, ongoing funding and difficulty in finding collaborators (17% each), being unable to submit funding proposals (16%) or publications (14%), missing out on business opportunities or losing clients (13%) and being unable to take exams as scheduled (11%). Just under 5% of respondents reported directly losing their employment as a result of the pandemic.

Women actively participating in pandemic response

The survey responses also illustrated how scientists can find solutions even in the most challenging circumstances. There was the Sudanese molecular biologist leading an initiative to make ventilators using 3D printers, for instance, and the Sri Lankan biochemistry professor who had volunteered her lab for diagnostic testing, not to mention the professors at a Palestinian university who had organized a special course on Covid-19 to teach students the principles of epidemiology.

Many members reported being involved in the pandemic response. A small share (4%) were undertaking research directly on the Covid-19 virus itself, such as to develop treatments or vaccines, and 14% were studying the impact of the coronavirus on other health conditions, or its societal or economic impact. One in four scientists (26%) was raising awareness or disseminating information about the disease and a further 8% were involved in co-ordinating a policy response to Covid-19 at an institutional level.

With the pandemic having made policy-makers, governments and the general population actuely aware of the importance of science, some respondents saw an opportunity in adversity to push for greater investment in research and in public health.

Women have made the most of shorter working hours

Although 44% of survey respondents have had to cut back their working hours to assume greater household or care responsibilities during the pandemic, other respondents reported some positive outcomes. Most notably, 54% said that they had enjoyed more flexible working hours. Four in ten (42%) had been able to expand their professional skills or experience, 27% had found more time to work on their research, 26% stated that their employer had invested in new technologies for telework or telestudy, 20% had found an opportunity to broaden their public engagement and 19% had augmented their scientific publications.

Over half of respondents reported spending much more time than usual on household chores (52%) and childcare (61%) during the pandemic. On average, respondents indicated that the share of childcare falling to them had risen from 51% to 66% during the pandemic. They also reported being responsible for 69% of homeschooling.

However, the vast majority (83%) appreciated spending more time with their families, with some reporting a closer relationship with their children (41%) or with their partner (37%).

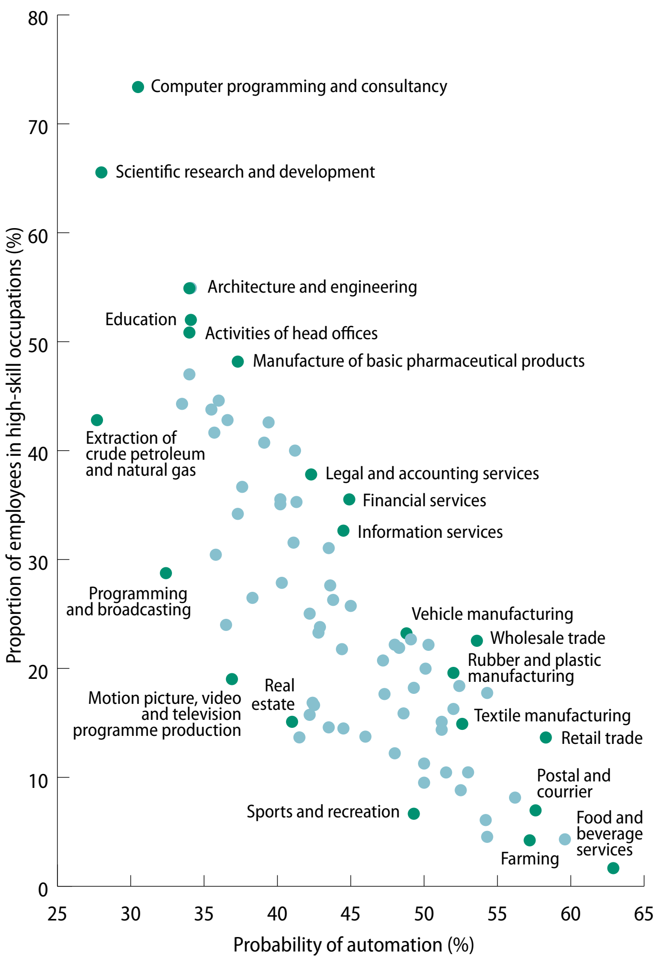
Source: adapted from Johnson, Erin (2020) *The Impact of Covid-19 on Women Scientists from Developing Countries: Results from an OWSD Member Survey*, 20 June.
See: https://www.owsd.net

A 2017 study found that closing the gender gap in STEM education would have a positive impact on economic growth in the EU, contributing to an increase in GDP per capita of 0.7–0.9% across the bloc by 2030 and of 2.2–3.0% by 2050. The study predicted a closure of the gender pay gap[4] by 2050, by which time 6.3–10.5 million jobs should have been added to the European economy, about 70% of these occupied by women (EIGE, 2017).

AI will play a key role in the Fourth Industrial Revolution. In 2019, companies lamented 'a shortage of skilled talent to clean, integrate and extract value from big data and move beyond baby steps toward AI'. This finding emerged from a 2018 survey by Price Waterhouse Coopers of nearly 1 400 chief executive officers (CEOs) in 91 countries. The report found that it was 'not only a matter of hiring or developing AI specialists and data scientists. It is equally important to cultivate a workforce ready to use AI-based systems' (PwC, 2019).

In the Asia–Pacific region and Africa, as many as 35% and 45% of company CEOs, respectively, expressed 'extreme concern' about the availability of necessary skills, in the survey. Globally, CEOs saw retraining and upskilling as the best answer but more than one-quarter of company CEOs in

Figure 3.1: **Probability of automation in England, 2017**



Source: UNESCO (2019), using data from the UK Office of National Statistics

the Middle East and one in five in Western Europe saw hiring outside their industry as a potential solution (PwC, 2019).

The skills shortage is driving competition, as companies and institutions vie to attract and retain talent (PwC, 2019). This can offer a window of opportunity for women trained in related fields, who may find themselves in a strong bargaining position when it comes to negotiating their working conditions with a prospective employer.

An ethical responsibility to avoid misuse of AI

Women have a stake in participating in the digital economy to ensure that Industry 4.0 does not perpetuate gender bias. AI is already defining societal priorities. If women are contributing less to big data or social media data, their needs are likely to be neglected by projects designed on the basis of these data, such as smartphone applications. To mitigate inappropriate policies and actions based on non-representative data, 'we need to put communities who will be impacted by the information systems into the process of making them,' says Catherine D'Ignazio, co-author of *Data Feminism* (Ignazio and Klein, 2020).

The disruptive potential of AI is so great because AI has evolved to the point where it can not only treat information but also interpret it, through machine learning, deep learning and natural language processing. Machine learning allows search engines to prioritize links to websites based on an internaut's browser history, for instance, potentially creating an echo chamber[5] that deprives the internaut of more varied sources of information.

Since the advent of deep learning in 2012, machines can interpret not only databases but also static and dynamic images such as photos and videos. This has led to the development of facial recognition software. Through natural language processing, a machine can now interpret the written and spoken word, paving the way to online services such as Google Translate and chatbots. It has become technically feasible to put words – literally – in the mouth of a person portrayed in a video that the person never uttered. This makes it easy to distort information. The Internet can then relay this false information to the masses, via websites and social media.

There are other forms of misuse. Virtual identities can be as fluid as we want them to be and even 'body-less', if we prefer, offering opportunities for sweeping behaviour change and a blurring of the distinction between men and women in the virtual realm. However, there is a very real danger that gendered differences will be magnified and embedded within technology. Digital images do not exist in neutral spaces free of stereotypical characteristics: avatars can walk, talk and behave in gendered ways and robots and automatons are programmed by men and women who (consciously or subconsciously) may endow their creations with gendered characteristics.

For example, a robot undertaking household chores may be given a female shape and voice, paving the way for gender dynamics to be reproduced in the relationship between robot and owner (Schiebinger, 2019). Google's speech recognition software is 70% more likely to recognize male speech than female speech, according to research conducted at the University of Washington. Another example is Siri, a servile female-gendered voice assistant used by hundreds of millions

Box 3.2: **A gender index to quantify progress towards the Sustainable Development Goals**

In 2018, Equal Measures 2030 and partners launched a pilot gender index, in response to the urgent need for tools to support data-driven analysis and hold governments to account for gender equality in the context of the Sustainable Development Goals (SDGs).

The SDG Gender Index compiles data on a wide range of issues at the national level that are crucial to the rights of girls and women, from health and education to economic empowerment. The 2019 SDG Gender Index extends beyond the goal dedicated to gender equality (SDG5) to measure gender equality aligned with another 13 of the 17 SDGs in 129 countries. The index examines 51 issues across these SDGs.

The 2019 SDG Gender Index has found that the world is furthest behind on gender equality issues related to public finance and better gender data (SDG17), climate change (SDG13), gender equality in industry and innovation (SDG9) and gender equality overall (SDG5). The highest gender equality scores for innovation (SDG9) go to Canada (87%), followed by New Zealand, Estonia, Norway and Denmark (85%).

The index has found that countries are performing best on issues where there has been a co-ordinated and concerted policy focus and related funding over the past 10–20 years. The highest gender equality scores have been attributed to the goals for hunger and nutrition (SDG2), water and sanitation (SDG6), health (SDG3) and education (SDG4).

Source: compiled by Tonya Blowers and Susan Schneegans; see: https://data.em2030.org

of internauts. She had been programmed to respond to insults with the words, 'I would blush if I could'. The algorithm behind Siri was updated in 2019 to react in a more gender-neutral way by saying 'I don't know how to respond to that' (UNESCO and EQUAL Skills Coalition, 2019).

The vast potential for abuse of AI illustrates the heightened ethical responsibility of individual scientists and engineers of both sexes in today's world to serve the community as vehicles of truth and human progress. The *2030 Agenda for Sustainable Development* provides a roadmap for harnessing Industry 4.0 for the public good. An index has been established to quantify the pace of progress towards gender equality in the context of the Sustainable Development Goals (SDGs) [Box 3.2]. The creative and thoughtful use of AI could be a key factor in achieving each of the 17 SDGs and their targets. In Japan, for instance, AI is being used to improve disaster readiness and recovery (see Box 24.2).

LITTLE DIVERSITY IN THE TECH SECTOR

Women a minority in Industry 4.0 fields

Women tend to be a minority in the digital labour market. In the EU, for instance, more than half of men earning degrees in information technology (IT) end up working in digital jobs, compared to one-quarter of women (UNESCO and Equal Skills Coalition, 2019).

This is all the more detrimental, in light of the severe shortage of people with the skills needed to drive Industry 4.0. The irony is that the fields most relevant to Industry 4.0 are the very ones where women remain underrepresented in most countries, namely IT, computing, physics, mathematics and engineering.

Japan is hoping that the centrepiece of its new growth strategy, Society 5.0, will enable society to adapt to a shrinking, ageing population through widespread use of AI and other digital technologies in industry, agriculture and the services sector. However, the government anticipates a shortage of 300 000 general engineers in IT in 2020 (see chapter 24).

In the USA, women made up 57% of professionals but only 25% of computer professionals in 2015. Women are more likely than men to leave the tech field. The most common reasons given concern workplace conditions, a lack of access to key creative roles and a sense of 'feeling stalled in their career' (Ashcraft *et al.*, 2016).

In 2017, women accounted for 23% of Brazilian engineers. Over the four-year period to 2017, much of which was marked by recession, 14% of male engineers lost their jobs, compared to 11% of their female colleagues. Female engineers earn 84% of what their male colleagues take home, despite having a higher level of educational attainment: 12.0% of female engineers held a postgraduate degree in 2017, compared to 7.4% of male engineers (see chapter 8).

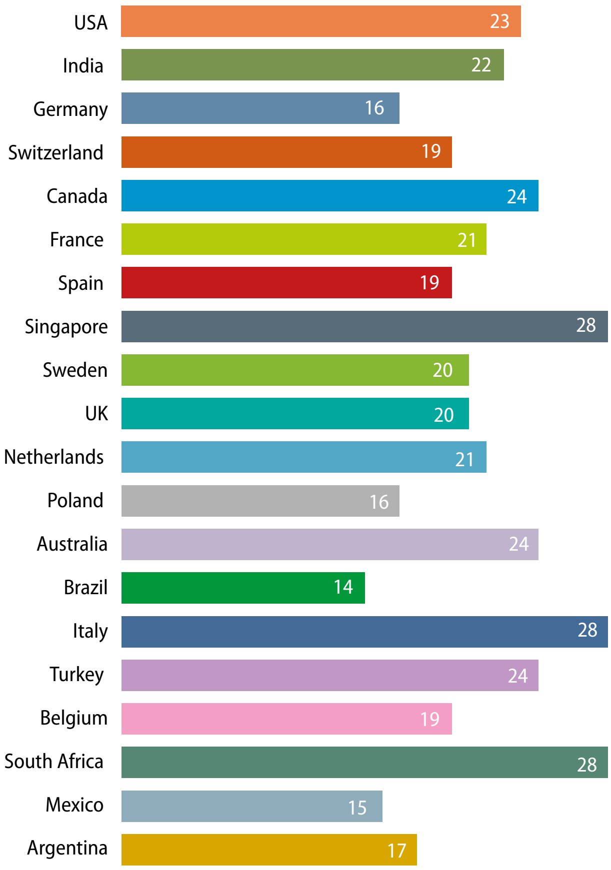
Women a minority in AI

The AI sector is expanding rapidly: from 2015 to 2017, the number of workers worldwide with AI skills increased by 190%, according to the World Ecnoomic Forum (2018a), which found that 'industries with more AI skills present among their workforce are also the fastest-changing industries'.

In the USA, AI has the highest-paid experts of any field of technology (Metz, 2017). According to the US Bureau of Labor Statistics and the Census Bureau, the pay gap in computer science is one of the smallest between male and female professionals in the USA, with women earning 94% of what men take home (AAUW, 2018).

Why, then, are women still a minority among employees of digital tech giants, even in the USA? According to data collected by the social networking site LinkedIn and published in the World Economic Forum's *Global Gender Gap Report,* only 22% of professionals working in AI around the world are female (WEF, 2018a). This gap is visible in all of the top 20 countries with the highest concentration of AI employees (Figure 3.2) and is particularly evident in Argentina, Brazil, Germany, Mexico and Poland, where fewer than 18% of women professionals have AI skills.

Figure 3.2: **Share of women in top 20 countries for share of professionals with AI skills, 2017 (%)**
In descending order for top countries



Source: WEF (2018) *The Global Gender Gap Report 2018*. World Economic Forum: Geneva.

Empowerment for the few

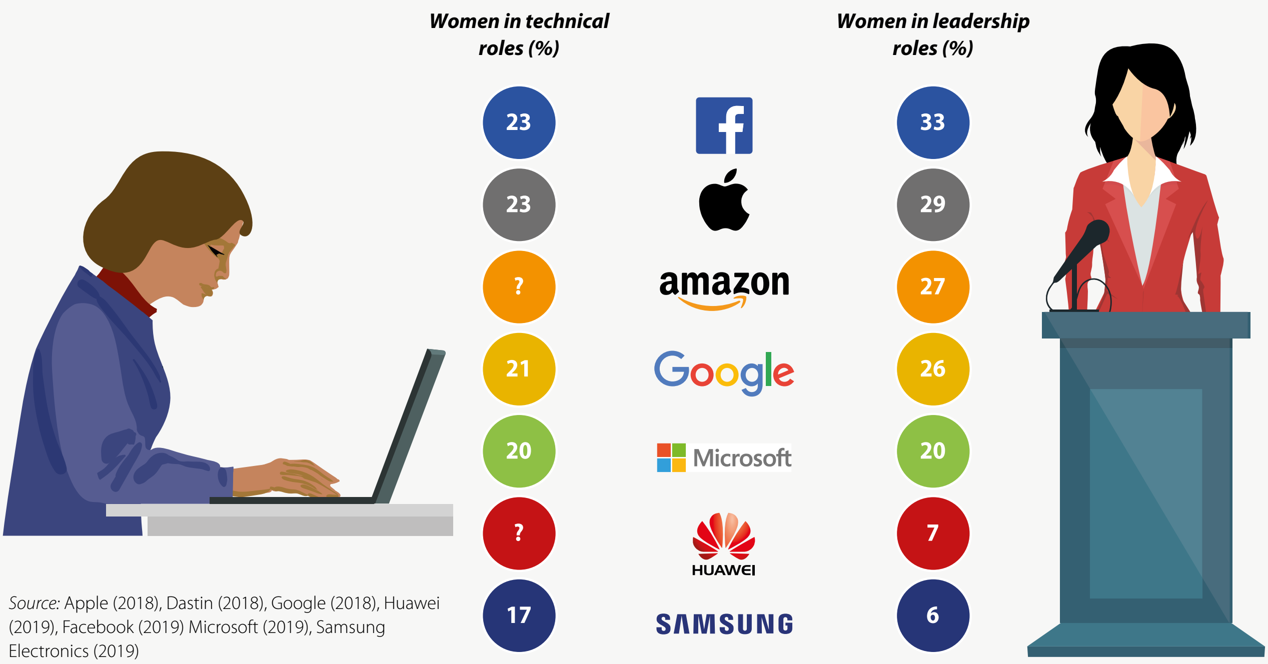
Although the top multinational technology companies are making progress, they are still not even close to closing the gender gap in technical and leadership roles (Figure 3.3). Although there has been some progress in the share of women hired by Google, less than a quarter of technical roles were filled by women in 2018 (Google, 2018).

We can see the same pattern at another US tech giant, Apple, the leading manufacturer of computers and smartphones. Despite implementing measures since 2014 to hire more women and underrepresented minorities each year, women made up only 23% of employees in technical roles and 29% in leadership positions by December 2018 (Apple, 2018).

Amazon, the world's largest e-commerce marketplace and cloud computing platform, is also attempting to correct the gender imbalance. It tracks the numbers and roles of women and underrepresented minorities among its employees. However, as of December 2018, only 27% of its managers around the world were women. When the company realized, in 2018, that its AI system was not rating candidates for software developer jobs and other technical posts in a gender-neutral way (Dastin, 2018), it committed US$ 50 million to supporting STEM programmes for underrepresented communities.

Huawei, a Chinese multinational specializing in telecommunications equipment and electronics, including smartphones and 5G technology, has launched a host of initiatives aimed at increasing diversity in the workforce (with respect to nationality, gender, age, race and religion) by, for example, emphasizing gender equality in employment and prohibiting gender bias. However, the ratio of female employees has remained low: in 2018, women made up only 7% of the

Figure 3.3: **Women in technical and leadership roles in selected top multinational technology companies, 2018–2019**



Source: Apple (2018), Dastin (2018), Google (2018), Huawei (2019), Facebook (2019) Microsoft (2019), Samsung Electronics (2019) management team (Huawei, 2019). Neither Huawei nor Amazon disclose the gender breakdown of their technical workforce.

Similarly, Samsung, the electronic and smart appliance tech giant from the Republic of Korea, reported in 2019 that only 17% of the company's employees working on product development were women and that women made up only 6% of executive directors (Samsung Electronics, 2019).

American giant Microsoft, which specializes in developing and manufacturing computer software, consumer electronics and personal computers, is making an effort to recruit women and support their career development. Although the number of women in technical roles and leadership positions has progressed in the past few years, it is still hovering around 20% (Microsoft, 2019).

Facebook fares better than its fellow tech giants for the number of women holding senior leadership positions (33%) but the percentage of women employed in technical roles remains low, at 23% (Facebook, 2019). Chief Operating Officer of the giant US social media and networking company since 2012, Sheryl Sandberg was ranked the eleventh-most powerful woman in the world in 2019 by Forbes.[6] In 2013, Sandberg published her bestselling book *Lean in: Women, Work and the Will to Lead.* She followed this with the offshoot *Lean in Circles*, a website-based movement to encourage women around the world to take up positions of influence and power.

Although many women may have been empowered to act through the *Lean In* philosophy, Sandberg's mantra has come under fire for placing the responsibility for success on individual women, rather than on pervasive societal structures around them, such as gender-based pay inequality, the disproportionate burden of domestic responsibilities on women and the minimal maternity and family leave granted by most US workplaces – all of which remain largely unchanged. 'Critics questioned the sort of advice that seemed tailor-made for a particular brand of ambitious, corporate go-getters bestowed with certain privileges' (Gibson, 2018).

Taking the directive approach to diversifying board members

At the World Economic Forum in Davos in January 2020, Goldman Sachs' CEO David Solomon told the news station CNBC that the investment bank would not be taking companies in the USA and Europe public after 1 July 2020 unless the company had at least one 'diverse' board member, with a focus on women. Four out of eleven of Goldman Sachs' own corporate board members are women. Solomon stated that companies with greater diversity performed better in the markets. Citing Goldman Sachs' data, he added that companies with one diverse board member had seen a 44% jump in their average share price within a year of going public, compared to 13% for those with no diverse board members (Dilts Marshall, 2020).

Similarly, The Pipeline (2020) found that FTSE 350 companies in the UK with no women on their executive committee had a net profit margin of 1.5%, compared with a 6.9% profit margin for companies with up to 25% of women, a 10.6% profit margin for companies with 26–49% of women and a 12.5% profit margin for companies with 50% or more women on their executive committee.

This directive approach is gaining traction. It posits that businesses which fail to take diversity seriously are at risk of losing the confidence of their investors. In early 2020, for the third consecutive year, the Investment Association warned nearly 20% of the 350 British companies participating in the Hampton Alexander review that they were not on track to achieve the 33% target for the proportion of women in boardrooms and on executive committees by 2020.

The Silicon Valley Bank undertook A *Women in Technology Leadership* survey in 2019 to measure gender parity in start-ups in technology and health care in Canada, China the UK and USA. It found that almost half (46%) had no women at all in executive positions, 40% had at least one woman on the board of directors and only 28% at least one woman among the founders. The report also showed that six in ten start-ups had programmes designed to boost the number of women in leadership positions.

In the USA, there is a new tendency to oblige publicly traded companies by law to have at least one woman on their board of directors. The State of California has already adopted a law to this effect: by 2021, boards with five members will be required to include two women and those with six directors three women. Bills along the same lines have been drafted in the states of Illinois, Massachusetts, New Jersey and Washington (Elsesser, 2020). According to research by the firm Heidrick and Struggles (2019), in the USA, women made up 22.5% of corporate boards in Fortune 500 companies in 2018. This figure should gradually improve, since the share of women appointed to corporate boards more than doubled between 2009 and 2018 from 18% to 40%.

The European Commission has a policy of promoting gender balance on the boards of publicly listed EU companies. This policy is encapsulated in its *Strategy for Equality between Women and Men* (2010–2015) and its *Strategic Engagement for Gender Equality* (2016–2019). The Commission manages a database monitoring men and women in leadership positions. Between 2010 and 2018, the share of women board members almost doubled from 11.9% to 23.3%, according to the Commission's database on women and men in decision-making. However, just 5.1 % of the largest publicly listed companies in Europe have a woman CEO.

In Africa, women make up one in four board members (McKinsey Global Institute, 2019). That is a higher ratio than either the EU (23%) or Latin America (7%).

Africa keen to embrace Industry 4.0

Currently, most AI experts are based in North America, Europe and Asia. In Africa, a growing number of governments have come to recognize the importance of training researchers and developers in AI. In 2013, a local group of industry practitioners and researchers began Data Science Africa, an annual workshop where participants can share resources and ideas. In 2017, another group formed the organization Deep Learning Indaba, which now has chapters in half of the continent's 54 countries. IBM Research opened its first African office in Nairobi in 2013 then a second in Johannesburg in 2016 (see Box 20.3). The Government of Rwanda established the East African Institute for Fundamental Research in 2018, which teaches

Box 3.3: **Preparing African girls for a future in Industry 4.0**

A number of initiatives in Africa have been targeting Industry 4.0 fields to help high-achievers see a future for themselves in science and engineering.

One example is *African Girls Can Code*, a four-year programme launched in 2018 which aims to teach 2 000 teenage girls digital and business skills by 2022 through 18 coding camps. The initiative is a joint programme of the African Union Commission, UN Women Ethiopia and the International Telecommunications Union. The first two camps in 2018 and 2019 attracted a total of 570 girls from dozens of countries.

At the national level, too, governments are exploring unconventional ways to attract girls and young women to a career in science and engineering. In December 2019, the Ministry of Communications announced the three winners of its first Miss Geek Ghana competition for budding software app developers aged 13–25 years.* In addition to cash prizes, the young women will receive business training and financial support to develop their socially innovative project (see chapter 18).

Mali held its first Miss Science competition in 2018, with UNESCO support. All 80 contestants were given computers and mobile phones by the three Ministries of National Education, Higher Education and the Promotion of Women. In an interview, 11-year-old contestant Coulibaly Seydou spoke of her passion for mathematics and how the Miss Science quiz had given her the confidence to pursue a career as a mining engineer (see chapter 18).**

Source: compiled by authors

*See: https://msgeek.org.gh/

** See (in French): https://fr.unesco.org/news/premier-concours-miss-science-du-mali

courses in machine learning and data science (see Box 19.9). UNESCO organized its first-ever major international forum on AI for Africa in Morocco in December 2018 and Google opened Africa's first AI lab in Ghana in 2019 (see Box 18.2).

Typically, African women are less present in this space. They accounted for only three of the 20 MSc students at the East African Institute for Fundamental Research in the 2019/2020 academic year, for instance (see Box 19.9). To redress this balance, a flurry of initiatives have sprung up, including Women in Tech Africa, based in Accra, Ghana, which hosts an annual event dedicated to women in machine learning, and the Nairobi chapter of Women in Machine Learning and Data Science. Programmes have also been launched at the national and continental levels to prepare girls for a career in promising fields (Box 3.3).

Venture capital more elusive for women

Women find it harder than men to obtain venture capital for tech-based start-ups (WEF, 2016). Companies founded by women receive only 2.3% of venture capital[7] investment, according to the 2020 *Women in Tech Report* from TrustRadius, which surveyed 700 tech companies around the world.[8] It also found that women were almost twice as likely (58%) as men (31%) to find the gender funding gap for venture capital a cause for concern.

A 2019 UNESCO survey of women tech entrepreneurs in Africa found that access to finance was the most commonly identified barrier to starting a new business (Box 3.4).

In India, close to 38% of start-ups were headed by women in 2019, according to Amitabh Kant, Chief Executive Officer of the government think tank Niti Aayog. This compares with an overall economic participation by Indian women of just 22% (Dewan, 2020). The *Strategy for a New India @ 75* (2018) proposes tax incentives for firms which meet a 30% target for the share of female employees, along with easy access to credit for vulnerable female entrepreneurs.

In 2018, Chile introduced the Human Capital for Innovation in Women's Enterprises scheme. It provides tech-based start-ups founded by women with cofinancing of up to 30 million pesos (*ca* US$ 40 000) to help them hire staff for a given project, covering 80% of the hiring cost for men and 90% for women.

Female entrepreneurs account for less than 15% of companies founded since 2017 in the EU (ESM, 2016). A 2018 *State of European Tech* report shows that the gender gap is even wider in venture-backed European start-ups where, in 2018, women made up just 6% of chief executive officers and 2% of chief technical officers.

The gender gap is also evident in the European venture capital industry, where just 13% of decision-makers are women (Atomico, 2019). Furthermore, the number of female recipients of this capital investment is negligible: in 2018, 93% of all funds raised by European venture capital-backed companies went to all-male teams.[9]

The European Commission has launched initiatives to compensate, such as the EU Prize for Women Innovators and a call for female-led EU start-ups that opened in May 2018 as part of the Women in Digital initiative. A European Commission (2018) study found that only 24 out of every 1 000 female tertiary graduates held a degree in a subject area related to information and communication technologies (ICTs) and that only six went on to work in the digital sector. Of greater concern was the drop in this proportion since 2011 at 15%. The study also found that having more women enter the digital job market could inject an additional € 16 billion into the European economy.

GLOBAL TRENDS IN HIGHER EDUCATION AND RESEARCH

Too few women studying Industry 4.0 fields

In virtually every country, a growing number of women are enrolling at university. Globally, women have achieved parity among graduates at both the bachelor's (53%) and master's (55%) levels. Although many drop out once they get to PhD level, the threshold required for a career in research, women now account for 44% of PhD graduates, up from 43% in 2013 (Huyer, 2015).

Box 3.4: **Access to finance biggest obstacle for women tech entrepreneurs in Africa**

In order to understand how African women entrepreneurs are using science and technology, UNESCO commissioned a survey in 2019 of 459 women from ten African countries: Benin, the Democratic Republic of Congo, Djibouti, Ghana, Madagascar, Morocco, Mozambique, Senegal, South Africa and Tunisia.

Both rural and urban women were interviewed across different fields of industry. The majority of women had started a business in the food sector (30%) or in clothing and other textiles (14%), followed by web platforms (8%), beauty and personal care (7%) and digital marketing and services (4%).

Although engineers (less than 1%) and web designers (8%) made up a small share of the group surveyed, over 80% of respondents said that they used science or technology on a daily basis. About 25% had innovated by developing a new process or product.

Patenting was well understood but not always sought after, usually due to the cost or administrative burden. On average, 12% of entrepreneurs held a patent. Ghanaian women were the most likely to have patented their process or product, with over half reporting an invention and 19% having registered a patent.

Women from the Democratic Republic of Congo were most likely (91%) to have heard of a local innovation hub and to have been assisted by one (69%). They were followed by Ghanaians, with 57% and 25%, respectively. On average, 41% of the entrepreneurs knew of the existence of a local innovation hub but only 26% had been assisted by a start-up incubator in launching their business. It was common for the entrepreneurs to assume that they did not qualify for this form of support.

Access to finance was the most commonly identified barrier to starting a new business, faced by 67% of respondents. Only 18% reported having obtained a bank loan and less than 2% had accessed microfinance. Banks remain reluctant to finance start-ups, which they consider a risky investment, and women often lack sufficient financial guarantees; their home may be registered in their husband's name, for instance. Some respondents have also hesitated to invest in their own company over concerns about political instability in their country.

Some 17% of the women had faced challenges in obtaining premises or land for their business, the second-greatest barrier reported after lack of access to finance. Being able to rent office space was considered vital for both practical and societal reasons, because 'people are sensitive to appearances and therefore [if we] make an appointment [with a client] in a cafe, they do not take us seriously'.

Only 10% of respondents cited social or family resistance to their project, although many recalled their determination to turn a blind eye to criticism. Encouragingly, 84% said that their partner was either supportive or very supportive of their project.

Source: UNESCO and Africa Women's Forum (2021) *Challenges and Opportunities for Women Entrepreneurs in Africa: a Survey* ***of Science and Technology Usage***

Overall, female graduates are still overrepresented in most countries in the arts and humanities, journalism and information, social sciences and health and welfare (Table 3.1). A range of actors have come up with creative ways of attracting more girls and women to the study of science and engineering. Here are some examples:

- In 2016, Zimbabwe introduced free tuition and boarding fees for students in public schools taking advanced-level science subjects (see chapter 20).
- In 2018, the multinational corporation Intel began inviting Costa Rican pupils in their penultimate year of secondary school to their offices to hear company engineers tell their life story and interact with them.
- The Shilpa Sayura Foundation's extracurricular *NextGen Girls in Technology* programme provided 1 051 young women and 506 secondary school teachers across Sri Lanka with skills in machine learning, cybersecurity, design and other areas over the two years to 2020, through online and *in situ* courses. The foundation was awarded the UNESCO Prize for Women's and Girls' Education in 2020.
- Afghanistan's Higher Education Development Project is striving for a fairer participation by women. Of the 336 scholarships awarded in 2018 to master's students in priority disciplines dominated by science and engineering, 35% targeted women (see chapter 21).

The percentage of women graduating in computer science has actually decreased in the USA: according to the National Science Foundation, the percentage rose to 37% in 1984, around the same time that personal computers became popular, but has since declined to 18% (AAUW, 2018).

Israel considers computer science to be an essential subject and has allocated funds to augmenting the 32% share of women among students of mathematics, statistics and computer sciences in 2017. According to data from the Israeli Council for Higher Education, the number of women studying computer science at tertiary level has already almost doubled in eight years, from 2 658 (2009) to 5 237 (2017) [see chapter 16].

Many of the countries displaying gender parity among graduates in ICTs and other STEM fields have majority-Muslim populations (Table 3.1). Azerbaijan, Kuwait and Malaysia have some of the highest ratios of female engineers in the world (Table 3.2). At the Mohammed bin Rashid Space Centre in the United Arab Emirates, four in ten employees are women. The lead scientist is 33-year-old Dr Sarah Al Amiri, who served as deputy manager of the project which sent the Hope Probe into Mars' orbit on 14 July 2020 from a launch site in Japan. The country's youthful space industry – the average age of staff at the centre is 27 years – is one outcome of the government's drive to 'emiratize' the country's skilled workforce, in order to reduce reliance on foreign expatriates (see chapter 17).

In the Republic of Korea , more women are enrolling in engineering programmes than ever before; they accounted for 25% of student admissions in 2017, up from 22% in 2014. However, the *Fourth Basic Plan for Women Scientists and Engineers* notes low ratios of female graduates in high-demand sectors such as the automotive (4.0%), mechanical (7.9%), electrical (9.2%) and electronics (13.4%) industries. To address these shortages, the government is introducing measures to accompany women throughout their career, such as the provision of child care. The *Fourth Basic Plan for Women Scientists and Engineers* sets a target of raising the proportion of female scientists and engineers in their forties participating in the economy from 61% in 2017 to 70% by 2023 (see chapter 25).

More women researchers worldwide

Globally, women make up 33.3% of researchers (in head counts), according to data from the UNESCO Institute for Statistics for 107 countries covering the years 2015–2018 (Figure 3.4). This is a much higher proportion than five years ago (28.4%) but large data gaps remain. Sex-disaggregated data on researchers are not being collected regularly by most countries in the Caribbean, Oceania, South Asia, Southeast Asia and sub-Saharan Africa, for instance, or by the populous countries of Bangladesh, Brazil, India and Nigeria. Moreover, UNESCO estimates exclude North America and China on account of the international incomparability of these data. UNESCO is among those that have been conducting surveys to document the pressures that inhibit the regular collection of sex-disaggregated data (Box 3.5).

The observed data gaps make it difficult to draw conclusions for most regions. There are sufficient data, however, to confirm the trend observed in the previous *UNESCO Science Report* (Huyer, 2015) towards gender parity in Central Asia, Southeast Europe and Latin America and the Caribbean. These regions are home to 10 of the top 20 countries for the share of women researchers, namely Venezuela (61%), Trinidad and Tobago (56%), Argentina (54%), North Macedonia and Kazakhstan (53%), Serbia (51%), Montenegro (50%), Cuba, Paraguay and Uruguay (49%).

The persistently high ratio of women researchers in many European and Asian countries is a legacy of the Soviet Union, which valued gender equality. This is true, for example, of Azerbaijan (59%), Georgia and Kazakhstan (53%), Serbia (51%) and Armenia (50%).

In South and Southeast Asia, a growing number of countries have achieved gender parity. This is the case for Malaysia, Myanmar and Thailand, for instance. The most recent addition is Sri Lanka, where women accounted for 46% of researchers in 2015, up from 24% in 2006.

In sub-Saharan Africa, South Africa has attained gender parity, with women accounting for 45% of researchers since 2015. Mauritius also attained gender parity in 2015 but has since shed a percentage point. Senegal stands out for having raised the share of women from 10% to 29% of the research pool between 2006 and 2015.

A growing number of Arab countries have attained gender parity. Many have made remarkable progress over a short space of time, including Algeria (from 35% in 2005 to 47% in 2017), Egypt (from 36% in 2007 to 46% in 2018) and Kuwait (from 23%

Box 3.5: A holistic approach towards gender policies through the UNESCO SAGA project

Data on the participation of women in the mathematical and natural sciences are scattered, outdated and inconsistent across regions and research fields.

UNESCO launched its STEM and ender Advancement (SAGA) project in 2015, with funding from the Swedish International Development Agency, to help policy-makers draft, implement and monitor policies promoting gender equality in science and engineering using innovative indicators.

Each participating country shared a common dilemma: the presence of women diminished as researchers progressed in their career towards more senior positions.

SAGA developed a methodology for improving evidence-based policies which included different tools, such as the SAGA Indicator Matrix containing innovative indicators and a questionnaire to understand the drivers of careers in science and engineering and barriers to these. This questionnaire was subsequently adapted by the Gender Gap project* to survey more than 40 000 scientists worldwide with a view to informing policy.

Between 2015 and 2019, the SAGA project trained over 350 policy-makers from 26 countries in measuring gender equality in science, technology and innovation using the SAGA Indicator Matrix. This resulted in reports on the status of women in science and policy gaps being submitted by Argentina, The Gambia, Haiti, Sudan, Thailand, Uruguay and the Canadian Province of Quebec. An updated online inventory of policies and related instruments was established, the SAGA Online Database.

In pilot countries, governments established inter-institutional committees on gender equality in STEM. This was an important step, as policy dialogue has proven to be a strong incentive for reform.

Some participating countries have since included gender equality in science and engineering in their broader strategies, laws and planning documents, such as Argentina's *Third Open Government National Plan* and the science bill before the Gambian parliament in 2020.

Countries have also reinforced institutional support, such as through the gender unit established in 2019 within the Gambian Ministry of Higher Education, Research, Science And Technology or through the new UNESCO Chair in Women and Science for Development at Haiti's Institute of Science, Technology and Advanced Studies.

Source: Alessandro Bello;
see: https://en.unesco.org/saga

*Funded by the International Science Council in Paris (France), the Gender Gap project involved ten of its member unions, including the International Mathematic Union and International Union for Pure and Applied Chemistry.

Table 3.1: **Share of female tertiary graduates by field, 2018 (%)**

	Agriculture	Engineering	Health & welfare	Natural sciences	ICTs	Social sciences & journalism	Business, admin. & law	Arts & humanities
Albania	46.0	38.3	78.9	69.9	43.7	73.2	61.1	70.3
Algeria	76.8	48.5	70.5	83.1	48.9	68.4	57.7	80.2
Angola[-3]	28.2	22.4	66.8	66.3	38.0	55.0	48.3	39.2
Armenia	24.5	22.4	72.5	60.5	38.5	58.4	49.8	75.0
Australia[-1]	58.5	23.2	74.7	51.3	21.8	66.9	52.8	69.8
Austria[-2]	46.9	21.5	69.3	49.6	14.3	64.3	57.0	78.0
Azerbaijan	52.0	26.6	78.3	65.3	46.0	57.1	39.6	75.6
Bahrain	–	30.6	73.2	87.1	47.1	73.2	62.2	79.4
Bangladesh	21.2	46.1	25.3	14.9	27.3	27.8	26.2	32.7
Belarus	55.3	23.2	85.2	62.0	23.0	78.9	71.1	–
Belgium[-1]	62.1	23.4	75.6	41.4	9.9	70.3	54.1	68.4
Belize[-3]	35.3	9.1	69.9	52.8	19.4	69.8	68.6	74.1
Benin[-3]	60.5	54.6	63.7	54.9	55.1	61.5	61.4	56.8
Bosnia & Herzegovina	57.0	39.4	73.4	71.9	28.2	58.7	57.2	64.8
Botswana[-1]	58.0	–	70.0	–	–	–	–	–
Brazil[-1]	49.5	36.7	75.7	59.5	14.6	70.9	58.0	71.1
Brunei Darussalam	–	52.3	76.5	73.4	41.9	74.1	68.3	67.1
Bulgaria[-1]	46.2	28.7	70.3	68.1	38.7	66.7	67.7	66.1
Burkina Faso	33.8	21.6	42.7	18.7	–	45.4	48.7	27.8
Burundi[-1]	65.1	8.0	40.4	21.1	26.6	55.1	35.9	17.6
Cabo Verde	100.0	32.7	77.4	66.7	44.0	68.9	66.8	61.0
Cambodia[-3]	31.3	15.1	56.2	34.1	8.4	23.0	49.4	43.5
Cameroon[-1]	29.1	25.2	60.7	36.3	–	–	54.4	53.8
Canada[-2]	54.2	19.7	76.5	53.8	30.0	70.2	55.8	65.6
Chile[-1]	47.2	17.7	78.0	46.5	12.7	66.7	56.3	68.3
Colombia	44.7	34.6	72.1	54.2	23.3	70.6	62.7	58.5
Comoros[-4]	–	–	44.4	–	–	–	–	–
Congo[-1]	21.9	15.7	37.0	22.9	26.7	41.9	48.8	37.0
Congo, Dem. Rep.[-2]	25.9	9.8	45.8	32.6	36.7	35.4	38.3	31.8
Costa Rica	42.7	35.4	76.0	51.7	20.3	69.0	61.5	69.5
Croatia[-1]	56.3	35.7	79.8	68.6	21.0	73.7	66.9	62.0
Cuba[-2]	39.0	41.7	59.5	52.2	33.2	73.7	70.4	44.0
Cyprus[-1]	34.5	32.9	76.4	69.5	28.5	74.4	55.5	80.3
Czech Rep[-1]	63.2	33.7	82.4	59.9	15.6	68.6	64.7	69.1
Denmark[-1]	64.3	29.0	75.6	54.4	24.0	60.5	50.8	63.2
Dominican Rep[-1]	29.0	38.4	79.7	54.1	39.4	57.0	60.7	75.8
Ecuador[-2]	35.0	20.7	71.3	47.9	36.8	64.5	59.8	66.3
Egypt[-2]	49.4	20.9	56.0	64.2	36.8	41.3	35.9	67.8
El Salvador	30.1	18.7	74.4	50.2	26.2	69.1	58.8	65.1
Eritrea[-2]	51.6	28.1	37.4	28.6	–	51.5	35.8	37.4
Estonia[-1]	57.9	32.1	88.7	63.9	28.9	74.4	68.7	70.1
Finland[-1]	61.1	22.2	85.0	53.8	20.8	71.3	61.0	72.0
France[-2]	43.2	26.1	74.0	49.0	16.5	65.8	59.0	67.9
Georgia[+1]	43.4	15.7	71.0	68.1	20.6	64.6	58.5	71.1
Germany[-1]	42.3	21.1	70.6	46.8	19.4	65.7	53.1	73.5
Ghana	26.8	16.4	60.9	26.8	19.9	40.1	44.8	43.5
Greece[-1]	47.8	33.9	70.6	52.4	35.7	63.8	58.6	73.2
Grenada	77.2	12.7	47.6	64.9	24.1	76.5	64.2	82.3
Guatemala[-3]	30.9	35.0	70.5	45.2	21.1	64.3	54.9	70.1
Honduras	24.7	38.5	73.5	54.9	27.1	72.9	62.4	72.3
Hungary[-1]	48.4	29.9	73.7	52.2	16.7	68.6	65.2	75.0
India	27.5	30.8	61.6	51.4	46.3	55.1	46.8	59.4
Indonesia	48.3	24.9	78.0	74.3	34.7	50.6	57.9	67.7
Iran[-1]	47.5	22.7	62.0	68.0	39.1	55.5	40.9	57.4
Ireland[-2]	39.6	17.6	76.4	50.9	20.9	61.5	49.5	59.0
Italy[-2]	50.4	31.9	62.3	58.0	16.1	71.4	52.1	74.6
Japan[-1]	41.8	14.0	64.2	25.8	–	48.6	36.7	–
Jordan	37.6	34.8	64.4	–	–	66.2	46.9	–
Kazakhstan[+1]	37.5	28.5	77.3	67.0	30.4	71.2	50.7	67.4
Kenya[-2]	37.3	19.5	49.1	38.0	30.1	56.2	47.0	48.5

Share of women: <15% | 15–25% | 25.1–35% | 35.1–45% | 45.1–55% | >55%

	Agriculture	Engineering	Health & welfare	Natural sciences	ICTs	Social sciences & journalism	Business, admin. & law	Arts & humanities
Korea, DPR-3	19.1	16.6	57.5	53.2	36.3	53.4	20.3	65.8
Korea, Rep.-1	44.8	20.1	71.5	49.2	24.3	60.2	49.0	64.7
Kyrgyzstan	25.9	18.4	74.0	72.9	47.4	49.6	52.6	83.4
Lao PDR	44.7	18.0	67.1	55.0	40.8	48.0	57.3	59.9
Latvia-1	46.5	26.6	83.9	63.0	22.7	75.0	68.2	68.4
Lesotho	48.8	18.4	72.8	45.2	31.3	77.5	61.8	67.0
Lithuania-1	53.4	25.5	83.0	57.8	16.8	74.0	68.5	71.9
Luxembourg-2	22.9	19.8	70.4	45.2	19.6	67.7	50.2	63.4
Madagascar	41.2	18.5	67.9	37.3	33.6	46.0	53.8	52.3
Malaysia	47.7	27.1	72.4	70.7	46.0	69.2	67.4	64.9
Malta-1	50.0	28.2	71.9	53.0	16.0	62.8	55.7	62.7
Mauritania-1	–	11.7	57.7	29.6	41.3	37.6	48.6	20.4
Mauritius-1	29.1	25.3	64.6	66.1	31.6	73.5	59.2	73.2
Mexico-1	36.8	28.5	68.2	51.1	28.4	70.4	55.1	65.7
Moldova, Rep.	22.8	29.7	68.8	54.8	22.9	76.3	60.7	76.5
Mongolia	51.9	30.8	82.5	51.9	37.7	69.1	64.8	68.1
Morocco-1	44.2	42.2	72.3	48.7	41.3	55.8	48.7	47.9
Mozambique	35.4	28.6	75.2	45.3	21.0	57.0	55.1	41.6
Myanmar	53.9	42.3	57.2	66.4	67.4	51.0	70.8	68.8
Namibia-1	53.1	33.9	79.5	60.1	38.2	71.4	66.0	73.9
Netherlands-1	55.4	23.1	75.9	43.8	14.5	68.2	47.3	63.6
New Zealand-1	64.6	28.6	79.9	55.7	23.1	68.3	54.1	66.2
Niger	18.7	7.5	31.4	20.7	22.8	45.9	27.1	46.1
North Macedonia-1	39.5	47.8	74.1	69.5	35.1	61.4	55.4	62.1
Norway-1	55.6	23.9	82.8	51.5	15.2	63.1	56.9	62.4
Oman	81.5	43.2	84.2	75.5	75.6	71.8	60.6	84.2
Palestine	35.6	32.9	65.6	78.1	45.6	61.5	50.4	76.5
Panama-2	42.9	40.0	76.7	59.9	43.9	68.8	68.3	68.5
Peru-1	40.6	47.5	78.8	46.0	49.6	51.5	58.0	61.8
Philippines-1	53.4	24.5	71.9	62.0	48.1	70.0	67.5	68.0
Poland-1	56.8	42.1	72.2	70.8	21.2	72.1	68.3	75.3
Portugal-1	58.1	32.3	77.9	62.1	17.4	69.9	60.2	60.9
Qatar	–	37.2	88.1	75.8	53.4	77.5	65.8	73.7
Romania-2	40.7	35.3	71.8	66.9	33.2	75.3	67.0	60.7
Rwanda	37.5	26.6	58.3	41.3	39.1	47.8	55.4	43.4
Saudi Arabia	–	2.7	60.4	67.5	46.0	54.6	45.5	69.1
Serbia	48.9	38.5	74.9	71.2	28.6	65.4	60.0	67.9
Singapore-1	65.0	27.8	71.0	61.7	32.2	65.8	58.3	66.8
Slovakia-1	59.3	28.2	77.0	63.7	12.2	70.8	66.0	68.8
Slovenia-1	58.6	26.7	77.7	61.4	14.1	70.4	65.7	74.4
South Africa-1	52.2	32.2	74.9	56.4	38.4	68.3	57.3	73.2
Spain-1	43.5	26.6	72.6	49.9	13.0	64.0	55.9	64.7
Sri Lanka	58.3	28.4	62.5	56.9	37.6	–	56.5	–
Sudan-3	55.1	46.3	49.9	47.7	–	48.0	–	49.8
Sweden-1	66.0	32.8	80.8	52.0	30.2	66.4	64.4	73.0
Switzerland-1	36.5	16.0	73.8	41.9	9.9	68.5	44.6	59.6
Syria-2	50.2	43.9	54.9	60.5	57.3	65.9	47.4	73.5
Thailand-2	52.0	16.8	76.3	70.7	47.9	62.2	69.2	66.7
Tunisia	73.9	44.2	75.3	77.2	55.6	77.3	71.3	74.4
Turkey-4	43.6	27.1	67.0	58.0	34.5	53.1	47.0	59.2
United Arab Emirates-1	81.0	33.3	81.1	85.9	55.4	77.4	43.2	83.7
Ukraine	32.9	25.2	77.7	58.3	17.5	73.0	59.2	60.8
UK-2	65.0	23.5	75.4	53.0	19.4	62.4	53.7	68.0
Uruguay-1	39.7	45.9	77.5	70.7	17.7	74.3	62.7	64.3
USA-2	52.0	20.4	81.4	52.5	23.6	65.3	50.5	62.1
Uzbekistan	26.7	17.7	41.6	52.3	17.8	55.0	23.1	60.7
Viet Nam-2	53.0	37.1	58.7	50.6	26.4	57.2	59.5	60.0
Zimbabwe-3	50.9	20.5	30.8	30.6	46.1	45.7	51.8	44.7

-n: data refer to *n* years before reference year

Source: UNESCO Institute for Statistics

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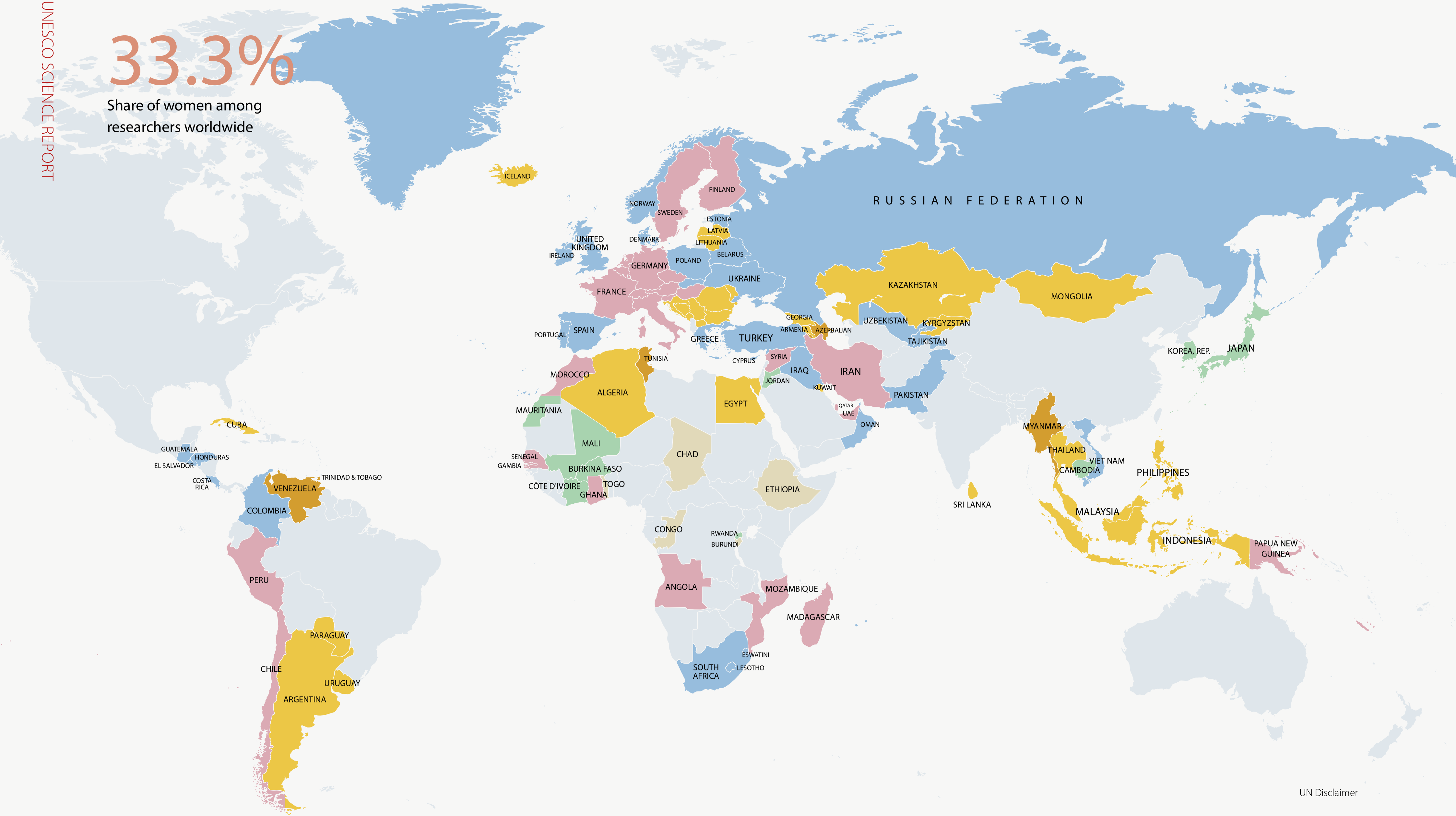
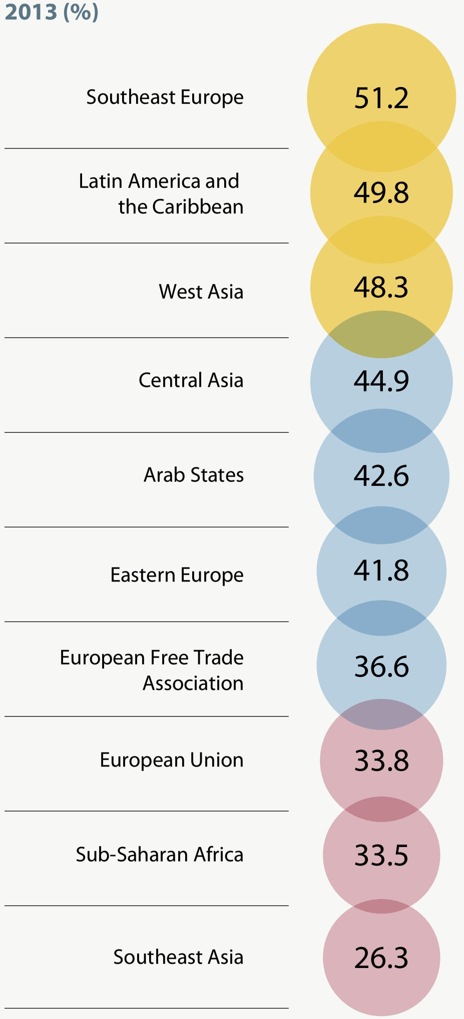
Figure 3.4: **Women as a share of total researchers (HC), 2018 or closest year (%)**

33.3%

Share of women among researchers worldwide



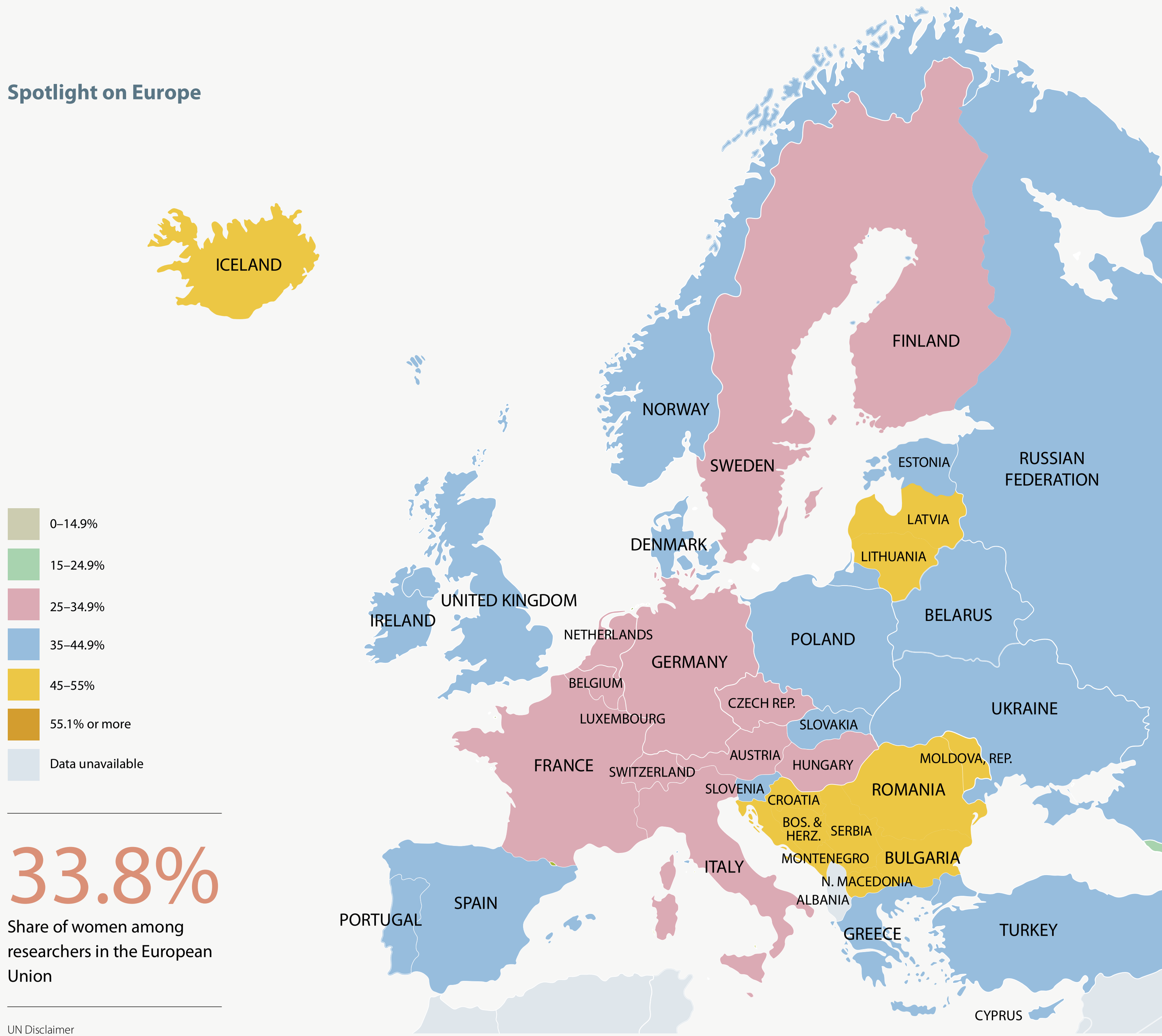
Regional shares of female researchers, 2013 (%)



Note: Data are for the most recent year since 2015. There are no available data for some of the most populous countries: Bangladesh, Brazil, China, India, Nigeria and USA; this limitation compromises the reliability of the global total and most regional totals. There is no regional total for South Asia or Oceania because data are available for only one or two countries. Eastern Europe excludes countries that are members of the European Union.

Source: UNESCO Institute for Statistics

Spotlight on Europe



33.8%

Share of women among researchers in the European Union

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in 2008 to 53% in 2018). Tunisia now has a slight imbalance in favour of women in its research ecosystem (56%). Also of note is the rapid progress made by Oman between 2015 (28%) and 2018 (36%). Among those countries reporting data in the Arab world, only Jordan (20%) and Mauitania (24%) fall below the global average.

Many OECD countries have a low density of female researchers

There is no guaranteed correlation between a country's wealth and its success in achieving gender parity. Among countries having reached this status, only a handful are OECD members, including Iceland, Latvia and Lithuania (Figure 3.4). Other OECD countries still have a strikingly low proportion of women researchers, including the Republic of Korea (20%) and Japan (17%), which also have the largest gender pay gaps among OECD countries (see chapters 24 and 25). In France and Germany, just over one in four researchers (28%) is a woman, less than the global average (33%).

Even OECD countries leading in gender equality rankings (WEF, 2018b) have a share of women researchers that hovers around the global average; such as Finland (33%), Norway (38%) and Sweden (33%). By contrast, in a least developed

Table 3.2: **Female researchers as a share of total researchers (HC) by field, 2018 (%)**

	Total	Natural sciences	Engineering & technology	Health & welfare	Agricultural sciences	Social sciences & humanities
Algeria -1	47.1	71.7	42.7	60.3	51.8	50.9
Angola -2	28.7	32.4	19.4	50.9	25.0	22.9
Armenia	50.4	46.5	42.1	65.2	59.4	58.5
Azerbaijan	58.6	61.4	52.0	50.0	42.8	64.2
Belarus	39.3	48.9	28.7	68.0	57.4	60.0
Bosnia & Herzegovina	47.1	48.7	37.0	62.7	47.6	52.4
Brunei Darussalam	45.2	40.7	28.7	66.2	33.3	48.1
Burkina Faso -1	17.0	17.4	16.9	18.4	12.1	15.8
Burundi	14.3	14.5	8.1	21.7	12.8	15.2
Cambodia -3	23.7	23.0	14.8	31.6	20.8	27.4
Chad -2	3.4	8.7	0.7	5.5	5.9	5.9
Colombia -1	37.4	34.3	25.6	48.6	31.4	41.4
Congo, Dem. Rep. -3	8.7	8.2	13.4	15.0	7.6	6.2
Costa Rica -1	44.3	41.2	24.0	55.3	36.7	56.1
Côte d'Ivoire -2	17.0	15.4	9.6	23.4	14.6	14.7
Egypt	45.6	40.6	28.9	48.9	35.3	54.6
El Salvador -1	38.6	46.0	21.6	63.2	16.7	41.4
Eswatini -3	41.4	11.1	29.2	63.2	29.3	50.5
Ethiopia -1	11.5	14.1	11.5	13.4	12.0	8.8
Gambia	27.2	37.5	–	28.8	18.2	50.0
Georgia	53.0	46.6	38.2	63.0	50.2	59.1
Ghana -3	26.1	9.3	6.8	11.2	24.7	40.8
Guatemala -1	43.9	44.1	30.6	72.0	22.1	46.7
Honduras -1	36.4	43.9	21.5	45.8	30.8	47.4
Iran -1	31.2	43.0	18.6	46.9	27.6	31.9
Iraq	38.1	45.4	31.6	45.5	26.0	37.5
Japan -3	16.6	13.6	5.6	31.9	22.4	32.7
Jordan -1	19.5	17.8	16.8	37.1	21.5	22.9
Kazakhstan	52.8	53.4	44.0	65.3	48.9	60.2
Korea, Rep. -3	20.4	28.3	10.6	45.9	27.3	43.1
Kuwait	53.2	58.5	47.3	57.6	26.9	53.1
Kyrgyzstan -1	46.5	44.9	33.3	49.1	44.4	54.5
Latvia -1	52.2	47.6	37.4	67.3	58.7	70.1
Lesotho -3	36.4	39.7	10.3	33.3	60.9	40.0

Share of women: <15% | 15–25% | 25.1–35% | 35.1–45% | 45.1–55% | >55%

country like Myanmar, women consistently make up more than 80% of researchers and dominate senior positions in academia (Figure 3.4).

Women still a minority among researchers in industry

Female researchers have now reached parity in the government and academic sectors in four out of ten countries reporting data. In 2018, Ireland took the step of linking research funding from the Higher Education Authority to an institution's ability to reduce gender inequality.

Men tend to be overrepresented in the business sector, where salaries are higher (Figure 3.5). This is true even for those countries that have reached gender parity across all sectors. Indeed, only eight countries have reached parity in the business sector out of the 73 for which recent data are available: Algeria, Azerbaijan, Kazakhstan, Kyrgyzstan, Mozambique, North Macedonia, Sri Lanka and Trinidad and Tobago. Of these countries, women are overrepresented in three: Azerbaijan, North Macedonia and Trinidad and Tobago.

The percentage of women in the business sector is particularly low in OECD countries, with a few exceptions, such as Iceland, Latvia, Lithuania and Spain, where women account for about 30–40% of researchers in industry. Elsewhere, fewer than one in four researchers is a woman in

	Total	Natural sciences	Engineering & technology	Health & welfare	Agricultural sciences	Social sciences & humanities
Lithuania -1	49.5	48.0	33.3	64.0	57.1	63.8
Madagascar	33.0	32.7	24.9	34.6	37.5	38.7
Malaysia -3	48.2	47.8	47.2	50.3	50.5	50.2
Mali -1	15.1	22.2	4.5	34.6	9.8	12.1
Mauritania	24.5	24.3	25.0	8.6	12.5	25.4
Mauritius	43.7	36.8	23.4	63.3	49.7	57.6
Moldova, Rep.	48.6	50.0	23.1	55.6	49.7	57.3
Mongolia	48.9	55.1	33.2	57.3	53.6	43.2
Montenegro	49.9+2	49.8	35.6	56.3	50.0	46.9
Morocco -2	33.8	–	–	40.4	26.7	29.9
Mozambique -3	28.9	27.0	24.4	53.5	25.6	25.3
Myanmar -1	75.6	72.7	78.5	72.0	75.0	70.8
North Macedonia	53.4	57.0	42.9	73.4	46.9	53.0
Oman	36.4	23.3	15.5	54.7	5.7	34.4
Pakistan -1	38.8	44.2	22.0	49.3	21.6	42.3
Papua New Guinea -2	33.2	37.4	34.2	34.8	19.5	46.9
Paraguay -1	49.3	50.8	25.5	72.8	40.1	51.2
Peru	28.6	24.4	18.9	35.2	30.1	26.7
Philippines -3	51.2	54.0	42.9	64.0	53.4	56.2
Qatar	34.1	30.7	16.7	44.6	23.8	40.1
Russian Fed. -3	39.2	41.8	34.8	59.6	56.4	59.9
Rwanda -2	22.6	18.1	16.5	21.5	17.9	27.1
Senegal -3	29.3	23.1	19.9	36.7	29.6	30.9
Serbia	51.4	58.1	40.4	58.6	51.5	53.1
Sri Lanka -3	46.6	47.7	39.3	43.2	48.2	49.4
Syria -3	34.9	30.2	32.3	26.5	34.8	46.0
Tajikistan	37.5	36.2	24.1	61.4	27.4	31.9
Togo	11.2	9.5	10.2	10.7	8.5	13.0
Trinidad & Tobago -1	55.9	52.2	31.5	59.9	52.9	69.0
Ukraine	44.7	43.0	34.1	65.2	53.0	64.2
Uruguay	49.3	49.6	35.1	53.5	48.1	52.6
Uzbekistan	40.8	35.2	31.2	54.3	27.0	47.5
Venezuela -2	61.4	56.1	50.6	72.3	59.0	66.0

-n: data refer to *n* years before reference year
Note: Countries with data older than 2015 for female researchers by field are excluded, including much of the EU.
Source: UNESCO Institute for Statistics

Chapter 3

the business world. In some cases, the percentage is even lower, such as in Germany (15%), Japan (10%) and Saudi Arabia (2%).

Few female engineers in the workforce

When it comes to engineering, the trends analysed earlier with regard to higher education are even more pronounced in the research community: in many countries, women are overrepresented in medical and health sciences, humanities, social sciences and the arts (Table 3.2). Only a handful of countries (Azerbaijan, Kuwait, Malaysia, Myanmar and Venezuela) have achieved gender parity among researchers in engineering and technology (Table 3.2).

The vast majority of countries reporting the lowest proportions of women researchers in engineering and technology are African, with the notable exception of Japan, where the proportion (6% in 2015) is much lower than for any other OECD country. Senegal is actively seeking to turn the situation around. National research funding is targeting the advancement of women through the Project for Supporting Female University Researchers in Senegal (see chapter 18). By 2015, 20% of Senegalese researchers in engineering and technology were women.

African female engineers less mobile than men

Mobility tends to be beneficial for a researcher's output and career. In a recent survey of 7 513 African scientists, the largest gender difference in mobility was found in the field of engineering and applied technologies: here, 85% of women but only 63% of men had obtained their PhD in Africa and only 23% of female respondents had studied or worked abroad in the past three years (Prozesky and Beaudry, 2019).

Mobile African women were more likely to collaborate internationally: 47% of mobile and 35% of non-mobile female researchers collaborated regularly with researchers at institutions outside Africa. Mobile women were also more likely than their non-mobile female peers to have been primary recipients of research funding, at 54% versus 45% (Prozesky and Beaudry, 2019).

Fellowships for women in the South

To facilitate scientific mobility, the Organization for Women in Science for the Developing World has partnered with the Swedish International Development Cooperation Agency since 1998 to award South to South PhD Fellowships to enable women from least developed countries to study in another developing country. By 2020, over 300 women from 30 countries participating in the programme had graduated.

The organization also helps female scientists to maintain high-level research in their home countries. Since 2018, it has offered 61 Early Career Fellowships in partnership with the Canadian International Development Research Centre. Fellows may use the grant to set up a laboratory, buy equipment and consumables, invite visiting scholars, attend conferences, publish in open-access journals, buy software, develop a patent and pay for child or elder parent care. Training in leadership skills and in linking with industry is built into the programme.

Women remain a minority among inventors

Despite 2019 having marked a record high for the percentage of patent applications that include at least one woman, women still make up just 19% of inventors (Figure 3.6). Progress may have been slow but at least it has been steady; women accounted for 14% of inventors in 2013.

The global average for international (Patent Cooperation Treaty, PCT) patent applications submitted by at least one female inventor increased from 28% to 35% between 2010 and 2019, according to data from the World Intellectual Property Organization (WIPO) [Figure 3.7]. The only region not affected by this change was Africa. This ratio compares with 20% of filed patents counting at least one female inventor in 2000.

Figure 3.5: **Share of women among researchers in the business enterprise sector, 2018 or closest year (%)**

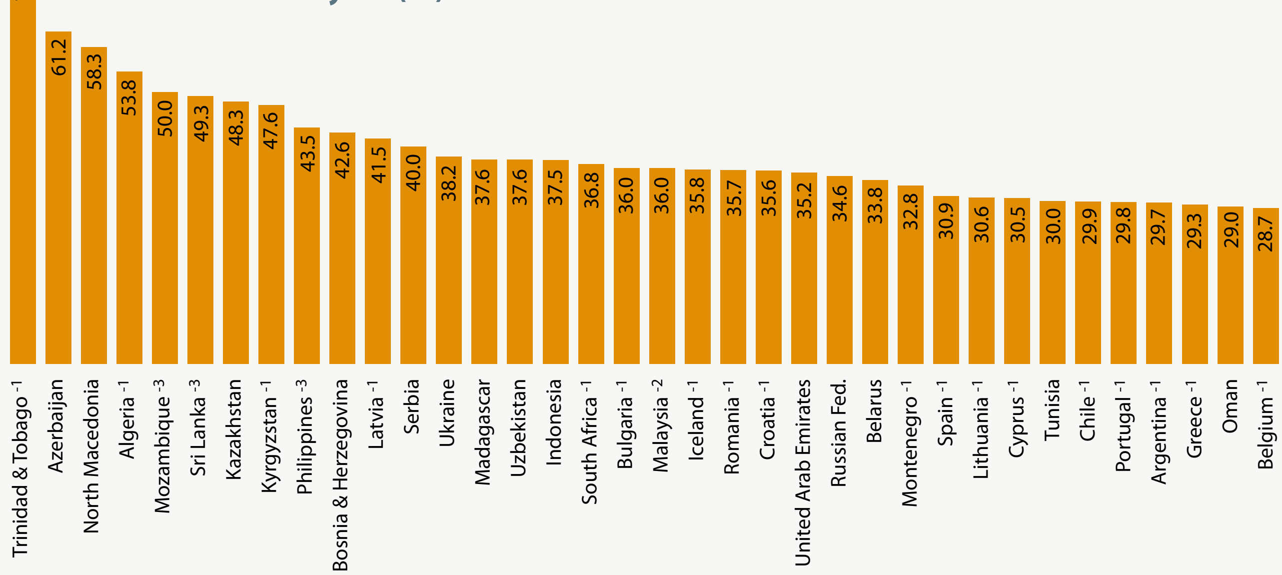
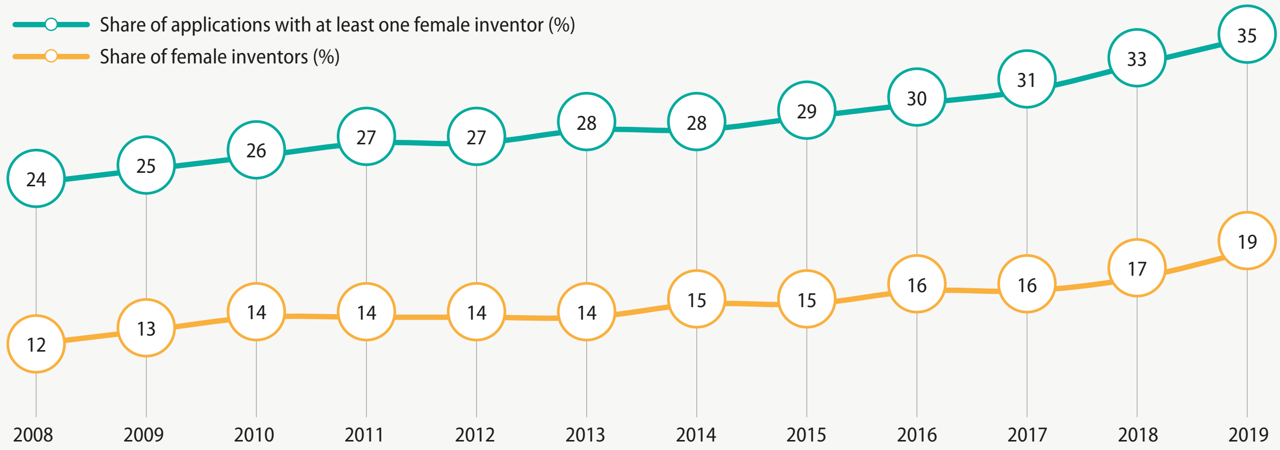


Figure 3.6: **Share of Patent Cooperation Treaty applications with female innovators, 2008–2019**



Source: : World Intellectual Property Organization, May 2020, see: https://www.wipo.int/pct/

The share of female inventors among patent applicants varies from one country to another: in 2019, the highest proportions of women were found in Iran (70%), Antigua and Barbuda (64%), China (55%), the Republic of Korea (51%) and Sri Lanka (47%), whereas the countries with the lowest proportions were Serbia (7%), Oman and Romania (both 8%).

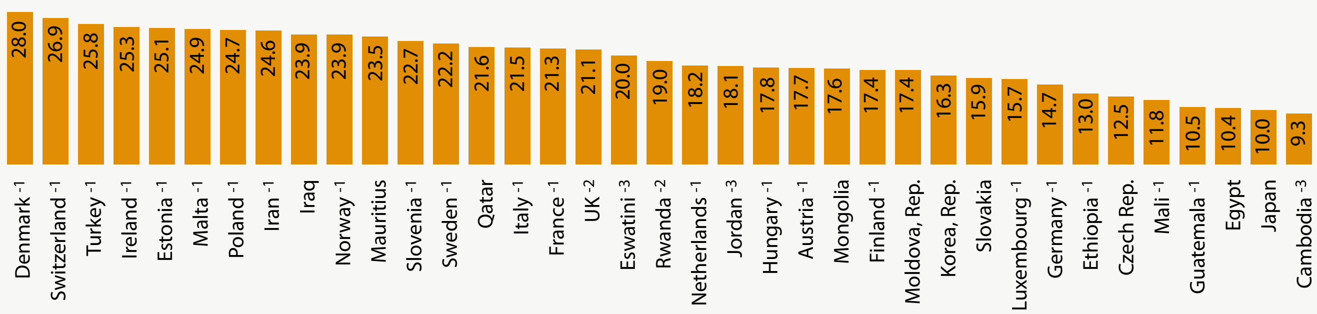
Although women account for only 17% of researchers in Japan, 23% of PCT patent applications from Japan included at least one female inventor in 2019, the same proportion as Sweden, where one-third of researchers are women.

There is also a large variation by year. For instance, of all the patents filed in Uruguay, 70% included at least one female inventor in 2018 but only 45% in 2019, according to WIPO data.

These trends reflect the picture we have already observed in higher education and at the research level: fields related to life sciences have a higher uptake among female inventors. More than half of PCT applications included at least one female inventor in 2019 in the fields of biotechnology, organic fine chemistry, pharmaceuticals, the analysis of biological materials and food chemistry (Figure 3.7).

Although the number of PCT applications by women has grown in every field in the past decade, their share remains below 20% in fields related to engineering, such as civil engineering (18%), machine tools (18%), mechanical elements (16%) and engines, pumps and turbines (16%).

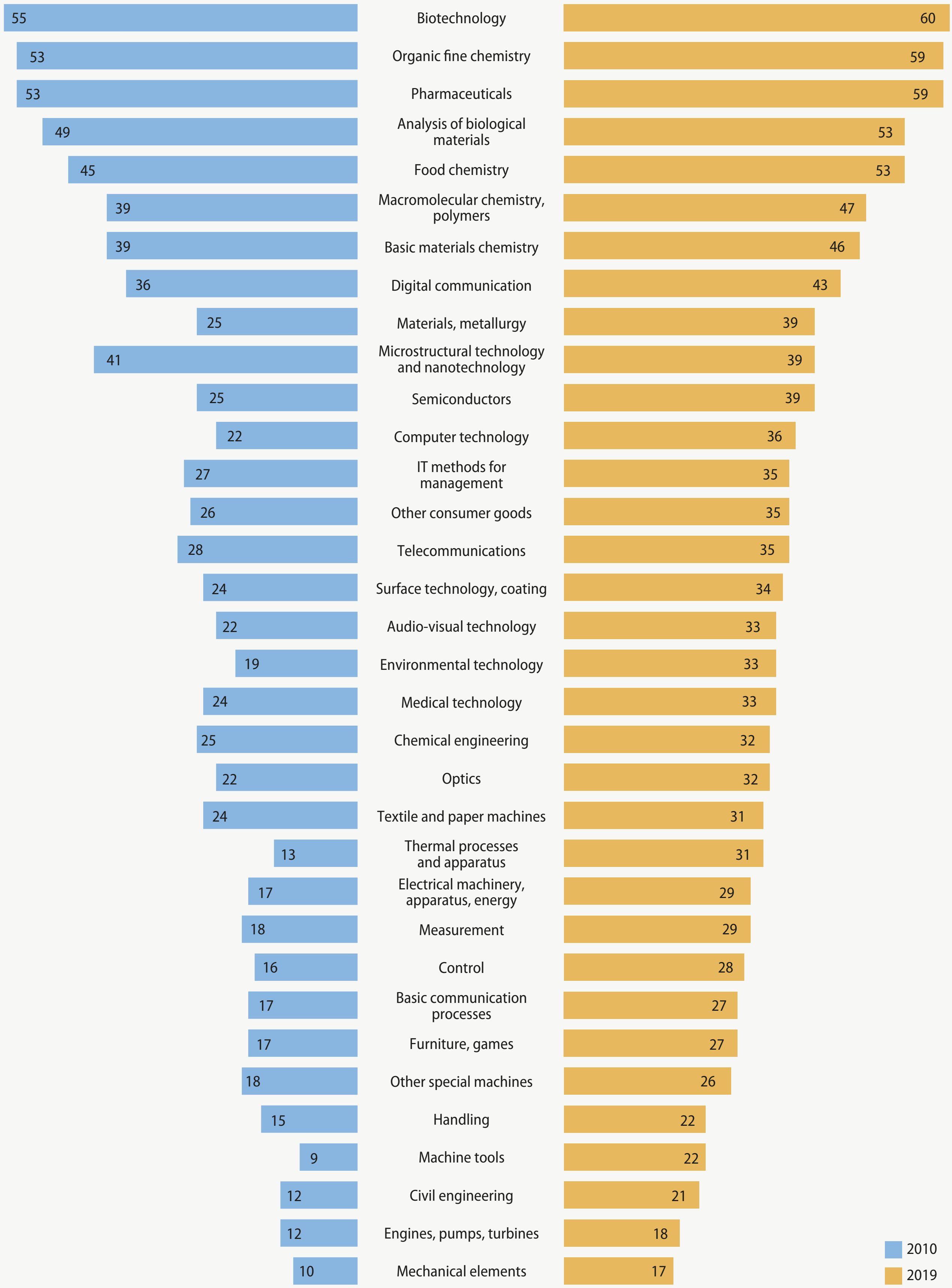
According to WIPO, female inventors are proportionally more internationally mobile than men, although men are closing this gap. Men are also more likely than women to participate in registering patents with a larger group of inventors (WIPO, 2016).



-n: data refer to *n* years before reference year

Source: UNESCO Institute for Statistics

Figure 3.7: **Share of Patent Cooperation Treaty applications with at least one woman inventor by technology, 2010 and 2019 (%)**



Source: World Intellectual Property Organization, May 2020, see: https://www.wipo.int/pct/

VERTICAL SEGREGATION IN ACADEMIA

An impenetrable glass ceiling?

As we saw earlier, women have now largely achieved gender parity at university, although they remain a minority in Industry 4.0 fields. It is as women embark upon a scientific career that the gender gap widens. Their presence becomes increasingly rarefied as they reach the higher echelons of research governance structures, such as academies of science (Box 3.6) or science councils.

Although women account for four out of ten academics worldwide, they often face an impenetrable glass ceiling.

Box 3.6: **Women still a minority in academies of science**

Members of science academies are elected on the basis of agreed academic indicators of scientific excellence. The number of women among members of a national academy of sciences can serve as a litmus test of the perception and status of women scientists in a given country.

In October 2015, the Interacademy Partnership published the first comprehensive survey of science academies belonging to its global network, in order to ascertain the extent of inclusion and participation of women scientists. Across 69 national science academies for which data were available, (Figure 3.8) women made up 10% or less of members in almost half (30) of countries. In most European countries (8), only one out of 10 members was a woman. Women were better represented in the governing bodies (20%) of academies than in overall membership (12%).

Among the top 10 academies for the share of female members, six are from Latin America and the Caribbean: Cuba (27%), the Caribbean Academy of Science (26%,) Mexico and Nicaragua (23%), Peru (20%) and Uruguay (19%).

That women should remain severely underrepresented in national science academies is a major challenge, since these academies often form the backbone of efforts to strengthen countries' national innovation systems.

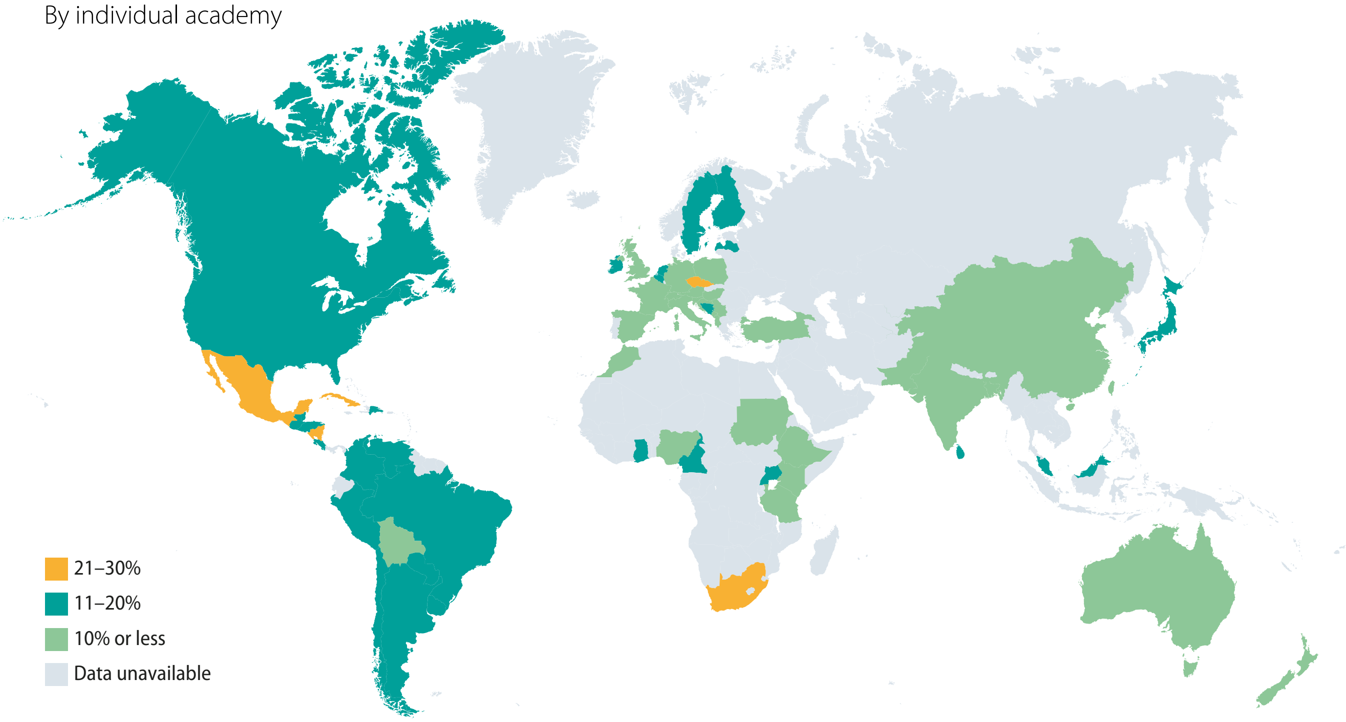
The survey also found that women academicians were better represented in the social sciences, humanities and arts (16%), biological sciences (15%) and medical and health sciences (14%). The lowest percentages of women academicians were to be found in mathematical (6%) and engineering sciences (5%).

In the year following the report, the Royal Netherlands Academy of Arts and Sciences took the radical step of accepting only female nominations for membership to reduce the Academy's perpetual gender imbalance: at the time, men accounted for 87% of its 556 members.

Source: compiled by Tonya Blowers, particularly from ASSAf and IAP (2015) *Women for Science: Inclusion and Participation in Academies of Science.* Academy of Science of South Africa: Pretoria

Figure 3.8: **Share of female members of national science academies, 2013 (%)**

By individual academy



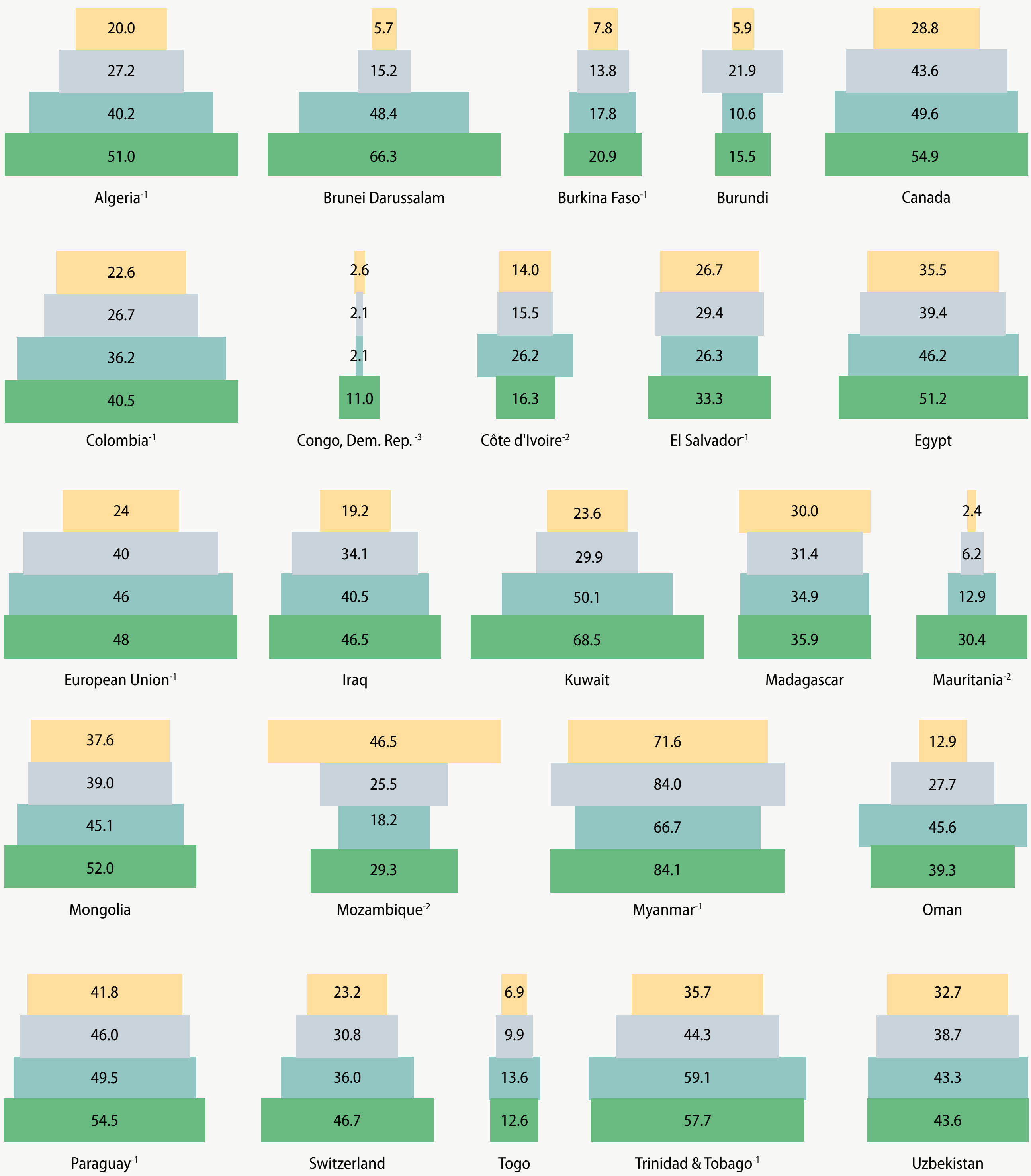
Note: For each country aside from Switzerland, the data reflect one academy of science; for Switzerland, the data reflect the combined membership of the Swiss Academy of Medical Sciences (17% women) and the Swiss Academy of Engineering Sciences (10% women).

Source: ASSAf (2015) *Women for Science: Inclusion and Participation in Academies of Science: a Survey of the Members of IAP*: the Global Network of Science Academies. Academy of Science of South Africa: Pretoria

UN Disclaimer

Figure 3.9: **The career pyramid: 24 case studies**

Share of female researchers by seniority grade (HC), 2018 (%)



-n: data refer to *n* years before reference year

Note: Seniority levels are classified as follows:

Category A: the single highest grade/post at which research is normally conducted. Examples: Director of Research or Full Professor.
Category B: researchers working in positions that do not qualify as Category A but are more senior than newly qualified doctoral graduates. Examples: Senior Researcher, Principal Investigator or Associate Professor.
Category C: the first grade/post into which a newly qualified doctoral graduate would normally be recruited. Examples: Researcher, Investigator, Assistant Professor or Post-doctoral Fellow.
Category D: either doctoral students who are engaged as researchers or researchers working in posts that do not normally require a doctorate. Examples: PhD student or Junior Researcher. Master's students counted as researchers would also fall into this category.

Source: UNESCO Institute for Statistics; for Switzerland: Federal Bureau of Statistics; for European Union: EC (2019b)

The representation of women decreases with the level of seniority. This vertical segregation can be encountered in almost every country and not only in science. Although data by seniority are available for only a score of countries and comparisons of women by seniority grade are unreliable owing to variations across countries, the data available clearly point to this trend, with a few notable exceptions such as Mozambique and Myanmar (Figure 3.9).

Considered a world leader in innovation, Switzerland is still mired in gender inequality. By 2016, the country's 12 universities had established equality action plans with the explicit goal of increasing the percentage of women on different rungs of the academic ladder (Figure 3.9). Most Swiss universities have introduced gender-specific requests in advertising positions, minimum quotas and at least one equality delegate on appointment committees. Most have also introduced preference rules favouring the less-represented gender in the hiring process, as long as both candidates are equally competent. Despite these efforts, the target set in the Federal Equal Opportunity Programme of having women make up 25% of full professors by 2017 has been missed. The trend for new appointments offers cause for optimism, however, since women represented 33% of new hires in 2016, according to swissuniversities, a lobby group for 14 Swiss universities.[10]

Gillian Norton, chair of the trust that runs St George's University Hospital in London, one of the largest in Europe, observed in 2020 that 'if you are a woman even now, I would say you have to work harder, be more on the ball and be more persistent to get to senior levels than men have had to be in the past'. In 2020, women represented 77% of the National Health Service's 1.4 million employees and 46% of those in executive roles but only 29% of medical directors – albeit an improvement on 25% in 2017 (NHS Confederation, 2020).

Tougher standards for women

Career prospects for female researchers remain daunting. Women are held to tougher standards for funding applications, peer review, tenure review and job applications (Brower and James, 2020; Witteman *et al*., 2019; Kaatz *et al.,* 2016; Hengel, 2017).

The calibre of women is often underestimated, even though they show greater and faster rates of improvement throughout their career, in terms of writing standards and contributions to research (Brower and James, 2020; Hengel, 2017). They are typically given smaller research grants. In Argentina, for instance, female researchers who led scientific projects in 2015 tended to request and receive 25% less in funding than their male counterparts (UNESCO, 2018).

It has been demonstrated that women are as productive as men in terms of research output but tend to have shorter careers, with greater rates of departure at each stage of their career (Huang *et al*., 2020). The difficulty in balancing work and family has been documented as one reason why women cut short their research career.

The gender pay gap in academia may be another reason (Box 3.7). In October 2020, Princeton University in the USA agreed to award backpay totalling US$ 925 000 to 106 women occupying the position of full professor, in a settlement with the Department of Labor over alleged gender pay discrimination. The university considered that its pay model by academic discipline accurately reflected the labour market but agreed to conduct annual equity reviews of salaries for all full professors over the years to 2025 (Tomlinson, 2020).

Article 24 of the *UNESCO Recommendation on Science and Scientific Researchers* (2017) urges member states to ensure that scientific researchers enjoy equitable conditions of work, recruitment and promotion, appraisal, training and pay without discrimination on the basis of their sex.

Box 3.7: **This unique scheme can track the gender pay gap among researchers**

New Zealand is the only country that scores the research performance of every academic using a common metric.

The government's Performance-based Research Fund tracks an academic's publication record alongside factors that include peer esteem, student supervision, public dissemination and non-publication contributions to research. The scores are calibrated to account for potential variations among academic fields.

In parallel, New Zealand uses a clear pay scale across all universities. Although both an academic's pay and score are confidential, the standardized metrics make it possible to analyse the impact of a researcher's career and their quality of life within the science system.

Brower and James (2020) were, thus, able to analyse data from 2003 to 2012 for all researchers in New Zealand. They found that each female academic was paid, on average, NZ$ 400 000 less than her male colleague over the course of her career. About half of this gap could be explained by differences in age, research prowess and field of expertise.

However, men still progressed farther in their career and earned greater pay than women who obtained the same score, with the pay gap varying among fields. In engineering, for example, 58% of the pay gap was unexplained by research performance.

Brower and James (2020) tested several common explanations for the gender pay gap at university. They found that effort alone did not suffice for a woman to catch up. Among researchers at an early stage of their career, women improved their research scores by 13 points more than men, on average between 2003 and 2012, but still stood a lesser chance of being promoted.

The authors found that 'a man's odds of being ranked professor or associate professor were more than double a woman's with a similar recent research score, age, field and university'.

They concluded that no field of science would achieve gender parity by 2070 under current hiring practices.

Source: Brower and James (2020)

In the Republic of Korea, research expenditure per senior researcher amounted to KRW 200 million (*ca* US$ 190 000) for women and KRW 410 million for men in 2017 (see chapter 25). The Ministry of Science and Information and Communication Technologies uses a point system to assess research grant applications. Under the *Fourth Basic Plan for Fostering Women in STEM* for 2019–2023, bonus points are being allocated to projects which respect at least one of the following criteria: the supervising manager is a woman; women account for more than 20% of participating researchers; or women account for more than 20% of participating researchers in the supervising organization. The ministry also allocates 20% of its total research expenditure to female senior researchers in 'veteran researcher assistance projects', providing KRW 50–300 million over one to five years. This practice is to be adopted by non-profit organizations and other government ministries by 2023.

Less visibility for female academics

Vertical segregation, with a low percentage of women in higher and senior academic positions, is partly a result of reduced visibility, owing to the lower number of papers

Box 3.8: **The world needs science and science needs women**

For the past 20 years, the L'Oréal–UNESCO Programme for Women in Science has been raising the profile of exceptional women researchers through a system of annual prizes and research fellowships, in order to change attitudes towards female researchers and provide young girls with positive role models. The programme's slogan is 'the world needs science; science needs women'.

In 2019, the programme extended its own international prizes and fellowships to include mathematics and computer science, in recognition of the lack of visibility of female role models in fields which are at the heart of the Fourth Industrial Revolution. Two mathematicians figure among the five regional laureates of the 2019 edition of the prize, Claire Voisin (France) and Ingrid Daubechies (USA). Each of these five laureates took home € 100 000.

Among the 15 rising talents distinguished by L'Oréal and UNESCO in 2020, one is a mathematician (Olena Vaneeva from Ukraine), two are physicists (Huanqian Loh from Singapore and Paula Giraldo Gallo from Colombia) and one is a material engineer (Vida Engmann from Denmark).

Four Nobel Prize winners, Emmanuelle Charpentier (Chemistry, 2020), Jennifer A. Doudna (Chemistry, 2020), Ada Yonath (Chemistry, 2009) and Elizabeth Blackburn (Physiology and Medicine, 2009) were nominated *after* being distinguished by the L'Oréal–UNESCO Awards for Women in Science.

Source: UNESCO

Dr Nazek El-Atab in her laboratory in Saudi Arabia. Dr El-Atab's research focuses on the fabrication of 3D nanotube-based nano-electronics for implantation in the brain. Brain implants could enable the deaf to hear, the blind to see and the paralyzed to control robotic arms and legs. Her work is tackling the major problem of maintaining sufficient data memory in tiny electronic devices. Dr El-Atab is a Postdoctoral Research Fellow at the King Abdullah University of Science and Technology. In 2017, she won the L'Oréal-UNESCO For Women in Science International Rising Talent award. © l'Oréal Middle East published by women (de Kleijn *et al*., 2020). This difference is related to women's shorter careers, despite similar publication output per career year (Huang *et al*., 2020). Although publication in high-profile journals is a key factor in career advancement, female authors have been persistently underrepresented.

An analysis of nearly 3 million computer science papers published in the USA between 1970 and 2018 concluded that gender parity would not be reached in this field until at least 2100, even under a scenario in which women authored 90% of all publications in the coming years. The authors noted that, in comparison, gender parity in the biomedical literature was attainable within three decades. Co-authorship by men and women in computer science had actually decreased since 1970. Although both men and women were more likely to collaborate with authors of their own gender, the degree of same-gender preference was declining among female authors even as it rose among male authors (Wang *et al.* 2019).

Women are less likely than men to be first or last authors and women-authored publications receive fewer citations. Since having a low citation rate negatively affects a journal's impact factor, this can discourage publishers from accepting women-authored papers for publication (Wang *et al*., 2019; de Klein *et al*., 2020; Shen *et al*., 2018). In clinical and basic science journals, female authors are less likely to be listed as first author (Aakhus *et al*., 2018).

Gender bias can also be found in the peer-review process. A study analysing over 23 000 research manuscripts submitted to six journals in ecology and evolution from 2010 to 2015 found that, on average, women received slightly worse scores and were more likely to be rejected during peer review (Fox and Paine, 2019).

Being invited to give keynote and plenary presentations provides recognition of scientific excellence and visibility; however, female scientists are invited and assigned oral presentations less often than men (Ford *et al*., 2018; Farr *et al*., 2017). Men are invited to speak on scientific panels at twice the rate of women. An analysis of attendance rates at the world's top machine-learning conferences in 2019 found that just 18% of participants overall were women, with the 19% average for academia inching ahead of the 16% average for industry (Kiser and Mantha, 2019).

The Request a Woman Scientist database is one response to this trend. Part of the 500 Women Scientists organization, this database connects a multidisciplinary network of vetted women in science with anyone who needs to consult, invite, collaborate with or identify a female specialist (McCartney, 2019).

Prestigious prizes are another way to showcase excellence and, thereby, challenge negative stereotypes about women in science. One example is the L'Oréal–UNESCO Programme for Women in Science (Box 3.8). The Awards for Early Career Women Scientists are another; since 2013, the Organization for Women in Science for the Developing World has teamed up with the Elsevier Foundation to present these annual awards to five women from developing countries who have overcome considerable obstacles to achieve research excellence.

CONCLUSION

Women still a minority in Industry 4.0 fields

There are signs that women are inching closer to parity in science, at least in terms of numbers. In higher education, they have achieved parity (45–55%) at the bachelor's and master's levels of study and are on the cusp at PhD level (44%). Women accounted for 33% of researchers in 2018, up from 28% in 2013. In many countries, they have achieved parity in life sciences, or even dominate the field.

However, women remain a minority in digital information technology, computing, physics, mathematics and engineering, the very fields that are driving the Fourth Industrial Revolution and, thus, many of the jobs of tomorrow. This trend is all the more problematic in that there is a skills shortage in many of these very fields, such as in artificial intelligence. This trend suggests that progress towards righting the gender imbalance could be compromised, unless strenuous efforts are made at the government, academic and corporate levels not only to attract girls and women to these fields but, above all, to retain them.

Women are leaving tech fields in greater numbers than men. They cite workplace conditions, lack of access to creative roles and a stalled career as the primary reasons for their decision. This correlates with their underrepresentation in company leadership and technical roles, even if corporate attitudes are evolving as studies link investor confidence and greater profit margins to having a diverse workforce. Be they large corporations or start-ups, the picture is similar. A 2019 study by the Silicon Valley Bank of start-ups in technology and health care in Canada, China, the UK and USA found that almost half (46%) had no women at all in executive positions.

Even when women lead start-ups in tech fields, they struggle to access venture capital and other forms of financial support. Just 2.3% of venture capital is being channelled towards start-ups led by women, according to a 2020 global survey of 700 firms by Trustradius.

In academia, women tend to receive less grant funding, even though they are as productive as men. On an annual basis, they publish as much as men but are less likely to publish in high-profile journals or to be first or last authors. Women-authored publications receive fewer citations. Women are passed over for promotion. One New Zealand study found that 'a man's odds of being ranked professor or associate professor [were] more than double a woman's with similar recent research score, age, field and university' (Brower and James, 2020).

A need to transform gender relations

In light of the foregoing, it is hardly surprising that many female graduates are opting not to pursue a career in research – women now account for 44% of PhDs but only 33% of researchers – or choosing to leave the research profession altogether.

There are support programmes targeting women in underrepresented fields such as computing, physics, mathematics and engineering. However, scholarships, fellowships and other incentive measures can only be as effective as the quality and number of applicants. If a high number of girls are not attracted early on in their educational *parcours* to such fields, there will not be the critical mass of quality female applicants to apply for fellowships in advanced research or to receive awards for excellence.

To this extent, such programmes remain gender-accommodating, rewarding those with the tenacity to make it through the system against the odds, rather than changing the system itself. Although this approach can make a difference to individual careers, it cannot reduce gender inequality or address the gender systems that contribute to inequality. To be truly transformative, gender policies and programmes need to transform gender relations.

This will entail eliminating gender stereotypes in education, through initiatives such as *African Girls Can Code*, but also in the workforce. It will entail building awareness among senior managers of the need to level the playing field at work to ensure that men and women enjoy equal opportunity and equal pay. It is not enough to attract a woman to a scientific or technical field of study. We must also ensure that her career is not strewn with obstacles that men do not have to face. As we have seen, women are leaving the tech field in the USA primarily because they feel undervalued.

Whenever awareness-building campaigns prove insufficient, more coercive measures may be needed to change the status quo. The quota system introduced by the State of California in the USA obliges publicly traded companies by law to have boards of directors composed of at least 40% women by 2021.

The good news is that having a diverse workforce is becoming a determinant of investor confidence and higher profit margins. The desire to project an image of social responsibility is inciting companies – and large public bodies like the National Health Service in the UK – to initiate change themselves.

Industry 4.0: an opportunity for those with the right skills

Advances in artificial intelligence and other digital technologies hold the promise of making the male and female characteristics that have been a pretext for gender inequality for so long less relevant in a virtual world. However, there is also a danger that, without due oversight from both men and women, these technologies could further entrench gender stereotypes, cancelling out any advantages.

Industry 4.0 will lead to widespread automation of jobs. Automation could eliminate hazardous manual occupations and repetitive tasks, while creating new professional opportunities for those who can acquire the right skills. It will be important for women to seize this opportunity, as the alternative could be dire. As we have seen, women in England accounted for 70% of employees in jobs with a high risk of automation in 2017 (UNESCO, 2018).

The current shortage of skills in fields such as artificial intelligence, computer science and engineering offers women an opportunity to fill this gap, both as employees and as employers. It will be important to put mechanisms in place to ensure that female entrepreneurs in tech fields have much greater access, in future, to venture capital and other sources of finance.

One advantage of digital businesses is that they tend to be less capital-intensive and less labour-intensive than traditional industries. They also tend to require less office space. In countries where women face impediments to accessing capital, or to leasing and owning property, being able to dispense with the need for expensive real estate could make all the difference to female entrepreneurs.

Digital technologies, which facilitate telework and networking, while providing broader access to information, have been invaluable in ensuring social distancing and information-sharing during the Covid-19 pandemic.

Some of the radical changes to the work–family balance induced by the pandemic may be here to stay. It will be important for these changes to be converted into policies which ensure that women do not spend a disproportionate amount of time as unpaid carers, homemakers and educators but, rather, have the time and the energy to make their mark on the science and innovation of tomorrow, to tackle the defining challenges of our time: climate change, biodiversity loss, pandemics of disease, environmental degradation, unsustainable urban development and so on.

You cannot manage what you cannot measure

One last issue that must be addressed is the lack of comprehensive data on gender trends. This is a chronic problem. Sex-disaggregated data on researchers are not being collected regularly by most countries in the Caribbean, Oceania, South Asia, Southeast Asia and sub-Saharan Africa. UNESCO estimates of women researchers worldwide also exclude North America and China, owing to the international incomparability of these data. These data gaps limit the conclusions that can be drawn at national, regional and global levels.

UNESCO is one of several actors that have been conducting global and national surveys to document the pressures that inhibit the regular collection of sex-disaggregated data. Through its STEM and Gender Advancement (SAGA) project, UNESCO has designed a toolbox for a holistic approach to gender policies, including through an Indicator Matrix blending existing and innovative indicators.

Attitudes are changing. We can see from the examples in the preceding pages and throughout the present report that initiatives to foster gender equality have proliferated in recent years. These have been initiated by a wide range of actors, including governments, legislators, regional bodies, universities, research centres, civil society and private companies. It would be worthwhile for these actors to co-ordinate their initiatives, to ensure greater impact and coherence.

Numerous countries have launched gender-specific equality policies in science and engineering in recent years, signalling that the topic is rising to the top of their domestic agenda. Many of these initiatives remain sporadic, fragmented and limited in time and space but they are widespread. This dynamic gives cause for optimism.

Alessandro Bello (b. 1981: Italy) served as project officer for UNESCO's STEM and Gender Advancement (SAGA) initiative from 2015 to 2019. His work focuses on science, technology and innovation policy and its linkages with indigenous knowledge systems, as well as gender equality issues. He holds dual master's degrees in policy governance and political science and international development from the Universities of Bologna and Pisa (Italy). He is currently pursuing a PhD at the University of Salamanca (Spain) on strengthening research and innovation systems in least developed countries.

Tonya Blowers (b. 1965: UK) has been Co-ordinator of the Organization for Women in Science for the Developing World (OWSD), a UNESCO programme unit, since 2013. She coordinates all OWSD programmes, including fellowships, awards and networking and works with the OWSD executive board to develop strategic plans, fundraise and liaise with members, donors and partners. She holds a PhD in Women and Gender from the University of Warwick (UK) and a Master's in World Literature in English from Marlboro College (USA).

Susan Schneegans (b. 1963: New Zealand) is Editor in Chief of the *UNESCO Science Report* series. In 2013 and 2014, she co-edited three reports profiling the national innovation systems of Botswana, Malawi and Zimbabwe, within UNESCO's Global Observatory of Science, Technology and Innovation Policy Instruments. From 2002 to 2013, she was Editor of the UNESCO journal, *A World of Science*, which she also founded. She holds a Master of Arts degree from the University of Auckland (New Zealand).

Tiffany Straza (b: 1987: Canada) serves as Deputy Editor and Statistician for the *UNESCO Science Report*. She holds a PhD from the University of Delaware (USA) in oceanography, with a specialization in marine microbial ecology. Her work has focused on communicating science and building inclusive systems for environmental management. This led her to provide technical backstopping on sound ocean and island management in the Pacific Islands region from 2013 to 2019.

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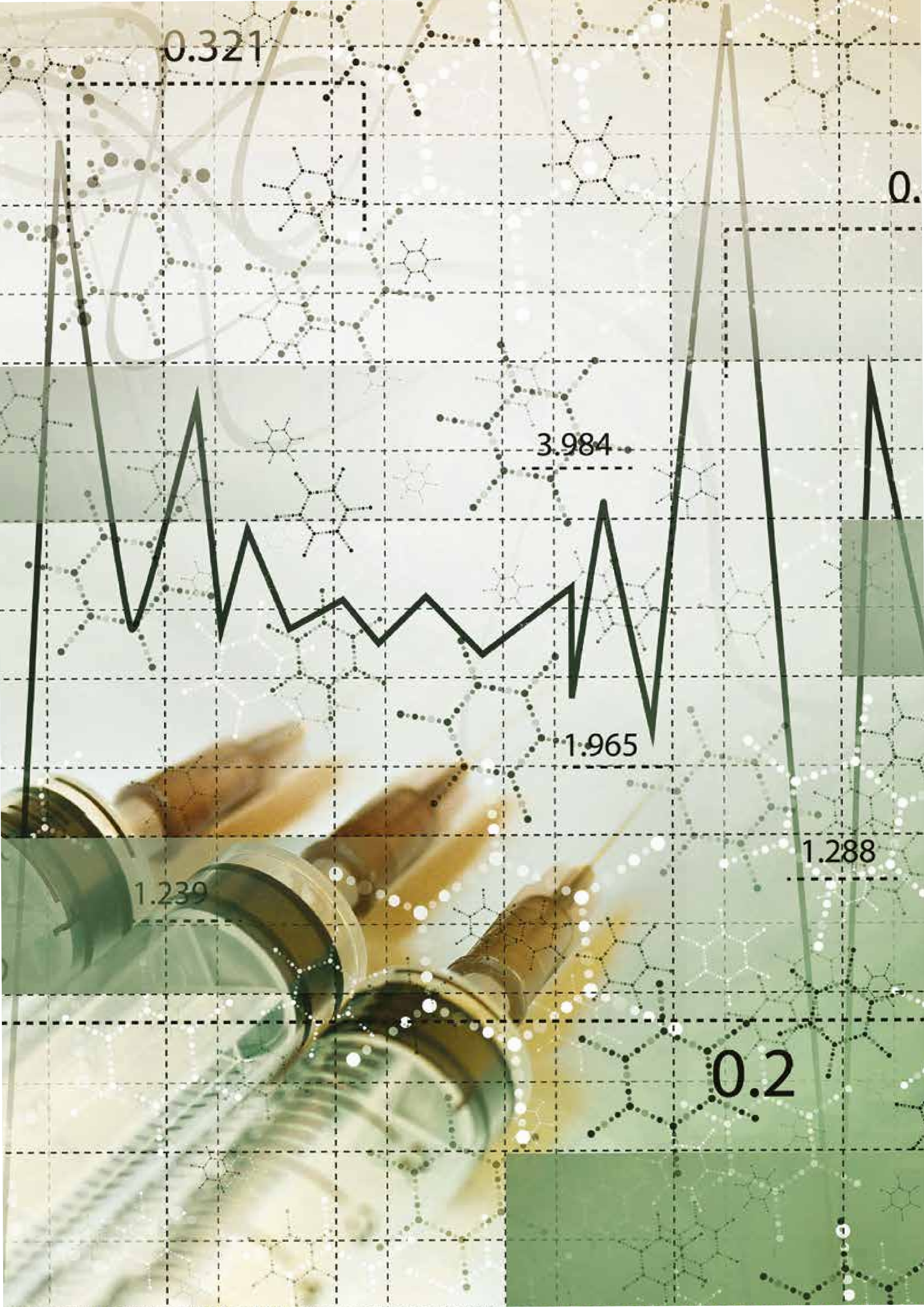
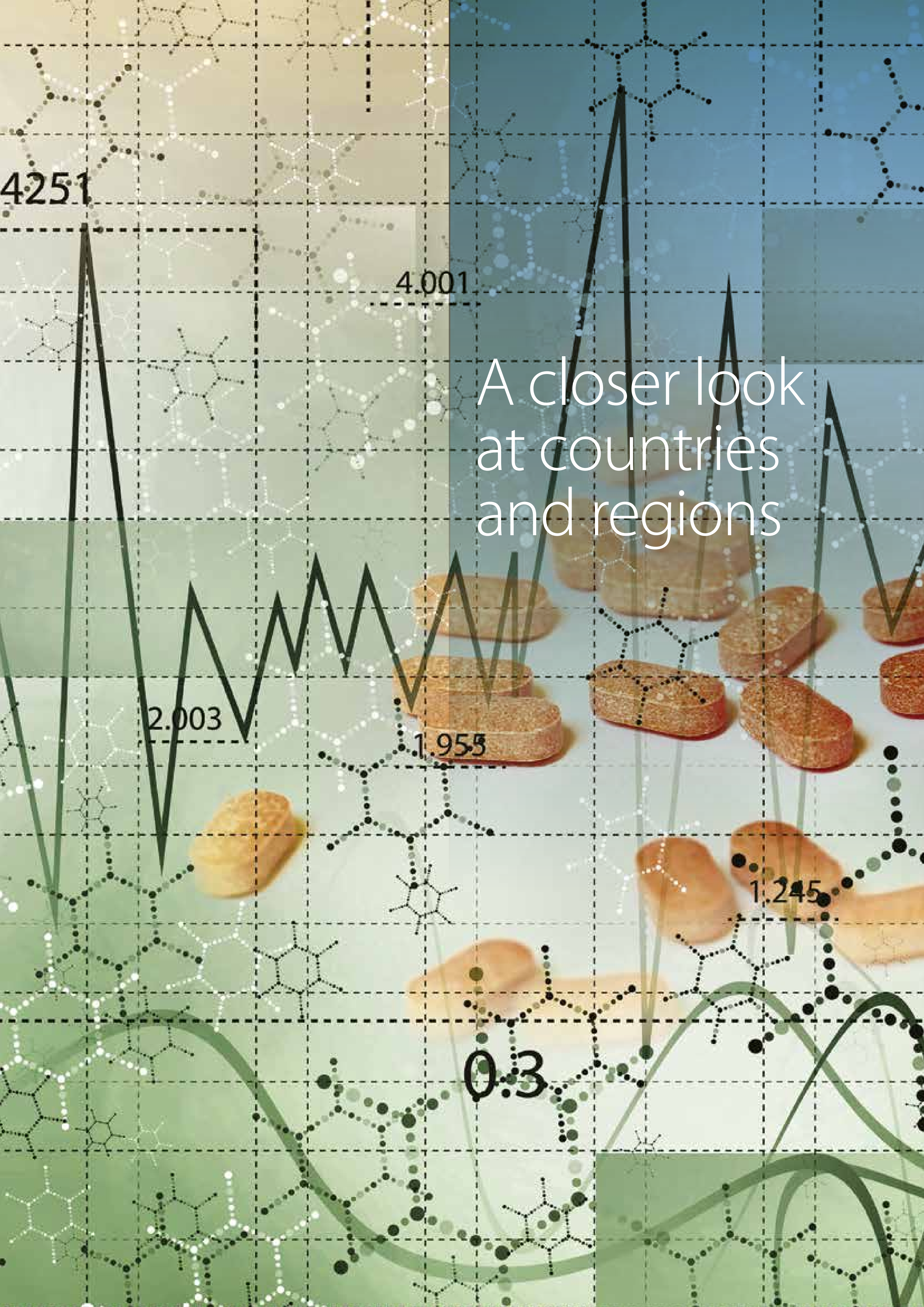
ENDNOTES

1 STEM refers in the present chapter to the fields of study under the International Standard Classification of Education, namely natural sciences and mathematics, information and communication technologies and, thirdly, engineering, manufacturing and construction.
2 See: https://www.article19.org/data/files/Internet_Statement_Adopted.pdf
3 See: https://globalfindex.worldbank.org/
4 A year after the adoption of the EU's gender pay gap action plan in 2017, France, Ireland and Portugal introduced labour laws which impose financial penalties on employers who do not take pro-active measures to reduce the gender pay gap. In Iceland since January 2018, companies and government agencies with more than 25 employees are required to obtain government certification from an independent entity that their pay policies are gender-equal, or face fines. This measure aims to close Iceland's gender pay gap by 2022 (EC, 2019b).
5 An echo chamber (also known as a filter bubble), is an unwanted feature of an algorithm which does things that were not explicitly intended by its programmer. For instance, the algorithm that builds a person's Facebook feed filters information to show the person the things they like most. In this way, it is easy to convince a person that an idea is false, such as that vaccines cause autism. The person can then live in a virtual bubble (or echo chamber) in which almost everyone in their feed is convinced that vaccines cause autism (UNESCO, 2019).
6 See: Forbes (2019) The World's 100 Most Powerful Women.
7 According to the Venture Capital Female Founders Dashboard, US companies created solely by women received 2.7% of the total venture capital invested in start-ups in 2019 but this value slid back to 2.0% in 2020.
8 See: https://www.trustradius.com/buyer-blog/women-in-tech-report
9 See: dealroom.co
10 See: https://www.swissinfo.ch/eng/gender-inequality_universities-fail-to-fulfil-female-quotas/42551926


0.321
3.984
1.965
1.239
1.288
0.2

A closer look at countries and regions



Andrew Arreak (left), the head of SmartICE Regional Operations, and Christian Haas stand next to a tool used to measure sea-ice thickness along travel routes in Nunavut. Known as a SmartQAMUTIK, this climate monitoring tool was co-designed by Inuit researchers employed by Canada's SmartICE programme, which operates from research stations in the Arctic circle.

AT A GLANCE

- The government's support for evidence-based decision-making is reflected in the appointment of a Chief Science Advisor in 2017.
- The decline in industrial research spending is of concern. The government is investing in five innovative 'superclusters' to support public–private collaboration on the ocean economy, next-generation manufacturing, digital technology, protein industries and artificial intelligence.
- Under the Pan-Canadian Artificial Intelligence Strategy (2017), the government is investing in scientific excellence and in 'global thought leadership', such as through the Montreal Declaration for Responsible Development of Artificial Intelligence (2018).
- In 2020, the government adopted a target of achieving net-zero carbon emissions by 2050 through investment in clean technology. It is difficult to adopt a national approach to science, however, as each province has its own strategies and programmes.
- The nascent Canada Research Coordinating Committee aims to improve co-ordination at federal level, including through the New Frontiers in Research Fund designed to bolster federal support for high-risk, game-changing research.

4 · Canada

Paul Dufour

INTRODUCTION

Decisions grounded in science and evidence

Since the previous edition of the *UNESCO Science Report* (Dufour, 2015), Canada's national innovation system has advanced on a number of fronts. For instance, there has been strong support for potentially disruptive technologies such as artificial intelligence (AI) and quantum computing. The *Pan-Canadian Artificial Intelligence Strategy* adopted in early 2017 has been billed as one of the first.

There has been some progress in broadening the participation of Canada's indigenous populations in science, technology, engineering and mathematics (STEM), including at university level. In 2016, the government announced that it would be co-developing a new Arctic policy framework with indigenous, territorial and provincial partners, a pledge that has since been realized. Moreover, in 2019, the government committed to working with First Nations to ensure that the Indigenous Languages Act is fully implemented and to translate the United Nations Declaration on the Rights of Indigenous Peoples into law.

A new Council for Science and Innovation is expected to assist the government in its strategic planning for research and technology, with calls for candidatures having been launched in 2019. Over the past five years, the government has stressed the value of science and evidence to inform decision-making. One sign of this priority was the creation of a dedicated Ministry of Science in November 2015. However, the portfolio of sport was added to the minister's mandate in 2018 before the science portfolio itself was absorbed into the new Ministry of Innovation, Science and Industry in late 2019.

Almost ten years after the position of National Science Advisor was abolished, the government appointed Dr Mona Nemer as Chief Science Advisor in 2017. Since early 2020, she has been mobilizing scientific research and analysis to help tackle the Covid-19 pandemic. A series of expert panels and task forces have been established across the country to address research challenges associated with the pandemic, including a task force on the impact of Covid-19 on children.

The federal, provincial and territorial governments have largely grounded their response to Covid-19 in scientific evidence. The trust factor has been essential in securing public support for mitigation efforts such as social distancing.

The pandemic has affected a wide range of socio-economic indicators. Statistics Canada reported a 2.6% drop in GDP in the first quarter of 2020. At the time of writing in June 2020, employment rates have fallen sharply across the board. Sales of manufactured goods are at their lowest level since 2016, with those of automobiles and parts down by over 30%. Inflation in consumer prices has also dropped below 1%, following steep declines in energy prices; the volatility of energy prices since the outbreak has had a significant impact on the economy, since mining and oil and gas extraction accounted for 7.8% of GDP in 2018. Taken together, oil and gas make up about 70% of Canada's primary energy supply (Figure 4.1).

Trade in manufactured goods has been affected by the closing of the border with the USA for non-essential travel: in 2019, 75% of Canadian merchandise exports crossed this border, according to Statistics Canada. One illustration of this economic interconnectedness is the fact that lung ventilators produced in the USA for Covid-19 patients contain key components sourced in Canada.

The health care system will undergo a major rethink as a result of the pandemic. In particular, several provinces have announced plans to launch formal enquiries into how to strengthen homes for long-time care and senior citizens, which have been particularly hard hit by the epidemic.

The education sector has had to adapt to the new reality of online learning and universities and colleges[1] are, themselves, weighing new options for scholarly activity. Student groups and other bodies have been undertaking surveys to understand how Covid-19 is affecting graduate students, including with regard to health, employment prospects, research outlook and teleworking.

The annual Canadian Science Policy Conference in November 2020 is expected to reflect on the long-lasting impact of Covid-19 and the role that science and innovation policy play in public policy and economic development.

TRENDS IN SCIENCE GOVERNANCE

Mobilizing industry to fight Covid-19

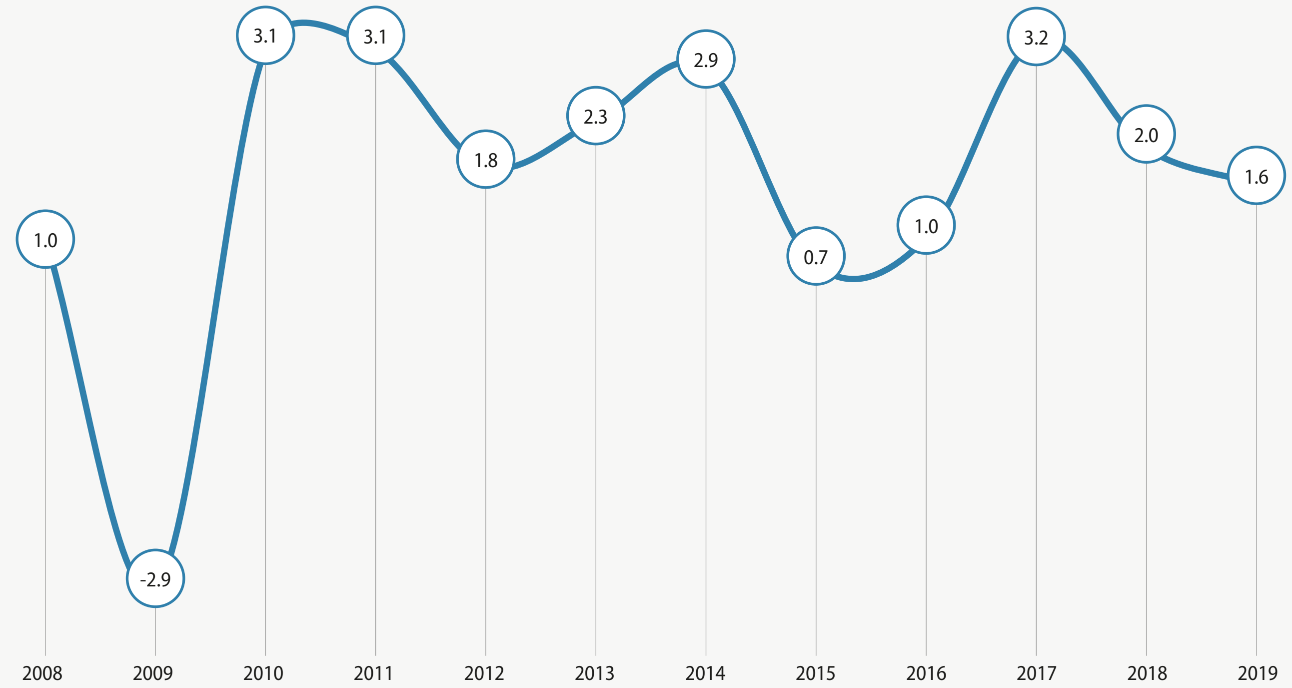
In March 2020, the government published *Canada's Plan to Mobilize Industry to fight Covid-19*, which requires the Innovation Superclusters (Box 4.1), the Strategic Innovation Fund and the National Research Council to prioritize funding and support for goods and services that respond to the Covid-19 pandemic.

The federal government appointed an Industry Strategy Council in May 2020 to assess the scope and depth of Covid-19's impact on industry and inform the government's understanding of specific sectoral pressures, including in advanced manufacturing, agrifood, clean technology, digital industries, health and biosciences, resources of the future, tourism and hospitality, retail and transportation.

As part of its rapid response arsenal for Covid-19, the federal government has earmarked Can$ 1 billion for a national medical research strategy that includes vaccine development, the production of treatments and virus tracking. Of this amount, Can$ 192 million is being channelled through the Strategic Innovation Fund directly to institutions

Figure 4.1: **Socio-economic trends in Canada**

Rate of economic growth in Canada, 2008–2019 (%)

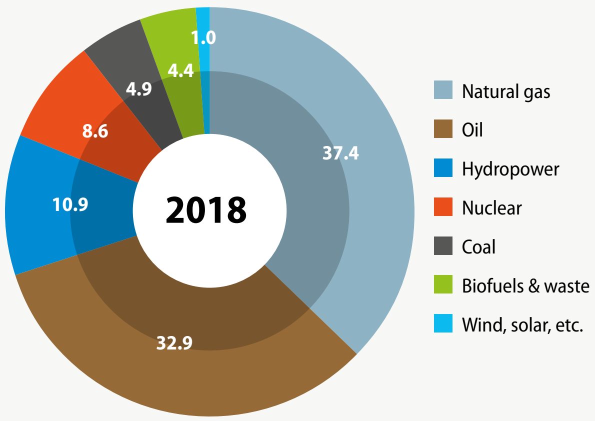


50%
Anticipated growth of Canadian crude oil production between 2018 and 2040

30%
Anticipated growth of natural gas production between 2018 and 2040

1.7%
Share of clean energy in Canada's GDP in 2017

Total primary energy supply in Canada by source, 2018 (%)



Capital investment in Canada's domestic oil sands industry

Can$ 44 billion
in 2014

Can$ 12 billion
in 2019 (forecast)

The cost-incentive of putting a price on carbon pollution of Can$ 50 per tonne by 2022 is designed to boost the implementation rate for renewable energy.

The Canadian Association of Petroleum Producers attributes this dip to the difficulty in building new pipelines, as well as investor concerns over the cost and uncertainty of Canada's regulatory system.

Source: OECD.Stat, May 2020; for energy data, International Energy Agency and CER (2019) developing vaccine candidates for the virus. These recipients include the University of Saskatchewan's Vaccine and Infectious Disease Organization, the International Vaccine Centre (VIDO-InterVac), the National Research Council's research on vaccines and the Toronto-based digital health firm BlueDot.

Genome Canada has also launched a rapid response fund to support genomics-informed solutions for Covid-19 at local, provincial and national levels, through collaborations between academia and the industrial, not-for-profit and public sectors.

Meanwhile, Canada's Industrial Research Assistance Program, which promotes innovation in small and medium-sized enterprises (SMEs) employing fewer than 500 staff, has adapted to the crisis by offering a challenges programme for SMEs with near-to-market solutions related to Covid-19 that require financial support to refine and sell their product or process.

A Covid-19 Immunity Task Force is working to establish priorities and oversee a series of country-wide campaigns to gather blood samples, in order to gauge how far the virus has spread and provide reliable estimates of potential immunity and vulnerabilities in the Canadian population.

Until 2020, when Covid-19 radically transformed Canadians' way of life, compelling them and the rest of the world to re-assess the role of medical and health research, scientific literacy and innovation, there had been no crisis to spark any serious national conversation about the direction in which Canada was taking science, technology and innovation (STI). This global pandemic has energized Canada's knowledge production systems. It may, ultimately, redefine Canada's science processes, output and governance in ways that cannot yet be foreseen. It will also affect the next generation of researchers and the mechanisms by which science itself is funded.

Steps taken to achieve the SDGs

Positioning Canada as a global leader in clean technology continues to be a major plank of government efforts to diversify and upgrade Canada's large oil- and gas-based economy. The government is implementing the *Pan-Canadian Framework on Clean Growth and Climate Change* (2016). This document commits to reducing Canada's greenhouse gas emissions by 30% below 2005 levels by 2030 (Govt of Canada, 2017). Putting a price on carbon pollution is a cornerstone of the plan, with a target of Can$ 50 per tonne by 2022. This cost-incentive is designed to boost the implementation rate for renewable energy in a country with a low population density and high technical capacity.

For example, the Saskatchewan Chamber of Commerce (2019) has estimated that it has the capacity to generate half of its power from renewable sources by 2030. Saskatchewan has the greatest solar potential among the provinces as well as strong wind power potential. It also has reserves of coal, oil and natural gas, with coal-fired plants being the primary source of electricity. The neighbouring Province of Manitoba was already producing 99% of its electricity from renewables in 2015.

Conversely, the Province of Alberta cancelled its own Renewable Electricity Program in June 2019 (CER, 2019).

Many provinces have policies supporting low- and zero-emission vehicles, including Quebec and British Columbia. There are also subsidies at the federal level for electric vehicles and related charging infrastructure (CER, 2019).

In line with federal regulations, coal is to be phased out by 2030. According to projections which assume that announced pipeline projects will proceed as planned, crude oil production should grow by nearly 50% and natural gas production by over 30% between 2018 and 2040, driven largely by *in situ* oil sands and shale resources (CER, 2019).

The Canadian Association of Petroleum Producers (CAPP), meanwhile, forecasts that capital investment in the domestic oil sands industry will dip for the fifth year in a row in 2019, from Can$ 44 billion in 2014 to Can$ 12 billion. CAPP attributes this trend to the difficulty in building new pipelines, as well as investor concerns over the cost and uncertainty of Canada's regulatory system.

In 2017, the federal government invested in a *Clean Technology Data Strategy* to provide the foundation for measuring the socio-economic and environmental impact of clean technology in Canada. In 2017, clean energy accounted for 1.7% of Canada's GDP.

Climate change has come to the fore as a key public policy issue and research focus. According to a July 2019 survey, 77% of Canadian climate scientists think that highly qualified researchers are leaving the field for lack of support for their work and 94% of climate scientists say that they rely on foreign resources to carry out their research. The survey argues for a climate science funding strategy that meets the needs of this diverse, multidisciplinary area of research over the long term (MacLean, 2019).

In 2020, the government adopted a more ambitious target of achieving net-zero carbon emissions by 2050, with legally-binding five-year milestones; this effort is to be partially financed by the investment of profits from the eventual sale of the Trans Mountain Expansion Project in clean energy projects and climate-related solutions.

Other objectives are to increase Canada's international assistance each year and plant two billion trees over the next decade in pursuit of the Sustainable Development Goals (SDGs).

To mark World Oceans Day on 8 June 2020, the prime minister announced the target of protecting 25% of Canada's land and oceans by 2025. This plan is to be grounded in science, indigenous knowledge and local perspectives. The government adopted a Can$ 1.5 billion *Oceans Protection Plan* in 2016. By 2018, nearly 14% of marine and coastal areas had been protected, up from around 1% in 2015 (PMoC, 2020).

To guarantee safe, clean and well-managed water supplies, the federal government mandated the Minister of Environment and Climate Change and the Minister of Agriculture and Agri-food in December 2019 to create a Canada Water Agency which would work in conjunction with provinces, territories, indigenous communities, local authorities and scientists.

To monitor these and other commitments, Statistics Canada launched the Sustainable Development Goals Hub (SDG Data Hub) in May 2018.[2]

A reboot of public research

Canada's gross domestic expenditure on research and development (GERD) amounted to Can$ 35.7 billion in 2017; this represents a 2% increase over the previous year. The increase was mainly tied to a 3.8% rise (to Can$ 14.3 billion) in research expenditure for the higher education sector, the eighth hike in as many years. This underscores the role that the Canadian higher education sector plays as a prime driver of innovation – even as a surrogate for industrial research and development (R&D) – particularly in comparison to other members of the Organisation for Economic Co-operation and Development (OECD).

The 2018 budget introduced almost Can$ 4 billion in new funding over five years. Of this, Can$ 925 million was channelled to universities and colleges for basic research, via the three federal granting councils, namely, the Natural Sciences and Engineering Research Council of Canada, the Canadian Institutes of Health Research and the Social Sciences and Humanities Research Council of Canada.

By contrast, the 2019 budget directed funding primarily towards federal organizations and institutions. Despite a forecasted 2.6% decline in overall government expenditure in 2019 (Statistics Canada, 2019a), the public research infrastructure and apparatus are receiving a reboot after decades of decline, with considerable investment in new facilities and experimental models of co-operation trialled between federal laboratories and the academic and business sectors.

The Strategic Innovation Fund was established as part of Canada's *Innovation and Skills Plan* (2017) to spur innovation in large-scale projects by industry, including R&D and commercialization of the fruits of this work. Over 65 projects had been supported by Can$ 2.2 billion by early 2020. An additional Can$ 2.8 billion has been set aside for the 2018–2022 period to renew federal laboratory infrastructure.

As for expenditure on industrial R&D, it has flatlined, despite attempts to provide new incentives with academic research partners, including through shared technology clusters in targeted areas such as proteins, oceans and AI (Box 4.1). Only one Canadian company spends more than Can$ 1 billion on R&D, a heavily subsidized aerospace and transport firm that is currently encountering financial difficulties.

Box 4.1: **Superclusters to boost innovation**

In 2017, the government allocated Can$ 950 million over a five-year period to support innovative 'superclusters'. In so doing, the government is challenging Canadian enterprises to enter into collaborative partnerships with research institutions, in order to develop 'bold and ambitious' innovation strategies. The government expects the initiative to result in the creation of 50 000 jobs over ten years.

These superclusters are an attempt to define a new model for enhancing strategic investment in innovation, in which the private sector is required to match government funding. After a nine-month competition that led to over 50 letters of intent, the winning superclusters covered five sectors and were spread across the country.

The first of these is the **Next Generation Manufacturing Supercluster**, based in Ontario. It is working with over 1 000 collaborators to scale up new manufacturing capabilities in the automotive, aerospace and biomedical sectors, among others. Since the outbreak of the novel coronavirus, this supercluster has allocated up to Can$ 50 million through its Covid-19 Response Program, which is helping companies to produce essential equipment and medical products and develop their technological capacity in the process.

Canada's **Ocean Supercluster** on the Atlantic coast targets the development of the ocean economy, which currently accounts for 1% of Canadian GDP, compared to the global average of 3.5%. Canada has the world's longest coastline and fourth-largest ocean territory. The Halifax-based supercluster aims to bring together leaders in ocean-related industries to co-invest in R&D to solve key ocean challenges. As part of one of its first projects, the cluster has invested Can$ 5.9 million over three years to advance capacities for data acquisition and analytics using underwater robots, for the purpose of assessing ocean environmental metrics and marine habitats, among other uses.

The **Protein Industries Supercluster** in the Prairie provinces, meanwhile, plans to integrate plant genomics, novel processing technologies, information technology and AI from the crop level in the supply chain for plant protein food and feed. With more than 120 participants, it aims to raise Canada's share of global agricultural exports to 8% by 2025, up from 5.7%.

Over 350 organizations are working together in the **Digital Technology Supercluster** based in British Columbia to innovate in areas that include virtual, mixed and augmented reality, data analytics and quantum computing. Pilot projects are underway in precision health, natural resources and manufacturing. This supercluster is investing up to Can$ 60 million through its Covid-19 Program in projects building technological solutions to problems related to the coronavirus, as well as future outbreaks.

The **Scale Artificial Intelligence Supercluster**, based in Montreal, Quebec, is arguably the most far-reaching of the five experiments in innovation. It is focusing on integrating AI and data science in supply chains, particularly in the retail, manufacturing and infrastructure sectors. In May 2020, this supercluster launched a call for projects to find ideas and solutions to the Covid-19 crisis that leverage technology. Within three weeks, more than 120 projects had been submitted and eight approved, representing a total investment of over Can$ 3.4 million.

Source: compiled by author

The risk of erosion

Since 2015, three Canadians have received the Nobel Prize in Physics: Art McDonald for his work at the Sudbury Neutrino Laboratory; Donna Strickland for her work on lasers, becoming only the third woman to be awarded a Nobel Prize in Physics; and James Peebles, for theoretical discoveries in physical cosmology.

Despite these accomplishments, Canada's international standing as a leading performer of research is in jeopardy, according to the Council of Canadian Academies (CCA, 2018), following a sustained slide in private and public investment in R&D. Canada's industrial research intensity (Figure 4.2) is only half the OECD average (CCA, 2018).

Although Canada retains respect in some classic fields and ranked 10th globally for the volume of output in 2018 (Figure 4.3), it produces a relatively small share of the world's research in promising areas for most enabling and strategic technologies (CCA, 2018).

Canada's place in the scientific world is being challenged both by traditional and rising players. This can be explained by various factors. For one thing, provinces and territories all have their own programmes and strategies but there is no national approach to science and technology and, thus, no national vision.

In addition, Canadian industrial research spending is declining and remains concentrated in industries that are intrinsically less research-intensive, even if there are pockets of research strength across several industries, including those of computer systems, communications equipment and aerospace manufacturing (CCA, 2018). The relative scarcity of data is constraining a sounder assessment of research activities, particularly in industry and in the social sciences, arts and humanities (CCA, 2018).

Industrial R&D remains a weak link, with foreign-controlled firms accounting for one-third of all in-house R&D, a persistent trend over recent decades. Industry is increasingly outsourcing R&D abroad. According to Statistics Canada, outsourced research expenditure by companies in Canada rose for the third consecutive year to Can$ 4.9 billion in 2017.

Canadian innovators produce about 1% of global patents, ranking 18th in the world (Figure 4.4). The barriers between innovation and wealth creation in Canada are greater than those between research and innovation (CCA, 2018). The result is a deficit of tech-based start-ups growing to scale in Canada and a loss of economic benefits.

Although macro-economic conditions and the regulatory environment appear to be conducive to business creation and development, Canada's promising start-ups are often being acquired and developed in other countries, leading to a loss of economic and commercial benefits. Survey evidence from Canadian firms and technology stakeholders also suggests that a lack of managerial talent and experience in expanding domestic technology firms to scale is a critical impediment (CCA, 2018).

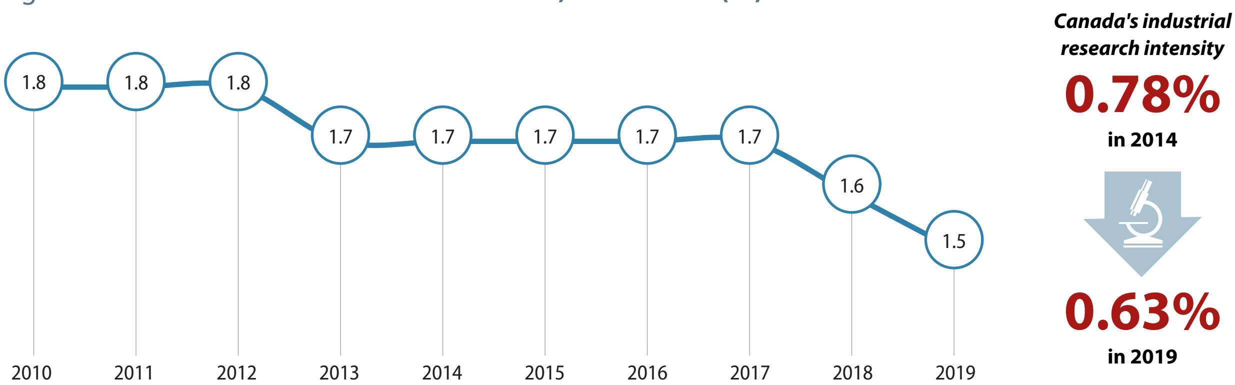
Industry groups maintain that governments continue to operate with the supply-side view that innovation takes a linear approach. They consider that policy frameworks, intellectual property and regulations need to be treated as priorities. For them, adding to Canada's list of scientific programmes will not suffice to solve the country's problems. In fact, the federal government has been doing the opposite: downsizing its suite of programmes by consolidating almost 100 programmes into 38.

A number of surveys suggest that the performance of Canada's industrial sector is declining (CCA, 2018). Research Infosource Inc.'s 2019 survey of Canada's Top 100 Corporate R&D Spenders, for instance, suggests that innovation policy in Canada is 'running on fumes' and that new initiatives will take time to emerge. The survey recommends lowering expectations. With the likely reprofiling of some industrial sectors in the wake of Covid-19, this situation is not likely to improve, although the new Industry Strategy Council may offer novel options for a renewed innovation and research focus in Canada's business sectors in the post-Covid-19 era. This council is discussed in the following section.

A new research co-ordination body

In 2018, the longstanding Networks of Centres of Excellence programme was cancelled (Dufour, 2015). This programme has been replaced as part of a new approach that saw the establishment of the Canada Research Coordinating Committee (CRCC), further to a recommendation by Canada's *Fundamental Science Review* of 2017, also known as the Naylor Report.

Figure 4.2: **GERD as a share of GDP in Canada, 2010–2019 (%)**

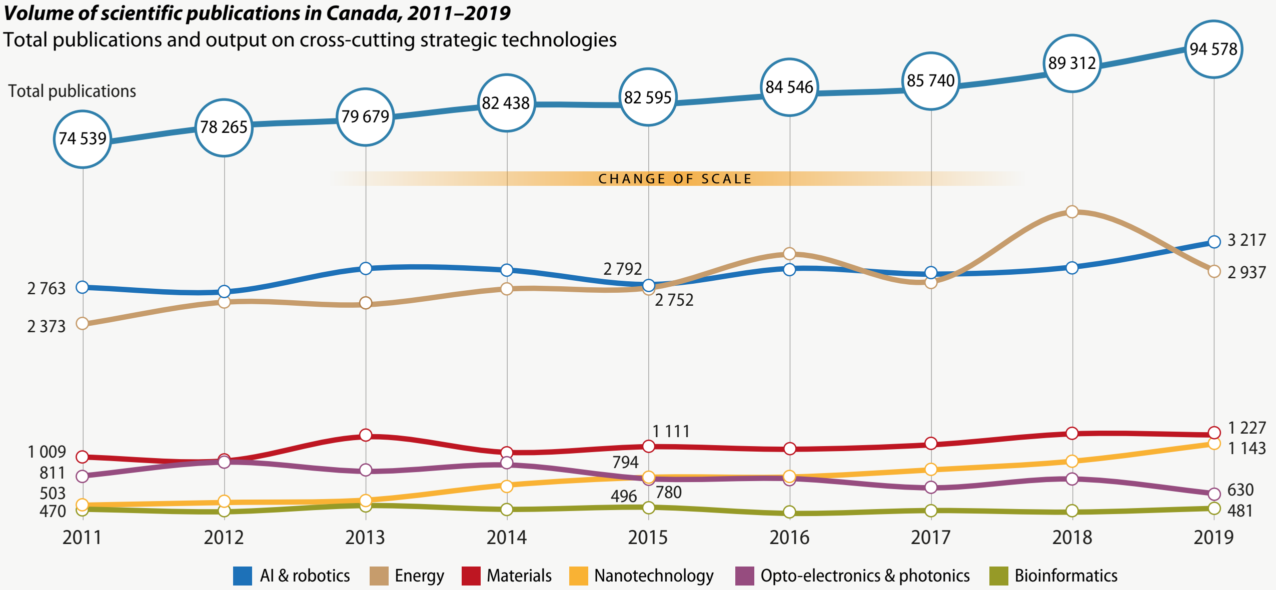


Source: OECD (2020) Main Science and Technology Indicators. Organisation for Economic Co-operation and Development: Paris. July

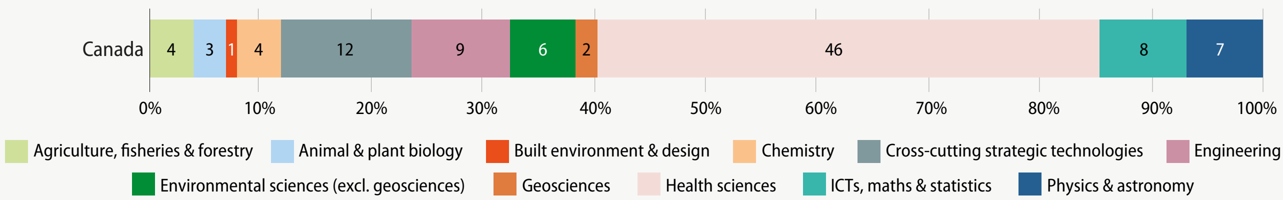
Figure 4.3: **Trends in scientific publishing in Canada**

Volume of scientific publications in Canada, 2011–2019

Total publications and output on cross-cutting strategic technologies



Scientific publications in Canada by broad field of science (%), 2017–2019



56%

Share of publications with foreign co-authors in Canada, 2017–2019; the OECD average is 34%

1.38

Average of relative citations for Canada, 2014–2016; the OECD average is 1.11

Scientific publications per million inhabitants in Canada, 2011, 2015 and 2019

How has output on SDG-related topics evolved since 2012?

Canadian researchers published more on several topics related to biodiversity and climate change than would be expected, relative to global averages, including carbon pricing and carbon capture and storage. Putting a price on carbon is a cornerstone of the *Pan-Canadian Framework on Clean Growth and Climate Change* (2016).

The intensity of output on the use of ecosystem-based approaches in protected areas was even five times the global average, despite modest numbers: 94 (2012–2015) and 88 (2016–2019) publications. Researchers also published 3.1 times and 1.7 times the global average on the local impact of climate-related hazards and disasters and on strategies to mitigate such hazards, respectively.

The intensity of output was no higher than would be expected, however, on traditional knowledge, cleaner fossil fuel technologies and industrial waste management, despite the logistical and environmental challenges of waste management in the Athabasca oil sands.

With the exception of growth in publications on smart-grid technologies from 1 328 (2012–2015) to 1 869 (2016–2019), output on renewable energy technologies remained modest; it was even half the global average intensity for photovoltaics: 857 (2012–2015) and 950 (2016–2019).

For details, see chapter 2

Canada's top five partners for scientific co-authorship, 2017–2019 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Canada	USA (65 364)	China (26 604)	UK (22 433)	Germany (15 721)	France (15 318)

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

The CRCC harmonizes programmes and policies adopted by the three councils responsible for research grants (granting councils), in order to ensure that these councils operate as a coherent system. Historically, the lack of an effective co-ordination mechanism has been a weakness of the federal research system (APoFSFS, 2017).

More funding for 'high-risk' research

The CRCC launched a New Frontiers in Research Fund in 2018 to bolster federal support for game-changing research. This fund is investing Can$ 275 million between 2018 and 2023, and Can$ 65 million on an ongoing basis in 'international, interdisciplinary, fast-breaking and high-risk research'. The fund selects projects for grants under three strands: 'exploration' grants for high-risk, high-reward research; 'transformation' grants, providing large-scale support for interdisciplinary and transformative research; and 'international' grants to support Canadian engagement with partners abroad. The inaugural call for proposals received over 1 700 applications, far exceeding expectations.

The federal government also proposes establishing a Strategic Science Fund. Within a 'principles-based framework', an independent panel of experts would select recipient organizations and determine the level of funding for each recipient, as part of a competitive and transparent allocation process. Third-party organizations such as the Perimeter Institute for Theoretical Physics, Brain Canada, CCA, Genome Canada and CIFAR (formerly known as the Canadian Institute for Advanced Research) would be eligible to apply to the fund, which could be operational as early as 2022.

In the meantime, the CCA is leading an assessment of the practices of funding agencies around the world. The aim is to examine the ways in which Canada can apply innovative practices at home in a rapidly evolving and increasingly interconnected environment.

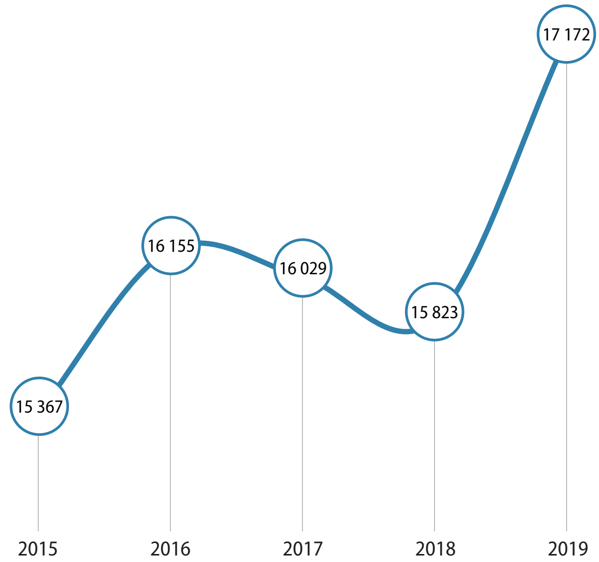
A chief advisor to bridge government and science

Almost ten years after its abolition, the position of Chief Science Advisor was revived in 2017. This followed a campaign by several groups, including Evidence for Democracy and the Royal Society of Canada. The latter had argued that a new high-level science and technology advisory committee should replace the defunct Science, Technology and Innovation Council (RSC, 2018).

The Royal Society of Canada also recommended that the government further empower the newly appointed Chief Scientific Advisor through legislation recognizing the incumbent as the key interlocutor for connecting external science and government research. The Royal Society of Canada's proposals stem from its diagnosis of a gap between Canada's scientific capacity and government decision-making, with 'few clear pathways [to] enable and facilitate engagement between those inside government and leading scientists and scholars across Canada' (RSC, 2018).

Borrowing from the UK's science advisory model, the Chief Science Advisor has established science advisors in several federal departments and agencies, including those with a portfolio for space, the environment, natural resources, fisheries and oceans, as well as at the National Research Council.

Figure 4.4: **Number of IP5 patents granted to Canada, 2015–2019**



Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China.

Source: PATSTAT; data treatment by Science-Metrix

A Youth Council has also been established to support the Chief Science Advisor's mandate. It counts 20 members selected from among more than 1 100 applicants. The council has been asked to include in its mandate reporting and research on the barriers that Black and other minority ethnic groups come up against in STEM.

The Chief Science Advisor has produced a model policy on scientific integrity for use by federal government researchers, in conjunction with the Professional Institute of the Public Service of Canada. This model policy encourages federal scientists to speak openly about their work and provides a framework for employers and employees on the conduct of government science. It also recognizes the role played by researchers in communicating scientific information to the public.[3]

In November 2019, the prime minister tasked the Minister for Innovation, Science and Industry with assisting the Chief Science Advisor in ensuring that the outcome of government-funded research in the basic and applied sciences is made available to the public, that scientists are able to speak freely about their work and that scientific analysis from across Canada and beyond is considered when the government makes decisions.

The Chief Science Advisor is participating in a global network of science advisors that is sharing the latest research on the fallout from the Covid-19 pandemic. Together with Prof. Rémi Quirion, Chief Scientist for Quebec, Dr Mona Nemer is planning the 2021 edition of the International Conference on Science Advice to Governments, which is due to take place in Montreal and is slated to launch a North American chapter of the International Network for Government Science Advice.

The Inuit Tapiriit Kanatami, a body representing the 65 000 Inuit residing in Canada, published its *National Inuit Strategy on Research* in March 2018. This strategy redirected attention to the issue of integrating community-based knowledge into Canada's knowledge ecosystem. Among other recommendations, the implementation plan calls for an Inuit Nunangat Deputy Chief Science Advisor to help oversee the development of an Inuit Nunangat research policy.

A roadmap for open science

The Chief Science Advisor has released a *Roadmap for Open Science* (2018) which specifically applies to scientific output funded by federal government departments and agencies. Its key recommendation to the government is for a common, phased approach to implementing open science[4] across science-based departments and agencies. As a starting point, it proposes that all federal research articles be openly accessible without an embargo period from January 2022 onwards.

The rise of citizen science

Increasing activism by groups such as Evidence for Democracy, Science Outside the Lab North, Science and Policy Exchange and its alter ego, the Toronto Science Policy Network, combined with the activism of youth groups, visible minorities and women's groups, has strengthened public engagement with science, including when it comes to addressing systemic racism.

Citizen science has become increasingly prominent. For instance, Quebec's Chief Scientist has been championing a novel participative science project on birds during the period of the Covid-19 pandemic.

A focus on AI at home and abroad

The *Pan-Canadian Artificial Intelligence Strategy* (2017) has been billed as one of the first national AI strategies (Stromme *et al*., 2018).

The Canadian AI strategy is led by CIFAR with support from the country's three centres of excellence in AI located in the cities of Edmonton, Montreal and Toronto,[5] along with universities, hospitals and organizations across the country. The pan-Canadian AI strategy aligns with the work of the Scale Artificial Intelligence Supercluster (Box 4.1).

Federal funding of Can$ 125 million supports the objectives of increasing the number of outstanding AI researchers and skilled graduates in Canada, establishing nodes of scientific excellence at the three major AI centres, developing 'global thought leadership' on the economic, ethical, policy and legal implications of AI advances and supporting a national research community working on AI.

The Canada CIFAR AI Chairs Program is the cornerstone of the strategy. It benefits from funding of Can$ 86.5 million over five years to attract and retain world-renowned AI researchers. The 80 Canada CIFAR AI Chairs announced to date work across industry and academia and are conducting research in fields that range from machine learning for health to autonomous vehicles and artificial neural networks to monitor climate change.

The private sector has contributed more than Can$ 100 million to the three centres of excellence in AI (Stromme *et al*., 2018). There were about 650 start-ups in AI by 2018. Although the growth rate of start-ups flattened in 2019, according to the CEO of Element AI (Gagne, 2019), investment in the surviving companies more than doubled to Can$ 660 million and revenue for companies proposing AI solutions rose by 65% between 2017 and 2018.

CIFAR is working with researchers and organizations across Canada to support training programmes for the next generation of AI researchers, with a special focus on those that advance equity, diversity and inclusion in AI and deliver a positive social impact. CIFAR's AI and Society Program facilitates cross-sectoral discussion of the challenges that AI poses to society, including its implications for the practice of medicine and for democracy, climate change, children and other vulnerable groups.

In response to Covid-19, CIFAR has set up workshops and funding opportunities for research. One of these, the Catalyst Grant Program, provided seed funds for 14 AI research projects in May 2020 for interdisciplinary collaboration on public health issues.

The federal government appointed an Advisory Council on AI in May 2019 with a focus on examining how to build on Canada's strengths to ensure that AI advancements reflect Canadian values, such as human rights, transparency and openness. The Advisory Council on AI has established a working group on extracting commercial value from Canadian-owned AI and data analytics. It will also provide guidance on strategies to achieve the goals of the *Canada–France Statement on Artificial Intelligence*, approved at the G7 Summit held in Quebec in 2018.

Canada is seeking to assume a leadership role in the international endeavour to understand the societal implications of AI. In 2017, the Université de Montréal launched the *Montreal Declaration for a Responsible Development of Artificial Intelligence*, in collaboration with civil and academic partners. The *Declaration* looks to the potential benefits that AI and related technologies could bring, such as by improving efficiency in agriculture, reducing health care costs, assisting people with disabilities, optimizing energy resources and aiding conservation efforts. It also warns of potential risks, stating that, without regulations and due diligence, intelligent machines could restrict the choices of individuals and groups, lower standards of living and disrupt the job market, or even damage ecosystems and influence the climate.

According to a June 2020 report from the UK think tank Nesta, institutions from China, USA, UK, India and Canada together account for 62% of AI applications developed in response to Covid-19 (Mateos-Kinger *et al*., 2020).

Shortly after several countries announced the Global Partnership on Artificial Intelligence (GPAI)[6] in June 2020, Canada joined the project to become one of its founding members. Simultaneously, the federal government and Government of Quebec announced the opening of the International Centre of Expertise in Montréal for the Advancement of Artificial Intelligence, which will advance the cause of responsible development of AI.

The GPAI secretariat will be hosted by the OECD secretariat in Paris, France. GPAI's mandate covers four themes, two of which are supported by the new Centre of Expertise in Montreal, namely, responsible AI and data governance. A corresponding centre of excellence in Paris, yet to be identified, will support the other two themes on the future of work and innovation, and commercialization. GPAI will also investigate how AI can be leveraged to respond to the Covid-19 pandemic.

Canada's International Development Research Centre (IDRC) has assumed a prominent role in global efforts to assess the potential impact of AI in the global South. In a 2018 white paper, the IDRC argued that inherent biases and inequities within a dataset could be amplified by machine learning, if datasets are inadequate (Smith and Neupane, 2018). The risk of job losses as a result of AI and automation is not unique to developing nations but may be exacerbated by weak regulatory capacity. The IDRC is embarking on a programme to help developing countries build innovative AI for good and to regulate and govern AI technologies.

SCIENCE DIPLOMACY

An emphasis on responsibility in global science

Canada's key *cachet* remains its openness and global connections as a G7 and G20 partner with an international outlook. The government is reviewing its international strategy for science with a focus on enhancing partnerships and science diplomacy. Canada produces about 3.6% of the world's scientific output, partly as a result of its partnerships with active countries and global research bodies (CCA, 2018).

As host of the G7 Summit in May 2018, Canada received input from the national academies of science of all seven countries in two areas of national and global concern: countries' digital future and Arctic sustainability.

Concerning the digital future, the national academies of science state that 'international cooperation will be essential in key areas of security, accessibility, and regulation to secure a digital future that is inclusive, democratically governed and ethically minded in which open data and reliable information can circulate.' The academies recommend 'democratic governance in the form of regulatory frameworks to set up an oversight of Internet service providers, social media and other entities and prevent private monopolistic or oligopolistic power in the digital economy and to ensure open and neutral Internet, protection of digital data and respect for norms of individual privacy' (G7 AoS, 2018).

On the theme of Arctic sustainability (Box 4.2), the national academies of science call for broad international collaboration to support research and promote thriving coastal communities. They observe that longer ice-free shipping seasons and other climate-related changes to the Arctic regions could stimulate investment ranging from US$ 85–265 billion over the next decade in Arctic tourism, fisheries and natural resource development. They also observe that these socio-economic changes heighten 'potential risks such as oil spills, shipping disasters and environmental contamination with subsequent public health risks.'

Chapter 4

Box 4.2: **Responding to rapid northern change**

The circumpolar Arctic is warming at about three times the global average, making this region – and the people who call it home – among the most affected by climate change. Rapid and often irreversible changes are redefining its environmental and socio-economic landscapes.

According to Canada's *Changing Climate Report* (2019), northern warming will continue, whether the world follows a high or low trajectory for greenhouse gas emissions. The high-emission scenario could lead to temperatures and extreme events that are four times the global average. Loss of sea ice and thawing permafrost are forming feedback loops that will exacerbate climate change.

The Canadian High Arctic Research Station Act (2015) created Polar Knowledge Canada as the lead federal agency for strengthening Canadian leadership in polar science and technology. Polar Knowledge Canada is funding innovative research to support efforts in mitigation and adaptation.

For example, the Oceans Network Canada, which is based at the University of Victoria, received support in 2018 that has enabled it to set up community observatories in northern areas for joint research with indigenous communities. This research will combine physico-chemical water sampling with change monitoring and traditional and local knowledge.

From 2020 to 2023, Polar Knowledge Canada's pan-northern Science and Technology Program will fund projects on the three following themes: understanding dynamic northern ecosystems in the context of rapid change; advancing sensible energy, technology and infrastructure solutions for the North; and bridging northern community wellness and environmental health. These projects will build on previous efforts, such as the Arctic Zoonoses Network, a community-centred monitoring network for vector-borne diseases and wildlife zoonosis in a changing Arctic.

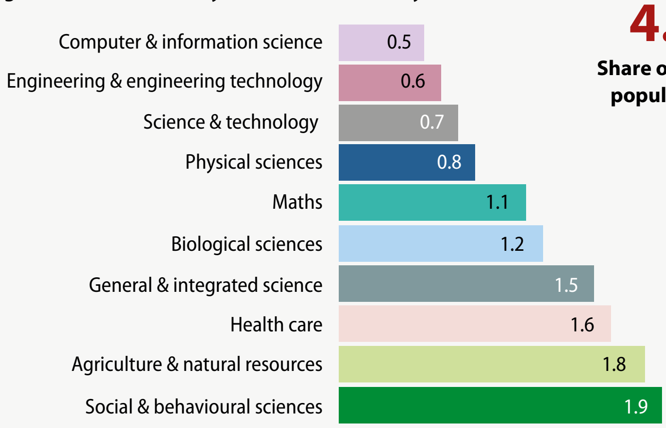
The Canadian High Arctic Research Station opened in 2019 in Cambridge Bay. It offers a unique space for enhancing international co-operation in Arctic research. The station provides access to research sites, infrastructure and data and has already hosted international researchers from several countries, including Japan and the Republic of Korea. Built from a design benefiting from Inuit knowledge, the station is embedded in a local community and is intended to develop bridges between science and society. The aim is to develop research capacity attuned to community needs in the Arctic.

If there is a single argument for a collaborative approach to a shared Arctic and northern future, it is the shared and complex challenges posed by climate change. The response of all partners to this challenge must be no less transformative in scale, scope or duration.

Source: Polar Knowledge Canada; Ministry of Crown-Indigenous Relations and Northern Affairs (2019) *Arctic and Northern Policy Framework*. Government of Canada: Ottawa

Figure 4.5: **Trends in human resources in Canada**

Share of indigenous graduates among total tertiary graduates in Canada by selected field of study, 2016 (%)



4.8%

Share of indigenous population, 2016

Canadian researchers (FTE)

161 982

in 2014

158 890

in 2017

Canadian researchers (FTE) per million inhabitants

4 542

in 2014

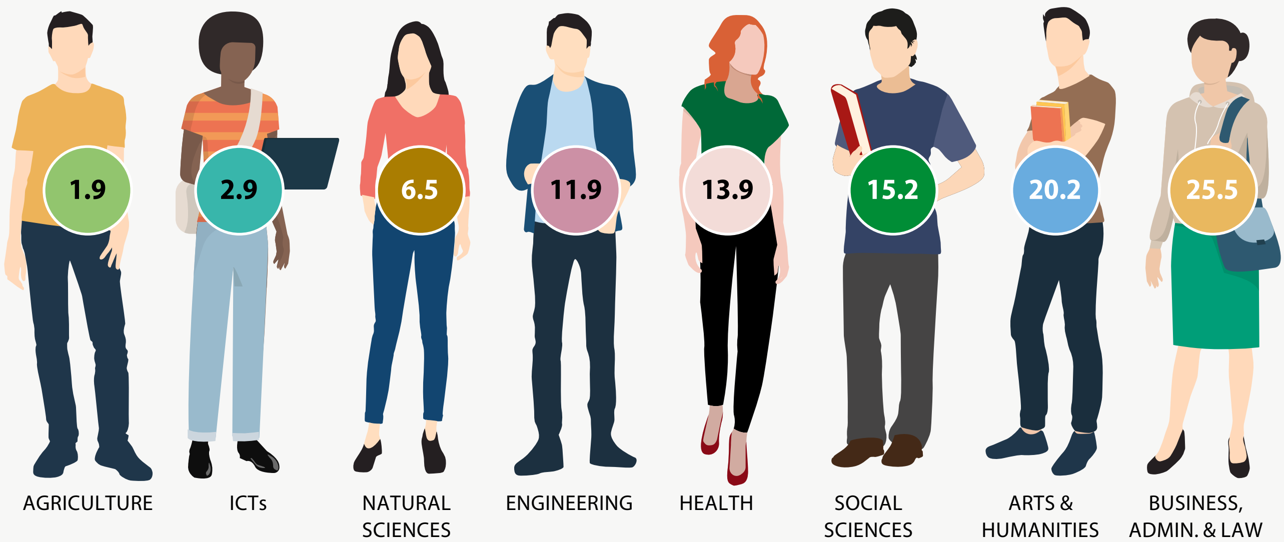
4 326

in 2017

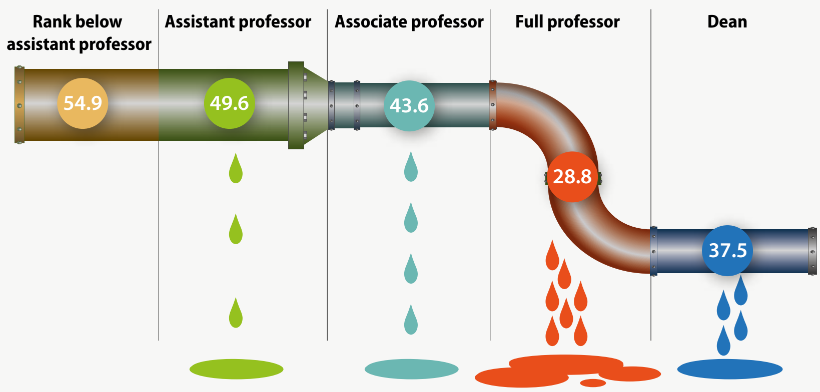
58%

Share of Canada's population aged 25 to 64 with a tertiary degree, 2018; the proportion rises to 64% for women

Distribution of Canadian students by programme, 2016 (%)



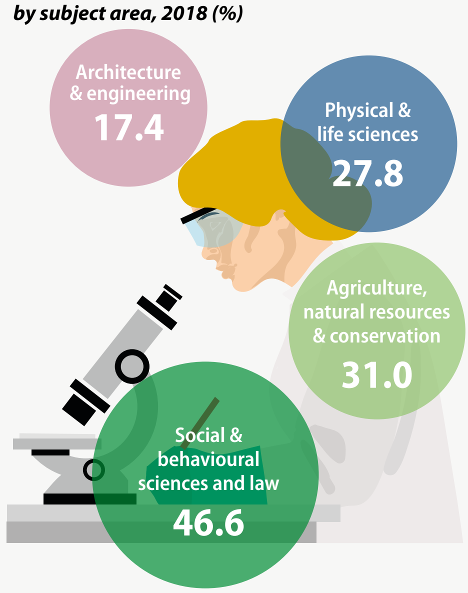
Share of female faculty in Canada by rank, 2018 (%)



40.6%

Share of women among full-time faculty in Canada, 2018

Share of full-time female faculty in Canada by subject area, 2018 (%)



Note: Graduates represent people over the age of 25 years holding a degree at the bachelor's level or above; 2% of graduates held degrees in unspecified fields of study. Indigenous graduate statistics are based on values for people reporting 'Aboriginal identity' in the 2016 Canada census.

Source: for GERD: OECD.Stat; for female faculty and indigenous graduates: Statistics Canada; for students by programme and researchers: UNESCO Institute for Statistics

A focus on the Arctic

The Arctic is a strategic zone where there is potential for Canada to strengthen international linkages (Box 4.2).

Canada's *Arctic and Northern Policy Framework* (2019) sets clear priorities and actions for the federal government and its partners. Selected priorities include investing in energy, transportation and communications infrastructure, fostering innovation and jobs in northern economies and supporting science and research that is meaningful for northern communities. These efforts advance the national agenda of reconciliation and frame new relationships among Inuit, First Nations, Métis and non-indigenous residents in the North and throughout the country.

Canada is active in the Arctic Council (see also Box 13.2) and has played a strong role in the Arctic Science Ministerial, the third edition of which is slated to take place in May 2021, co-hosted by Iceland and Japan. Among its themes will be capacity-building in education, and knowledge with Arctic residents and communities.

In the 2019 federal budget, Can$ 34 million was set aside to enhance Canada's global Arctic leadership over a five-year period by creating Canada's first permanent secretariat within the Arctic Council for the Working Group on Sustainable Development.

A 'green' focus in international agreements

Canada is also implementing the *Ocean Plastics Charter* and the *Charlevoix Blueprint for Healthy Oceans, Seas and Resilient Coastal Communities*, which take up the challenges raised by the academies of science of the G7. These agreements were championed by Canada when it hosted the G7 in 2018. The *Ocean Plastics Charter* was endorsed by the European Union, France, Germany, Italy and the UK at the G7. The *Charter* highlights the importance of avoiding single-use plastics and commits to specific targets for recycling plastics. It has since been signed by the International Union for Conservation of Nature and by dozens of countries and businesses around the world.

Together with Kenya and Japan, Canada co-hosted the first global conference on the sustainable blue economy in 2018, where Can$ 9.5 million was pledged in support of the United Nations Decade of Ocean Science (DFO, 2018).

In 2018, the European Union (EU) and Canada updated their Comprehensive Economic and Trade Agreement (CETA), which had entered into force the previous year, by including a reference to promoting 'the mutual supportiveness of trade and climate policies,' in the context of their commitment to the *Paris Agreement* (2015) on climate action.

For its part, the tripartite Canada–United States–Mexico Agreement which replaced the North American Free Trade Agreement in July 2020, contains an Environmental Cooperation Agreement emphasizing green growth.

TRENDS IN HIGHER EDUCATION

A challenge to engage youth

In the 2018 rankings of the OECD's Programme for International Student Assessment, 15-year-old Canadian students scored higher than the OECD average for science, mathematics and reading. However, performance in mathematics and science has declined by ten points or more per decade since 2003 and 2006, respectively.

In 2015, about half of Canadian 15-year-olds were aware of key environmental issues but rarely followed news about science (Statistics Canada, 2019b). This lack of engagement presents a challenge for scientists and science communicators,[7] especially as concerns issues relating to health, society, the environment and the economy.

One Canadian non-governmental organization, in particular, has been instrumental in shaping the next generation's understanding of the evolving knowledge landscape in the North. Students on Ice takes youth from Canada and around the world on journeys to the polar regions, introducing them to a broad spectrum of dialogue ranging from arts, culture and history to science, sustainable development and geopolitics. It celebrated its 20th anniversary in 2020.

In May 2020, the Natural Sciences and Engineering Research Council awarded over Can$ 9 million, within its PromoScience programme, to more than 80 organizations that engage in scientific outreach across the country.

Efforts to make education more inclusive

The government is working to make education more inclusive. As of May 2020, Canada has a fully-fledged, degree-granting university north of the 60th parallel: Yukon University, based in Whitehorse.

In 2016, only 10.9% of indigenous people held a tertiary degree, compared to 28.5% of the total population. This imbalance is being addressed at the university level, including by three indigenous-specific STEM programmes. For instance, Mount Royal University in Alberta ran the Aboriginal Science and Technology Education Program from 2012 to 2019. Between 2011 and 2017, the indigenous student population at the university's Faculty of Science and Technology rose from 1.7% to 4.2% of the student cohort.

In addition, the CRCC has instituted a wide-ranging strategic plan to support indigenous research and training over the 2019–2022 period. This plan is anchored in four key principles:

- *self-determination*: fostering the right for First Nations, Inuit and Métis peoples to set their own research priorities;
- *decolonization of research*: respecting indigenous ways of knowing and supporting community-led research;
- *accountability*: strengthening accountability when it comes to respecting indigenous ethics and protocols in research and identifying the benefits and impact of research in indigenous communities; and
- *equitable access*: facilitating and promoting equitable access and support for indigenous students and researchers.

By 2018, gender parity had been reached at the rank of assistant professor (49.6%), although only 28.8% of full professors were women and the share of women among full-time faculty varied strongly from one field to another (Figure 4.5).

Notably, women accounted for only 17.4% of faculty in architecture, engineering and related technologies in 2018. With two notable exceptions, all of Canada's major research organizations are led by men.

Greater exposure abroad for young minds

Canada leads the G7 countries for the share of the population (58%) with a tertiary degree (Figure 4.5), followed by Japan (53%) and the USA (47%).

Among its G7 peers, Canada hosted a higher proportion of international students (12.9%) in 2017 than Germany (8.4%), Japan (4.3%) or the USA (5.2%), according to OECD data. There has been steady growth in the share of international students since 2011, when they accounted for less than 10% of university enrolment (Frenette *et al*., 2020).

In the 2016/2017 academic year, three countries accounted for more than half of foreigners studying in Canada: China (32%), India (15%) and France (8%). A June 2020 survey by Statistics Canada noted the risk of the Covid-19 pandemic reducing international demand for tertiary education (Frenette *et al*., 2020).

Only about 11% of Canadian undergraduates travel abroad for study purposes. This is a significantly lower proportion than their French (33%), Australian (19%) or US (16%) counterparts (Study Group on Global Education, 2017). Of those Canadian students who do decide to study abroad, many choose traditional destinations, such as the USA, UK, Australia or France.

To help address this lack of global exposure, the new *International Education Strategy* (2019–2024) strives to help Canadian students seize study, work and travel opportunities abroad. At the same time, it aims to promote Canada as a destination for international students to diversify demand.

The 2019 federal budget has set aside Can$ 147.9 million over five years for this purpose, followed by Can$ 8 million per year of ongoing funding. The launch of an outbound student mobility pilot initiative has been deferred to early 2021, on account of the Covid-19 pandemic. This initiative will provide up to 11 000 undergraduate and college students with Can$ 5 000–10 000 each year.

CONCLUSION

A time for statecraft and sage advice

The government's policy rhetoric has been to advocate a more intermestic relationship between domestic and foreign policy. However, as long as international issues in science and technology remain somewhat peripheral in policy spheres there will be a dissociation between Canada's participation in international scientific affairs and domestic policy.

The Covid-19 outbreak has revealed a dichotomy between strategies that focus almost exclusively on national responses and the demands of participation in global affairs. As the President of the National Academy of Sciences, Marcia McNutt, has underscored, 'the Covid-19 pandemic is the classic example of a problem that we will not solve anywhere until we solve it everywhere [...] during an era of growing nationalization, researchers must resist that constriction and continue to share knowledge so that lessons learned in one country can inform response and recovery in other nations' (McNutt, 2020).

Two scholars of international relations have made the same point. They write that 'societies should not assume that international scientific collaborations will flow naturally but rather should nurture them carefully – although urgently – through renewed diplomatic efforts, funding programs and policy instruments. So far, global research and innovation collaboration on the pandemic is a positive story but the world will need to fast-forward such efforts to minimize damage over the coming year' (Guimon and Narula, 2020).

Many observers have argued that, in international scientific co-operation, Canada should target areas that improve the standard of living. For example, they argue that Canada could strengthen North–North co-operation through fora such as the Arctic Council and, at the subnational level, through the exchange of knowledge and best practices in areas that include mental health, education, indigenous languages and renewable energy.

They argue that Canada could also expand the development work of organizations such as the IDRC, which celebrated its 50th anniversary in 2020, and Grand Challenges Canada, which has supported a pipeline of over 1 000 inventions in 95 countries in its ten-year history. Both of these programmes have tackled global health problems with like-minded global players.

As science diplomacy has received growing recognition as a concept and practice, the real-world intersection between science and diplomacy has been transformed. In part, this is a result of the growing digitalization of knowledge, which has facilitated its diffusion. Youth groups and others are now engaging in citizen science as the role of science becomes more embedded in statecraft. For instance, in May 2018, Canada's Science and Policy Exchange network hosted a workshop on the theme of students as stakeholders in science diplomacy. The organizational ecology of global summitry has become increasingly complex, as a result.

Several statements addressed to G7 summit leaders by the national academies of science demonstrate a growing recognition that building knowledge capacity to address rapidly evolving challenges will require a new mindset, one that is inclusive of the voices of all stakeholders in an interconnected world. For example, the statement on basic research issued in 2020 advocates fostering global co-operation and information-sharing to accelerate discovery, spread the benefits and reduce knowledge-based inequities, including through open science. The G7 science academies declaration on artificial intelligence and society of March 2019 argued for a public policy debate on the destructive or military usage of AI.

It will only be possible to solve global challenges through cross-border collaboration. Canadians are participating in this type of endeavour, as exemplified by the efforts of the InterAcademy Partnership and Global Young Academy to address the Covid-19 challenge.

At the heart of this global response will be how global science and research can be effectively deployed and how governments can use and deliver this emerging knowledge for improving the human condition. The *G7 Science and Technology Minister's Declaration on Covid-19* of 28 May 2020 drove this message home by promising to make related research results, data and information accessible to the public in machine-readable formats, to the greatest extent possible. The *Declaration* includes a promise to enhance co-operation on shared Covid-19 research priority areas, such as basic and applied research, public health and clinical studies.

The pandemic has demonstrated that placing science at the heart of government policy can have its rewards but is not devoid of risk. If the role of the advisory apparatus is simply to support the government's position uncritically without communicating the evidence effectively and ethically to the public, the price to pay can be the loss of public trust (Dufour, 2020). In some cases, the very speed at which information is being produced and disseminated, coupled with the lack of 'social distancing' between independent scientific advice and polity has led to a backlash from both informed citizens and the scientific community itself.

Canada faces the balancing act of simultaneously managing its domestic advisory apparatus for science and its global research partnerships in the new post-normal, post-pandemic world.

KEY TARGETS FOR CANADA

Canada plans to:

- achieve net-zero carbon emissions by 2050;
- reduce greenhouse gas emissions by 30% below 2005 levels by 2030;
- charge Can$ 50 per tonne of carbon emissions by 2022;
- phase out coal by 2030;
- protect one-quarter of Canada's land and oceans by 2025; and
- raise its share of global agricultural exports to 8% by 2025.

Paul Dufour (b. 1954: Canada) has been Fellow and Adjunct Professor at the Institute for Science, Society and Policy at the University of Ottawa since 2011. For over three decades, Dufour has worked in science and technology policy with such bodies as the Science Council of Canada and the Ministry of State for Science and Technology. Between 2004 and 2008, he was interim Executive Director at the former Office of the National Advisor to the Canadian Government. Dufour holds a Master's in the History of Science from the University of Montreal (Canada).

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ENDNOTES

1 In Canada, colleges focus on specific skills for employment and career development. They offer technical training and diplomas, often serving local communities. Universities offer bachelor's degrees and higher.

2 See: https://www144.statcan.gc.ca/sdg-odd/index-eng.htm

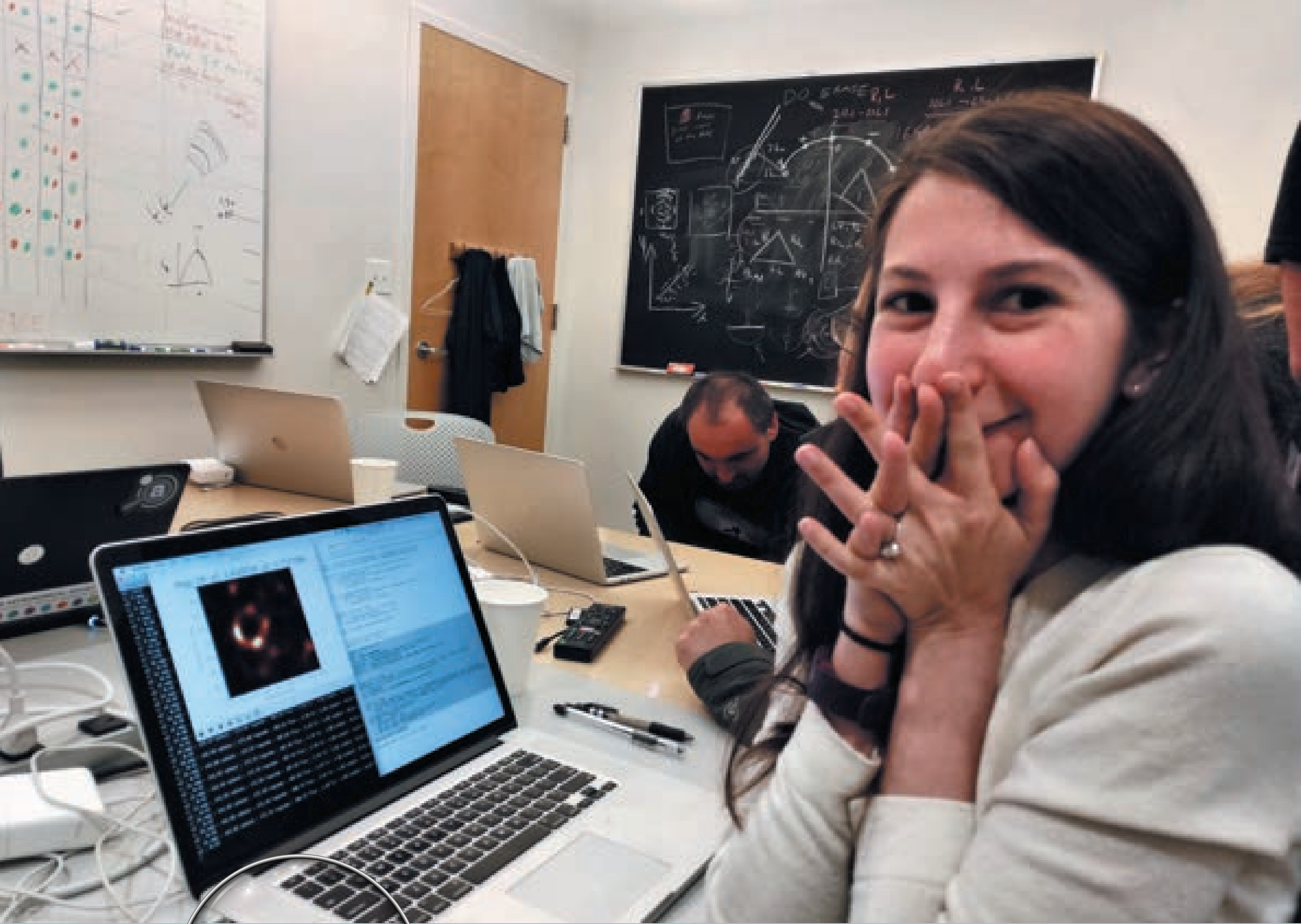
3 See: https://www.ic.gc.ca/eic/site/052.nsf/eng/00010.html

4 The Montreal Neurological Institute–Hospital at McGill University in Canada is a frontrunner. In 2017, it took the step of embracing open science fully in its approach to publishing research.

5 These centres are the Alberta Machine Intelligence Institute (Amii) at the University of Alberta in Edmonton, the Montreal Institute for Learning Algorithms (Mila) at the University of Montreal and the Vector Institute for Artificial Intelligence in Toronto.

6 The current members of the Global Partnership on Artificial Intelligence are Australia, France, Germany, India, Italy, Japan, Mexico, New Zealand, the Republic of Korea, Singapore, Slovenia, UK, USA and the European Union.

7 For a wider discussion, see, for example: Tippett and Milford (eds) [2019] Science Education in Canada – Consistencies, Commonalities and Distinctions. Springer Verglag: https://doi.org/10.1007/978-3-030-06191-3.



Dr Katie Bouman, an engineer and computer scientist from the California Institute of Technology, reacts as a composite image of a black hole forms on her computer, in a world first in April 2019. This accomplishment was the culmination of the work of a global team of more than 200 scientists.
© Andrew Chael

AT A GLANCE

- The federal research budget for 2021 proposes raising investment in cutting-edge technologies such as artificial intelligence and quantum computing.
- Burgeoning digital start-ups have become tech giants amid growing concern about market monopolization.
- There has been a surge in applicants for new company registrations in 2020, even as the amount of venture capital available to start-ups has dropped as a consequence of the Covid-19 epidemic.
- The America First policy agenda has led to new sector-specific policy goals, such as that of addressing the US trade deficit, and to a US withdrawal from the Paris Agreement and other multilateral agreements. A number of states are, nonetheless, respecting their commitments to the Paris Agreement.
- Technological advances have reduced the price of renewables and natural gas, making coal less economic. Carbon emissions have, consequently, dropped but the rollback of federal environmental protections is cause for concern.

5 · United States of America

Nicolas Vorontas, with Brennan Hoban and Connor Rabb

INTRODUCTION

A crisis 'like no other'

The USA[1] enjoyed economic growth rates well above 2% over the 2016–2019 period (Figure 5.1). For 2020, by contrast, the median expectation is for a 6.5% decline in GDP, according to the Federal Reserve, the country's central bank. Forecasts run as low as -10% (Cox, 2020).

At the global level, the year 2020 shaped into an economic 'crisis like no other'. As the Covid-19 pandemic tightened its stranglehold on the global economy in June 2020, the International Monetary Fund felt obliged to revise its projection for global growth down to -4.9% (IMF, 2020).

As of late April 2021, Covid-19 has claimed the lives of more than 570 000 US citizens according to the Johns Hopkins Coronavirus Resource Center. The US death rate of 175 per 100 000 inhabitants is one of the highest in the world.[2]

The impact of the coronavirus has been compounded by conflicting messages emanating from the government and scientific community, with the former striving to downplay the gravity of the pandemic and the latter recommending that measures such as social distancing and mask-wearing be generalized to limit the spread of infection. This fits a pattern, whereby the government has sought to restrict scientific research and the discussion and publication of scientific information, in an attempt to control the narrative over Covid-19 but also other topics over the past four years, such as climate change and environmental protection, in the name of national security. Columbia Law School has established a Silencing Science Tracker to document this.[3]

The pandemic has exposed weak points in the response by federal science agencies. When Covid-19 was first detected in the USA, the Food and Drug Administration (FDA) applied an existing 'emergency use authorization' clause that had been used in past viral pandemics, such as with regard to Ebola, Zika and Swine Flu, to bypass the FDA's usual six-month review period. The aim was to accelerate approval of the Covid-19 diagnostic tests developed by the Centers for Disease Control and Prevention (CDC) for rapid distribution to health laboratories across the country. However, many laboratories reported problems with validating the test results. Since tests cleared by the Emergency Use Authorization during past pandemics had always been successful, there was no contingency plan or alternative test immediately available. This set the USA back months in obtaining reliable diagnostic tests, hindering the country's pandemic response.

Unemployment trends on a roller coaster

Employment numbers are indicative of the pandemic's impact: the US unemployment rate, which had been at a 50-year low of 3.5% as recently as February 2020, leapt in April to 14.7%, an 80-year high, before falling back to 10.2% in July, according to the Bureau of Labor Statistics. A staggering 20.5 million jobs were lost in April alone, the steepest decline in payrolls since the Great Depression of the 1930s. More jobs were lost in March and April 2020 than had been created in the previous nine years combined, according to the Vice-Chair of the Board of Governors of the Federal Reserve System (Clarida, 2020).

By November 2020, however, the unemployment rate had already dropped back to 6.9%, after a surge in nonfarm payroll employment added 638 000 additional jobs in October.[4]

To counter the vertiginous rise in unemployment, the Federal Reserve cut its key overnight interest rate to almost zero in March 2020 and, the following month, rolled out up to US$ 2.3 trillion in loans to bolster local governments, households and employers. In parallel, the federal government approved a US$ 2.2 trillion relief package covering the period to the end of August 2020, which consisted of a combination of aid and loans for state, local and tribal governments, households and employers, with a particular focus on small and medium-sized enterprises (SMEs).

The uncertainty as to the depth and duration of the economic downturn, which largely depend on the course of the coronavirus and the public health policies to contain it, make it nearly impossible to project the economic situation until mid-2021 beyond constructing scenarios for the months and years ahead (Deloitte, 2020). Released in June 2020, the Federal Reserve's projections for growth in the next calendar year range from -1% to +7%; officials are divided on whether 2021 will see a continued recession or the biggest rebound since the mid-1980s (Cox, 2020).

An unprecedented mobilization by the bioscience industry

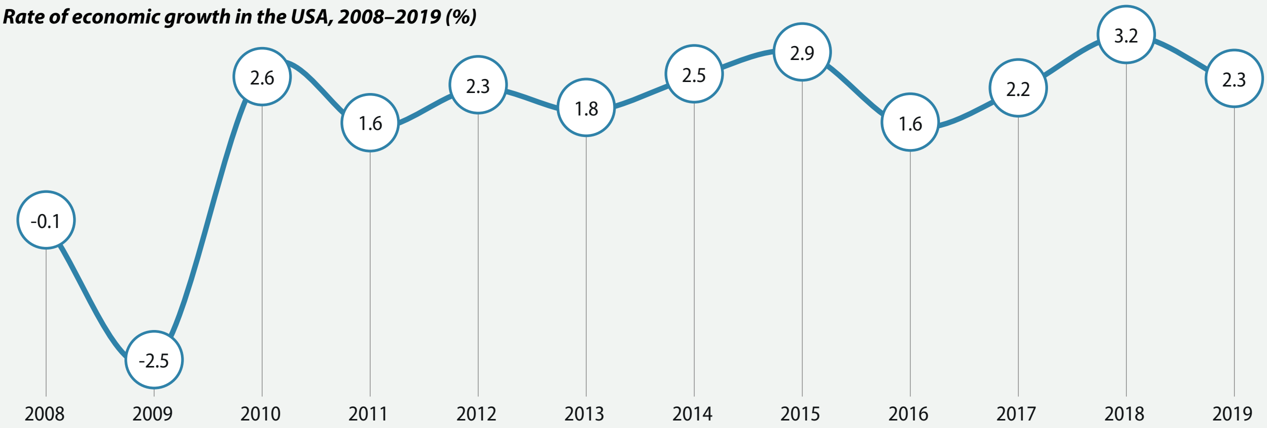
The Covid-19 pandemic has mobilized America's bioscience industry in an unprecedented manner. It has been estimated that there are more than 400 drug programmes in development in the USA aimed at eradicating the disease, including over 100 vaccine programmes and 135 antiviral programmes (TEConomy and BIO, 2020).

These efforts are grounded in the White House's Operation Warp Speed, a public–private partnership infused with a sense of urgency, as its name suggests. The federal government has allocated more than US$ 9 billion to develop and manufacture candidate vaccines. An additional US$ 2.5 billion has been earmarked for vials to store the vaccines and syringes to deliver them, as well as to pay for efforts to ramp up manufacturing capacity.

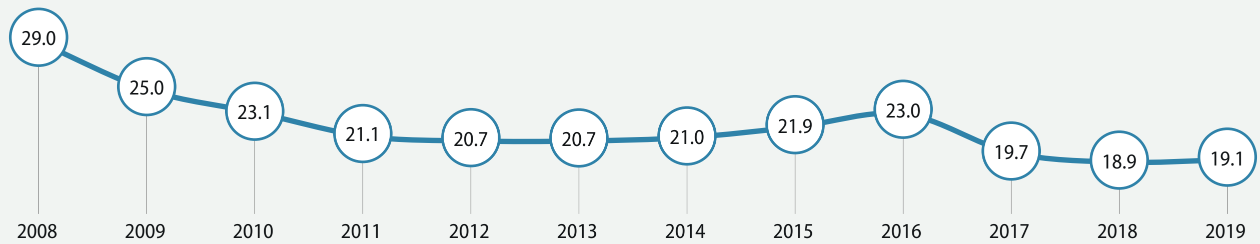
The list of bioscience companies receiving government funding covers a range of companies of different sizes and geographical origins, including AstraZeneca, BioNTech, GlaxoSmithKline, Pfizer, Janssen, Moderna, Merck, Novavax

Figure 5.1: **Socio-economic trends in the United States of America**

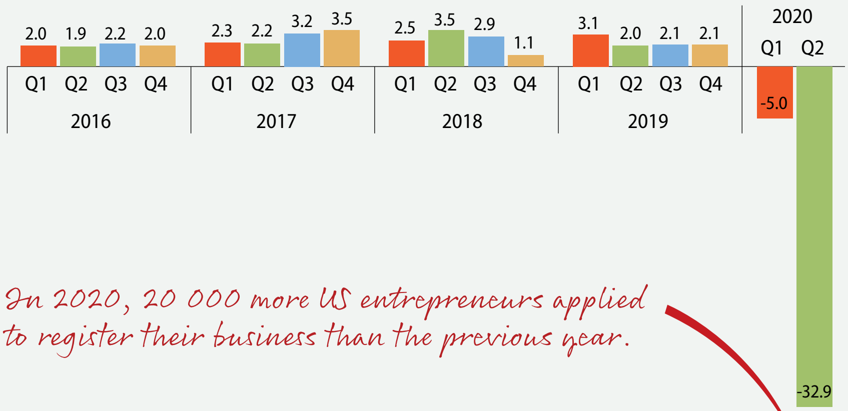
Rate of economic growth in the USA, 2008–2019 (%)



High-tech exports from the USA as a share of manufactured exports, 2008–2019 (%)

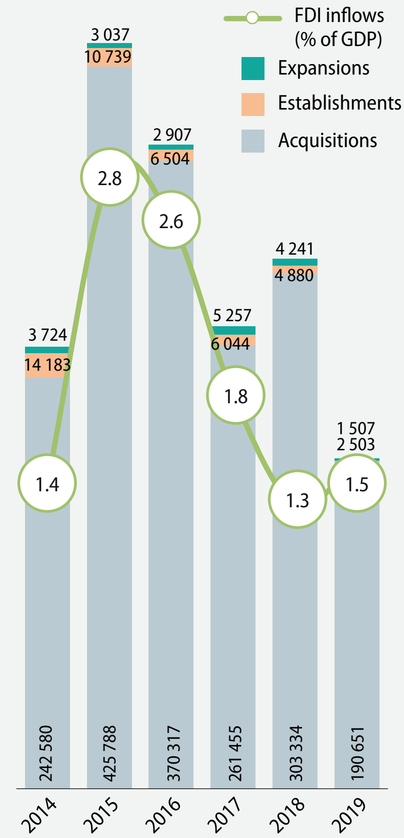


Change in real US GDP from the preceding quarter, 2016–2020 (%)



FDI flows to the USA as a share of GDP and new FDI expenditure by type, 2014–2019

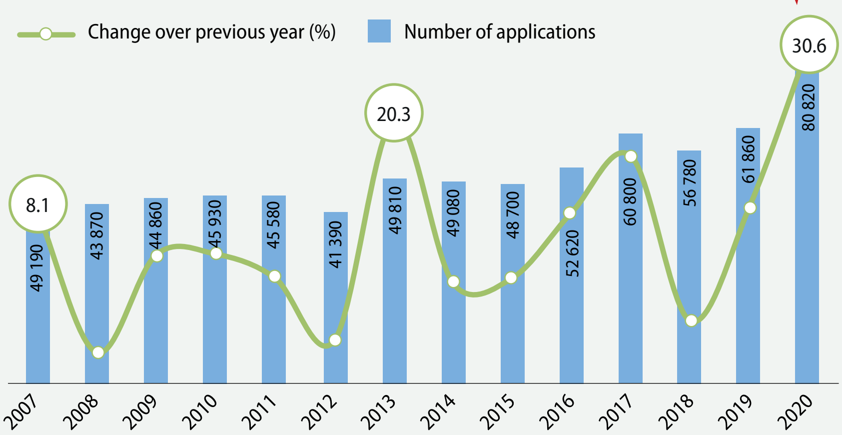
Expenditure by type in US$ millions



In 2020, 20 000 more US entrepreneurs applied to register their business than the previous year.

Applications by US start-ups to register their business, 2007–2020 (%)

Data for week 45



Note: Data represent new FDI used to acquire, establish or expand US businesses.

Source: for GDP growth and exports: World Bank's World Development Indicators, August 2020; for quarterly GDP and FDI: BEA (2020) New Foreign Direct Investment in the United States, 2019. U.S. Bureau of Economic Analysis: Maryland, USA; for business applications: US Census Bureau (2020) Business Formation Statistics and Sanofi. Some projects involve international collaboration, such as the experimental vaccine developed by the German firm BioNTech for Pfizer. In the UK, British multinational AstraZeneca has teamed up with Oxford University.

By September, scientists participating in the White House's Operation Warp Speed had reportedly identified 14 vaccines for development. In December, the FDA approved the BioNTech/Pfizer and Moderna vaccines. The government had already prepurchased millions of doses of each to offset some of the company costs in developing them. The BioNTech/Pfizer vaccine must be stored at -70°C, complicating its roll-out.

Meanwhile, AstraZeneca has signed a memorandum of understanding with the World Health Organization (WHO) committing the firm to supplying 300 million doses of Covid-19 vaccines to the Covid-19 Vaccines Global Access Facility (Covax), a mechanism designed to guarantee rapid, fair and equitable access to Covid-19 vaccines worldwide. In August 2020, the US government signalled that it would not be participating in Covax, shortly after announcing plans to withdraw from WHO.

America First

This position is consistent with the America First policy agenda adopted in 2017. This agenda has led to US withdrawal from a number of multilateral agreements, including the nascent Trans-Pacific Partnership for trade, the *Paris Agreement* on climate action and the *Joint Comprehensive Plan of Action*, also known as the Iran nuclear deal (see chapter 15).

Incoming President Joe Biden returned the USA to the *Paris Agreement* in February 2021. He has signalled his intention to use a planned massive infrastructure investment plan to support the development of 'green' industries.

The America First agenda has influenced domestic policy in broad strategic areas such as health, space and energy, as epitomized by the titles of the *America First Energy Plan* (2017) and *America First National Space Strategy* (The White House, 2018). These broad strategic areas will be discussed later.

In the realm of trade policy, the America First priority sought to reverse the country's persistent negative international trade balance in goods through the imposition of tariffs on several of its trading partners. In particular, the US and Chinese economies have been perturbed since 2018 by a trade dispute that has spilled over into the arena of high technology, technology transfer and intellectual property protection (see chapter 23).

The first negative trade balances in goods date from the early 1970s and have been quite severe since the turn of the century. By contrast, the USA has enjoyed significant trade surpluses in services, especially knowledge-intensive services.

Between 2015 and 2019, the negative balances of combined trade in goods and services rose from US$ 498.5 billion to US$ 616.4 billion. The biggest trade deficit, by far, was with China, which accounted for more than half of the total.[5]

In 2018, China was the USA's biggest supplier of goods and third-biggest market for US exports of the same. According to the Office of the United States Trade Representative (2020), the top export categories to China in 2018 were aircraft, machinery, electrical machinery, optical and medical instruments and vehicles. US exports of services to China grew by 272% between 2008 and 2018 to US$ 58.9 billion, topped by travel, intellectual property and transportation.

The volume of inward foreign direct investment (FDI) in the USA totalled US$ 312.5 billion in 2018, up 14.6% over the previous year. However, 2019 saw a steep fall in inward FDI of 37.7% (Figure 5.1). The vast majority of inward FDI has taken the form of acquisitions of US companies by foreign investors. In 2018, as part of the Foreign Investment Risk Review Modernization Act, the USA enacted the most sweeping reforms to the Committee on Foreign Investment since 2007, expanding its jurisdiction and providing a new level of scrutiny of FDI (CRS, 2020a).

Even though China and the USA were one another's largest trading partner in 2018, the level of bilateral FDI is relatively low. Increasingly stringent regulations on both sides have severely affected investment flows. In 2018, net FDI flows to China were down by 22.9% over the previous year to US$ 7.6 billion; net Chinese FDI flows into the USA turned negative (US$ -754 million, down from US$ 25.4 billion in 2016), reflecting the divestiture of assets (CRS, 2019a).[6] The difference with trade volumes is stark.

It is against this backdrop that science, technology and innovation (STI) policy has evolved since 2016 in the USA.

RESEARCH TRENDS

US research enterprise strong

In 2019, the USA crossed the 3% threshold for research intensity (Figure 5.2). The US national innovation system still performs the largest share of global research and development (R&D) and generates the largest share of research-intensive industrial output (Figures 5.2 and 5.3).

In relative terms, though, the picture is changing. The US share of global research expenditure has been shrinking as other countries ramp up their own efforts (see Figure 1.1).

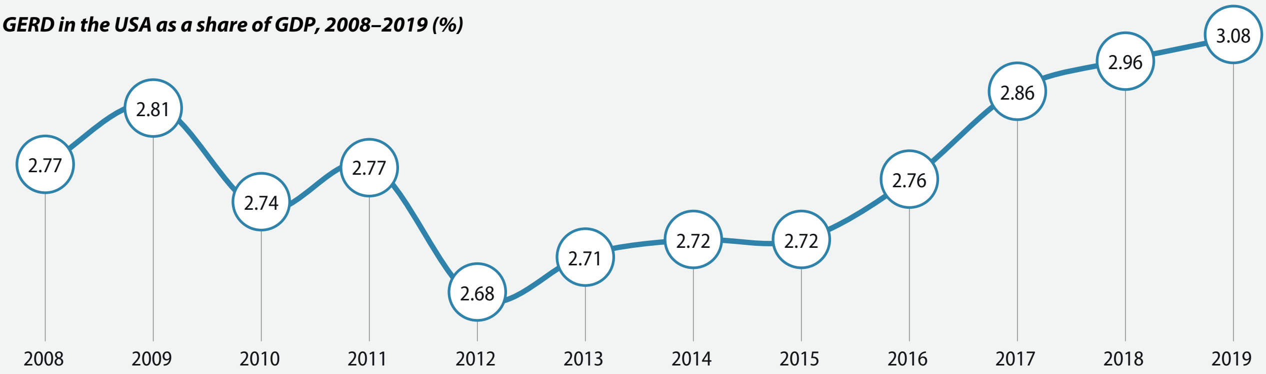
From 2003 to 2018, US value-added output by research-intensive industries almost doubled from US$ 570 billion to US$ 1.04 trillion (NSB, 2020). However, the US share of patents awarded by the top five patent offices remained stable at 22% between 2015 and 2019, even as China's share progressed from 27% to 32% (see chapter 23).

Business sector funding more basic research

In 1980, the business sector's share of research expenditure matched that of the federal government. Since then, the gap has widened. The National Science Board (NSB, 2020) estimates that the federal government funded 22% of gross domestic expenditure on R&D (GERD) in 2017, down from 31% in 2010. By 2017, the business sector was funding 70% of R&D and performing 73% (Figure 5.2). Of note is that the business enterprise sector, which prioritizes applied research and experimental development, extended its funding for basic research to 30% of the total in 2017. This is up from 23% in 2010 and 27% in 2013 (NSF, 2019).

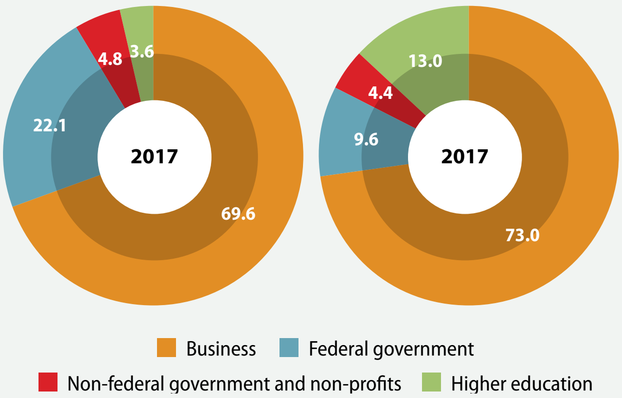
Figure 5.2: **Trends in research expenditure in the United States of America**

GERD in the USA as a share of GDP, 2008–2019 (%)

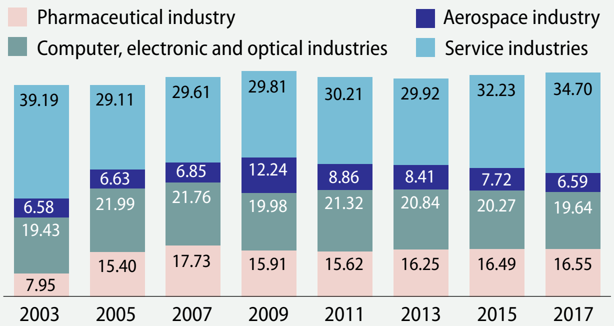


GERD in the USA by source of funds, 2017 (%)

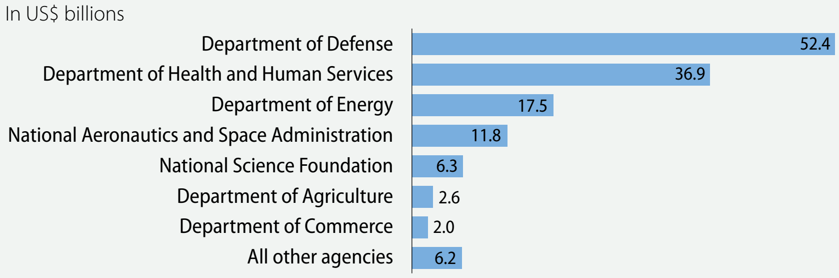
GERD in the USA by sector of performance, 2017 (%)



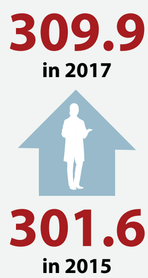
Share of business enterprise expenditure on R&D performed by industry in the USA, 2003–2017 (%)



GERD by major US federal agency, 2018
In US$ billions

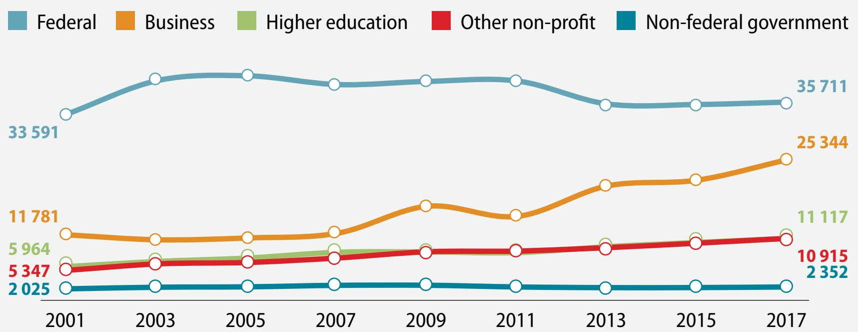


GERD per researcher (FTE) in the USA In PPP$ thousands, constant 2005 prices



Note: Estimates are based on agency and Office of Management and Budget data. R&D includes conduct of R&D and facilities.

Expenditure on basic research in the USA by sector, 2001–2017
In US$ millions, constant 2012 values



In dollar terms, business spending on basic research has doubled since 2007. By contrast, federal spending levels for the same have remained stable since 2013.

Source: NSB (2020); for expenditure by federal agency: CRS (2020) Federal Research and Development (R&D) Funding: FY2020. Congressional Research Service Report R45715; for GERD as a share of GDP: UNESCO Institute for Statistics; for expenditure on basic research: Boroush, M. (2019) *U.S. R&D Increased by $22 Billion in 2016, to $515 Billion; Estimates for 2017 Indicate a Rise to $542 Billion*. National Center for Science and Engineering Statistics. National Science Foundation: Alexandria, Virginia, USA; for business expenditure on R&D by subject: OECD Main Science and Technology Indicators

Federal government sticking to core missions
The bulk (93.2%) of federal research expenditure was allocated to five federal agencies in 2020 (CRS, 2020b). Two-thirds went to the Department of Defense (41.4%) and the Department of Health and Human Services (26.2%), which administers the National Institutes of Health. The other three were the Department of Energy, the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF). This allocation reflects the three core national missions of the US federal research system since the 1940s: basic research, health and defence.

More funding for strategic technologies
The White House's 2021 research budget proposes[7] an 8.8% drop for federal agencies relative to the 2020 enacted level. Should Congress endorse this proposal, all but the Department of Veterans Affairs will see a decline in research funding. The biggest cuts in percentage terms would affect the Department of Transportation (-47.6%) and the Environmental Protection Agency (-35.4%). The biggest cuts in monetary terms would affect the Departments of Defense, Energy and Health and Human Services (CRS, 2020b).

The White House's 2020 research budget proposal (US$ 162 billion) targeted strategically important technologies underpinning the industries of the future: artificial intelligence (AI), quantum information science (QIS), fifth-generation wireless technology (5G), biotechnology and advanced manufacturing (OMB, 2019).

The budget proposal for 2021 has again included major increases for QIS and AI as part of the Administration's goal of doubling government-wide investment in R&D in these two areas by 2022 relative to 2019 levels (OMB, 2020).

A less generous tax environment for firms
The private sector has developed a large research presence, despite relatively anaemic tax incentives for R&D. The USA ranked 26th for this indicator among members of the Organisation for Economic Co-operation and Development (OECD) in 2018,[8] compared to 10th in 2000.

The Tax Cuts and Jobs Act (2017) has made provision for reducing this generosity further from 2022 onwards. This change will require companies to amortize research over a five-year period, instead of counting it among their expenses in their tax return (Kennedy, 2019). Expert projections indicate that this change is likely to discourage business R&D (Bellafiore, 2019).

A surge in new business registration
Entrepreneurship and knowledge-intensive start-ups are a vital component of the US high-tech scene. The Great Recession of the late 2000s sent start-up activity into a tailspin that culminated in a 20-year low for the share of new entrepreneurs in 2009 (Kauffman *et al*., 2017).

In subsequent years, the number of new start-ups started to recover slowly again – as did their positive outlook on business conditions. According to the *2020 Startup Outlook US Report* published by the Silicon Valley Bank, more than two-thirds of all start-ups were in this optimistic frame of mind by 2020.

An exciting phenomenon during the year of the pandemic has been the surge in the number of new businesses, as reported by the US Census Bureau. Some 80 820 applications had been received by November 2020, a year-on-year increase of 30.6%. This is a major reversal of the trends of the previous decade when applications only twice exceeded 60 000, in 2017 and 2019 (Figure 5.1).[9]

Less venture capital for start-ups since pandemic
The long-term effect of Covid-19 on risk capital may be chilling. The PitchBook Financial Database anticipates a drop in both the volume and value of transactions into 2021. However, although the number of deals had dropped as of the second quarter of 2020, the value of transactions was holding steady (Figure 5.3).

The reality of venture capital investment typically diverges from entrepreneurs' expectations. Venture capitalists tend to favour certain economic activities which receive the lion's share of investment. According to the Kauffman Capital Report of March 2019, only 0.5% of all start-ups manage to attract venture capital. Even in good times, the level of this type of investment is insignificant, with rare exceptions: in 2018, there were fewer than 7 000 venture capital deals for a total value of US$ 130 billion; of these, 191 deals were worth US$ 100 million or more (what are known as megarounds). The pandemic will provide opportunities for entrepreneurs in fields of direct relevance to the treatment of Covid-19.

Venture capital funding is also subject to significant regional disparities. Traditionally, Silicon Valley, San Francisco and Orange County (Los Angeles) in the State of California and metropolitan New York and the Boston area on the Eastern Seaboard have attracted by far the most venture capital. This was still the case in 2020 (PwC, 2020). On aggregate, over two-thirds of all start-ups are fully dependent on personal or family sources and over 16% are dependent on business loans from banks or other financial institutions.

The availability of venture capital, coupled with centres of excellence such as the Massachusetts Institute of Technology (Boston area) or Stanford University (California), makes the States of California, Maryland, Massachusetts, Delaware, Michigan and Washington best-positioned to support future growth in knowledge-based industries, both in terms of research funding and human resources (Figure 5.4).

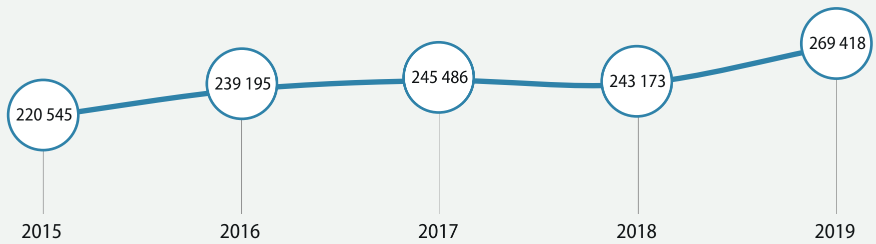
STRATEGIC PLATFORMS IN DIGITAL TECHNOLOGY

An AI strategy since 2016
There is a broad consensus between federal agencies and the executive and legislative[10] branches that the USA needs to adapt to an increasingly competitive international environment. In response, the federal government has prioritized key strategic platforms in digital technology since 2016 in fields that include AI, quantum computing, advanced mobile network technology and cybersecurity.

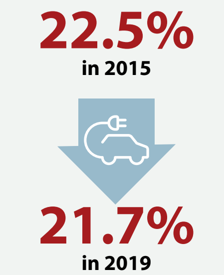
In recognition of the growing importance of AI for economic growth and national security, the National Science

Figure 5.3: **Trends in innovation in the United States of America**

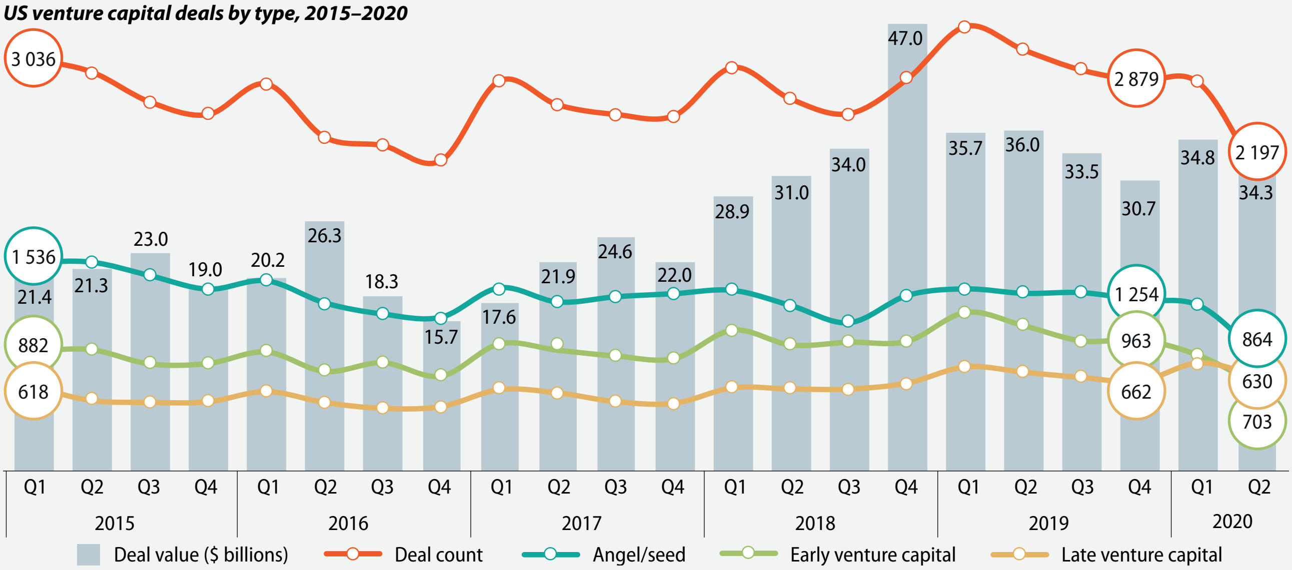
Number of IP5 patents granted to the USA, 2015–2019



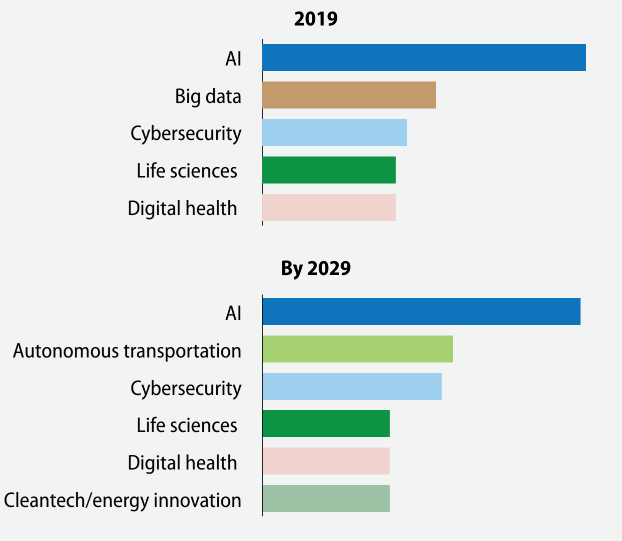
Share of IP5 patents granted to US inventors



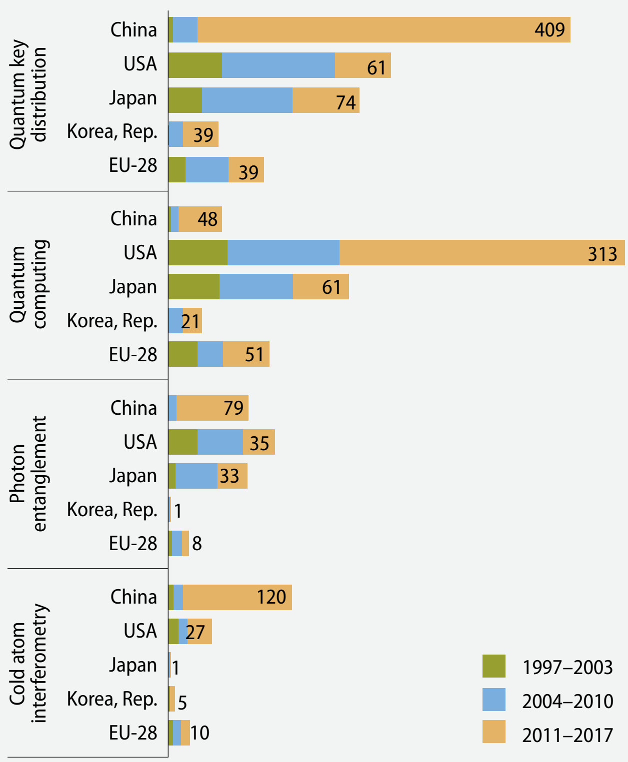
US venture capital deals by type, 2015–2020



Survey responses from US entrepreneurs and start-ups asked to identify promising fields in the innovation economy in 2019 and by 2029



Quantum patents granted to selected countries and regions, 1997–2017



Note: Respondents (1 377) in Canada, China, USA and UK were asked to identify up to three technologies they felt were the most promising in 2019 and those that would be most promising by 2029.

Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China. For venture capital deals by type, data are available only for the first two quarters of 2020.

Source: for IP5: PATSTAT, data treatment by Science-Metrix; for venture capital: PitchBook (2020) *Venture Monitor: Q2 2020*. PitchBook Data, Inc.: Seattle, USA; for survey of entrepreneurs: Silicon Valley Bank (2019) *US Startup Outlook 2019*. Silicon Valley Bank: Santa Clara, California, USA; for quantum patents: Travagnin (2019) and Technology Council (NSTC) published the first *National Artificial Intelligence Research and Development Strategic Plan* for the USA in 2016.

The *Plan* identifies scientific and technological requirements for the development of AI. It advocates a public-sector strategy focusing primarily on areas in which industry would be less likely to invest but which could be transformational in the long term. Seven broad action themes have been proposed (NSTC, 2016):

- making a long-term investment in AI research;
- developing effective methods for human–AI interaction;
- understanding and addressing the ethical, legal and societal implications of AI;
- ensuring the safety and security of AI systems;
- developing shared public datasets and environments for AI training and testing;
- measuring and evaluating AI technologies through standards and benchmarks; and
- better understanding the needs of the national AI research workforce.

In August 2018, the government asked the NSTC Select Committee on Artificial Intelligence to update the 2016 *Plan*. Based on responses to a public request for information, the updated 2019 plan includes an eighth theme, namely that of expanding public–private partnerships to accelerate advances in AI (NSTC, 2019a).

In February 2019, the *National Artificial Intelligence Research and Development Strategic Plan* became part of the broader American Artificial Intelligence Initiative, which itself originated from President Trump's executive order[11] on Maintaining American Leadership in Artificial Intelligence. This initiative serves to co-ordinate efforts to promote AI technology and innovation across federal agencies, the private sector, academia and the public.[12] In November 2019, the NSTC published a progress report on the status of implementation in each of the aforementioned eight areas and concluded that the federal agencies were playing a critical role in promoting research in AI (NSTC, 2019a and 2019b).

Funding for research on AI has trended upwards in recent years, leading to a growing number of publications on this topic (Figure 5.5). The White House's budget request for 2020 even included AI as a separate category, allocating US$ 973.5 million to non-defence research in AI. Although defence-related research in AI remains classified, the US Chief Technology Officer, Michael Kratsios, hinted at the size of the increase in total research funding for AI when he stated that, 'in 2016, the federal government spent US$ 1 billion on AI R&D in total, including defense spending. Today's nearly US$ 1 billion figure doesn't include defense' (Castellanos, 2019).

Recent initiatives have also highlighted the extent to which the Department of Defense values AI technology. In 2018, the Defense Advanced Research Projects Agency (DARPA) announced a US$ 2 billion investment in a new AI Next campaign, stating that 'DARPA sees this next generation of AI as a third wave of technological advance, one of contextual adaptation' (DARPA, 2018).

In May 2020, Congress unveiled a major bipartisan proposal to bolster US technology leadership. Championed in both the House of Representatives and the Senate, the Endless Frontier Act would provide a major funding boost to US innovation efforts. The role of the National Science Foundation would be expanded and its name would be changed to the National Science and Technology Foundation as a consequence. A new Technology Directorate would also be established with a budget of US$ 100 billion over five years to lead investment and research in ten areas, including AI and machine learning, high-performance computing, robotics, automation and advanced manufacturing.

Although this legislation was not put to a vote during that particular session of Congress, it is indicative of the impetus in both Congress and throughout the government to shore up the federal research enterprise and expand efforts to develop technologies deemed strategically important, accompanied by dramatic reforms if necessary.

Meanwhile, the 2021 budget request from the White House (OMB, 2020) has proposed significant increases for non-defence AI, including a more than 70% increase over the previous year for the National Science Foundation (NSF). This increase will enable the NSF to create several national AI research institutes, in collaboration with the Departments of Agriculture, Homeland Security, Transportation and Veterans Affairs. These institutes will serve as focal points for multisector, multidisciplinary research involving academia, industry, federal agencies and non-profit organizations.

On 7 January 2020, the White House (2020a) published the latest addition to the American Artificial Intelligence Initiative. In a Memorandum for the Heads of Executive Departments and Agencies, it conveyed ten principles designed to deter agencies from adopting any regulations that might stifle innovation in AI (Table 5.1).

Central to these principles (Table 5.1) is the need for AI to be developed in accordance with human rights and democratic values, to ensure public confidence and trust in the technology. The USA is one of the founding members of the Global Partnership on Artificial Intelligence launched in June 2020,[13] which espouses these same values, as outlined in the *OECD Principles on Artificial Intelligence* (2019).

The USA is, of course, far from the only country focusing on AI. Half of the top 20 universities and public research organizations for scientific publications on AI are located in China, compared to just six in the USA (Figure 5.6). Of the 30 leading patent-holders, only five are US companies – but these include IBM and Microsoft, those with the biggest AI portfolios (Figure 5.6).

Universities are a particular strength of the Chinese system: no fewer than 150 Chinese universities are ranked among the top 500 for the number of patent applicants in AI, including all top 10 positions. Twenty US universities have also made it onto this list, with the University of California leading in 15th place, followed by the Massachusetts Institute of Technology in 17th place (WIPO, 2019).

Competition has also extended to venture capital. In 2012, venture capitalists poured US$ 282 million into AI. By 2017, this amount had almost doubled to US$ 5 billion but China had still overtaken the USA by this point (Deloitte, 2019). A year later, the USA had reclaimed the top spot with US$ 9.7 billion in AI investment, which translated into 52.3% of global venture capital investment in AI. This investment gap is projected to grow further (ABI Research, 2019).

According to Deloitte (2019), this wave of investment has helped to transform many US firms into sophisticated users of AI technology: 30% of those responding to the Deloitte survey were managing 11 or more AI production systems. The primary difficulty for these firms appeared to be the lack of human resources, with 68% of respondents qualifying the talent gap as being moderate to extreme.

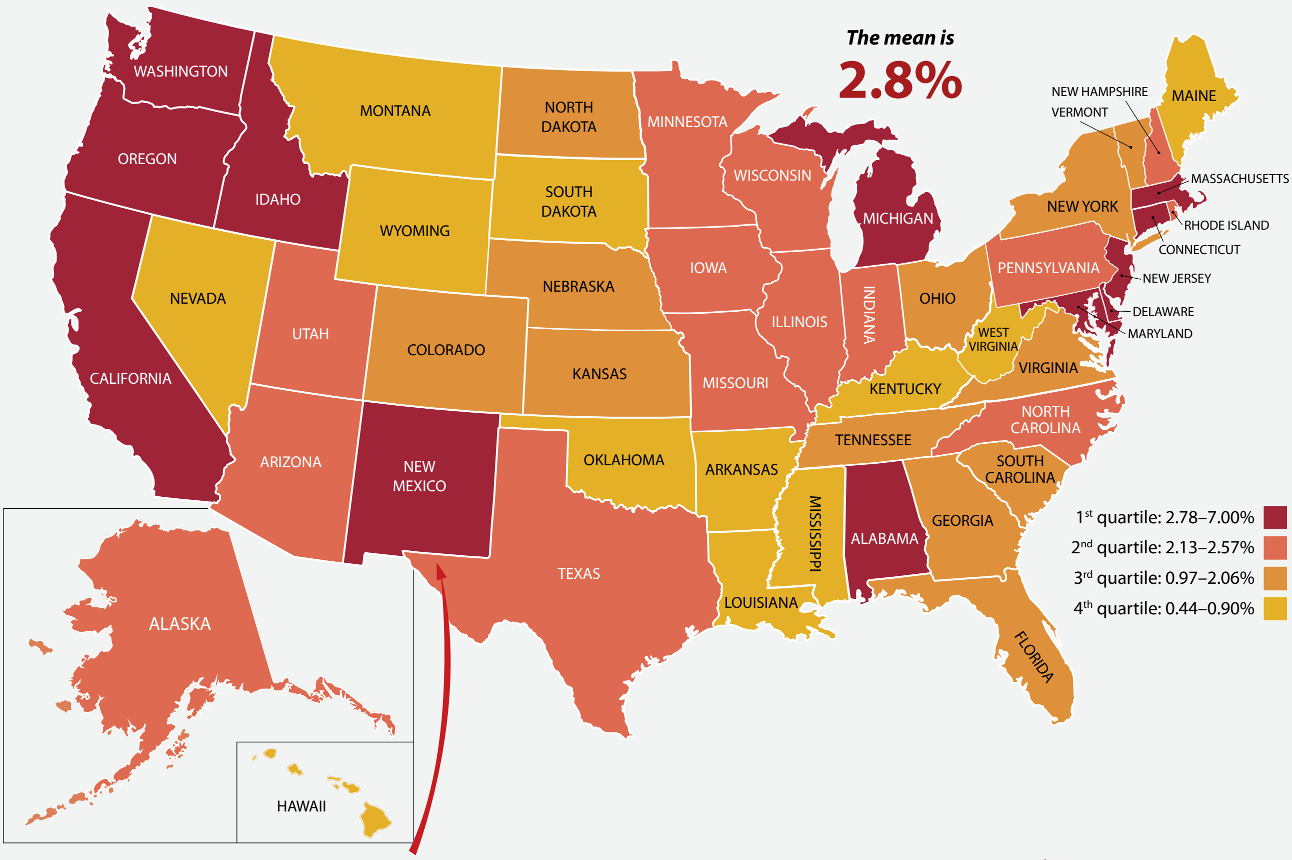
Quantum information science: a public and private priority

In September 2018, the US National Science and Technology Council (NSTC) published the *National Strategic Overview for Quantum Information Science*. This document attempts to create a systematic national approach to quantum information R&D co-ordinated by NSTC's Subcommittee on Quantum Information Science (NSTC, 2018a). The report identifies six policy areas for QIS: a science-first approach; the workforce; federal engagement with industry; critical infrastructure; national security; and international co-operation.

Shortly thereafter, Congress passed the National Quantum Initiative Act with overwhelming support from both the Senate and House of Representatives. President Trump signed the legislation into law on 21 December 2018, formalizing a multi-agency effort to develop research and a skilled workforce in QIS. Additionally, the legislation requires that the National Science Foundation and the Department of Energy each establish between two and five 'multidisciplinary centers for quantum research and education,' with each receiving approximately US$ 10 million in funding (Thomas, 2019).

Figure 5.4: **Science and engineering in the United States of America, by state**

R&D performed as a share of state GDP in the USA, 2017 (%)



The presence of two huge federal government laboratories, Los Alamos and Sandia, explains why New Mexico has the USA's highest research intensity.

In 2017, women accounted for 29% of workers in science and engineering occupations, despite accounting for 52% of the college-educated workforce overall.

Note: R&D includes R&D performed by federal agencies, businesses, universities, other non-profit organizations, federally funded research and development centres and state agencies. US total R&D reported here includes US territories.

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Although it is difficult to determine the exact amount spent by the federal government as a whole on QIS research, estimates for 2018 range between US$ 200 million and US$ 250 million (CRS, 2018b). This figure may swell with the new National Quantum Initiative and the growing recognition of the importance of QIS for the USA.

As with AI, the White House's budget proposal for 2021 has reflected this reprioritization. The requested budget allocation for QIS has increased by 50% over the previous year on the path to doubling the level of investment by 2022. The NSF's investment in QIS is set to more than double with an additional US$ 120 million to support the National Quantum Initiative. As for the Department of Energy, it should be in a position to bolster quantum efforts at the national laboratories and in academia and industry, thanks to an increase of US$ 75 million (OMB, 2020).

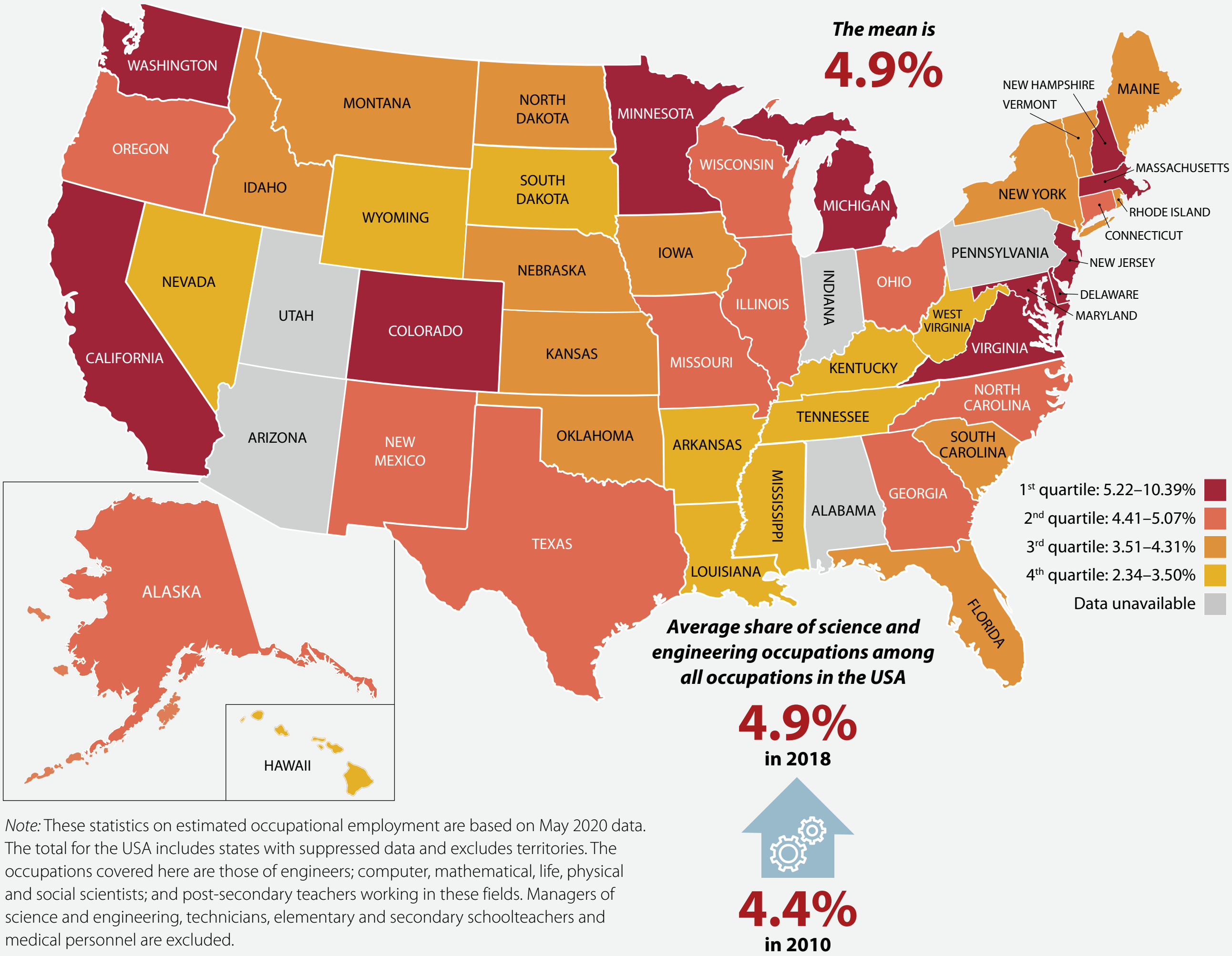
The private sector has already established itself as a world leader in this field. For instance, Google claimed to have achieved 'quantum supremacy' when announcing in 2019 that its 54-Qubit Sycamore processor had performed a calculation in 200 seconds that would have taken the world's most powerful supercomputer 10 000 years (Metz, 2019; Porter, 2019).

Patents also reflect the strong US position in quantum computing. Using European Patent Office data, Travagnin (2019) estimated that, although China led for the overall number of QIS patents, particularly when it came to quantum communication, the USA had the largest number of patents in quantum computing (Figure 5.3).

Likewise, a higher proportion of known global private-sector investment in quantum computing in the USA reflects both the number and quality of US technology giants and the volume of venture capital flowing towards start-ups in quantum computing since 2016 (Gibney, 2019).

The US lead is increasingly being challenged by other nations, such as Australia, Canada and China, as well as by countries in Europe (Kania *et al*., 2018).

Individuals in science and engineering occupations as a share of all occupations in the USA, 2018 (%)



Note: These statistics on estimated occupational employment are based on May 2020 data. The total for the USA includes states with suppressed data and excludes territories. The occupations covered here are those of engineers; computer, mathematical, life, physical and social scientists; and post-secondary teachers working in these fields. Managers of science and engineering, technicians, elementary and secondary schoolteachers and medical personnel are excluded.

Source: National Science Board (2020) *S-41 R&D as a Percentage of Gross Domestic Product*. Science & Engineering Indicators: State Indicators. National Science Foundation: Alexandria, Virginia, USA; National Science Board (2019) *S-32 Individuals in Science and Engineering Occupations as a Percentage of All Occupations*. Science & Engineering Indicators: State Indicators. National Science Foundation: Alexandria, Virginia, USA

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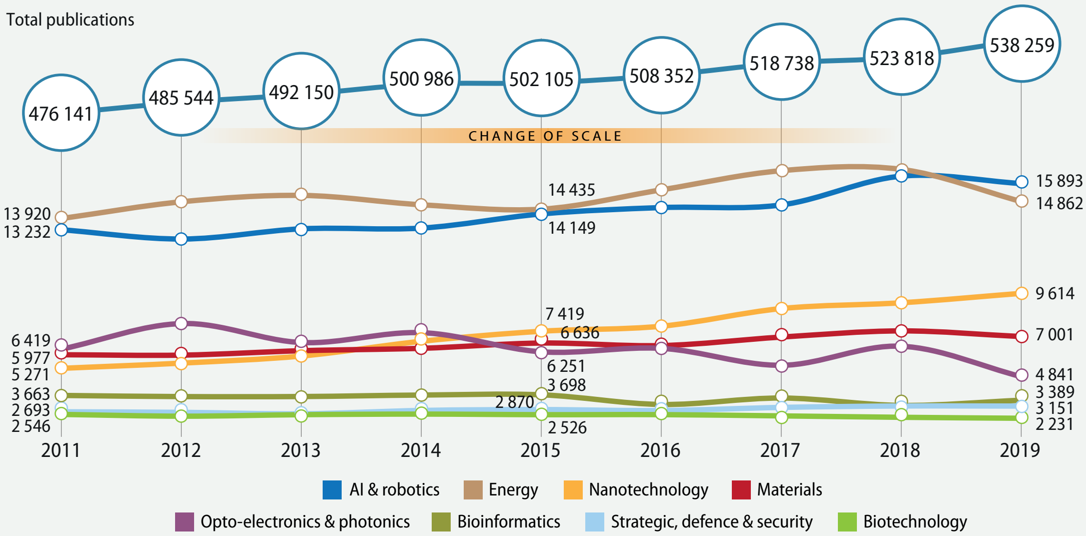
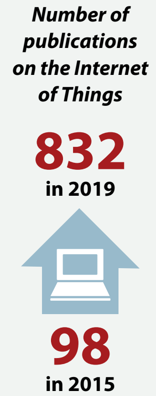
Chapter 5

Figure 5.5: **Trends in scientific publishing in the United States of America**

Volume of scientific publications in the USA, 2011–2019

Total publications and output on cross-cutting strategic technologies

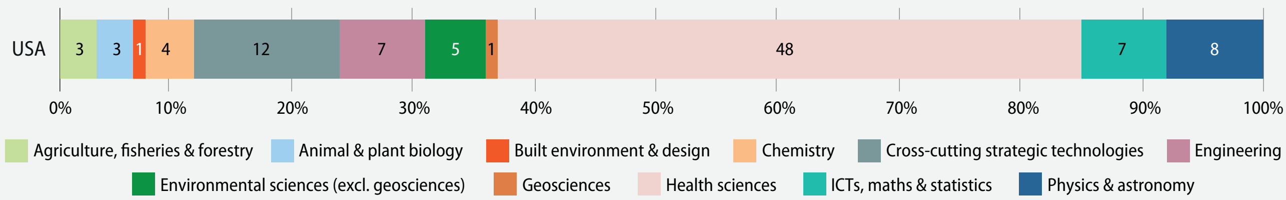




The USA's publication output accounted for 30% of the world total in health sciences in 2019.

The first journals on blockchain technology date from 2018. US researchers produced 10 publications in those journals in 2018 and 76 in 2019.

Scientific publications in the USA by broad field of science, 2017–2019 (%)



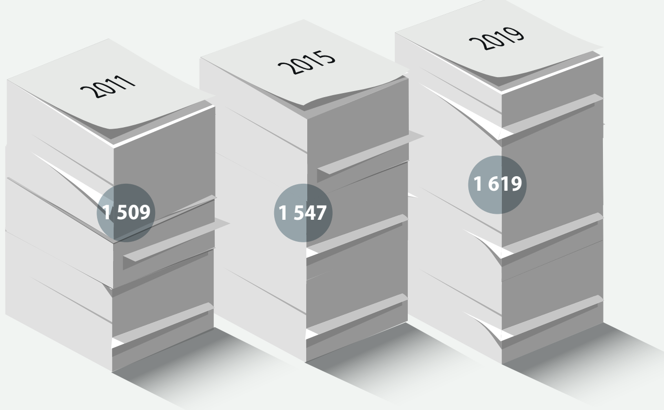
1.32

Average of relative citations for the USA, 2014–2016; the OECD average is 1.11

40%

Share of publications with foreign co-authors in the USA, 2017–2019; the OECD average is 34%

Scientific publications per million inhabitants in the USA, 2011, 2015 and 2019



How has output on SDG-related topics evolved since 2012?

Scientists in the USA are publishing more on the following topics than would be expected, relative to global averages: HIV (1.9 times the global average intensity), invasive species, ocean acidification and new or re-emerging viruses that can infect humans. They have published extensively on the Zika virus (see chapter 8).

Scientists produced less than would be expected on the clean energy topics studied. Output grew substantially between 2012–2015 and 2016–2019 only on battery efficiency (from 7 479 to 10 647 publications) and smart-grid technologies (from 5 801 to 7 369). Output even dropped on biofuels and biomass (from 8 675 to 7 820), photovoltaics (from 8 661 to 7 647), wind-turbine technologies (from 4 289 to 4 092), hydrogen energy (from 4 115 to 4 034) and cleaner fossil fuel technology (from 1 334 to 1 116).

Among the selected topics with at least 1 000 publications during the period under study, the fastest-growing topic was that of sustainable transportation (+162%), with output rising from 4 871 (2012–2015) to 7 869 (2016–2019) publications.

For details, see chapter 2

USA's top five partners for scientific co-authorship, 2017–2019 (number of publications)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
USA	China (158 219)	UK (83 678)	Germany (69 443)	Canada (65 364)	France (45 675)

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

Table 5.1: **Ten principles to ensure agency support for innovation in AI in the USA**

Public Trust in AI	The government's approaches to AI should promote reliable, robust and trustworthy AI applications which will contribute to public trust in AI.
Public Participation	Agencies should provide ample opportunities for the public to provide information and participate in the rule-making process.
Scientific Integrity and Information Quality	Agencies should hold information that is likely to have a clear and substantial influence on public policy or private-sector decisions to a high standard of quality, transparency and compliance.
Risk Assessment and Management	Regulatory and non-regulatory approaches to AI should be based on a consistent application of risk assessment and risk management.
Benefits and Costs	Agencies should carefully consider the full societal costs, benefits and distributional effects before implementing regulations related to the development and deployment of AI applications.
Flexibility	Agencies should pursue performance-based, flexible approaches that can adapt to rapid changes and updates to AI applications.
Fairness and Non-discrimination	Agencies should consider in a transparent manner the possible impact of AI applications on discrimination.
Disclosure and Transparency	Transparency and disclosure can increase public trust and confidence in AI applications
Safety and Security	Agencies should promote AI systems that are safe, secure and operate as intended, while encouraging the consideration of safety and security issues throughout the process of AI design, development, deployment and operation.
Inter-agency Co-ordination	Agencies should co-ordinate with each other to share experiences and ensure consistency and predictability of AI-related policies, while protecting privacy and civil liberties and allowing for sector- and application-specific approaches, where appropriate.

Source: The White House (2020a)

QIS is seen as being of critical importance not only in terms of economic competitiveness but also cybersecurity. This concern reflects a broad sentiment underlying the US intelligence community's *Worldwide Threat Assessment* identifying emerging and disruptive technologies and threats (Coats, 2019):

> *For 2019 and beyond, the innovation that drives military and economic competitiveness will increasingly originate outside the USA, as the overall US lead in science and technology shrinks; the capability gap between commercial and military technologies evaporates; and foreign actors increase their efforts to acquire top talent, companies, data, and intellectual property via licit and illicit means [...] Advances in quantum computing foreshadow challenges to current methods of protecting data and transactions [...] Foreign deployment of a large-scale quantum computer, even ten or more years in the future, would put sensitive information encrypted with today's most widely used algorithms at a greatly increased risk of decryption.*

Challenges in deploying 5G technology

There is little doubt that the fifth generation of mobile network technology (5G) will be one of the main drivers of economic growth for years to come. This next generation of wireless infrastructure will offer new and improved capabilities – such as lower latency, flexibility, adaptability, higher capacity and support for a larger number of connections – and it will underwrite a continuing frenzy in the digitization and automation of systems. It will allow for the seamless connection of smart sensors with AI. It will enable connectivity to be tailored to a much wider variety of uses, including machine-to-machine interaction. As a consequence, it is expected to enable the Internet of Things (Brake, 2020).

The strategic importance of 5G has captured the imagination of policy-makers and private-sector strategists alike and is constantly being touted in penned strategies and the popular media. The impression given is that we are engaged in a competitive race to develop and deploy 5G.

The USA faces a variety of unique challenges in the deployment of 5G. The domestic telecommunications equipment industry has declined from its peak in 2001 and the country no longer has comparably sizable companies to provide the necessary equipment for 5G (Brake, 2020).

This lack of major vendors is particularly acute when it comes to Radio Access Network (RAN) equipment, which connects wireless devices to the main core network and comprises more than two-thirds of the total cost of the 5G network. The USA also faces challenges in deploying 5G to geographically dispersed populations and in making critical portions of the spectrum available for commercial use (Brake, 2020).

Base stations offer one example. It is estimated that Chinese mobile providers have, so far, deployed about 15 times as many 5G base stations as US providers. They have done so by utilizing the C-band allowing each base station to cover a wider area than those in the USA which use the mmWave (Brake, 2020). The US lacks a company that can compete with Huawei for the manufacture of base stations. The shorter propagation range, higher manufacturing and supply costs and lagging deployment in the USA mean that America pays more for fewer, shorter-ranged 5G base stations. This is coupled with pre-existing challenges in deploying wireless capabilities to rural populations. Together, these challenges make deploying 5G base stations in the USA relatively difficult and expensive (DIB, 2019).

The public sector has initiated moves to accelerate 5G deployment. Despite an ongoing effort to provide a unified policy front, Brake (2020) characterizes efforts to date as taking a 'scattershot' approach that seeks to focus on infrastructure and spectrum policy, while managing national security concerns associated with utilizing the telecommunications equipment of certain foreign companies.

The strategy of the Federal Communications Commission (FCC, 2016) to *Facilitate America's Superiority in 5G Technology* (*5G FAST Plan*) focuses on making additional bandwidths available for commercial use, developing infrastructure and updating regulations. A highlight of the spectrum policy is that it makes available the sub-6 spectrum, in particular the C-band of 3.7–4.2 GHz. In December 2020, the FCC plans to auction 280 megahertz of satellite C-band spectrum to 5G cellular networks (Henry, 2020). The proceeds from these auctions will then be used to incentivize the incumbents to co-operate in a swift transition so that they are ready to relinquish the spectrum completely by September 2023.

The FCC has also adopted new rules to reduce federal regulatory impediments to deploying 5G infrastructure and has taken steps to prevent cities from imposing excessive fees on the deployment of 5G equipment. One such move was the 2017 Restoring Internet Freedom Order repealing the 2015 Title II regulations on Internet service providers to ensure what has been termed 'net neutrality' (FCC, 2016).

Citing the benefits of moving away from Title II regulations, the FCC Chairman announced the agency's intention of giving broadband providers stronger incentives to build networks, especially in 'unserved areas, and upgrade networks to reach gigabit speeds and offer 5G' (FCC, 2018).

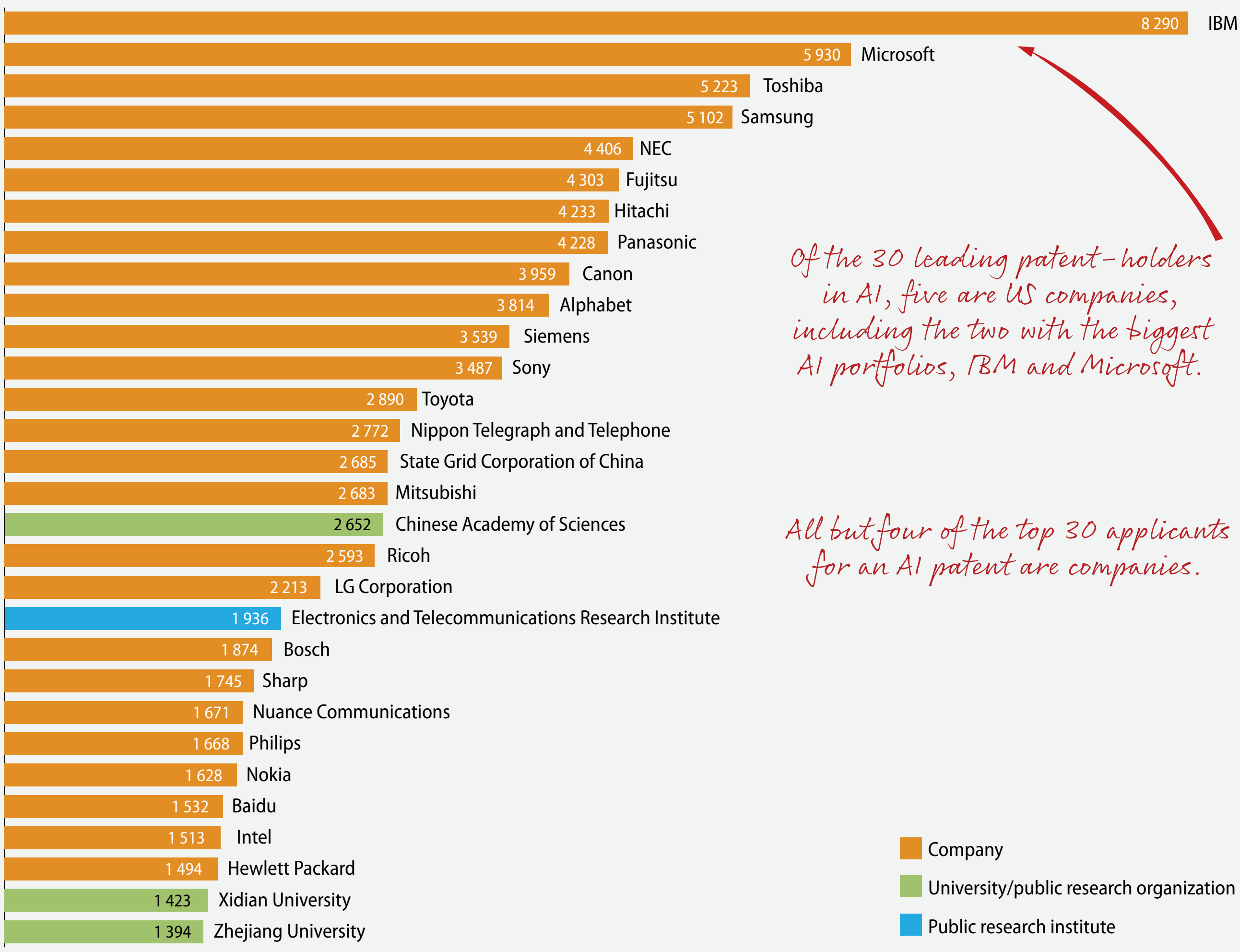
Another regulatory change by the FCC has been to ensure that equipment purchased through the Universal Service Fund does not pose a national security risk. Managed by the FCC, this fund enables interstate long-distance carriers[14] to subsidize telephone service delivery to low-income households and high-cost areas.

Legislation passed by Congress has also emphasized national security; it has established similar security standards for telecommunications equipment across the federal government. Most recently in March 2020, President Trump signed the Secure 5G and Beyond Act, which requires the development of a more comprehensive national strategy for 5G deployment, competitiveness and security.

The same month, the White House released the *National Strategy to Secure 5G*. It identifies four missions for the

Figure 5.6: **Top companies and research institutions publishing and patenting in artificial intelligence worldwide**

Top 30 applicants for patents in artificial intelligence, 2018
By number of patent families within their portfolio



administration: facilitate domestic 5G rollout; assess risks to, and identify, core security principles of 5G infrastructure; address risks to the US economic and national security in 5G infrastructure development and deployment; and promote responsible global development and deployment of 5G (The White House, 2020b).

The push for security in telecommunications equipment has been central to the administration's trade and diplomatic efforts related to 5G. In May 2019, President Trump signed an executive order to prevent the importation and use of 5G equipment that pose a national security threat. The administration has also added China's leading telecommunications company Huawei to the Department of Commerce's Entity List, barring US companies from selling technology to the company. Simultaneously, the USA has been urging allies to adopt similar national security requirements around 5G equipment.

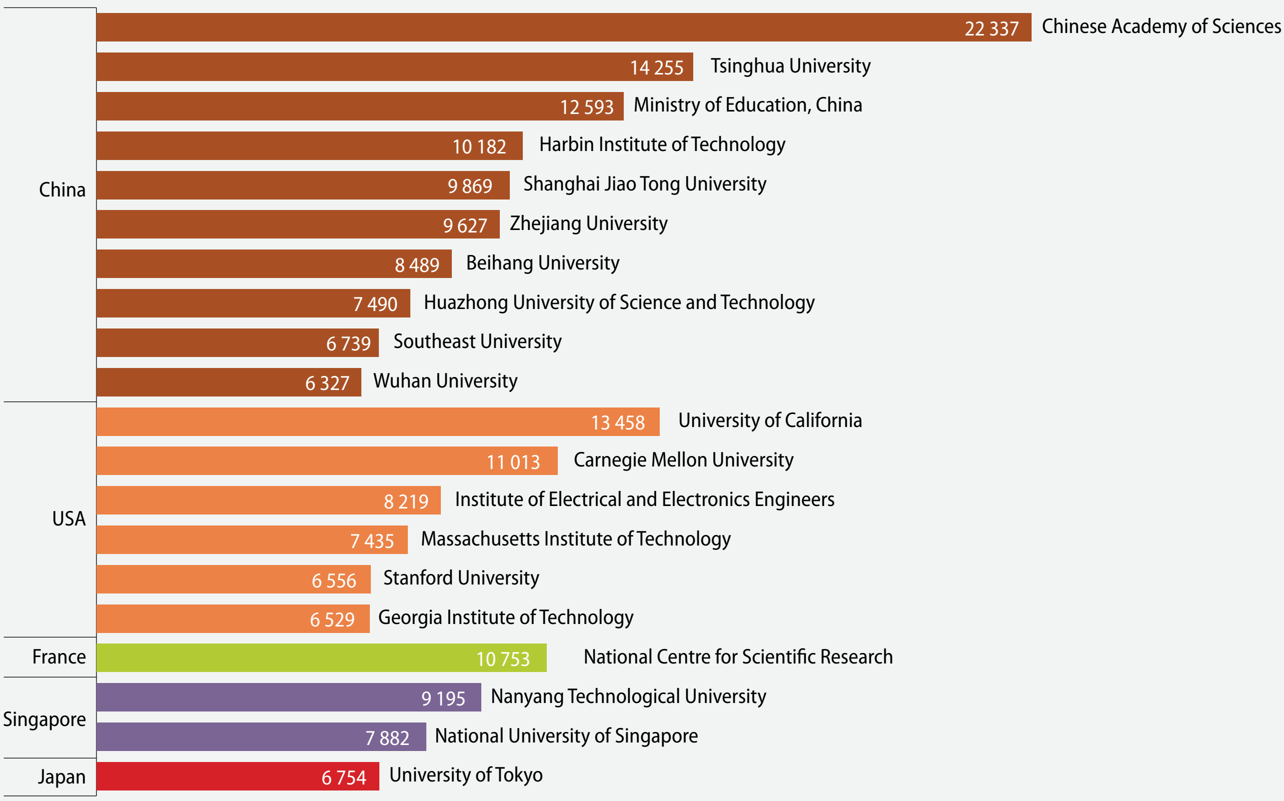
The *National Strategy to Secure 5G*, combined with the legislative requirement for the government to develop a comprehensive national strategy for 5G, suggests that the various scattershot policies may soon coalesce into a more unified effort.

So far, various federal agencies have approached 5G in accordance with each agency's mandate. With the Department of Defense occupying large portions of the sub-6 spectrum and the FCC moving to clear sub-6 spectrum for commercial use, a unified approach to spectrum policy and 5G may offer a viable policy response. Overcoming the spectrum, security and geographical challenges will be vital for the development of 5G networks. In this effort, the USA expects to benefit from its strong advantages in terms of the dynamic competition among private actors, its proven innovative capacity and leading semiconductor sector.

Steps to improve cybersecurity readiness

Federal budgets for cybersecurity have been growing rapidly. Although cybersecurity is not a new concern, the significant breaches surrounding the 2016 US presidential election have shone a spotlight on cybersecurity for the American public (Geller, 2019). According to a 2019 survey by

Top 20 universities and public research organizations publishing on artificial intelligence, by number of publications, 2018



Note: Fujitsu includes PFU; Panasonic includes Sanyo; Alphabet includes Google, Deepmind Technologies, Waymo and X Development; Toyota includes Denso; and Nokia includes Alcatel.

Source: for universities and public research organizations publishing on AI: Scopus (Elsevier) data collated in WIPO (2019) *Technology Trends 2019: Artificial Intelligence*, see their Figure 4.4; for AI patent applications: WIPO (2019) *Technology Trends 2019: Artificial Intelligence*, using the Questel Orbit Intelligence, Fampat Database, March 2018 the Pew Research Center, Americans see cyberattacks from other countries as the top international threat, above that of terrorist militant groups and global climate change. (Poushter and Huang, 2019). Data privacy has also become an issue of major public importance (Box 5.1).

Despite cybersecurity being an issue of growing importance for US citizens, companies and the government, leadership on cybersecurity in the US federal government remains decentralized. This has created a fairly disjointed system, with overlap among multiple federal agencies creating cracks in government oversight. The most notable of these agencies are the Department of Defense's Cyber Command and the Department of Homeland Security's Cybersecurity and Infrastructure Security Agency.

The USA does not yet have a federal-level consumer data privacy law or a data security law. Instead, it relies on a patchwork of regulations from various levels of government and domains to cover its cybersecurity and data privacy legal framework.

A recent report by the Center for a New American Security found that the USA's current cybersecurity legal framework 'is ill-suited to address cybersecurity questions either for legislative oversight or effective policy-making' and that 'existing laws, executive structure and congressional oversight mechanisms are a mismatch for the nature of the cybersecurity challenges presented by a complex, technologically integrated society' (Cordero and Thaw, 2020).

The federal government has taken steps to improve the country's cybersecurity readiness by increasing funding and setting up a Cyberspace Solarium Commission in 2020. The federal budget has increased from US$ 15 billion in 2018 to US$ 18.8 billion in 2021. A majority of this funding goes to the Departments of Defense and Homeland Security.

The Cyberspace Solarium Commission has been created to 'develop a consensus on a strategic approach to defending the USA in cyberspace against cyberattacks of significant consequences' (CSC, 2020). It makes recommendations to Congress around five pillars: government reform; strengthening norms; promoting resilience; operationalizing work with the private sector; and using military power. The focus is on working with allies and partners to shape and promote responsible behaviour in cyberspace, frustrating adversaries who exploit cyberspace to American disadvantage and imposing costs on actors who target the USA in, and through, cyberspace. There is a strong emphasis on defence against catastrophic cyberattacks (Lewis, 2020).

With regard to the first pillar on government reform, one key recommendation by the Solarium concerns the appointment of a National Cyber Director. Supported by dedicated staff within the Executive Office of the President, he or she would serve as the president's principal advisor for cybersecurity-related issues and lead national-level co-ordination of related policies both within the government and with the private sector.

A second key recommendation is for a select committee to be established in both the House and Senate to provide integrated oversight of the cybersecurity efforts dispersed across the federal government.

Further recommendations are for Congress and the executive branch to pass legislation and implement policies designed to recruit, develop and retain cybertalent more effectively to deepen the pool of candidates in the federal government.

All of these recommendations were published in a report by the Solarium in 2020 but have not yet been acted upon (CSC, 2020).

Box 5.1: **Are tech giants monopolizing the information technology sector in the USA?**

Just before the Covid-19 pandemic hit the USA in early 2020, a growing public outcry against what many perceive as the monopolization of the information technology sector led federal regulators to start a wide-ranging effort to determine whether the acquisition strategies of the five US giants were harming competition and, thereby, penalizing consumers, while evading regulatory scrutiny.

These five giants are Alphabet (Google's parent company), Amazon, Apple, Facebook and Microsoft. They had a combined net worth over US$ 5.6 trillion in 2018 that grew by more than 52% in 2019 (The Economist, 2020a). An unbroken flow of mergers in the information technology sector has contributed significantly to this market concentration.

The 'big five' are able to amass and access reams of personal data that are a commercial goldmine but also raise ethical issues about data privacy. They support social media platforms that have been used for political advertising and to disseminate disinformation, with the potential to sway voters. A scandal involving the usage of Americans' data by British political consulting firm Cambridge Analytica to influence the 2016 US presidential election has opened a fierce debate about how major tech companies use and store Americans' data.

This dominant position has raised concerns in Congress and beyond about the 'big five's' growing influence on American society, the economy and politics.

In 2020, the Federal Trade Commission (FTC) ordered the 'big five' to provide detailed information of their acquisitions of smaller rivals. These investigations are being shared with the Department of Justice (DOJ) and the US Congress, who are conducting their own independent antitrust reviews of these technology companies.

The FTC has the power to sue companies to put an end to anti-competitive behaviour. It can take them to court or agree to a settlement that may include a financial penalty. The FTC can block mergers or acquisitions and can even unwind acquisitions or mergers that have already been consummated.

For its part, the DOJ's Antitrust Division can prosecute antitrust violations in criminal court.

The outcome of these investigations was pending as of early November 2020.

Source: compiled by authors

BROAD PRIORITIES: ADVANCED MANUFACTURING

Advanced manufacturing to bolster sector

Beyond the aforementioned strategic platforms in digital technology, American core policy efforts extend to broader fields that include advanced manufacturing, energy and the environment, health and space.

The decline of traditional manufacturing has become a sensitive issue in the USA. Manufacturing output in 2017 was at least 5% greater than in 2000 but the sector has become more capital-intensive and less labour-intensive, owing to the widespread introduction of automation. Some 5.5 million manufacturing jobs were lost between 2000 and 2017. This drop can also be attributed to a skills mismatch for today's more sophisticated manufacturing sector (Hernandez, 2018).

The manufacture of modern devices such as smartphones and medical equipment, but also household items such as desk lamps equipped with light-emitting diode bulbs, requires considerable specialization, owing to the complexity of their components. Manufacturers, thus, have recourse to subcontractors who specialize in a narrow field and who, themselves, rely on other suppliers for essential materials such as display driver chips made in semiconductor factories ('fabs') around the world. Having such a tiered supply system, or value chain, makes it very difficult to reshore manufacturing, or to repurpose a production plant overnight (Shih, 2020).

Manufacturing contributed 11.2% of national GDP in 2017, compared to 12.8% a decade earlier. This decline is of policy concern, even though the sector still plays a large role in the economy. In 2018, the USA had the second-largest manufacturing output in the world (US$ 1.9 trillion) after China (US$ 2.1 trillion). US manufacturing output accounts for 16% of the global total (Manufacturing USA, 2019).

Manufacturing also figures high on the policy agenda on account of the sector's importance to science and technology, high value-added jobs and security concerns (Bonvillian and Singer, 2018; Ramaswamy *et al.,* 2017). It is the manufacturing sector that attracts the lion's share (70%) of private-sector funding and where the bulk of private-sector research is performed. It is, thus, hardly surprising that most new products and processes have historically originated in the manufacturing sector.

Fourteen institutes in advanced manufacturing

In light of such concerns, the Obama Administration embarked on an ambitious Manufacturing USA programme in 2014, the year that Congress passed the Revitalize American Manufacturing and Innovation Act. This programme set out to blend industry, academia and government in a network of advanced manufacturing institutes to promote US competitiveness. Headquartered in the National Institutes of Standards and Technology, Manufacturing USA brought together the National Aeronautics and Space Agency (NASA), the National Science Foundation and the Departments of Commerce, Defense, Energy, Education, Agriculture and Labor.

Fourteen Manufacturing USA institutes were established between 2012 and 2017, sponsored by the Departments of Defense, Energy and Commerce (Figure 5.7). Collectively, these institutes reach 1 291 member organizations, of which 844 are manufacturing firms and 65% are small- and medium-sized manufacturers. These 14 institutes cover a broad range of technological fields ranging from fabrics and lightweight materials to integrated photonics and advanced robotics (Figure 5.7).

An Industry 4.0 campaign

Advanced manufacturing has attracted policy attention throughout the White House's Industry 4.0 campaign, which is using a combination of emerging digital technologies to transform industry. These include industrial robotics, AI, additive manufacturing (also known as 3D printing), high-performance materials, semiconductor and hybrid electronics, photonics, advanced textiles, biomanufacturing and agrifood.

Developed by the National Science and Technology Council (NSTC, 2018b), the Industry 4.0 strategic plan presents a vision for American leadership in advanced manufacturing across industrial sectors to ensure national security and economic prosperity. Its three goals are: to develop and transition to new manufacturing technologies; to educate, train and connect the manufacturing workforce; and to expand the capabilities of the domestic manufacturing supply chain. It is not yet clear which instruments will be used to implement the plan.

BROAD PRIORITIES: ENERGY AND ENVIRONMENT

Rapid growth in natural gas and renewables

The US energy system has undergone a metamorphosis over the past couple of decades, thanks to technological advances in energy production and efficiency. This has led to steep drops in the price of renewables and to exploitation of huge oil and natural gas deposits in unconventional formations like shale, through hydraulic fracturing (fracking) and horizontal drilling, which have raised environmental concerns; widespread fracking has, in turn, reduced the price of natural gas.

Coupled with changes in consumption patterns, these trends have reversed the course of the country from being a growing importer of most forms of energy to a declining importer and even net exporter of oil, natural gas and natural gas liquids.

Since 2017, the government has been pushing hard for energy pre-eminence and security. Although the rise in fossil-fuel production has taken place mostly on onshore non-federal lands, legislation adopted since 2017 has opened up vast public lands to energy prospecting. For instance, nearly 80 million acres of federal waters off the Gulf of Mexico were leased in 2019 for the purpose of oil and gas drilling. This reverses the trend between 2008 and 2017, which saw the share of total gross withdrawals of oil and gas from federal public lands drop from 25% to 13% (CRS, 2018a).

The expansion of oil, natural gas and renewables has been supported by active private- and public-sector investment, including generous tax incentives and steady increases in research funding at the Department of Energy. Between 2015 and 2020, this agency saw its overall research funding increase by 22% to about US$ 19.2 billion (AAAS, 2019).

Between 2010 and 2018, the USA accounted for the most growth in investment in the global energy supply. In 2018, the USA was the second-largest market for investment in energy after China (Figure 5.8) but the lion's share of this investment flowed towards the supply of fossil fuels.

Major transformations are anticipated in the electric power sector, especially. This is because the current infrastructure is ageing and the relative shares of fuel types are changing. There are also considerable uncertainties about how to modernize the power grid by improving transmission and reliability in the face of potential cybersecurity threats and growing interest in renewable energy.

US investment in renewable power has remained high since 2015 (IEA, 2019). It even jumped by 16% in 2018. Investment in distributed solar photovoltaics that year amounted to around US$ 15 billion, second only to China. Investment in renewables is being bolstered by falling costs, federal tax credits that were extended by five more years in December 2015, state portfolio standards and corporate procurement (IEA, 2019; Mai *et al*., 2016).

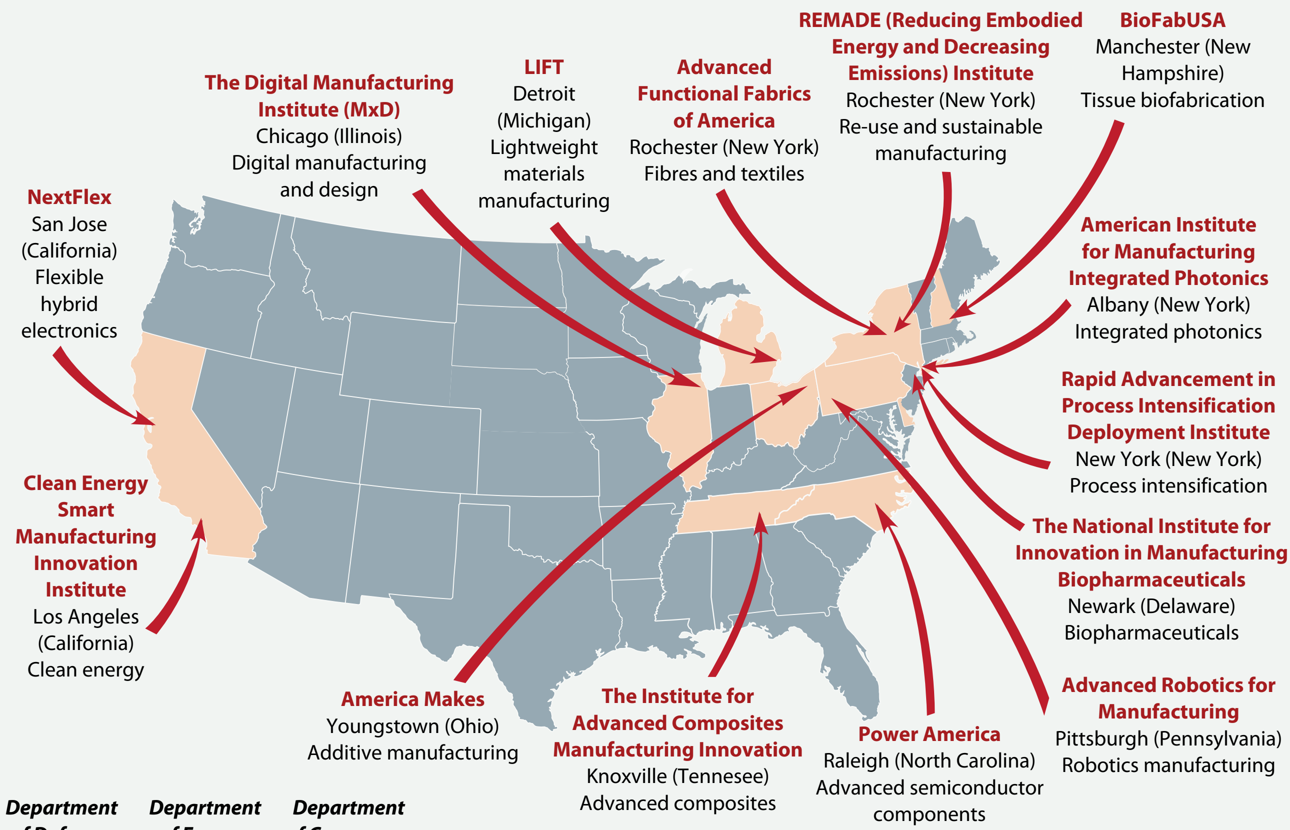
A serious roadblock to encouraging renewable energy deployment has been the huge legacy investments of large established energy companies (Pickl, 2019). US supermajors Chevron and ExxonMobil, for instance, have not followed the path of Royal Dutch Shell, Total, BP, Eni and Equinor in transitioning to broader energy companies with portfolios that include a much larger proportion of renewables.

Greater federal spending on energy research

The amount of federal spending on overall energy R&D has steadily increased since the 1990s, with research on renewables and efficiency gains making up a greater proportion of spending over time. This increase has continued unabated since 2017, despite the large cuts proposed in each of the Administration's annual budget requests, because Congress has not endorsed these proposals. For instance, under the White House's budget proposal for 2021, the allocation for energy research would drop by 45.0% over the enacted 2020 level.[15] 'Funding for energy efficiency and renewable energy R&D would decrease by 70.1% and the

Figure 5.7: **Manufacturing USA institutes, 2017**

The Manufacturing USA institutes are collaborating on over 270 major research projects of priority to broad industrial sectors. They have leveraged US$ 2 billion in private investment and US$ 1 billion in federal funds. More than 200 000 employees have acquired advanced manufacturing skills.



Department of Defense: **8** institutes

Department of Energy: **5** institutes

Department of Commerce: **1** institute

Note: States in California, New York, Ohio, Pennsylvania, New Hampshire, Tennessee, Michigan, Illinois, Delaware and North Carolina host a Manufacturing USA institute

Source: Manufacturing USA. See: https://www.manufacturingusa.com/institutes

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Advanced Research Projects Agency-Energy (ARPA-E), would be terminated. ARPA-E has funded more than 800 'potentially transformational' energy technology projects for US$ 2.3 billion since its inception in 2009 (CRS, 2020b).

The Department of Energy accounts for about three-quarters of the federal government's annual investment in clean energy innovation, estimated at US$ 6.4 billion.[16] Investment in clean energy innovation accounted for more than 90% of the department's total investment at the stages of basic and applied research in 2016. Since 2014, funding for energy efficiency and renewable energy R&D at the Department of Energy has more than doubled, steadily increasing each year from US$ 961 million in 2014 to over US$ 2 billion in 2020 (AAAS, 2020).

Most of the business sector's funding of basic and applied research was complemented by federal funding in 2016. More than half of funding at this stage concerns generation technologies (Breakthrough Energy, 2019). Taken together, the public and private sectors invested about US$ 55.5 billion in clean energy in 2019. This places the USA second in the world for the size of overall investment in clean energy, trailing China's US$ 83.4 billion investment the same year.

A rollback of environmental protections

Although investment in clean energy and R&D has increased, the USA has also seen a widespread rollback of environmental protections since 2017. Popovich *et al.* (2019) identified more than 90 environmental rules and regulations which had been rolled back by mid-2019. The Trump Administration is promoting deregulation on economic grounds, arguing that this will bring greater choice, productivity and competition and less red tape for businesses.

The decision to withdraw from the *Paris Agreement* was made on similar grounds (Pompeo, 2019). This move has been highly contested, including by several states which have committed to respecting their share of the USA's *Nationally Determined Contribution* under the *Paris Agreement* (Figure 5.8).

For example, the California Air Resources Board signed an agreement with four automakers – Ford, Honda, Volkswagen and BMW – in July 2019 to increase fuel-efficiency standards gradually and support the transition to electric vehicles. This agreement covers about 30% of new cars and sport utility vehicles sold in the USA. In parallel, a California programme is helping to fund the development of hydrogen refuelling stations for zero-emission fuel-cell vehicles. According to the US Energy Information Administration, about 40 of the country's 60 or so hydrogen refuelling stations are situated in the State of California. Transportation accounted for 28% of energy consumption in the USA in 2019, according to the US Energy Information Administration's website.

On 8 July 2019, the US Environmental Protection Agency published its final Affordable Clean Energy Rule to regulate greenhouse gas emissions from certain existing coal-fired power plants (EPA, 2019). This rule is part of the *America First Energy Plan* (2017) and replaces the former administration's *Clean Power Plan* (2015). The *Clean Power Plan* set emissions reduction goals for each state, allowing flexibility on how to meet those goals, thus putting pressure on high-emitting coal plants.

The Affordable Clean Energy Rule has a narrower scope than the *Clean Power Plan*, in that it will regulate the emissions of individual power plants. Although it is unlikely that this regulatory relief will save the coal industry from being marginalized by the burgeoning oil, natural gas, wind and solar industries, the new rule does remove some regulatory pressure from coal plants (EPA, 2019).

The USA has achieved significant reductions in carbon dioxide (CO_2) emissions. These are approximately at the level of the early 1990s, despite the economy having doubled in size since then (Breakthrough Energy, 2019). In addition to efficiency gains, this trend is largely due to the shift away from coal in electricity generation in favour of the cheaper options of natural gas and renewables (Figure 5.8).

This shift is reflected in the *US Energy and Employment Report* (2020). It relates that, in 2019 alone, 8 000 jobs were lost in coal-fired generation, even as 11 000 jobs were created in the renewable technology sector and 9 100 jobs in the natural gas sector (Brady, 2020). In Congress, there are signs of a growing bipartisan consensus on the need to address climate change, leaving room for additional policy support to lower emissions and increased production.

BROAD PRIORITIES: HEALTH

Pandemic has brought remote health technologies to the fore

Besides pharmaceutical compounds, US industry is playing a leading role in advancing health care technology in fields that include automation, robotics and AI. Robotic surgical machines are already a regular presence in American operating rooms, the fruit of billions of dollars of investment by US companies such as Intuitive Surgical, Johnson & Johnson, Medtronic and Stryker.

The Covid-19 pandemic has demonstrated the importance of remote health technologies, which are destined to outlive it. These include technologies for monitoring and diagnosis such as wearables and mobile phone applications that have originated from other sectors. General Electric's Mural virtual care is being used for remote monitoring of ventilated Covid-19 patients, for instance.

Life expectancy is not rising

Despite these achievements, recent health statistics call into question whether the country is using its well-oiled and expensive health machine effectively, especially against the backdrop of the Covid-19 pandemic. Life expectancy is not rising and deaths and morbidity from cardiovascular disease are not falling. Four in ten (42.4%) adults were obese in 2017–2018, up from three in ten (30.5%) in 2000, according to the CDC. A recent study by the University of North Carolina at Chapel Hill found that obese patients (those with a body mass index of 30 or more) were 48% more likely to die from Covid-19. For the authors, 'a major concern is that vaccines will be less effective for the individuals with obesity' (Popkin *et al.*, 2020).

The USA is also experiencing an opioid epidemic. Doctors prescribe opioids to treat chronic and acute pain but these substances can lead to addiction. Opioids were involved in 46 802 overdose deaths in 2018, according to the CDC, representing 70% of all deaths from a drug overdose that year. The Administration's research budget for 2021 proposes a specific allocation of US$ 1.4 billion to the National Institutes of Health 'for the opioid and methamphetamine epidemic' (CRS, 2020b).

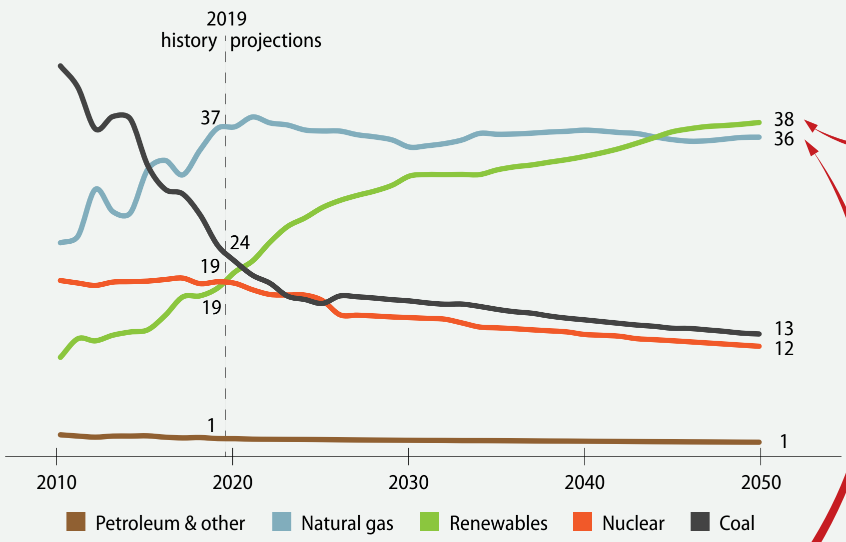
An inequitable health system

The health system suffers from issues of access and equity. The USA spends more per capita on prescription drugs than any other OECD country.[17] The 2018 *National Healthcare Quality and Disparities Report* underlines financial reasons as a major factor for lesser care among populations of lower income levels and ethnic backgrounds (AHRQ, 2018). An estimated 14% of the population remains uninsured (Maddox, 2019).

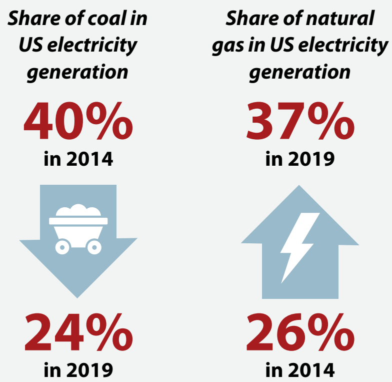
The formal request by the Trump Administration on 25 June 2020 for the Supreme Court to strike down the Patient Protection and Affordable Care Act (2010, familiarly known as Obamacare), which has extended access to health insurance,[18] sparked a heated debate. Such a move has been possible since 2017 when the US Congress removed the penalty for Americans

Figure 5.8: **Trends in energy in the United States of America**

Share of electricity generation by source in the USA, 2019 and projection to 2050 (%)
2020 reference case,



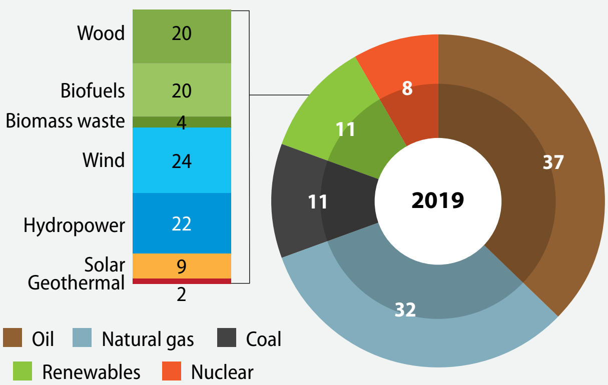
Electricity generation from renewable sources such as wind and solar is projected to surpass nuclear power and coal by 2021 and natural gas by 2045.



The share of renewables in the US electricity generation mix is projected to rise from 19% in 2019 to 38% by 2050.

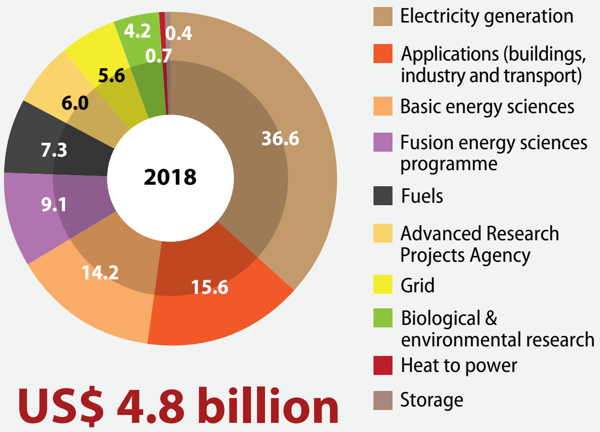
About 28% of total US energy consumption in 2019 was used to transport people and goods.

US primary energy consumption by source, 2019 (%)



100.2
Total consumption: quadrillion British thermal units

Department of Energy budgetary structure, by application, 2018
In US$ millions



US$ 4.8 billion
Total

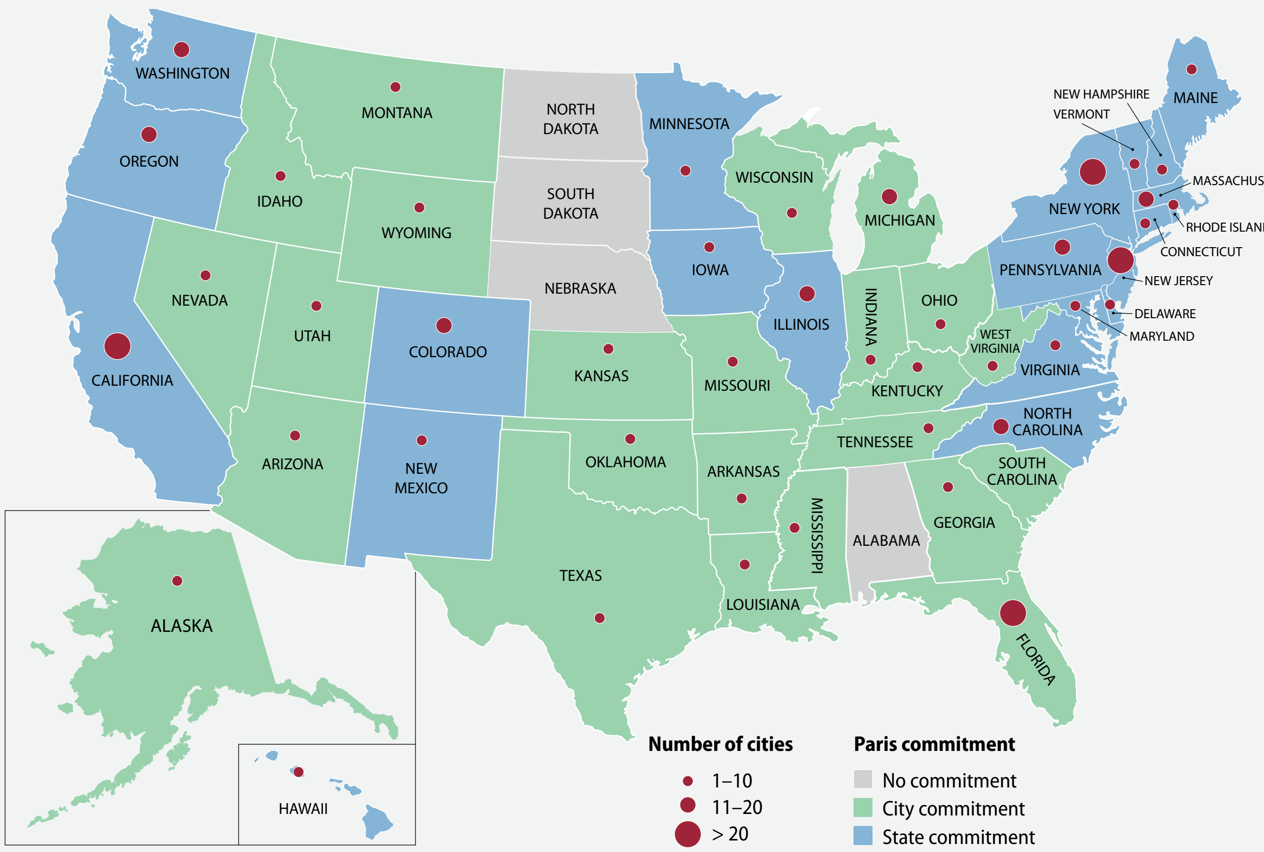
without health insurance. Two lower federal courts have already ruled that this action made the Affordable Care Act's individual mandate unconstitutional, an argument seized upon by the solicitor-general when he filed the legal brief on behalf of the government in 2020 (Dwyer, 2020).

An unsustainable trajectory?

US health care spending reached an astronomical US$ 3.5 trillion in 2017, about 18% of GDP (Maddox, 2019; CMS, 2019). Recent projections are for national health expenditure to grow at an average annual rate of 5.4% between 2018 and 2028 and represent 19.7% of GDP by the end of this period (US$ 6 192.5 trillion), while the insured share of the population is expected to fall from 90.6% to 89.4% over the same period (Figure 5.9).

The share of health care financed by federal, state and local governments is expected to rise by 2% to 47% by 2028, with the cost of Medicare being instrumental in driving up the federal government's share from 28% to 31%. The projected business and household share is expected to fall from 55% to 53% over the same period (Keehan *et al.*, 2020). This appears to be an unsustainable trajectory.

Subnational commitments to meeting the USA's Nationally Determined Contribution under the Paris Agreement



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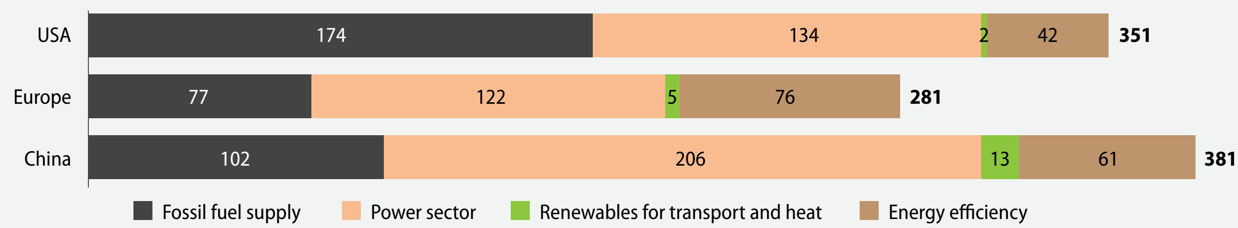
Energy investment by sector in selected markets, 2018
In US$ billions

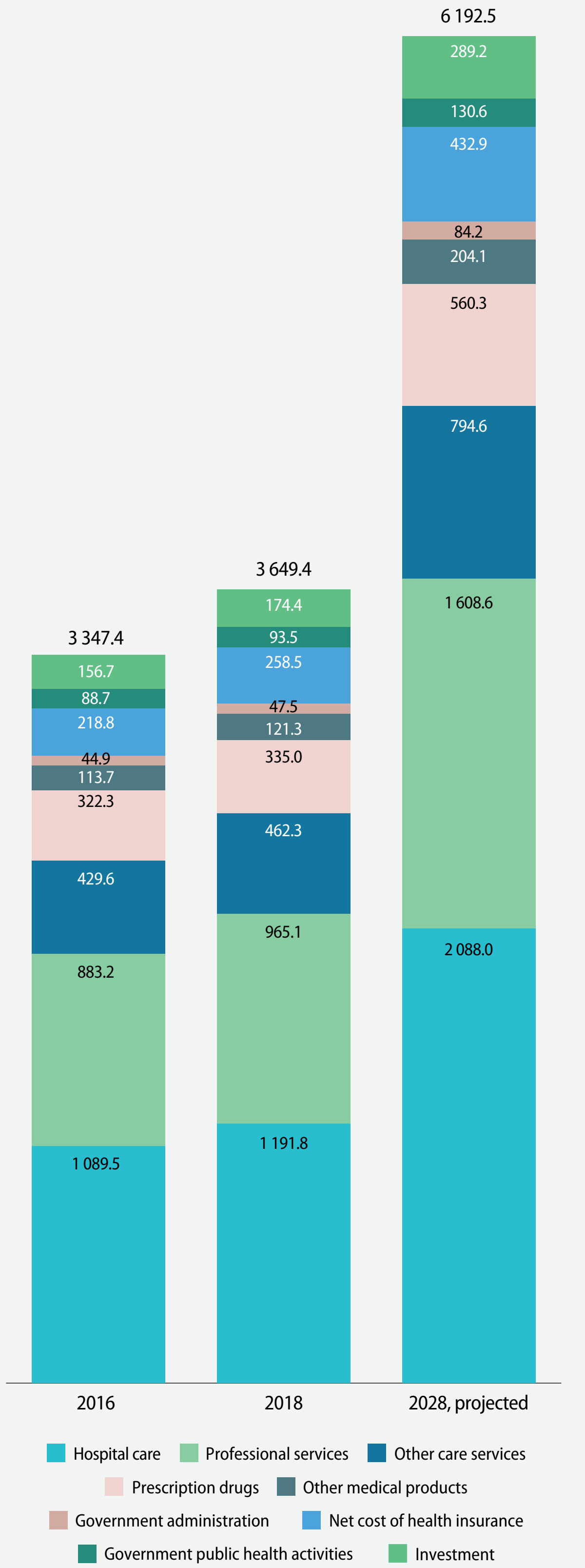


Note: Renewables for transport and heat include transport biofuels and solar thermal heating. Here, Europe covers Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Source: Capuano, L. and EIA (2020) *Annual Energy Outlook 2020*. Presentation by Dr Linda Capuano. US Energy Information Administration; EIA (2020) *April 2020: Monthly Energy Review*; for DOE budget and Paris Agreement commitments: Breakthrough Energy (2019), Figures 1–4 and 1–7; for energy investment: International Energy Agency (2019) *World Energy Investment 2019*. All rights reserved

Figure 5.9: US national expenditure on health care by spending category, 2016, 2018 and projections to 2028

In US$ billions



Note: Other care refers here to health, residential and personal care, home health care, nursing care facilities and continuing care retirement communities.

Source: Adapted from Keehan *et al.* (2020), Exhibit 4, p. 708

Hospitals account for about one-third of the budget, physician and clinical services for another one-fifth and prescription drugs for almost another one-tenth (Figure 5.9). An additional significant cost relates to medical devices. It is projected that both the cost of these devices and the cost of drugs will increase substantially in the coming years. It is in these two areas that much of scientific research and innovation is taking place, as we shall see in the following paragraphs.

How much innovation are Americans prepared to pay for?

Prescription drugs typically cost more in the USA than elsewhere (Kliff, 2018). The USA is exceptional, in that it neither regulates, nor negotiates the prices of new prescription drugs. Other countries employ public agencies to negotiate with pharmaceutical companies an appropriate price, typically on the basis of the incremental benefits of the new drug over extant medication.[19] The USA has no such agency.

Medicare, which covers about 55 million Americans over the age of 65 years and which, together with Medicaid, shoulders a substantial share of medical expenses (Figure 5.9), is prohibited by federal law from negotiating drug prices or making decisions about drug coverage. Medicare is, instead, required to cover nearly all drugs approved by the FDA, irrespective of whether these constitute an improvement over extant medication.

Thousands of other health insurance plans negotiate their own prices with pharmaceutical producers separately. The exception is the Veterans Health Administration, which can negotiate drug prices and, as a result, covers fewer products at prices usually one-third or more cheaper than Medicare.

The rationale is industry profitability: the expectation of higher profits, the argument goes, makes the pharmaceutical industry attractive to investors; higher investment, in turn, means more research towards new and innovative cures.

This generous subsidy at the back end is supplemented by another sizeable subsidy at the front end, in the form of the investment in basic research provided by the National Institutes of Health and, thus, by the American taxpayer. This translates into approximately US$ 31 billion in expenditure on basic research to assist the pharmaceutical sector.

US consumers pay the highest prices in the world for the medication they buy over the counter. These high drug prices help to subsidize pharmaceuticals research in the rest of the world but this model is reaching its limits as health care costs spiral upward. The question for policy-makers is: how much innovation are Americans comfortable paying for?

Intellectual property protection is a salient part of this system. Intellectual property rights play an important role in the development and pricing of pharmaceutical products. Patents give inventors temporary monopolies, allowing them to charge less competitive prices by delaying the entry of competitors manufacturing generic drugs and biosimilars.[20] Congress has legislated on both, with the Hatch-Waxman Act (1984) serving to speed up the introduction of generics and the Biologics Price Competition and Innovation Act (2009) doing the same for biologics (CRS, 2019b).

Precision medicine gaining traction

Twenty years on from the first sequence of a human genome, and at huge expense, we now know that the vast majority of diseases do not depend on individual genes. Rather, everyone's genome is unique. This has led to precision medicine. The 21st Century Cures Act (2016) was a milestone, in that it allowed new clinical trials to factor in personalized parameters, such as biomarkers and genetics.

The 21st Century Cures Act established four projects under the National Institutes of Health, namely, the Cancer Moonshot, the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative, the Precision Medicine Initiative and Regenerative Medicine. These research programmes have no statutory basis,[21] meaning that they may be eliminated at the discretion of the president (CRS, 2018a). Between 2017 and 2020, all budgetary amounts authorized by the 21st Century Cures Act were fully appropriated (CRS, 2020b).

In 2019, 25% of the 48 new molecular entities approved by the FDA's Center for Drug Evaluation and Research for therapeutics (44) and diagnostics (4) were personalized medicines, according to the Personalized Medicine Coalition. These approvals are part of a trend that began in 2014, when the Coalition classified 21% as personalized medicines. The share of personalized medicines peaked at 42% in 2018.

Precision, of course, brings complexity, namely, the need to understand the molecular variation of individual patients, in order to develop ever-more effective treatments. A drug that works well on one subtype of a disease might fail in a trial that includes patients with another subtype. Cancer, diabetes and Parkinson's disease have already benefitted extensively from precision medicine (*The Economist*, 2020b).

Under the Precision Medicine Initiative, the All of Us Research Program began enrolling volunteers in May 2018 in a study which prioritizes populations traditionally underrepresented in biomedical research (Whitsel *et al*., 2019).[22] The aim is to compile a vast database to inform research on a wide variety of health conditions. The data platform will be open to researchers worldwide. By September 2020, the programme had recruited 225 000 volunteers out of the 1 million it hopes to enrol in the programme.

The Million Veteran Program launched in 2011 takes a broadly similar approach to the All of Us Research Program, gathering reams of data from individuals but with an additional emphasis on conditions that disproportionately affect veterans, such as post-traumatic stress disorder. This programme is still active; it is part of the president's budget request for 2018 for the Department of Veterans Affairs.

As costs have dropped with the growing sophistication of genome-sequencing technologies, related programmes in the USA and elsewhere have produced torrents of data on individual human genomes, spawning a booming pharmacogenetic industry. In order to analyse this burgeoning volume of data, pharmaceutical companies will become highly dependent on artificial intelligence and cloud computing. They will need to work together with data giants.

New biological insights, new ways of analysing patients and new forms of drugs are opening up a wide range of therapeutic possibilities. Unfortunately, that does not automatically translate into profitable opportunities, since precision medicine also raises costs.

This may help to explain at least part of the cost projections (Figure 5.9). It also suggests that the public health system will need a master plan in order to avoid a situation in which an inordinate share of the public health budget is monopolized by a single disease affecting only a few thousand citizens (orphan drugs).

BROAD PRIORITIES: SPACE EXPLORATION

An America First space policy

Since taking office in January 2017, the Trump Administration has released four space policy directives. The first announced the *National Space Policy* focusing on pioneering and exploration, peace through strength and improving space architecture and capabilities. This directive announced the intent to create policies supporting the US commercial space industry over foreign companies while continuing to rely on foreign partners for burden-sharing on larger, more ambitious projects like the International Space Station.

The next three directives addressed the commercialization of space, space traffic management and the creation of a US Space Force military corps, respectively. The Administration has announced plans to return to the Moon and to be the first to 'set foot' on Mars (Box 5.2).

Released in February 2019, the Space Policy Directive-4 (The White House, 2019) announced the creation of a sixth service of the US military, the Space Force. It will be structured as a corps within the US Air Force.

In support of these ambitious plans, the NASA budget received a 5% boost between 2019 and 2020 to US$ 22.6 billion. In the government's budget proposal for the 2021 fiscal year, NASA was one of only four agencies to receive an increase in its overall budget, with the government proposing a 14% jump.

A Space Force

The goal of the Space Force is 'to consolidate authority and responsibility for national security space in a single chain of command, to build a robust cadre of space professionals who can develop space-centric strategy and doctrine and to avoid the conflicts of interest inherent in the other services that have short-changed space programs for decades' (Harrison, 2018).

Several other countries have already announced similar space commands, including China, France and the Russian Federation. The weaponization of space is rapidly becoming a serious geopolitical and security concern, complicating international relations (The Economist, 2019).

NASA tasking commercial partners with space economy

NASA is returning human spaceflight capabilities to the USA for the first time in nearly a decade. Since the retirement of the Space Shuttle Program in 2011, American astronauts have relied on the Russian Federation for launches to the International Space Station orbiting Earth at an altitude of 400 km.

The retirement of the Space Shuttle Program was one consequence of years of budget cuts. This long period of austerity had left NASA's research budget smaller in 2014 than 20 years earlier (in billions of constant 2012 US$), obliging NASA to shift its focus 'away from human spaceflight, as part of a cost-cutting drive' (Stewart and Springs, 2015).

The retirement of the Space Shuttle was also part of NASA's effort to channel resources away from an old technological system to the next-generation Space Launch System (Box 5.2). The latter is now almost complete and should be far superior to the Space Shuttle.

NASA has adopted a strategy of increasingly tasking commercial partners with developing the space economy, while the agency focuses its own resources on deep space exploration. NASA said as much in a statement issued on 28 February 2017, in which the agency explained that it was 'changing the way it does business through its commercial partnerships to help build a strong American space economy and free the agency to focus on developing the next-generation rocket, spacecraft and systems to go beyond the Moon and sustain deep space exploration' (Thompson, 2017).

NASA's new Commercial Crew Program is partnering with the SpaceX and Boeing corporations. SpaceX transported astronauts Bob Behnken and Doug Hurley to the International Space Station on 3 June 2020, the first time that a private company had launched humans into space.

This feat has ushered in a new era. Public–private partnerships will enable NASA to offload some of its more regular space activities, in order to focus more on long-term, big budget projects such as Artemis and Moon to Mars (Box 5.2).

A space economy dominated by US firms?

The year 2019 marked a peak in global investment in space, with firms headquartered in the USA accounting for 55% of the total. The USA was followed by the UK (24%), France (7%) and China (5%) [Space Capital, 2020].

The US space industry was valued at approximately US$ 158 billion in 2016. It is estimated that 'space systems' within the aerospace and defence industries contributed US$ 39 billion to US economic output in 2018, making space commerce a lucrative industry for the US economy (Highfill *et al.*, 2019).

NASA's public–private partnerships have been key to the development of the private space industry in the USA. Currently valued at over US$ 33 billion, SpaceX is now one of the world's most valuable private companies; it has already launched the most powerful rocket in the world, Falcon Heavy, in February 2018.

SpaceX has even bigger plans, announcing its intention to develop Mars-destined rocket systems that it labels Starship. It also plans to roll out a constellation of 12 000 small satellites through its new Starlink system to provide global Internet connectivity. This system already has hundreds of satellites in orbit and has earned the support of the Federal Communications Commission.

Another US company, Blue Origin, is working on building and launching BE-4, a massive reusable rocket.

Boeing is the primary contractor for NASA's new Space Launch System rocket. The company is also competing with SpaceX to provide the necessary capabilities for a mission to Mars.

This reflects a growing private-sector focus on commercial space activities that range from space tourism to satellite communications and asteroid mining.

TRENDS IN HUMAN RESOURCES

Jobs in science and engineering pay better

There are about 7 million workers in the USA who employ their scientific expertise and technical knowledge in four broad occupational categories: construction and extraction (21%), health care (20%), installation, maintenance and repair (20%) and production (16%) [NSB, 2020].

Box 5.2: **The USA: back to the Moon then on to Mars**

Supporting the Administration's focus on space pioneering and exploration, NASA announced the Artemis project in 2018, as part of the *National Space Strategy*.

The Artemis project aspires to send the next man and the first woman to the Moon by 2024 (The White House, 2018). This mission will act as a testing ground for developing the capabilities necessary to reach Mars, making Artemis the foundation of NASA's Moon to Mars approach.

The project has been named after Artemis, the Greek goddess of wild animals, the hunt and the Moon, the twin sister of Apollo, god of the Sun. Apollo was the last NASA programme to land an astronaut on the Moon, Gene Cernan, in December 1972.

Unlike the Apollo missions of the 1960s and 1970s, the Artemis mission will aim to establish a sustainable presence on the Moon and will work in collaboration with commercial and international partners.

With an ambitious time-frame, Artemis will be powered by NASA's forthcoming Space Launch System. Artemis will include a new powerful rocket and command module, Orion, which will serve as an intermediary step for flying to the Moon then back to Earth. Orion will dock with another key component of the Artemis mission, a Lunar Gateway that will serve as an orbital outpost of the Moon to support human exploration there.

The development of a modern lunar lander and a new generation of spacesuits are also key elements to NASA's return to the Moon.

Beyond the Moon

Following a series of Artemis Moon missions over the next decade, NASA will aim to put astronauts on Mars in the 2030s.

Federal funding is also projected to support both an orbiter and a lander for Jupiter's moon Europa and Saturn's largest moon, Titan, not to mention a solar probe, a new Mars rover and research on the Kuiper Belt.

Source: compiled by authors

The great majority of these individuals work for the business enterprise sector (72%), followed by educational institutions (16%) and the government (12%). Many others with relevant training are employed in occupations not formally classified as science and engineering jobs (NSB, 2020).

Employment in science and engineering occupations has grown more rapidly than the workforce as a whole and now represents about 5% of all US jobs (Figure 5.4). In 2017, the median annual salary in science and engineering occupations across workers of all education levels was US$ 85 390, more than double the median salary for all US workers (US$ 37 690) [NSB, 2020].

Foreign-born workers employed in science and engineering occupations[23] tend to have higher levels of education than those born in the USA: 17% of foreign-born workers held a doctorate in 2017, compared to 9% of US native-born individuals in these same occupations, according to the National Science Board's science and engineering indicators. Among foreign-born computer scientists, mathematicians and engineers, more than half held a doctorate in 2017.

A need for greater inclusiveness

The number of underrepresented minorities – Blacks, Hispanics and American Indians or Alaskan Natives – working in science, technology and engineering in the USA has grown but these groups remain underrepresented, relative to their overall presence in the workforce and population. In 2017, they made up just 13% of the science and engineering workforce but 28% of the US workforce as a whole (NSB, 2020).

The number of women in science and engineering jobs rose from 1.3 million to 2 million between 2003 and 2017. However, even after this increase, women only accounted for 29% of the science and engineering workforce, despite making up 52% of the general workforce with tertiary education.

Many private companies and public agencies are currently making hiring a diverse workforce a pillar of their annual strategies (see chapter 3).

Distance learning imposed by the Covid-19 pandemic may accentuate the social divide in higher education. An April 2020 survey by McKinsey found that only 40% of students from low-income households were able to obtain the necessary equipment for distance learning, compared with 72% of students from high-income households. Only 56% of students from low-income households reported having reliable Internet access, compared with 77% of high-income students (Kim *et al*., 2020).

Automation and AI threatening jobs

The US science and engineering workforce is growing but the system faces major obstacles. Challenges include retraining workers displaced by automation, robotics and AI, encouraging students to enrol in science and engineering fields and recruiting a diverse workforce that is representative of the population.

Many workers are vulnerable to job displacement by automation, robotics or AI. Among those most likely to be displaced by automation are individuals with a high-school degree or less who are performing standardized tasks. These individuals are more than four times more likely to hold highly automatable jobs than those with bachelor's degrees (see also Figure 3.1). Twelve million such workers of Hispanic and Afro-American heritage have already been displaced by automation. In the coming decades, it is estimated that about 25% of US jobs (36 million in 2016) will face high exposure to automation (Muro *et al*., 2019a).

A relatively new phenomenon is that AI is threatening better-paid professional jobs in high-tech fields and metropolitan areas (Muro *et al*., 2019b). This trend will require considerable restructuring of career pathways and training programmes.

To compound matters, the Manufacturing Extension Partnership and the Economic Development Administration (est. 1965) were eliminated in 2019. The same White House budget also proposed a US$ 1.8 billion cut to the Trade Adjustment Assistance Program (TAA) over the next ten years, a 22.8% decrease. This move would severely cut funding to workers impacted by shifting trends in trade. The TAA is up for reauthorization in 2021.

Steady growth in doctorates

The USA will need to recruit new talent into science and engineering to maintain its technological pre-eminence and generate jobs for the industries of the future.

This starts as early as primary school, where the scores of US pupils participating in international assessments have seen little improvement over the past decade. Pupils perform above the OECD average for science but below the OECD average for mathematics, according to the 2018 edition of the OECD's Programme for International Student Assessment.

The higher education system does a much better job of preparing Americans to enter the science and engineering workforce. According to the Bureau of Labor Statistics, 66.2% of secondary school graduates in 2019 (aged 16–24 years) had enrolled in colleges or universities by October 2020 (NSB, 2020).

In 2016, the USA awarded nearly 800 000 bachelor's degrees in fields related to science and technology, compared to almost one million for the European Union. Community colleges play a key role in this achievement; among US students who earned this type of bachelor degree, almost half had done some coursework at a community college in 2016.

The number of doctoral degrees awarded has progressed steadily since 2000, with the exception of a dip in 2010 in the wake of recession. This growth trend is projected to continue. In 2017, the USA awarded almost 46 000 doctorates in science and engineering, 23% of which were conferred on engineers (Figure 5.10).

International students earning one-third of doctorates

One-third (34%) of doctoral degrees awarded in science and engineering went to international students holding a temporary visa in 2017, a stable proportion since 2015; half (54%) of these students came from just three countries: China, the Republic of Korea and India. By comparison, students on temporary visas earned just 6% of bachelor's degrees in science and engineering in 2017, even if their number has more than doubled over the past decade (NSB, 2020).

An April 2020 survey by the Institute of International Education found that 92% of all international students enrolled in US universities had decided to remain in the USA throughout the pandemic. It is likely, however, that the number of international students travelling to the USA for the new academic year will drop, especially those coming from China (Martel, 2020).

CONCLUSION

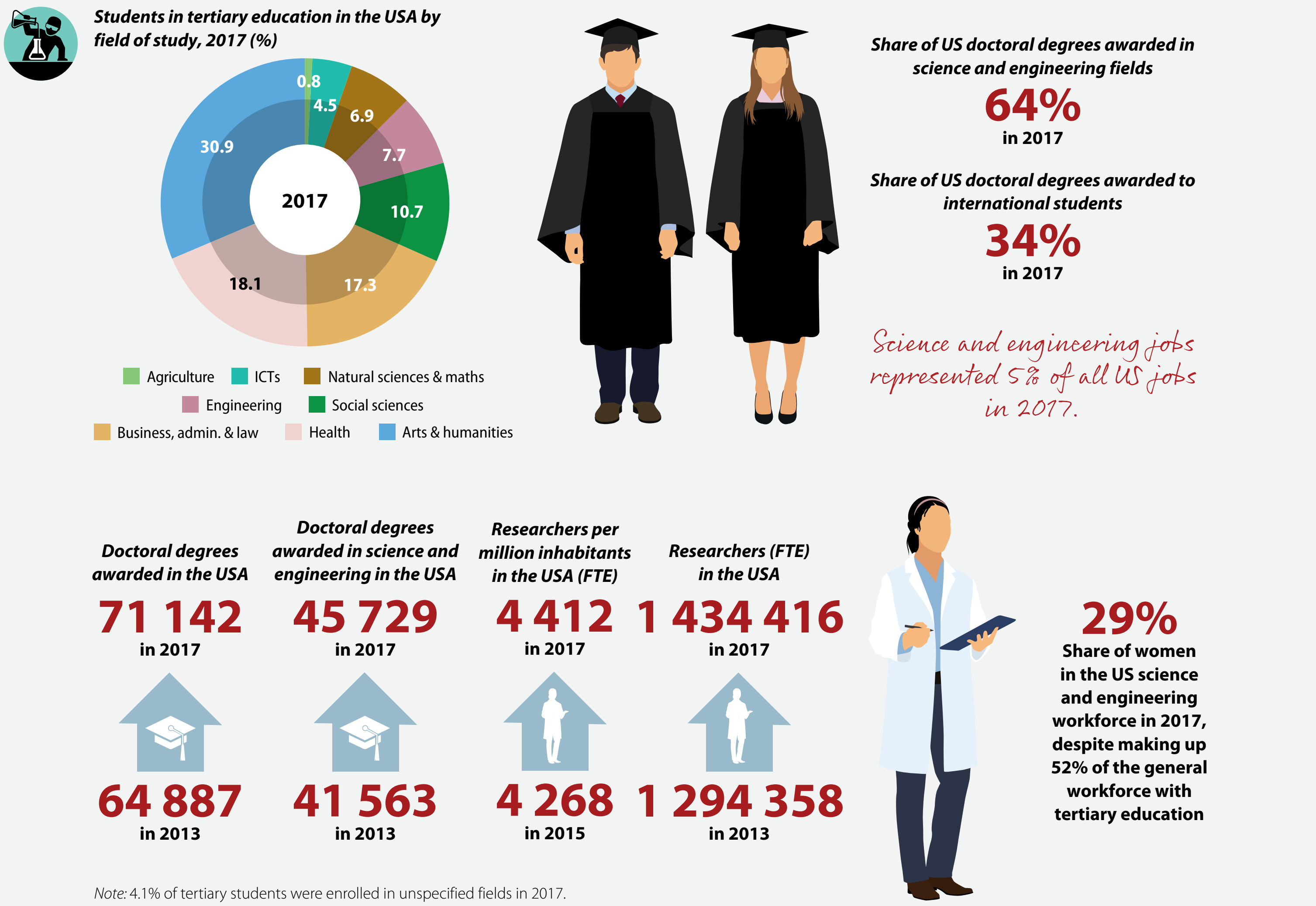
Putting the brakes on unfettered globalization

The national innovation system is being pulled in different directions by the naysayers and the champions of globalization. Totalling well over half a trillion dollars in annual expenditure on R&D alone, the national innovation system is a large 'ship' to manoeuvre. Notwithstanding this, the winds of change have been blowing over the policy ecosystem in the past five years. The USA faces increasing competition in science, technology and innovation from Asian players in particular, such as China, the Republic of Korea and India. This competition is likely to intensify.

To face that challenge, the USA is investing in cutting-edge technologies such as artificial intelligence, quantum computing, 5G technology and cybersecurity. At the same time, the country is training a diverse science and engineering workforce, developing green technology, building an advanced manufacturing industry and creating innovative and affordable health care to sustain the country's economy and workforce.

Looking back, although fears of a widespread increase in protectionism following the Great Recession of 2007–2009 did not materialize, the crisis did affect long-term trends underlying the process of globalization. Neither international trade, nor foreign direct investment and cross-border bank lending have returned to their peak of the early 2000s (The Economist, 2020c). Intensifying international competition, strong security concerns, the current pandemic and the inability of the global economy to completely recover from the Great

Figure 5.10: **Trends in human resources in the United States of America**



Note: 4.1% of tertiary students were enrolled in unspecified fields in 2017.

Source: UNESCO Institute for Statistics; for doctoral degrees: NSB (2019) *Trends in Undergraduate and Graduate S&E Degree Awards. Science and Engineering Indicators 2020.* NSB-2019-7, Table S2-10. See: https://tinyurl.com/y3qhswak

Recession a decade ago have sown doubts about the virtues of globalization for the US economy. Since 2017, protectionism has gained traction with the adoption of the America First policy agenda, one early expression of which has been the US withdrawal from plans for a Trans-Pacific Partnership, a major trading agreement that other countries have gone on to ratify. The process of globalization, which the USA had promoted since the end of the Second World War, is being severely tested.

Meanwhile, China has seized the window of opportunity offered by the Great Recession – from which it emerged largely unscathed – to pursue its rapid march towards the production of goods and services with a higher technology component. In so doing, it hopes to avoid the middle-income trap bedevilling so many other emerging economies (Lee, 2019). In the process, China has garnered new trading partners and become an economic heavyweight.

The economies of both the USA and China have been perturbed since 2018 by a trade dispute that has spilled over into the arena of high technology, technology transfer and intellectual property protection. There is a real risk of decoupling between the two countries in terms of technology and talent.

The virtues of a globalized research system

The emergence of Covid-19 in 2020, with its terrible consequences for the global economy, has provided additional fodder for the naysayers of globalization.

However, this knee-jerk reaction tends to overlook the other side of the coin. The Covid-19 pandemic has demonstrated the virtues of a globalized research system. In the USA and elsewhere, we have seen public and private actors working across borders and disciplines to come to grips with the complexity of this new coronavirus and accelerate the development of treatments, protective personal gear, medical equipment and vaccines for the public good. The current pandemic has made a convincing case for opening up research across borders and ensuring transparency in terms of data- and information-sharing. Be it related to public health, climate change, environmental degradation or other societal issues, scientific research must not be silenced under the pretext that this new knowledge represents a national security risk.

The full consequences of the Covid-19 pandemic are still unclear but there will most likely be major changes to all economic sectors that will affect the scale and direction of the 'technical enterprise'. The US higher education system, for instance, has been profoundly affected by the pandemic; more than half of universities reportedly do not meet basic remote learning preparedness metrics prior to the pandemic and are struggling to find viable ways to educate their students in a remote-only environment. In the current academic year, new enrolment in the US university system by international students, in particular, has taken a sharp downturn, a trend that could persist for years.

Another obvious consequence of the health crisis, as vividly projected in the White House's Operation Warp Speed, has been the pivot by many US experts in the biomedical sector away from long-term projects to short-term support in creating, producing and distributing vaccines, treatments and effective tests for the virus.

Longer-term changes may make a permanent dent in the process of globalization as we know it. The current geopolitical struggle between the USA and China, coupled with the Covid-19 pandemic, significantly raises multinational corporations' exposure to risk. This will elevate the importance of risk mitigation to the level of cost effectiveness as a consideration in determining the resilience of global value chains (Petricevic and Teece, 2019). Nevertheless, the national innovation system is dynamic and should manage to adapt to this rapidly evolving international environment.

KEY TARGETS FOR THE UNITED STATES OF AMERICA

The USA plans to:

- double government investment in research in quantum information science and artificial intelligence by 2022, compared to a 2019 baseline;
- send the next man and first woman to the Moon by 2024.

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ENDNOTES

1 The present report not only covers UNESCO member states. The USA's withdrawal from UNESCO came into effect on 31 December 2018.

2 See: https://coronavirus.jhu.edu/data/mortality

3 See: https://climate.law.columbia.edu/Silencing-Science-Tracker

4 US Bureau of Labor Statistics press release of 6 November 2020

5 For example, the combined trade deficit in goods and services with China was US$ 378.6 billion in 2018, whereas the deficit in goods alone reached US$ 419.2 billion. These deficits compare with a US surplus of US$ 33.4 billion in goods and services and US$ 31.0 billion in goods with China's special administrative region of Hong Kong. Although a significant share of the trade imbalance is attributable to American multinational corporations, reliable data are difficult to come by. Such numbers largely explain the eagerness of successive US administrations to address the huge trade imbalances with China (Office of the United States Trade Representative, 2020). For more details of bilateral trade balances, see US Census Bureau (2020).

6 The stock of US FDI in China amounted to US$ 116.5 billion in 2018 (up 8.3% from 2017), whereas Chinese FDI stock in the USA amounted to US$ 60.2 billion (up 3.7% from 2017), accounting for 1.4% of total FDI stock in the USA, up from 0.05% in 2002 (CRS, 2019a).

7 Congress may opt to agree with none, part or all of the president's request and may express different priorities through the appropriations process (CRS, 2020b).

8 The ratio between the Federal Research Tax Credit and Qualified Research Spending by business has declined since 2000.

9 See the Census Bureau, US Department of Commerce: www.census.gov/econ/bfs/index.html

10 The legislative branch in the USA is comprised of the House of Representatives and the Senate, collectively referred to as Congress.

11 An executive order is a directive from the president to the relevant federal agencies to act in a given area but it does not constitute an actionable strategy in itself. In issuing an executive order, the president does not create a new law or appropriate funds from the US Department of the Treasury, these steps being the purview of Congress.

12 See: https://www.whitehouse.gov/ai/

13 The other founding members of the Global Partnership on Artificial Intelligence are Australia, Canada, the European Union, France, Germany, India, Italy, Japan, Rep. Korea, Mexico, New Zealand, Singapore, Slovenia and the UK. The GPAI Secretariat is hosted by the OECD in Paris, France. UNESCO will be tabling an international instrument on the ethics of AI for adoption by 192 member states in November 2021.

14 A carrier is a wireless service provider that supplies mobile phones with cellular connectivity. There are now three major carriers in the USA, following the merger of T-Mobile and Sprint.

15 The other two categories at the Department of Energy are national security and science.

16 Other agencies conducting energy science research include the Department of Defense, the Department of Transportation and the Department of Agriculture.

17 The USA spent US$ 1 229 per capita on pharmaceuticals in 2018, well ahead of Switzerland's US$ 894, the next biggest spender among OECD countries. See: https://data.oecd.org/healthres/pharmaceutical-spending.htm

18 See: California *et al.*, Petitioners v. Texas *et al.*, case no. 19-10011.

19 In Australia, for instance, this body is the Pharmaceutical Benefits Advisory Committee (Kliff, 2018). It is estimated that American citizens pay twice as much as Australians for the same drugs.

20 For a discussion of biosimilars in the USA, see Stewart and Springs, 2015.

21 Multiagency research programmes with a statutory basis include the Networking and Information Technology Research and Development Program (est. 1991), the National Nanotechnology Initiative (est. 2001) and the US Global Change Research Program (est. 1990), which studies climate change.

22 See: https://databrowser.researchallofus.org/

23 Foreign-born workers employed in science and engineering occupations are a self-selected group, as related studies are conducted within US institutions of higher education.

Girls from the Canaries Infant School in St Lucia explain to the Minister of Education, Innovation and Gender Relations, the Hon. Dr Gale Rigobert, how they used plastic bottle caps to mend the bench upon which she is seated. The girls' design concept has the added value of providing body self-healing pressure point therapy; it qualified for the 2019 National Schools' Science and Technology Fair, in the innovation category. © Department of Innovation, Government of St Lucia

AT A GLANCE

- The growing cost of natural disasters has set the stage for bold collective initiatives in areas that include climate resilience and green innovation, attracting support from international donors.
- Strategic frameworks are closely aligned with the 2030 Agenda for Sustainable Development but detailed roadmaps and sustainable funding, monitoring and evaluation mechanisms are needed to support implementation.
- The near-total absence of data on R&D is hampering effective science management.
- Research output has grown, demonstrating a growing research culture, but the current emphasis on health research will not prepare Caribbean societies for the digital and green economies of tomorrow.
- With innovative firms in need of systemic, sustained support, Jamaica's new programme for Boosting Innovation, Growth and an Entrepreneurship Ecosystem could serve as a model for the region.

6 · Caricom

Antigua and Barbuda, Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Haiti, Jamaica, St Kitts and Nevis, Montserrat, St Lucia, St Vincent and the Grenadines, Suriname, Trinidad and Tobago

Alison S. Gajadhar and Ishenkumba A. Kahwa

INTRODUCTION

Pressures on growth

Since 2015, most of the members of the Caribbean Community (Caricom) have experienced low economic growth rates (Figure 6.1). The region's modest economic performance cannot be solely attributed to the weak performance of the global economy following the end of the commodities boom and the sluggish recovery of energy-related returns for the oil- and gas-exporting economies of Belize and Trinidad and Tobago. Rather, this trend is symptomatic of structural issues related to the labour market, public sector inefficiency and weak legislative support for business in the Eastern Caribbean (IMF, 2019).

Although Guyana's economy is poised to grow by 29.6% in 2020[1] and by 300% over the next five years (IMF, 2019), this will owe more to the recent discovery of offshore oil and gas reserves by ExxonMobil than any structural reforms. Oil production got under way in December 2020 with an estimated yield of 120 000 barrels a day. This should accelerate to 340 000 in 2022 and 750 000 per day in 2025. ExxonMobil is, meanwhile, stepping up its exploration of new fossil deposits and, thereby, attracting new players.

Regional economic growth has also been impeded by catastrophic hurricanes. Hurricane Dorian devastated the Bahamas in September 2019 and Hurricanes Irma and Maria were particularly destructive to Barbuda and Dominica in late 2017. The subsequent departure of Ross University's School of Medicine after 40 years has eroded about 19% of Dominica's GDP (Nixon, 2018). These disasters have focused attention on rebuilding more resilient infrastructure capable of withstanding the growing intensity and frequency of hurricanes. This requires greater capital investment in infrastructure, accentuating the fiscal burden on the islands.

The Caricom members remain plagued by some of the highest public debt in the world, relative to the size of their economies (ECLAC, 2018a). This high public debt is a major contributor to the huge fiscal deficits arising from the excessive non-discretionary expenditure associated with high debt service payments, wages and salaries, and welfare-maintaining transfers and subsidies.

Notwithstanding some gains since 2018 in Barbados, Grenada and Jamaica, in particular, through fiscal consolidation (debt stabilization) programmes assisted by the International Monetary Fund (IMF), fiscal deficits have remained a drag on the economic development of Caricom countries, limiting discretionary public spending on health, education and research and development (R&D). The region's margin for manoeuvre in its spending choices has even been narrowing, with a drop from the rank of 35 in 2014 to 31 in 2017 on the Fiscal Flexibility Index. The goods-producing economies have recorded a greater deterioration in fiscal flexibility than the service-oriented ones.[2]

Many of the service-oriented economies have also demonstrated weak economic growth, owing to their dependence on the tourism sector. The high cost of Caribbean destinations and impact of hurricanes have made tourism a volatile industry. After peaking in 2017, the number of visitors declined in 2018 for the first time in nine years (CTO, 2018).

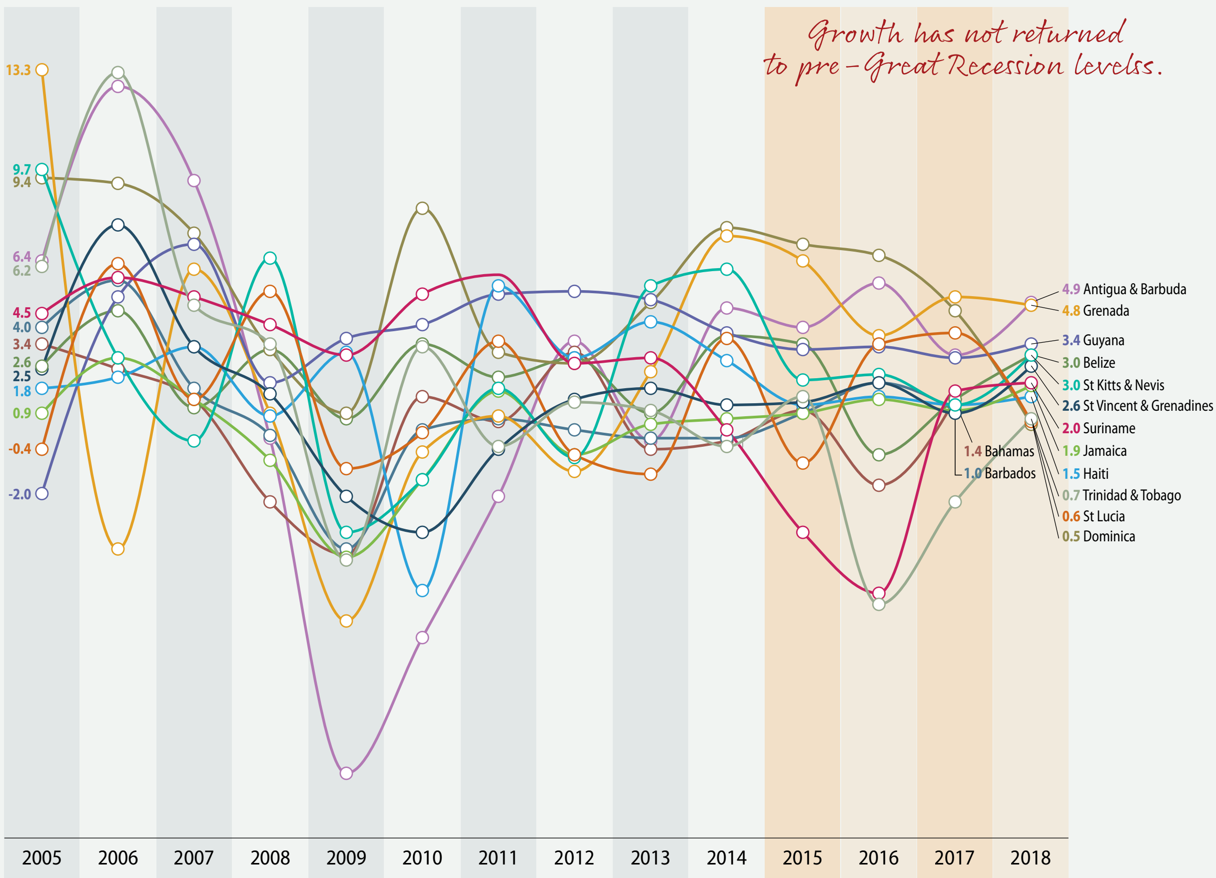
Tourism remains a priority sector for regional development, as outlined in Caricom's *Strategic Plan for the Caribbean Community, 2015–2019*. The other priorities are agriculture and fisheries, information and communication technologies (ICTs), air and maritime transport infrastructure and services, and energy efficiency, diversification and cost reduction (Ramkissoon and Kahwa, 2015).

The region's fiscal difficulties are symptomatic of the challenges small economies share, which include (ECLAC, 2018b):

- lack of competitiveness of the private sector and little scope for diversifying markets and products, owing to a lack of economies of scale in production;
- limited Internet penetration, hampering mobility (Figure 6.1);
- environmental vulnerability due to their geographical location and low-lying coastline;
- an inadequately skilled workforce, with a mismatch between the output of the region's education systems and the labour market, compounded by one of the world's highest levels of emigration of tertiary-educated individuals (Alleyne and Solan, 2019);
- excessive reliance on external financial inflows, especially remittances. Remittance inflows accounted for as much as 33% of GDP in Haiti and 16% of GDP in Jamaica in 2018 (Figure 6.1). Remittance outflows accounted for less than 4% of GDP in 2017;
- limited use of technology by firms;
- limited access to bilateral and multilateral grants and other concessional funding, owing to the classification of the Small Island Developing States within Caricom as middle-income countries, making it hard for these small, vulnerable economies to access international capital markets and, thereby, obliging them to borrow on onerous terms; and

Figure 6.1: **Socio-economic trends in Caricom countries**

Rate of economic growth in Caricom countries, 2005–2018 (%)



Key socio-economic indicators for Caricom countries

An extremely high debt-to-GDP ratio

	GDP per capita (current PPP$), 2019	Debt-to-GDP ratio, 2016 (%)	Fiscal balance (% of GDP), 2017	Unemployment rate, 2018 (%)	Youth unemployment rate, 2018 (%)	Exports of goods and services as a share of GDP, 2019 (%)	Remittances received (% of GDP) , 2018	FDI inflows (% of GDP), 2018	Internet penetration, 2017 (%)
Antigua & Barbuda	22 816	82.9^{-2}	-2.3	11.9	25.6	42.4^{-3}	2.2	8.4	76
Bahamas	37 266	51.4	-5.5	9.6	32.2	36.1^{-1}	–	4.0	85
Barbados	16 287	145.8^{-1}	-3.3	9.4	19.0	42.0	2.2	3.8	82
Belize	7 295	77.1^{-2}	-3.0	12.2	23.2	57.7	4.9	6.4	47
Dominica	12 659	64.9^{-2}	-5.8	13.5	29.7	51.6	8.4	2.4	70
Grenada	17 956	88.5^{-2}	3.2	9.4	32.7	54.5	4.1	13.2	59
Guyana	10 105	–	-4.5	20.9	51.0	33.0	7.4	30.4	37
Haiti	1 801	–	–	19.8	41.8	16.9	32.5	1.1	32^{+1}
Jamaica	10 166	122.7	1.4	7.6	13.6	38.0	15.9	4.9	55
St Kitts & Nevis	27 449	59.9^{-2}	2.0	2.8	4.5	63.7	2.3	9.3	81
St Lucia	16 089	66.6^{-2}	0.3	11.9	25.6	–	1.7	1.9	51
St Vincent & Grenadines	12 983	68.7^{-2}	-0.6	9.6	32.2	–	5.1	13.6	22^{+1}
Suriname	17 005	–	-7.8	9.4	19.0	–	0.01	1.8^{+1}	49
Trinidad & Tobago	27 261	–	-8.4	12.2	23.2	–	0.6	-2.9	77

+n/-n: data refer to *n* years before or after reference year

Note: Data are unavailable for some countries.

Source: World Bank's World Development Indicators, October 2019; data for debt-to-GDP ratio from July 2020; unemployment rates are modelled on International Labour Organization estimates; for unemployment rates: United Nations Economic Commission for Latin America and the Caribbean (2018) *The Caribbean Outlook*

- a restriction and, in some cases, a termination of correspondent banking services to several Caricom member states which are considered to be a high risk, threatening their exclusion from the global banking system.

From a social perspective, too, the region is losing momentum. Although Caricom countries are ranked in the upper half of the Human Development Index, there has been little or no improvement in the quality and inclusiveness of health and education, which are vital to building a resilient economy.

In addition, unemployment has remained relatively high during the period under review, with the notable exception of Jamaica, which recorded its lowest unemployment rate in 51 years in 2018. Youth unemployment rates remain among the highest in the world (Figure 6.1).

These social ills correlate with high levels of crime and violence in several countries.

Countries compelled to green their development strategies

Although most Caricom members have developed individual strategies to address the socio-economic and environmental challenges described above (Figure 6.2), *The 2030 Agenda for Sustainable Development* gives the region a common purpose. It is encouraging to note that the various national and regional development frameworks developed by Caricom governments are already closely aligned with the *2030 Agenda*.

For example, Caribbean nations are investing in a sustainable blue economy, through a US$ 100 million project awarded by the World Bank in 2015, after the Commonwealth and the Organisation of Eastern Caribbean States (OECS) had laid the groundwork. In parallel, the Caribbean Regional Oceanscape Project launched in 2017 has been investing US$ 6.3 million from the Global Environment Facility to support regional policies, private-sector collaboration and ocean data management.

In a context of increasingly costly natural disasters, some island states have felt compelled to invest heavily in building climate-resilient infrastructure to minimize loss of life and property, while developing geothermal reserves and other renewable energy resources to reduce their reliance on imported fuels (Box 6.1).

In the process, countries have been 'greening' their socio-economic development strategies and raising their research output. It is noteworthy that most improvements in research output have occurred in the smaller, more vulnerable states of Antigua and Barbuda, the Bahamas, Grenada and St Kitts and Nevis, which had hitherto experienced low or stagnant output. The larger countries of Guyana and Suriname have seen a similar trend.

It is remarkable that this progress should have been possible in largely chaotic environments for R&D lacking clear policy roadmaps and action plans.

This supreme effort has spawned collaboration between countries that has been facilitated by the Caribbean Community Climate Change Centre through multilateral projects, many of which are described in the present chapter.

REGIONAL INITIATIVES

Sustainability a focus of regional support for businesses

Since 2016, OECS has organized a number of small-scale initiatives in its member states[3] to support the business sector, many of them with a focus on 'green innovation'. For example:

- In 2018, OECS organized a Green Innovation Ideation boot camp and pitch competition for women entrepreneurs, in partnership with the St Lucia Coalition and the Caribbean Climate Innovation Centre. This activity facilitated the development of a pipeline of innovative and sustainable 'clean tech' start-ups owned and operated by female entrepreneurs.
- In 2018 and 2019, OECS organized several boot camps and pitch competitions for innovative start-ups involving youth as part of the Caribbean Entrepreneurial Challenge initiative. These were organized in collaboration with the Chamber of Commerce and Industry in Martinique and the trade and investment promotion agency, Caribbean Export.
- In 2016, OECS ran courses in e-commerce and e-business for youth and small and medium-sized enterprises. An e-business review and e-commerce diagnostic assessment was also carried out for OECS businesses. It found that the majority of member states did not yet have the necessary regulatory and infrastructural frameworks for e-commerce in place. Moreover, 40% of the businesses assessed indicated that lack of qualified personnel in ICTs was the primary impediment to developing their business.
- In 2015, OECS conducted energy audits in a number of small and medium-sized enterprises (SMEs) in its member states. As a result of this survey, which was funded by the European Development Fund, SMEs were informed of their energy consumption patterns and degree of inefficiency, and advised on how to improve their energy performance.
- In 2018, Caribbean Export redesigned its Direct Assistance Grant Scheme to allow for greater participation from SMEs. Created in 2012, it helps firms gain access to markets through exports by fostering innovation and improving productivity. The programme is helping SMEs take advantage of the opportunities offered by the bilateral and multilateral trade arrangements agreed by Caricom, including the *European Union's Economic Partnership Agreement* (2008) and the *Caricom–Dominican Republic Free Trade Agreement* (2001). The scheme provides financial assistance only through reimbursements. OECS enterprises, in particular, have encountered considerable problems in accessing this financial assistance.

A centre to implement Caricom's Energy Policy

Caricom is financing its *Energy Policy* (2013) and the related roadmap and strategy for implementation through its regular annual budget. The Caricom Secretariat has set up an Energy Unit to implement its Energy Programme, responsible for policies, strategies and regional co-ordination.

In July 2017, an agreement establishing the Caribbean Centre for Renewable Energy and Energy Efficiency (CCREEE) was signed by ten heads of government. The centre opened

Figure 6.2: **Status of development strategies in Caricom countries, 2020**

BELIZE

- *Horizon 2030: National Development Framework*, 2010

Priority areas for investment

- Fisheries & aquaculture
- Agribusiness & agro-processing
- Business process outsourcing
- Sustainable energy
- Light manufacturing & logistics
- Tourism & medical tourism

BAHAMAS

- *National Development Plan (Vision 2040)* [draft]

Priority areas for investment

- Tourist resorts
- Upscale condominium, time-share and second-home development
- Information and data processing services
- Assembly industries
- High-tech services
- Ship repair and other services
- Light manufacturing for export
- Agro-industries
- Food processing
- Mariculture
- Banking and other financial services
- Captive insurance
- Aircraft services
- Pharmaceutical manufacturing
- Off shore medical centres

BARBADOS

- *Medium-Term Growth and Development Strategy* (2013–2020)

Priority areas for investment

- ICTs
- Manufacturing
- International banking
- Maritime sector
- Medical schools
- Medical tourism
- Fintech
- Renewable energy

ST VINCENT & GRENADINES

- *National Economic and Social Development Plan (2013–2025)*, 2013

Priority areas for investment

- Tourism
- Light manufacturing
- ICTs
- International financial services
- Renewable energy
- Creative industries
- Agroprocessing

GRENADA

- *Medium-Term Debt Management Strategy (2019–2021)*

Priority areas for investment

- Tourism
- Agribusiness
- Education
- Health & wellness
- ICTs
- Energy

ST KITTS & NEVIS

- *National Adaptation Strategy (2006–2017)*

Priority areas for investment

- Tourism
- Agriculture
- Financial services
- ICTs
- Renewable energy
- International education
- Light manufacturing
- Ship registry

ANTIGUA & BARBUDA

- Country Programme for Green Climate Fund, 2017
- *Medium-Term Strategic Development Plan* (2016–2020), 2016
- *Antigua & Barbuda National Action Plan (2015–2020)*, 2015

Priority areas for investment

- Agriculture
- Diversified tourism
- ICT enabled services
- Outsourcing & specialized services

Notable targets

- By 2025, increase water desalination by 50% from 2015 levels
- By 2030, ensure that 100% of electricity is provided by off-grid renewable resources

JAMAICA

- *Science, Technology and Innovation Policy, 2020* (draft)

Priority areas for investment

- Logistics & infrastructure
- ICT-enabled services
- Tourism services
- Manufacturing
- Mining
- Energy
- Film, animation & music
- Agribusiness

DOMINICA

- *National Resilience Development Strategy 2030*, 2019

Priority areas for investment

- STI-driven climate-resilient infrastructure
- Green industries
- Geothermal and other renewable energy resources

Notable targets

- Economic growth >5%
- Carbon-negative economy by 2020
- Operational ICT centre of excellence by 2020
- 100% resilient roads by 2020
- 90% housing resilience by 2030
- First science and technology park by 2030

TRINIDAD & TOBAGO

- *National Development Strategy (2016–2030): Vision 2030*

Priority areas for investment

- ICTs
- Agriculture & agroprocessing
- Maritime services
- Aviation services
- Fish & fish processing
- Creative industries
- Manufacturing
- Tourism
- Financial services

ST LUCIA

- *Medium-Term Development Strategy (2019–2022)*

Priority areas for investment

- Tourism
- Agriculture
- Infrastructure
- Health & wellness
- Education
- Citizenry security

GUYANA

- *Green State Development Strategy (Vision 2040)*, 2018

Priority areas for investment

- Agriculture & agro-processing
- Seafood & aquaculture
- Forest products
- IT-enabled services
- Light manufacturing
- Mining
- Tourism

Notable targets

- Near 100% share of energy mix from domestic natural resources
- Low-carbon transport sector
- Improved sea defences, housing and amenities

SURINAME

- *Policy Development Plan (2017–2021)*

Priority areas for investment

- Infrastructure & logistics
- Agribusiness
- Ecotourism
- Renewable energy

UN Disclaimer

its doors a year later in Barbados. According to Caricom, the creation of the centre 'responds to the difficult energy situation in many of the Caribbean islands. They are facing the challenges of access to modern, reliable and affordable energy services, energy security and climate change mitigation and adaptation simultaneously' (CCREEE, 2019).

Caricom's target is to have renewables contribute 20%, 28% and 47% of the electricity generation capacity by 2017, 2022 and 2027, respectively.[4] Some countries with ample wind, geothermal and solar energy resources may even exceed these targets (see the **Country profiles**).

Besides renewable energy, CCREEE is mandated to assist the region in reaching the energy efficiency levels set out by the Caricom Regional Organization for Standards and Quality (CROSQ, Box 6.2). To meet these targets, a programme to phase out incandescent lightbulbs is being developed by the Caricom Secretariat and CROSQ, following a decision made by Caricom energy ministers on 19 April 2018.

Caricom's collaborative approach to implementing its *Energy Policy* is a welcome development, as the sustainable energy challenge is both complex and capital-intensive, cutting across all sectors. A collective approach has already proved effective for the Caribbean Community Climate Change Centre, which has been helping countries to become more climate-resilient.

Plans to become world's first climate-smart zone

Since 2015, the Caricom region has effectively engaged available expertise to mobilize support for programmes that build resilience to climate-related shocks. These focus on, for instance, constructing robust infrastructure, diversifying energy sources towards renewables and establishing climate-smart towns and green communities. Expertise has come notably from the Caribbean Community Climate Change Centre and the Climate Change Research Teams from various campuses of the University of the West Indies (UWI).

Shocked by the devastation of two back-to-back category 5 hurricanes in 2017 in Antigua and Barbuda, Dominica, the US Virgin Islands and British Virgin Islands, a 'coalition of the willing' formed in 2018 to establish the Caribbean Climate-Smart Accelerator Programme, which has the ambitious objective of making the region the world's first climate-smart zone. This coalition is comprised of the airline foundation Virgin Unite, Caricom, OECS, the Inter-American Development Bank (IADB) and World Bank. So far, some 26 countries and more than 40 private- and public-sector partners have joined the accelerator. It is expected to transform the region's economy by fast-tracking sound public and private investment opportunities that support climate solutions for resilience, social development and broad-based growth. Current interest is in waste-to-energy initiatives.

Greater regional investment in climate resilience

In March 2018, Caricom countries worked with the Caribbean Community Climate Change Centre to mobilize funds from the Green Climate Fund (GCF) to support a variety of projects.[5] These include US$ 42.16 million for a Climate-Resilient Water Sector in Grenada and US$ 27.61 million for the Water Sector Resilience Nexus for Sustainability in Barbados. Another US$ 20 million has been approved for a pilot project to help the public, private and civil society sectors in Antigua and Barbuda, Dominica and Grenada strengthen community resilience to climate-related shocks.

In 2016, US$ 80 million was approved for a Sustainable Energy Facility for the Eastern Caribbean, in collaboration with the IADB. This project comes with a Revolving Adaptation Fund Facility to support the installation of irrigation systems and rainwater harvesting systems, as well as water-saving devices for households, public buildings, hotels and farms. The Fund will pursue this work after the project ends.

GCF began consultations with Caricom countries in 2017. As of April 2019, it had invested over US$ 400 million in Caricom countries – one-third of the US$ 1.2 billion invested in Latin America and the Caribbean as a whole. GCF decided to capitalize on this interest by supporting a regional workshop in Jamaica in 2019 which sought to catalyse private-sector investment in climate action, support the accreditation of private sector entities to the GCF, share knowledge and promote co-operation among Caricom states.

Box 6.1: **Geothermal development set to reduce energy costs**

Most Caricom countries remain dependent on costly imports of fossil fuels. Through the Green Climate Fund and other partners, the previously stalled development of geothermal reserves was revived in 2016 by an investment of US$ 190.5 million benefiting five East Caribbean states: Dominica, Grenada, St Kitts and Nevis, St Lucia and St Vincent and the Grenadines.

The eight-year project is financed through loans and reimbursable grants. It is addressing financial, technical and institutional barriers to the development of vast geothermal reserves in the five countries. Through the project:

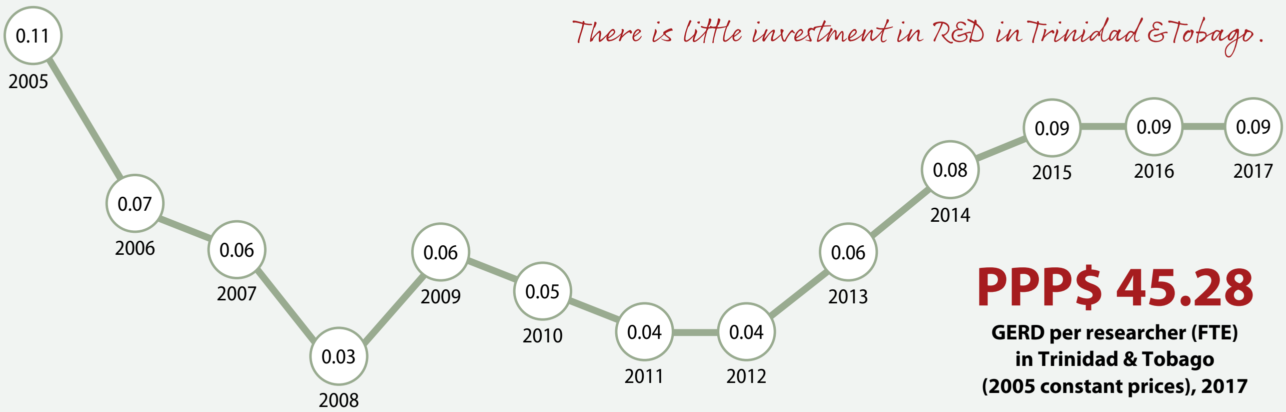
- a production well will be drilled in St Vincent and the Grenadines and a power station will be built in Dominica;
- 60 MW of geothermal power generation capacity will be installed through facilitated or financed schemes;
- 722 000 fewer barrels of oil will be imported by participating countries for electricity generation;
- US$ 50 million will be saved on oil imports (at an oil price of US$ 70 per barrel); and
- the average cost of electricity generation will drop. As long as these cost savings are passed on to customers, this should lead to an average decrease in tariffs from US$ 0.35 per kWh in 2015 (at a fuel price of US$ 70 per barrel) to US$ 0.28 per kWh.

By the end of the project, greenhouse gas emissions from these five countries are expected to have dropped by 9.4 million tonnes (tCO_2eq).

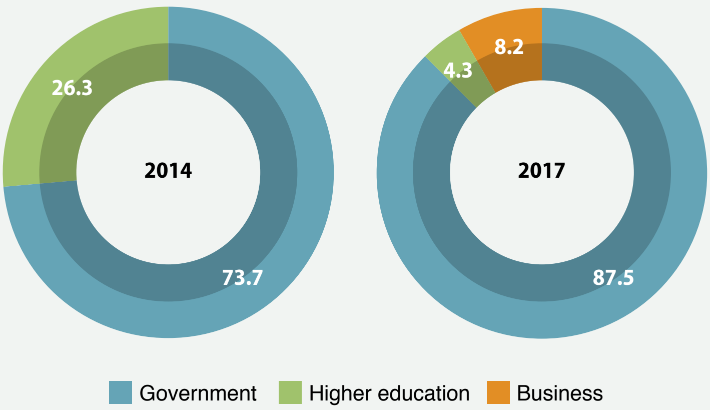
Source: https://www.greenclimate.fund/projects/fp020

Figure 6.3: **Trends in research expenditure and personnel in Trinidad and Tobago**

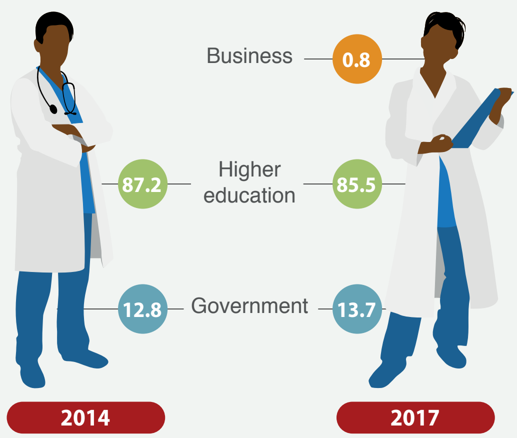
GERD as a share of GDP in Trinidad & Tobago, 2005–2017 (%)



GERD by sector of performance, 2014 and 2017 (%)



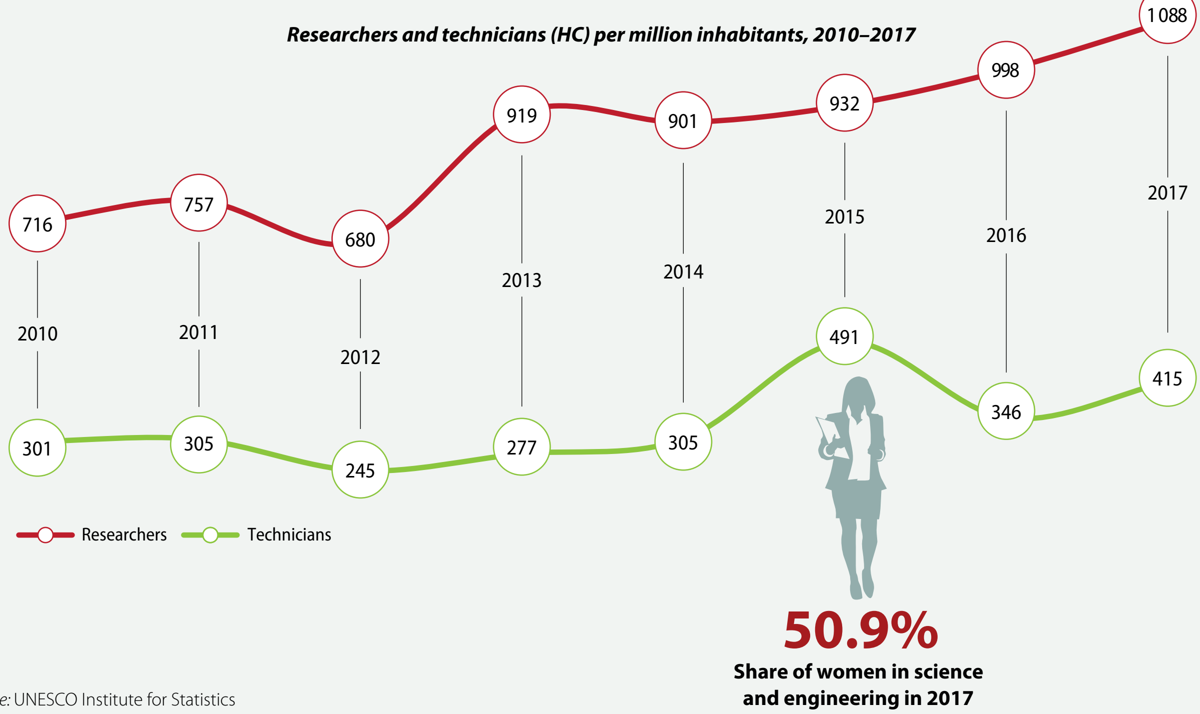
Researchers by sector of employment (HC), 2014 and 2017 (%)



The establishment of UWI Ventures in 2019 by the St Augustine Campus should nurture partnerships with the private sector.

Researchers are almost absent from the private sector.

Researchers and technicians (HC) per million inhabitants, 2010–2017



Source: UNESCO Institute for Statistics

Advancing the *Caricom Digital Agenda*

At the Caricom Heads of Government Meeting in February 2019, Caricom signed a Co-operation Agreement with the Government of Estonia to advance the *Caricom Digital Agenda 2025* and the creation of a *Single Caricom ICT Space*. The latter are premised on the *Regional Digital Development Strategy*, approved in 2013. The roadmap for the Single Caricom ICT Space was approved by Caricom Heads of Government in February 2017.

The main thrust of the *Digital Agenda* is to create an ecosystem of regionally harmonized ICT policies, legislation addressing cybersecurity and other concerns, technical standards and best practices, networks and services for the development of an ICT-enabled borderless space that fosters socio-economic and cultural integration.

Training will also be a key element of the *Caricom Digital Agenda*, given the current shortage of software engineers and low output in this field (Figures 6.4 and 6.5).

Cariscience, the region's scientific network, hosted the Caribbean's first international workshop on Big Data for Developing Countries in September 2019, in collaboration with the University of the West Indies (UWI) and University of Trinidad and Tobago. The previous year, the Caribbean Science Foundation had chosen the theme of coding and robotics for its annual summer camp. These camps are organized as part of the foundation's Student Programme for Innovation in Science and Engineering.

POLICY ISSUES

Steps to 'revolutionize our statistics'

The previous *UNESCO Science Report* identified the lack of scientometric data for Caricom countries as a major impediment to developing, exploiting and effectively managing science, technology and innovation (STI) in the region (Ramkissoon and Kahwa, 2015). The situation has since deteriorated. The only country for which recent data are available on human and financial investment in research and development (R&D) is Trinidad and Tobago (Figure 6.3). It is hoped that ongoing contacts initiated by the Caricom Science, Technology and Innovation Committee[6] with regional development agencies like the Caribbean Development Bank may yield funding for the requisite scientometric studies.

Lack of data has also hampered implementation of the *Strategic Plan for the Caribbean Community, 2015–2019*, with negative implications for related STI policy planning, implementation, accountability and transparency, monitoring and evaluation. In 2018, with the support from the Caribbean Development Bank, Caricom developed a Results-based Management System. This system has been designed to guide systematic data collection, analysis and use, as well as reporting on progress towards regional integration and development. It provides a tool for evidence-based strategic planning and decision-making at policy level. To encourage countries to use the system, Caricom has developed a model

Box 6.2: **Affordable accreditation to help Caricom businesses develop trade**

In the face of diminishing access to official development assistance for social programmes, the region has had little choice but to focus on augmenting revenue through trade. In order to do so, it will be imperative for domestic markets to prioritize innovation and raise the levels of productivity and competitiveness of the goods and services produced, while protecting consumers and the environment.

It is with this objective in mind that all 15 Caricom members adopted a *Regional Quality Policy* on 10 November 2017 for the development of quality infrastructure. The latter has five components: standards and technical regulations; metrology; accreditation; conformity assessment, encompassing inspection, testing and certification; and quality promotion through marketing, communication and education.

The Caricom Regional Organization for Standards and Quality (CROSQ) then embarked on a two-year consultative process to implement the Regional Quality Policy, with the support of Germany's Physikalisch-Technische Bundesanstalt and the Dominican Institute for Quality under the 10th European Development Fund's Technical Barriers to Trade Project.

The *Regional Quality Policy* commits all 15 Member States to strengthening technical competence to address issues related to productivity, innovation and competitiveness; and consumer, health and environmental protection. It also commits governments to inculcating a culture of quality across the economy. To this end, each Caricom country has begun developing or refining their own national quality policy. The Bahamas, Barbados, Jamaica and Trinidad and Tobago have already formally adopted theirs, whereas Grenada, St Kitts and Nevis and St Lucia are on the point of doing so.

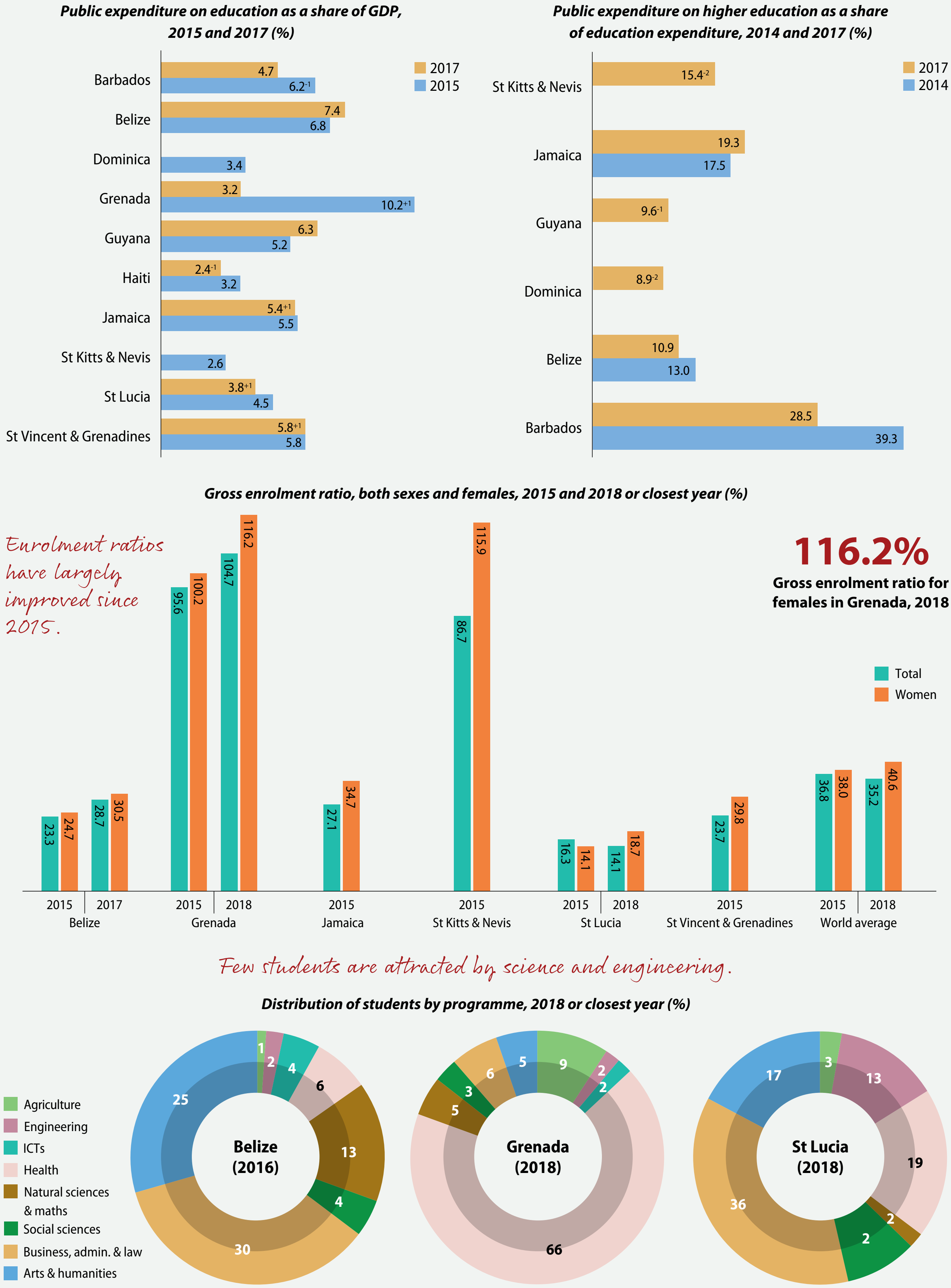
The process for accrediting inspection and testing bodies has always been taxing for small island states but the establishment of the Caribbean Cooperation for Accreditation (CCA) in April 2013 should lighten their burden. It provides manufacturers and service providers in the region with access to internationally recognized accreditation services at an affordable rate.

The CCA is based on principles of co-operation and collaboration among the recognized National Accreditation Bodies (NABs). CROSQ serves as the secretariat and co-ordinator of support services. The NABs provide authoritative oversight and accreditation of Conformity Assessment Bodies, which include testing and calibration laboratories, and inspection and certification bodies. The National Accreditation Focal Point in each member state provides an administrative link between potential clients and the NABs and CROSQ Secretariat.

Source: authors and UNIDO/International Network on Quality Infrastructure (2018) *Quality Policy – Guiding Principles*

Chapter 6

Figure 6.4: **Trends in higher education in the Caricom countries**



+n/-n: data refer to *n* years before or after reference year

Note: Recent data are unavailable for some countries.

Programmes of study were unspecified for 17% of students in Belize and 3% of students in Grenada.

Source: UNESCO Institute for Statistics

Results-based Management Policy, which it intends to put forward for adoption by member states. This policy should allow for more robust monitoring and evaluation to improve the Community's implementation of future strategic plans.

Meanwhile, OECS has launched a major initiative dubbed *Revolutionizing our Statistics: Developing our Societies*, which proposes a transformative agenda for the OECS subregion over the period 2017–2030. With the support of the Eastern Caribbean Central Bank and other development partners, OECS is creating an integrated regional statistics system, based on innovative technologies that should improve the collection, dissemination and interrogation of data.

Caricom is currently preparing an update of the *Strategic Plan for the Caribbean Community, 2015–2019*. Although this new *Strategy* is not yet ready for adoption, it is expected to address STI matters as a separate major pillar this time, for greater emphasis. It is also anticipated that the new *Strategy* will focus on the implementation of a regional risk management programme.

TRENDS IN RESEARCH OUTPUT

Smaller states leading growth in publications

The salient message from the growing volume of publications originating from Caricom countries since 2015 (Figure 6.5) is that the influx of universities across the region over the past 40 years or so is gradually instilling a culture of research in the smaller states, in particular. The previous *UNESCO Science Report* (Ramkissoon and Kahwa, 2015) had highlighted the success story of the private St George's University in Grenada: in 2018, it published 93% more publications than in 2015. Similarly, Ross University School of Veterinary Medicine in St Kitts and Nevis increased its output by 46% between 2015 and 2018, while Ross University School of Medicine in Dominica managed to sustain its own output from its new home in Barbados, despite back-to-back devastating hurricanes over this period. Publications from the American University in Antigua and Barbuda even grew by 300%, albeit from low levels. St Vincent and Grenadines also put itself on the map for R&D, thanks mainly to its resident university, the Trinity School of Medicine, as did St Lucia via the resident Spartan Health Sciences University and American International University. The new University of the Bahamas has also shown its potential; it is largely responsible for the Bahamas' impressive 58% growth in output since 2016 (Figure 6.5).

A study of the topics covered by these publications reveals that these universities are attuned to the challenges faced by the societies in which they operate: climate change and resilience; fisheries; animal diseases; ageing; HIV; mosquito-transmitted and tropical diseases; global infectious diseases; Caribbean coral reefs and marine life; and even the game of cricket!

It is, thus, not surprising to see a mutually supportive relationship between the guest offshore universities and the host countries. In 2018, Grenada's prime minister drew a parallel between six consecutive years of economic growth and the benefit of investment in educational services, estimating the economic contribution of St George's University from student spending and employment at not less than 22% of GDP (Straker, 2018).

Most output targeting agriculture and health

Between 2017 and 2019, Caricom researchers continued to publish mostly in areas related to health sciences (about 60% of the total; Figure 6.5). Jamaica and Grenada each contributed over 20% of articles in this field.

Output from the region on agriculture, fisheries and forestry came a distant second (less than 10% of the total; Figure 6.5). Trinidad and Tobago's solid lead (about 30% of total output) on agriculture, fisheries and forestry may be the result of efforts by the UWI in 2010 to revive a faculty devoted to agriculture and food sciences; academic programming in these areas had been absorbed by the Faculty of Science since the 1990s. Of note is that Trinidad and Tobago's output over 2016–2018 leads the region in most of the other broad fields of science, too. The most worrying trend is the region's low share of scientific articles in engineering sciences over this period: just 2% of total output.

In terms of research density, St Kitts and Nevis now leads the Caricom region, with as many as 1 931 publications per million inhabitants in 2019 (Figure 6.5). There is no ready explanation for Suriname's impressive performance – its output is up from 55 publications per million inhabitants in 2015 – but it may have benefited from the transformation of the Academic Hospital in Paramaribo in 2013 into the Academic Medical Centre linked to the Faculty of Medical Sciences at the University of Suriname. This transformation called for the upgrading of research facilities and capabilities. The University of Suriname collaborated with The University Medical Center Groningen in the Netherlands, for instance, to improve its capability in clinical genetics.

St Kitts and Nevis and the Bahamas have also shown strong growth in research intensity. Generally, however, the region is still underperforming, with only the small states of St Kitts and Nevis, Grenada, Barbados and Dominica having a research density in excess of the global average of 341 publications per million inhabitants.

Intra-Caricom collaboration still weak

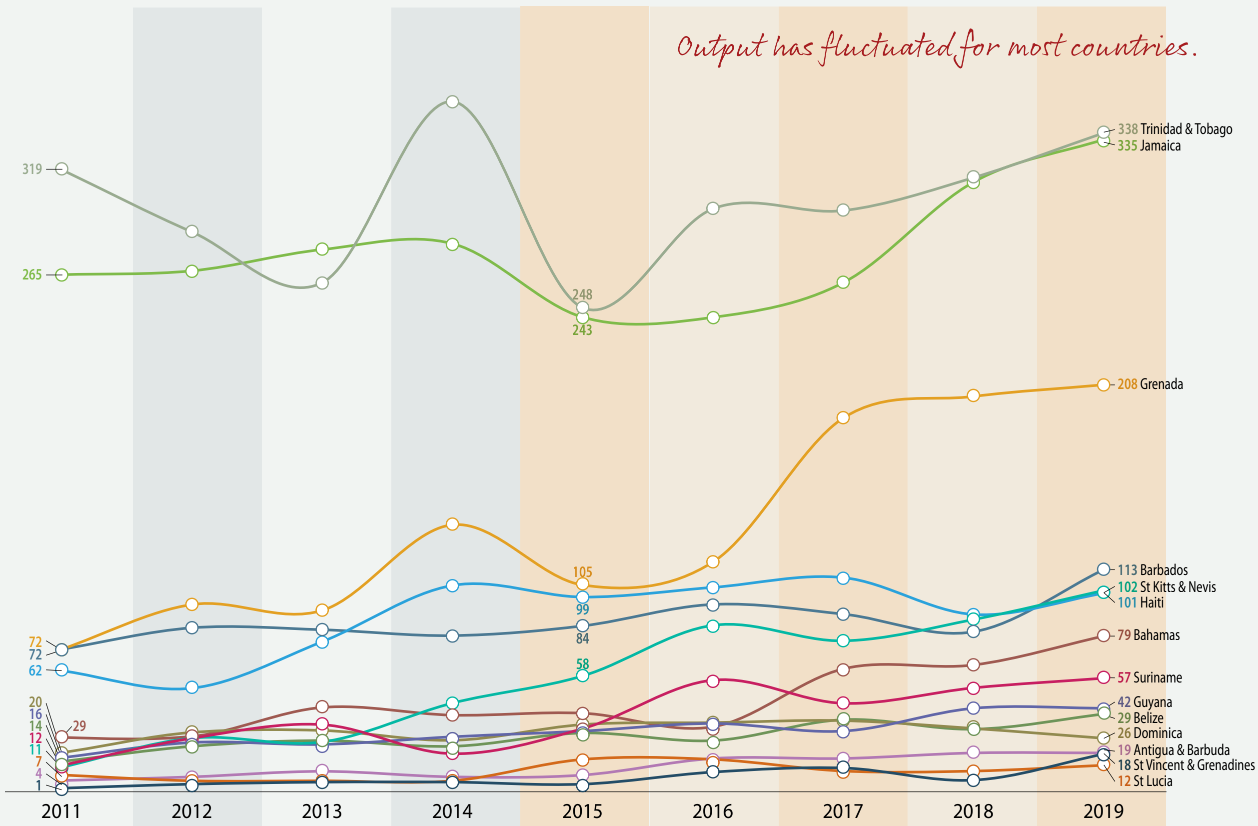
In nearly all Caricom countries, more than four out of five published articles have foreign co-authors, with the notable exception of Jamaica (68%) and Trinidad and Tobago (58%). Even in these countries with well-established university centres, the considerable level of collaborative work with foreign counterparts helps researchers keep up with developments in their field (Figure 6.5).

Collaboration among Caricom scientists has not improved since 2015. Intra-Caricom collaboration accounted for roughly 2% of all publications from Caricom countries over the 2016–2018 period. This contrasts with 40% of articles co-signed by researchers based in the USA. This poor intra-Caricom collaboration is all the more troubling, given that several Caricom research institutions have regional mandates.

One notable example is the UWI, which has four physical campuses in as many countries, as well as an open campus for distance learning. There is also the Caribbean Agricultural Research and Development Institute, with research stations in all Caricom countries except Haiti and Suriname. Another example is the Caribbean Environmental Health Institute.

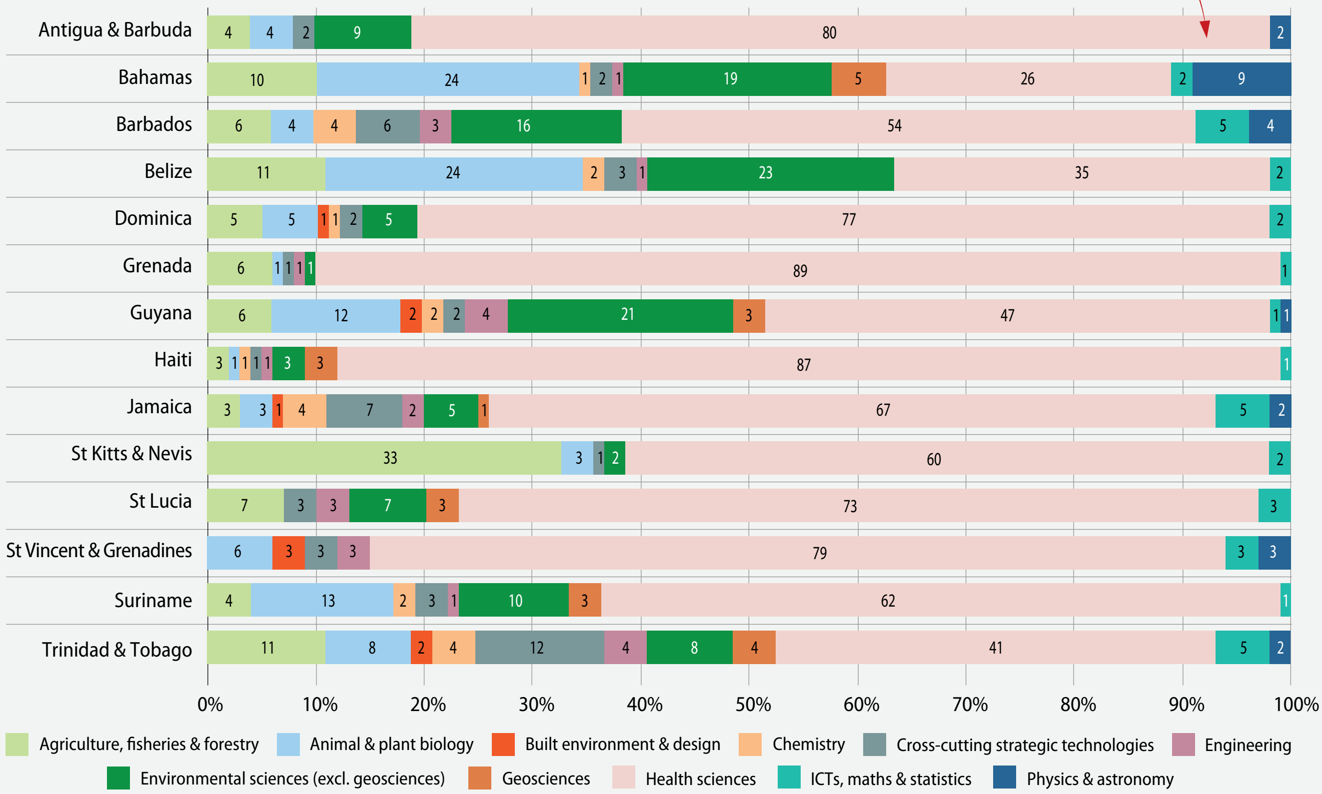
Figure 6.5: **Trends in scientific publishing in the Caricom countries**

Volume of scientific publications in Caricom countries, 2011–2019

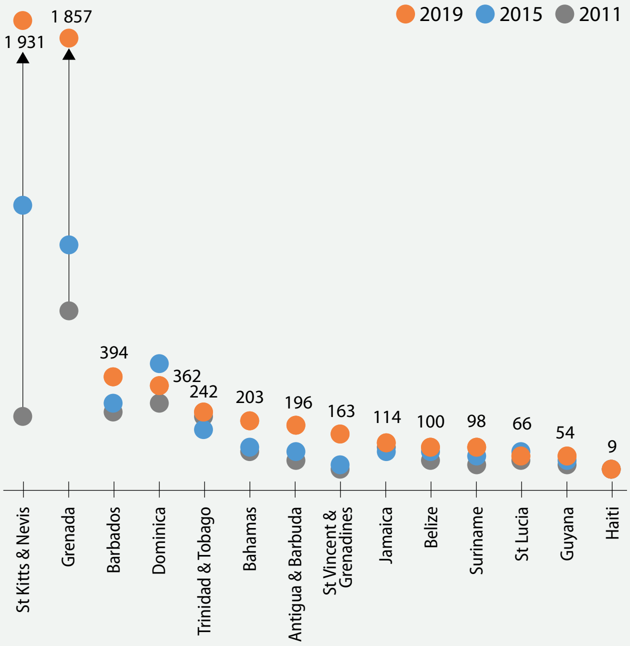


Health sciences account for the most publications, followed by environmental sciences.

Scientific publications in Caricom countries by broad field of science, 2017–2019 (%)



Scientific publications per million inhabitants in Caricom countries, 2011, 2015 and 2019 Data labels are for 2019



How has output on SDG-related topics evolved since 2012?

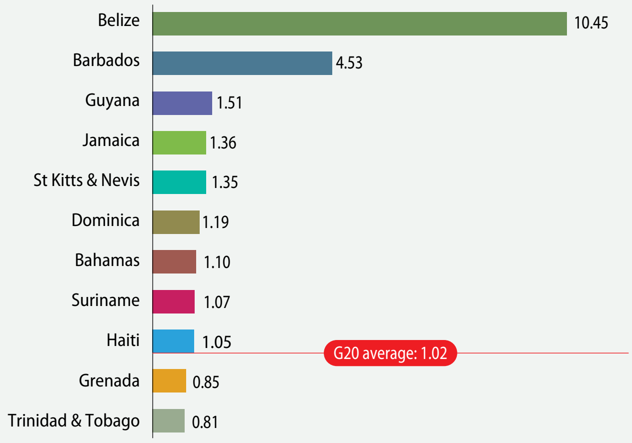
Caricom scientists have modest output on SDG-related topics but five countries (Barbados, Belize, St Kitts and Nevis, Suriname, Trinidad and Tobago) have recorded noticeable growth in research on three common topics: new and emerging viruses that can infect humans (plus Grenada, Haiti and Jamaica), the status of biodiversity and ecosystem services (plus the Bahamas) and the sustainable use of terrestrial ecosystems (plus the Bahamas, Dominica and Guyana).

Health is a dominant topic. Seven countries (Bahamas, Barbados, Belize, Guyana, Haiti, Jamaica and Trinidad and Tobago) published over three times more research than expected on HIV. Haiti's proportionate output on tropical communicable diseases and tuberculosis is even 29 and 23 times higher, respectively, than the global averages for these topics.

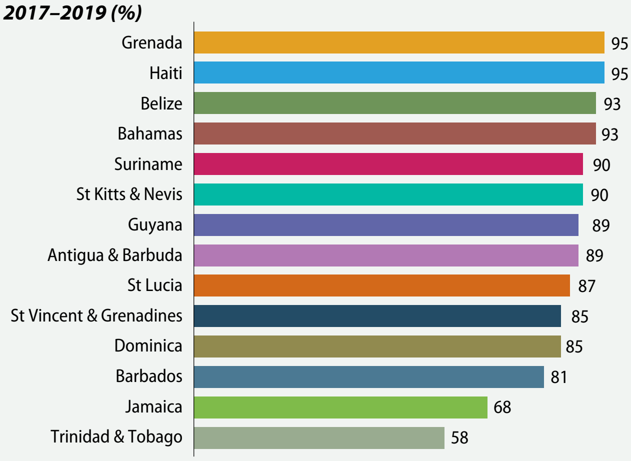
Despite the region's vulnerability to climate change, Caricom authors are conspicuously absent from research addressing the local impact of climate-related hazards and disaster risk reduction strategies, with fewer than 7 and 5 publications, respectively, from 2012 to 2019. Only one publication, in 2017, on the local impact of climate-related hazards and disasters included a Haitian author.

For details: see chapter 2

Average of relative citations in Caricom countries, 2014–2016



Share of publications with foreign co-authors in Caricom countries, 2017–2019 (%)



Intra-Caricom collaboration accounted for roughly 2% of members' output over the 2016–2018 period.

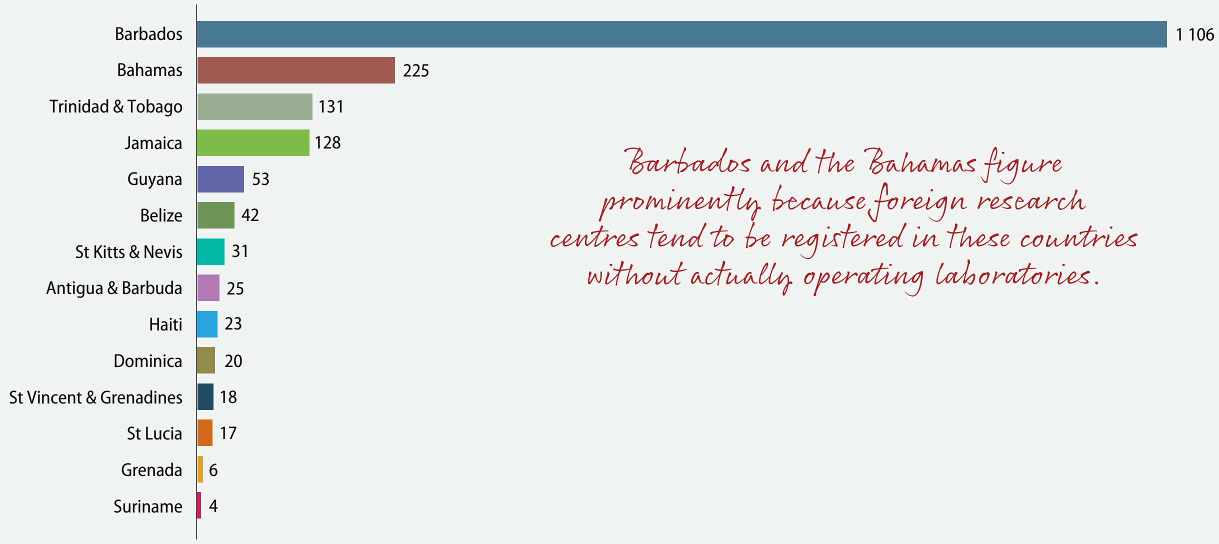
Top five partners for Caricom countries for scientific co-authorship, 2017–2019 (number of publications)

	1st collaborator	2nd collaborator(s)	3rd collaborator(s)	4th collaborator(s)	5th collaborator(s)
Antigua & Barbuda	USA (33)	Canada (6)	Egypt/Spain (5)		Australia/Dominica (4)
Bahamas	USA (137)	UK (51)	Canada (45)	Australia (29)	Germany (25)
Barbados	USA (112)	UK (67)	Canada (46)	Jamaica (33)	Trinidad & Tobago (31)
Belize	USA (65)	UK (23)	Mexico (18)	Canada (15)	Australia (11)
Dominica	USA (46)	Germany/UK (11)		Brazil/Nigeria (8)	
Grenada	USA (469)	Japan (95)	UK (58)	Canada (44)	Germany (34)
Guyana	USA (55)	UK (26)	Australia/France (18)		Brazil (17)
Haiti	USA (234)	UK (33)	France (29)	Canada (27)	Brazil (23)
Jamaica	USA (379)	UK (118)	Canada (95)	France (52)	Mexico (51)
St Kitts & Nevis	USA (114)	UK (46)	South Africa (27)	Canada/Denmark (23)	
St Lucia	USA (14)	Dominica/Nepal (5)		Barbados/Jamaica/ Trinidad & Tobago (4)	
St Vincent & Grenadines	USA (20)	Canada (6)	Nigeria/UK (4)		Barbados/Trinidad & Tobago (3)
Suriname	Netherlands (64)	USA (51)	France (34)	Belgium/Brazil (31)	
Trinidad & Tobago	USA (207)	UK (168)	India (92)	Canada (63)	Jamaica (45)

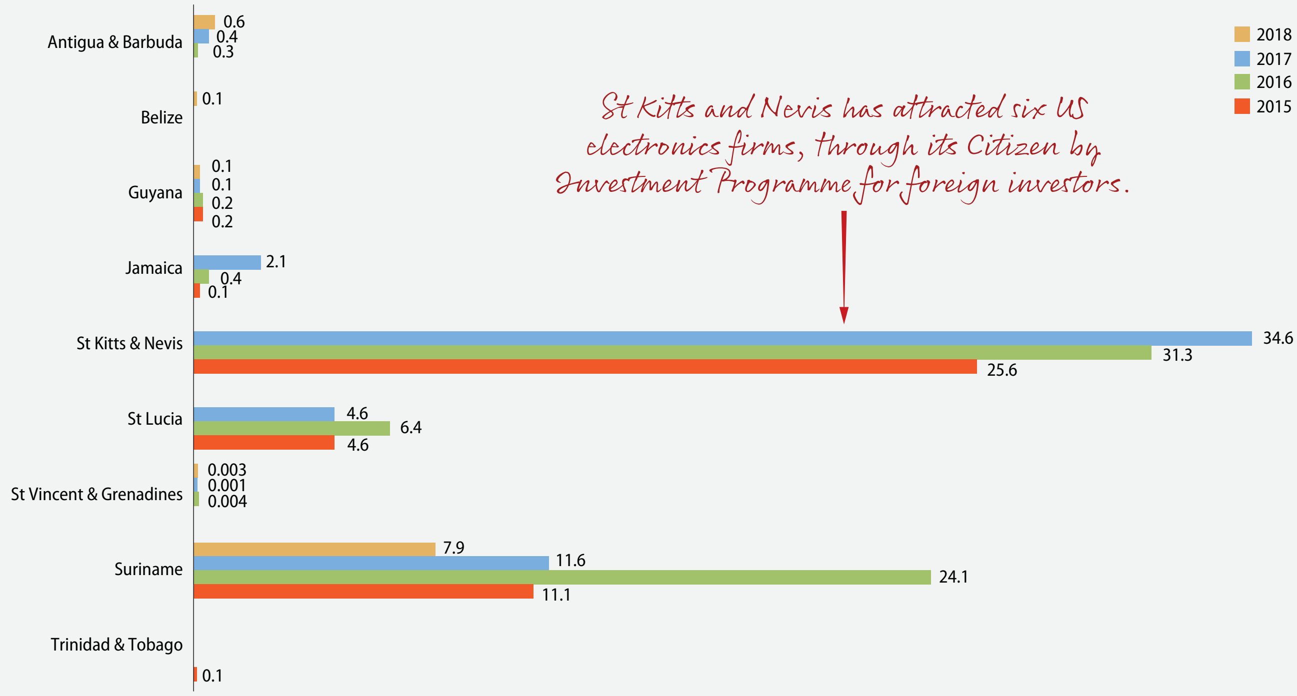
Source: Scopus (excluding Arts, Humanities and Social Sciences), data treatment by Science Metrix

Figure 6.6: **Trends in patenting and high-tech trade in Caricom countries**

Number of IP5 patents granted to Caricom countries, 2015–2019



High-tech exports as a share of manufactured exports, 2015–2018 (%)



Resident patent applications per 100 billion GDP (2011 constant US$), 2011–2018

	2011	2012	2013	2014	2015	2016	2017	2018
Antigua & Barbuda	–	–	–	–	–	–	–	218
Bahamas	–	27	9	9	18	28	37	–
Barbados	–	–	65	22	–	–	–	–
Guyana	–	–	–	19	–	18	–	34
Haiti	6	12	–	11	–	–	–	–
Jamaica	87	110	96	143	30	81	46	107
St Kitts & Nevis	–	–	–	–	–	–	–	–
St Lucia	–	–	–	–	–	232	134	89
Trinidad & Tobago	–	5	–	9	7	7	–	10

Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China.

Source: PATSTAT, data treatment by Science Metrix; for high-tech trade: World Bank's World Development Indicators, July 2020; for resident patent applications, World Intellectual Property Organization

Patents reflect the policy environment

Between 2015 and 2019, Jamaica (38), Trinidad and Tobago (33), the Bahamas (23) and Barbados (20) together accounted for 89% of the small number of patents awarded by the US Patent and Trademark Office to Caricom countries.

When all five of the main patent offices are considered, the share obtained by Jamaica and Trinidad and Tobago drops to just 7.4% and 7.6%, respectively (Figure 6.6).

Although Barbados and the Bahamas figure prominently in these statistics, this is because foreign research centres tend to be registered in these countries without operating laboratories there.

It is hardly surprising that the Caricom region is patenting below its weight, since state funding support for R&D in general, and entrepreneurs in particular, remains negligible.

When the Biotech Research and Development Institute,[7] a Jamaican firm, won an IADB Local Innovator Award in 2016, the company's founder, Dr Henry Lowe, recalled having invested more than US$ 6.5 million of his own savings to develop pharmaceutical products derived from indigenous plants, with no external financial support (Hines, 2016). In 2018, the Institute partnered with Maryland University via the company Flavocure Biotech Inc. to commercialize a patented drug candidate extracted from the marijuana plant, which was showing promise against metastatic pancreatic cancer (Moreau *et al*., 2019). The project has since been attracting investors.

Most innovation targeting health or agriculture

Most of the business innovation coming out of the Caricom region is focusing on health or agriculture.

High-quality research is taking place. For instance, the former Tropical Medicine Research Institute (now the Caribbean Health Institute) set up a company in 2013 called The UWI Solutions for Developing Countries (SODECO).[8]

According to SODECO's website, one focus of research is 'the molecular mechanisms underlying the greatly increased risk of obesity, diabetes, hypertension, stroke, heart attack and associated neurocognitive deficits affecting populations, poor for generations, who gain wealth and acquire lifestyles that promote obesity and its comorbidities'.

The Mona Institute of Applied Sciences, a company set up by the UWI in 2001, is in the process of turning the challenges faced by manufacturers and agro-processors into business opportunities. It secured support from the IADB in 2019 for castor oil production.

The Mona Campus is commercializing a growing number of its services to compensate for the chronic shortfall in government funding. The Caribbean Toxicology Unit now provides toxicology and consultancy services to members of the legal profession, while the company Carigen offers clients DNA testing and the Mona School of Engineering offers services in maintenance, R&D, training and certification, manufacturing and engineering support through its company, Mona-Tech.

Pooling Caricom's experts to develop the region's nuclear industry

Jamaica's Scientific Research Council initiated a collaboration in 2018 with a government agro-research laboratory to produce new and improved plant and animal varieties using radiation, with support from the International Atomic Energy Agency (IAEA).

The International Centre for Nuclear and Environmental Sciences on UWI's Mona Campus has also forged a close relationship with the ministry responsible for STI in Jamaica, drawing upon nuclear technology in pursuit of the government's socio-economic agenda. The aim is to combine the rigorous research standards of academia with government funding to produce effective, well-supported research programmes.[9]

The IAEA offers a wide range of support programmes but countries seeking assistance must meet the requirements of the *IAEA Code of Conduct* to ensure safe use of nuclear and ionizing radiation sources. This requires promulgating national legislation and establishing a competent regulatory agency.

The small Caricom economies, with their limited funding and qualified staff, have encountered difficulties in meeting these regulatory requirements, preventing them from accessing vital IAEA services.

Fortunately, a meeting of regional experts at IAEA headquarters in August 2018 came up with the solution of pooling Caricom's human resources in the nuclear and ionizing radiation industry and making them available to serve the entire region. The individual countries will then take charge of the regulatory process and of setting up the requisite legislative, administrative and regulatory mechanisms, with technical assistance from the collective pool of experts.

Anaemic growth in high-tech exports

Between 2014 and 2017, Caricom countries exported high-tech goods worth about US$ 201 million, the main exporter, by far, being Barbados, accounting for 61% (US$ 122 million) of total earnings. Barbados was followed by St Kitts and Nevis (US$ 26.1 million); Suriname (US$ 21.5 million, excluding 2015); Trinidad and Tobago (US$ 11.4 million for 2014–2015), St Lucia (US$ 10.6 million) and Jamaica (US$ 8.4 million).

Health care firm Carlisle Laboratories Ltd is the only local high-tech manufacturer in Barbados. St Kitts and Nevis has attracted six US electronics firms, through its Citizen by Investment Programme (CIP) for foreign investors. CIP funds are invested in areas conducive to high-tech development, such as housing, education, culture, health or renewable energy.

The low high-tech exports from Jamaica and Trinidad and Tobago and decline in Suriname (Figure 6.6) reflect poor investment. This said, there was steep growth between 2015 and 2018 in Jamaican exports of telecommunications equipment (US$ 1.4→11.2 million) and pharmaceuticals from Trinidad and Tobago (US$ 1.2→1.9 million).

ANTIGUA AND BARBUDA

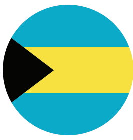
A campus close to home

The University of the West Indies has opened a new campus in Five Islands. In September 2019, the Five Island Campus admitted students to its three colleges: one in Health and Behavioural Sciences, a second in Management, Science and Technology and a third in Humanities and Education.

An innovation centre for clean technologies

In collaboration with the United Nations Office for Project Services, Antigua and Barbuda established a Science and Innovation Centre in 2018 to support national and regional innovation in areas related to climate change and clean technologies (UNOPS, 2018).

BAHAMAS



An upgrade to a university

The College of the Bahamas was transformed into a multi-campus university in 2016. The new University of the Bahamas sports a Faculty of Pure and Applied Sciences that operates a research complex. The Faculty counted more students (1 625) than the Faculty of Business, Hospitality and Tourism (1 325) in 2019, according to the university's website. In the aftermath of Hurricane Dorian in 2019, which caused losses estimated at US$ 3.5 billion, the university established its own Climate Change Adaptation and Resilience Research Centre to develop relevant policies and strategies.

BELIZE

A strategic focus on agriculture and tourism

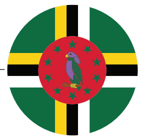
Belize has engaged the assistance of the Republic of Korea's Knowledge Sharing Programme to formulate a national STI strategy and action plan.[10] The plan recommends establishing a Belize–Korea Science, Technology and Innovation Institute to guide implementation, providing a structured mechanism for aligning government goals with those of private industry. The plan is to transform the agriculture and tourism sectors, in particular, by improving productivity and competitiveness in an environmentally sustainable way.

Within this collaboration, a detailed situation analysis of STI in Belize was conducted which led to the publication, in 2015, of a roadmap for implementing the strategy (KDI, 2015). This study recommended raising GERD from the current extremely low level of about 0.06% to 0.5% of GDP by 2020 and to 1% of GDP by 2025. A package of special taxes and foreign donations were to finance the proposed STI development strategy. Unfortunately, there is no evidence that these recommendations have been implemented or that the much-discussed Belize–Korea Science, Technology and Innovation Institute has been established.

Making the Barrier Reef System climate-resilient

The marine environment is critical to Belize's tourism-dependent economy. In collaboration with the World Bank and the Adaptation Fund, Belize has been implementing a six-year *Marine Conservation and Climate Adaptation Project* since 2015 to strengthen the climate resilience of the Belize Barrier Reef System.

DOMINICA



The world's first climate-resilient state?

Two years after Hurricane Maria destroyed the island's rainforest and inflicted losses estimated by the World Bank at 224% of GDP,[11] Dominica launched a *National Resilience Development Strategy 2030* in 2019 that boldly seeks to transform Dominica into the world's first climate-resilient state. The *Strategy's* objectives include the development and operation of a modern science and technology sector with a world-class telecommunications system and at least one science and technology park, and the prioritization of R&D through a separate allocation of funds in the government's annual budget. The *National Resilience Development Strategy 2030* has many other aspirations which draw on science and technology, such as: creating green industrial parks; exploiting geothermal and hydroelectric reserves to provide for domestic energy needs and leave a surplus for export; creating a major fisheries processing plant; maintaining an efficient waste management system; ensuring a viable, sustainable and resilient forest; and investing in a safe, affordable and reliable water system.

The launch of the *National Resilience Development Strategy 2030* follows the inauguration, in 2018, of the Climate Resilience Execution Agency. This agency is tasked with developing a plan and associated implementation strategies to make Dominica the first climate-resilient country in the world, with the support of the British and Canadian governments.

Dominica ultimately plans to have a carbon-negative economy, thanks to its vast geothermal resources (Box 6.1). It had even fixed itself an albeit unrealistic target of achieving this goal by 2020.

GUYANA

Using oil receipts to meet development goals

While gearing up to exploit its newly discovered oil and gas reserves, Guyana has set its sights on using its anticipated wealth to enhance sustainability by developing renewable energy sources.

To promote effective use of the expected funds, the government created a Sovereign Wealth Fund in 2019. Financed primarily from oil earnings, it will also accommodate funds from other extractive industries, such as mining and forestry.

A 24-member Public Oversight Committee made up of diverse stakeholders will be responsible for monitoring and evaluating the Fund's compliance with the law; monitoring and evaluating the Fund's management practices for compliance with principles of transparency, good governance and international best investment practices; providing an independent assessment of the Fund's performance; and facilitating public consultations on management of the Fund and on withdrawals, approved by parliament, for the purposes of national development.

The government plans to meet its national development goals through a low-carbon economic strategy stressing climate resilience and low deforestation. The Sovereign Wealth Fund offers a unique opportunity to develop the requisite skills for this transition.

Since the Guyana National Bureau of Standards will be in charge of oil and gas metrology, the bureau has been modernizing its infrastructure through the IADB's National Quality Program for Economic Diversification and Export Promotion.

An upgrade for the premier university

Between 2012 and 2017, a project supported by the World Bank implemented desperately needed reforms at the country's premier and only public university to 'strengthen the four science and technology faculties at the University of Guyana through infrastructure, research and curricular improvements while building the basis for improved facilities management and future growth' (World Bank, 2018).

The World Bank provided US$ 13.6 million in loans and the government contributed a further US$ 1.4 million. ICT facilities and services were installed and teaching and research laboratories modernized within the Faculties of Natural Sciences, Technology, Earth and Environmental Sciences and Agriculture and Forestry.

According to the final report, the project was a success (World Bank, 2018). Indeed, after years of stagnation, Guyana's scientific publications doubled in volume between 2012 and 2018 (Figure 6.5). This success story has led the World Bank to support a new US$ 14 million Education Sector Improvement Reform Project (2017–2023), one objective of which is to 'strengthen the teaching capacity and improve the learning environment of the University of Guyana's Faculty of Health Sciences'.

One pressing challenge will be for the higher education sector to train enough technicians, engineers and other professionals for the new oil and gas economy.

A model green town

As part of its policy for developing a green economy, Guyana selected Bartica as a Pilot and Model Green Town in 2016, the first such experiment in the Caribbean. Bartica is a small community situated on the Essequibo River, 80 km inland from the Atlantic Ocean. It is bound by the Essequibo, Cuyuni and Mazaruni Rivers, as well as by a rainforest. Bartica is known for being a gateway to Guyana's interior, home to gold and diamond mining. A number of programmes will be deployed to transition from total dependence on fossil fuels to the exclusive use of renewable energy sources.

There are also plans to develop a managed landfill and to build recycling plants and new sewage systems. The town will be restructured to make room for large-scale 'green' agriculture, tourism and manufacturing. There will also be a municipal airport. The concept has received support from the Governments of Japan and Italy.[12] The Caribbean Community Climate Change Centre is also assisting the project.

There have been notable efforts to intensify R&D which promotes greater use of Guyana's sustainable resources; particularly evident is the work of the Guyana Institute of Applied Science and Technology. Technologies have been developed that extract value out of Guyana's abundant biomass waste products such as bagasse, saw dust and rice mills; roofing shingles made out of biomass waste and plastics are already available on internal and export markets.

JAMAICA

Development of a new STI policy

Following online public consultations in June 2020, Jamaica's draft STI policy for 2020–2030 will be submitted to the newly elected parliament for approval.

The policy defines an implementation plan for 2020–2022 and calls for the development of another covering the period 2023–2030. Implementation of the plan will be overseen by the lead ministry, whereas co-ordination across ministries, sectors and institutions will fall to the revamped National Commission on Science, Technology and Innovation.

Importantly, the policy requires a commitment to funding its implementation through a variety of mechanisms yet to be agreed but eventually leading to a rise in gross domestic expenditure on R&D from about 0.06% of GDP at present to 1.5% of GDP by 2030.

Although defining research priorities has been left to an Implementation Planning Committee, the policy should enable Jamaican scientists and engineers to: garner 60% of available local consultancy earnings, up from the current 30% threshold; foster the collection and dissemination of critical scientometric data; and link research efforts to socio-economic needs by aligning them with national development goals.

In a sign of the government's commitment to strengthening R&D, the 2019 budget makes provision, for the first time, for JAM$ 200 million (*ca* US$ 1.5 million) in competitive seed funding for academic research projects (Henry, 2019). In another first, R&D output will be factored into the nation's GDP analysis from 2020 onwards (Clarke, 2019). These measures are expected to attract interest in monitoring and evaluating STI programmes.

In another positive move, the government re-established the Jamaica Energy Council in June 2019. It is chaired by the Minister of Science, Energy and Technology and counts representatives from 18 entities, including the Ministries of Economic Growth and Job Creation, Finance and the Public Service, Transport and Mining. Various professional associations also figure among the members, including the Chamber of Commerce, the Jamaica Solar Energy Association and Jamaica Gasoline Retailers' Association. The Council 'aims to facilitate consensus and minimize the negative influence of special interest groups and individuals on the energy sector', according to the minister (Linton, 2019).

The Council was originally established in March 2012 to support the *National Energy Policy 2009–2030,* which is oriented towards diversifying energy sources and improving energy efficiency.

There are plans to expand the Wigton Wind Farm by 60%, building on an earlier expansion in 2010 that saw its size swell by 87%. The move is designed to help the country raise the share of renewables in its energy mix to 50% by 2030, up from the previous government target of a 20% share. The Wigton Wind Farm was opened to public shareholding in 2019, when it became listed on the Jamaica Stock Exchange.

Overcoming the shortage of engineers

One factor holding businesses back in Jamaica is the chronic shortage of engineers. Just 200 graduate each year. In October 2017, the UWI's Mona Campus, the University of Technology and the Caribbean Maritime University vowed to train 1 000 engineers each year between them. New Fortress Energy, a company specializing in the provision of liquid natural gas, is investing in grants and scholarships for engineering students enrolled at the Mona Campus. The government is supporting the scheme by offering incentives to students to enrol in engineering disciplines, including preferential consideration for university places and lower interest rates on student loans, although the scheme is not mentioned in the Green Paper (Wilson-Harris, 2017).

A boost for entrepreneurship

In March 2019, Jamaica announced the launch of the Boosting Innovation, Growth and Entrepreneurship Ecosystem (BIGEE) programme, which is being implemented by the Development Bank of Jamaica with support from the IADB. A total of JAM$ 3.1 billion (*ca* US$ 25 million) will be disbursed over a five-year period to support innovation by existing micro-enterprises, start-ups and SMEs with high growth potential in the form of venture capital and grants, such as patenting matching grants. Programme funds will also be used to develop accelerators, incubators and technology transfer offices (Jamaica Observer, 2019).

ST LUCIA

A drive to develop a first STI policy

In 2019, St Lucia recommenced formulating a national STI policy through a major project called The National Competitiveness Agenda for St Lucia. This project is funded jointly by the government and the Compete Caribbean Partnership Facility (Govt of St Lucia, 2015; Commonwealth of Learning, 2017). The island is also on the verge of completing its *National Quality Policy* (Box 6.2) to help businesses reach foreign markets, with the assistance of UKAID. To showcase its commitment to 'embracing competitiveness through research and innovation', the government organized activities for Productivity Awareness Week on this theme in 2018.

Ensuring universal Internet access

Since 2015, St Lucia's education curriculum has been updated to promote STEM fields. A pilot Computer Coding and Robotics programme has also been launched in four secondary schools, with support from USAID. All secondary schools have been given access to the Internet and teachers have been trained in using ICTs in the classroom.

In addition, St Lucia launched a Government Island-Wide Network Project (GINet) in 2018, with the assistance of the Taiwan Province of China. Wi-Fi is now freely available in public places in the capital, Castries, and four other districts. By the project's end, it will have provided all public areas island-wide with free Internet access.

SURINAME

Support for innovation by firms

Suriname's largely informal economy is dominated by the services sector (49% of GDP in 2017) and mining, with the latter accounting for about 85% of exports (alumina, gold, crude oil) and 27% of government revenue, according to the Central Intelligence Agency's *World Factbook* (2018). The country's other main exports are also primary products: lumber, shrimp, fish, rice and bananas. The share of high-tech exports in manufactured exports dropped considerably between 2015 and 2018 (Figure 6.6).

The government has embarked on a four-year programme to help the private sector add value to the economy, while promoting a policy of sustainable growth and economic diversification. The Suriname Business Climate and Innovation Programme (SUBCIP) wound up in 2020. It had a budget of US$ 5.73 million and was co-financed by the IADB. One-third of SUBCIP's budget was allocated to a scheme promoting Innovation for Firms in Suriname (Box 6.3).

TRINIDAD AND TOBAGO

A new Vision 2030

A general election ushered in a new government in September 2015, amid falling energy prices and revenue which threatened the standard of living. The new government promptly embarked on a review of implementation of the *Development Plan Vision 2020* (2002). The review concluded that, while *Vision 2020* had stimulated the economy, employment and education, no significant progress had been made towards 30% of *Vision 2020's* objectives, including those promoting STI and the environment, with the notable exception of ICTs where 75% of the objectives had been achieved. *Vision 2020* had failed to reach its targets for GERD, patents, publications and the commercialization of R&D.

A new development strategy, *Vision 2030,* was, thus, rapidly crafted and approved in 2015 with short-term (2016–2020), medium-term (2021–2025) and long-term (2016–2030) goals. Closely aligned with the Sustainable Development Goals, *Vision 2030* focuses on improving implementation, strengthening partnerships and co-ordination across sectors and maximizing resource usage. One focus is to create a business environment conducive to entrepreneurship (Theme IV, Goal 2) by, *inter alia*: establishing centres of excellence and technology parks; promoting a culture of

Box 6.3: **Helping firms innovate in Suriname**

Launched in 2017, the Innovation for Firms in Suriname scheme is currently Suriname's only policy instrument supporting private-sector innovation. It focuses on the agriculture, food processing and tourism sectors.

The scheme is flexible, with funding being awarded to any initiative with the potential to boost sales, create jobs and reinforce value chains, including all types of innovation (product, process, marketing and organizational). Businesses owned by women are a priority target group for the programme.

The maximum grant awarded per project is US$ 250 000. Beneficiaries are expected to cover 20% of the total project cost, through monetary and/or in-kind contributions. The scheme's budget (US$ 1.83 million) covers 80% of project costs.

During the first two phases in 2017 and 2018, nine projects were selected for funding. Although these projects have only been implemented since March 2018, they have already generated positive outcomes.

One is the Agro Cooperation Redi Doti en Pierre-Kondre project, which boosted annual organic pineapple production from 40 000 kg in 2017 to 100 000 kg in 2018. The project trained 11 farmers from two indigenous communities (Redi Doti and Pierre Condre) in organic planting techniques. It also rented the requisite equipment on the farmers' behalf and hired a firm to confer organic certification on the plantation. The scheme obtained a grant of US$ 22 575 for this project.

Another project involves the 16-person strong North Commewijne Tourism Cluster. It is encouraging plantations to work together to design and offer innovative products and services, to attract more tourists to Suriname and encourage them to extend their stay. It is restoring the 24 km-long bike trail that previously ran alongside colonial plantations, for instance. The project received a grant of US$ 150 000 from the Innovation for Firms in Suriname scheme and has used this endorsement to leverage a further US$ 650 000 in in-kind contributions.

A third project is introducing hydroponic technology that does not require electricity to cultivate habanero peppers in the interior of Suriname.

Discussions were under way in 2020 to identify external funding to prolong the scheme, given that durable public support for firm innovation will be vital to diversify the economy and develop the private sector.

The Innovation for Firms in Suriname scheme is a component of the Suriname Business Climate and Innovation Programme (SUBCIP).

Source: Elci (2019)

innovation and entrepreneurship through education and training; and incentivizing green enterprise.

Under the theme on environment, there are plans to reduce the economy's carbon footprint by developing renewable energy sources, building climate resilience and improving waste and natural resources management.

The *National ICT Plan* for 2018–2022, the latest in a series of five-year plans, has been aligned with *Vision 2030*. It fixes a number of targets, such as that of raising the ICT sector's contribution to 5% of GDP to ensure that at least 85% of the population has broadband access and creating 30 000 jobs.

Support to bridge the 'Valley of Death'

Although no specific funding agency exists for STI, other bodies partially fulfill this function. For example, the UWI's St Augustine Campus operates the Trinidad and Tobago Research and Development Impact Fund on behalf of the government. This Fund supports projects that address pressing development challenges and run for 3–5 years through grants of up to US$ 300 000. Projects supported in 2019 focused on health, agriculture, tourism and ICTs. The university has used its experience of administering the fund to set up an Innovation and Technology Transfer Fund to help academic staff and students convert their intellectual property into viable goods and services. According to the university's website, the funds provided 'are meant to help bridge the "Valley of Death" often encountered when trying to commercialize academic research' (UWI, 2019). The Fund is administered through the university's St Augustine Centre for Innovation and Entrepreneurship. In 2019, the St Augustine Campus set up UWI Ventures, a holding company for start-ups which is nurturing partnerships between the university and the private sector (Augustine, 2019).

CONCLUSION

Time for effective roadmaps

Since 2016, Caricom countries have tackled some existential challenges head on. They have adopted long-term development plans and engaged in new levels of international collaboration to fund sweeping investments in climate change-resilient infrastructure and social services, clean geothermal energy sources and modern research infrastructure.

What will be important now is to consolidate this effort by drafting national and subregional policies that draw on effective instruments for implementation, such as detailed roadmaps, adequate and sustainable funding and monitoring and evaluation mechanisms to ensure accountability. The direct funding for research in the Jamaican government's 2019 budget could be a game-changer for the country once coupled with the country's new STI policy.

At the regional and national levels, there also needs to be a more systemic, sustained approach to supporting innovation by private firms. Boot camps should not be an end in themselves but, rather, part of a longer-term accompaniment for promising firms in need of stable financial and technical support to upscale their activity. The adoption of regional and national quality policies to help firms compete in foreign markets is a step in the right direction, as is Jamaica's new BIGEE programme for entrepreneurs.

Public universities must rethink their funding model

Currently, universities tend to function as enclaves with barely any linkages to the local economy. The success stories in the preceding pages are the exception, rather than the rule.

Although the current excellence in health research augurs well for social development and has been an asset in coping with the Covid-19 pandemic, health research alone will not prepare Caribbean societies for the digital and green economies of tomorrow. Today's technologies are increasingly rooted in multiple fields of science, blending nanotechnology, biotechnology, information technology and cognitive sciences. Governments need to be aware that the next wave of technologies will unfurl from the basic research laboratories of universities. Closer ties between the academic and business worlds can help universities to modernize their curricula and adapt their output to evolving market needs.

The current low levels of public research funding offer universities an incentive to interact with the local economy. Unlike their publicly funded counterparts, the private universities operating in small Caricom countries have adopted a successful self-financing model that has been responsible for dramatic growth rates in scientific output. A hybrid funding mechanism like that of the Mona Campus, which takes advantage of both private and public funding, is well worth pursuing. In point of fact, the research programme at UWI's Mona Campus could not have survived without an injection of self-financing activities, after the government slashed support for the campus from 65% to about 36% of budgeted expenditure between 1999 and 2017 (Ramkissoon and Kahwa, 2015).

Collaboration helping to green economies

Limited human and financial capital, combined with increasingly frequent and destructive hurricanes, has pushed countries to green their development strategies in the past few years. They have often been able to count on regional bodies such as the Caribbean Community Climate Change Centre, the Caribbean Centre for Renewable Energy and Energy Efficiency, OECS and UWI for the mobilization of resources and the execution of relatively complex multilateral projects related to climate change mitigation, adaptation and resilience. These trends augur well for countries' chances of realizing their Sustainable Development Goals, since it is only through regional co-operation that the challenges related to economies of scale can be overcome.

In parallel, countries are investing more in higher education, as evidenced by the new University of the Bahamas, the launch of the fourth physical UWI campus on the island of Antigua in September 2019 and the programme revamping science and medical curricula at the University of Guyana. These are very positive steps, given the shortage of skills in the region to nurture the desired digital and 'green' economies and the high migration rates of skilled personnel.

Bold aspirations such as Dominica's plans for achieving climate-resilient nation status, Guyana's development of a model 'green town' or Jamaica's and Trinidad and Tobago's investment in acquiring developed country status will require creative solutions and a long-term commitment to higher education, research and innovation in STI.

Time is of the essence. The bottlenecks currently hampering effective science governance must be unclogged as soon as possible, if the region is not to remain on the sidelines of the Fourth Industrial Revolution.

KEY TARGETS FOR THE CARICOM COUNTRIES

- Renewables are to account for 28% and 47% of total electricity generation capacity in the region by 2022 and 2027, respectively.
- Belize aims to raise GERD to 1% of GDP by 2025.
- Jamaica is targeting a 1.5% GERD/GDP ratio by 2030.
- In Trinidad and Tobago, 85% of the population is to have broadband access by 2030.

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ENDNOTES

1 The present chapter was written in January 2020, before the Covid-19 pandemic began affecting the economies of Caricom countries. In February 2020, the University of the West Indies (UWI) set up a regional multidisciplinary Covid-19 task force to co-ordinate testing at twelve sites across the region, in collaboration with the Caricom Secretariat and World Health Organization. UWI, St Georges University and other public and private laboratories played a key role in the region's response to the pandemic not only through analytical testing but also by conducting clinical research on the efficacy of drugs and genetic fingerprinting of the coronavirus.

2 The following are goods-producing economies: Belize (agriproducts and oil), Guyana, Haiti (agriproducts), Jamaica, Suriname (bauxite and alumina) and Trinidad & Tobago (oil, gas, methanol, ammonia, steel and agriproducts). They have been hit harder by the deterioration in fiscal flexibility than the service-based economies of Antigua & Barbuda, Bahamas, Barbados, Dominica, Grenada, Montserrat, St Kitts & Nevis, St Lucia and St Vincent & Grenadines, which are all reliant on tourism.

3 Antigua & Barbuda, Dominica, Grenada, Montserrat, St Kitts & Nevis, St Lucia and St Vincent & Grenadines

4 The Caricom Energy Report Card for 2017 indicates that renewable energy accounts for 11% of installed electricity generation among Caricom members. The major performers are Belize (48%), Suriname (46%), Dominica (26%), Jamaica (15%) and Guyana (14%).

5 See: https://www.greenclimate.fund/projects/fp060

6 This committee acts as an advisory body to the prime minister accorded responsibility at Caricom level for issues related to science, technology and innovation.

7 For a profile of this firm, see Ramkissoon and Kahwa, 2015, Box 6.2.

8 For more on this Institute, see Ramkissoon and Kahwa, 2015, Box 6.1.

9 Nuclear technology offers practical applications in health (nuclear medicine, cancer diagnosis and treatment), agriculture (developing new plant and animal varieties and sterilizing produce to eliminate disease-carrying insects), water resource development and management, mining and myriad other industries.

10 The Republic of Korea launched its Knowledge Sharing Programme in 2004 to share its own 'rags to riches' experience with other developing countries through the provision of policy advice. By 2020, 76 countries had benefited from the programme.

11 See: https://www.worldbank.org/en/news/feature/2017/11/28/a-360-degree-look-at-dominica-post-hurricane-maria

12 Japan has provided US$ 15 million through the UNDP to improve energy security planning for adaptation to climate change and Italy has provided US$ 650,000.

AT A GLANCE

Students practising maintenance on various types of aircraft engine for the skilled technician training programme at the National Aeronautics University, which is part of the Querétaro Aerospace Cluster in Mexico, in June 2018. For details, see Box 7.4.
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- More countries are developing 'home-grown' policies that involve experimentation, in preference to adapting policies designed abroad. These policies stress social innovation for sustainable development and are increasingly integrating indigenous and local knowledge systems.
- The research community is focusing more than in the past on topics related to The 2030 Agenda for Sustainable Development, including in countries with a modest scientific output.
- Policy-making in Latin America remains characterized by U-turns that can undermine investor confidence and hamper innovation. Some countries are also backtracking on broad public participation in decision-making.
- During the commodities boom, public investment targeted economic expansion, rather than upgrades to infrastructure or innovative risk-taking. Consequently, the region's resource-based economies have slowed since the drop in demand for exports.
- Bottom-up initiatives in biotechnology, space science, open science and other areas have helped to compensate for reduced multilateral collaboration.

7 · Latin America

Argentina, Plurinational State of Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Uruguay, Bolivarian Republic of Venezuela

Gabriela Dutrénit, Carlos Aguirre-Bastos, Martín Puchet and Mónica Salazar

INTRODUCTION

An economic slowdown

The Covid-19 pandemic of 2020 has struck at a time of stagnant economic growth in Latin America,[1] coupled with declining investment in science, technology and innovation (STI) from already low levels.

The economic slump of the past few years is the result of diverse phenomena: global prices for minerals and agricultural products have tapered off since 2015, as has demand for other primary products; there have been cutbacks in financial assistance programmes for the private sector; and, above all, the global economy has contracted, spurring a decline in monetary stimuli injected by the USA and European Central Bank associated with a drop in foreign direct investment (FDI) and capital inflows (CEPAL, 2018 and 2019a).

Most affected by these trends are the region's largest economies: Argentina, Brazil and Mexico. Venezuela has been plunged into recession (Figure 7.1). Many of the smaller countries showed healthy annual growth of at least 4% over the 2016–2018 period, namely Bolivia, Costa Rica, Cuba, the Dominican Republic, El Salvador, Honduras, Panama, Paraguay and Peru. They managed to compensate for the economic downturn in Argentina and Brazil by boosting their exports to North America or, in the case of Bolivia, Paraguay and Peru, to China. Cuba benefited from the lifting of US sanctions in 2014, even if it was short-lived.

Covid-19 has offered space for bottom-up initiatives

Leadership for designing and implementing the social confinement strategy to limit the spread of Covid-19 has fallen to the region's ministries of health, with varying degrees of involvement by other ministries, particularly those with portfolios for security, defence and the treasury. The extent of interaction between the ministries of health and science governing bodies in the initial phase has depended on the level of importance accorded to science by each government.

The Governments of Argentina, Colombia, Cuba, Chile, Mexico, Panama, Peru and Uruguay have supported laboratories in developing diagnostic tests. One example is Panama's Instituto Conmemorativo Gorgas de Estudios de la Salud, which rapidly sequenced the virus' genome. Another example is the development in Cuba of medicines to treat Covid-19 patients, such as the Anti-CD6 monoclonal antibody elaborated by the Centre of Molecular Immunology and the CIGB-258 peptide developed by the Centre for Genetic Engineering and Biotechnology.

The Governments of Bolivia, Colombia, Costa Rica, Chile, Mexico, Paraguay and Uruguay have also supported the manufacture of lung ventilators and protective gear for health personnel, with novel designs being made freely available online or patented.

Collaboration with universities, research centres, firms and hospitals has been vital. For instance, in Uruguay, the Pasteur Institute of Montevideo and the University of the Republic rapidly disseminated a virus detection test kit. This experience led them to establish the Centre for Innovation in Epidemiological Surveillance in June 2020 with private funding.

In the early days of the pandemic, rigid formal approval processes for research project proposals proved ill-adapted to an emergency situation. By early April, the innovation agencies of Argentina, Brazil and Uruguay had launched specific calls for Covid-19 research proposals and managed to accelerate the approval process. Peru's two innovation agencies even managed to shorten the response time to two weeks, setting a new record. As time went by, the number of calls grew across the region, contributing to the emergence of projects related to serological tests, lung ventilators and vaccines. A space for co-ordination was created under the Latin American Network of Innovation Agencies.

Between January and March 2020, a space for bottom-up initiatives emerged. For instance, a team of biomedical engineers from the University of Antioquia in Colombia developed a low-cost lung ventilator, in collaboration with the Hospital San Vicente de Paul, through a project supported by the Ruta N Medellin business development centre. In mid-2020, the ventilator was approved by the medical licensing institute, INVIMA. It will be manufactured by firms specializing in home appliances and automobiles, which have repurposed their assembly lines. Since the developers used open source techniques, other factories will be able to produce the same ventilators.

In another example, Mexican entrepreneurs have banded together to create a platform called the Innovation and Action Network for Covid-19. This network groups firms specializing in fields such as medical equipment design and manufacturing, online medical services, artificial intelligence and analytics. The platform is being promoted by the Red Innova Mexico City network. Some early results include the binational design of a Mexican–Spanish ventilator, the founding of a national mathematical modelling group, an open access algorithm platform and a roadmap for studying the 'urban metabolism' within a system that would analyse wastewater to monitor the prevalence of Covid-19 and other diseases. Public research centres have collaborated with local companies and CONACYT to produce lung ventilators.

On 29 May 2020, Costa Rica and the World Health Organization (WHO) launched a voluntary patent pool called

Solidarity Call to Action. This repository should ensure that any vaccines, medicines or other tools developed to cope with Covid-19 in signatory countries can be manufactured widely. Chile was the first to rally the pool. By July 2020, it had been joined in the region by Argentina, Belize, Brazil, Dominican Republic, Ecuador, El Salvador, Honduras, Mexico, Panama, Paraguay, Peru and Uruguay.

In parallel, Mercosur has launched a US$ 16 million dollar fund to support a co-ordinated approach to slowing the epidemic's progress through research and education.

By mid-2020, Latin American science had become more visible in the race against Covid-19, as illustrated by UNESCO's #NuestraCienciaResponde[2] social media campaign and website. The Central American Integration System (SICA) had teamed up with the Central American Higher Education Council (CSUCA) to create an online platform where researchers could submit their findings on the new virus.

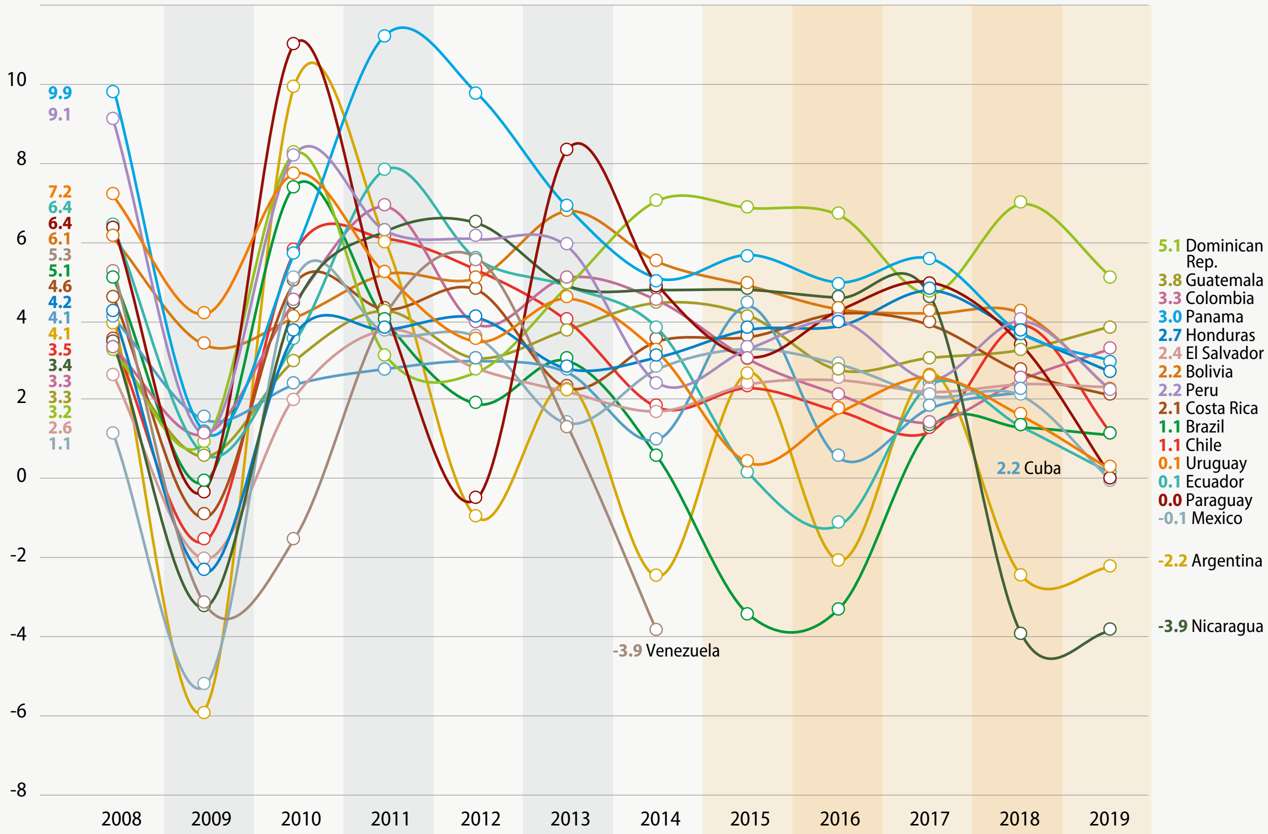
In addition, UNESCO and the Organization of Ibero-American States have developed a joint online platform[3] showcasing the region's progress in Covid-19-related research, through articles and bibliometric analyses inspired by PubMed.

For its part, the Inter-American Development Bank Lab has been mapping innovators in the region via its own online platform and showcasing the solutions that start-ups and entrepreneurs have devised, including diagnostic devices and temperature-screening tools for public spaces.[4]

The health crisis has created new models of co-operation in the region. In August 2020, Argentina and Mexico signed an agreement to co-produce the vaccine under development by AstraZeneca and Oxford University, once it has completed clinical trials.

Figure 7.1: **Socio-economic trends in Latin America**

Rate of economic growth in Latin America, 2008–2019 (%)



Average rate of economic growth in Latin America

1.3%

2013–2015

≈

1.4%

2017–2019

Internet penetration in Latin America

65.8%

in 2018

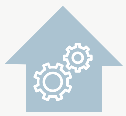
54.6%

in 2015

Manufactured exports as a share of merchandise exports in Latin America

49.9%

in 2019



48.6%

in 2015

Without investment, no innovation

The economic slowdown over the past five years follows an established pattern: during the commodities boom, investment was geared mainly towards economic expansion, rather than reinforcing existing infrastructure and supporting the kind of risk-taking that leads to innovation (CEPAL, 2018). Consequently, the region has found itself unprepared for the drop in demand for its exports.

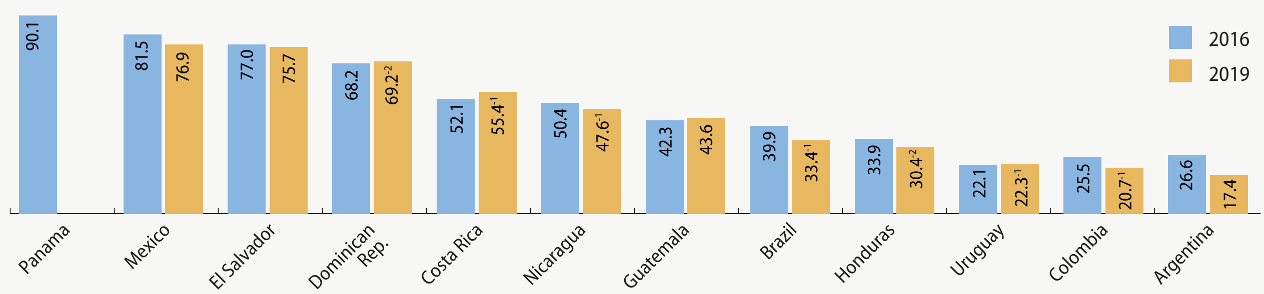
Latin America is characterized by two primary growth patterns, one based on industrial exports and the other on exports of natural resources. The former countries import large quantities of goods to re-export but add little value to these. There is also little recourse to local skills. This pattern is characteristic of the Central American economies of Costa Rica, the Dominican Republic, El Salvador, Honduras, Mexico and Panama.

Those economies based on natural resources tend to export raw materials to other countries, rather than importing inputs to assemble new goods. Argentina, Bolivia Brazil, Chile, Colombia, Ecuador, Peru and Venezuela all fall into this category.

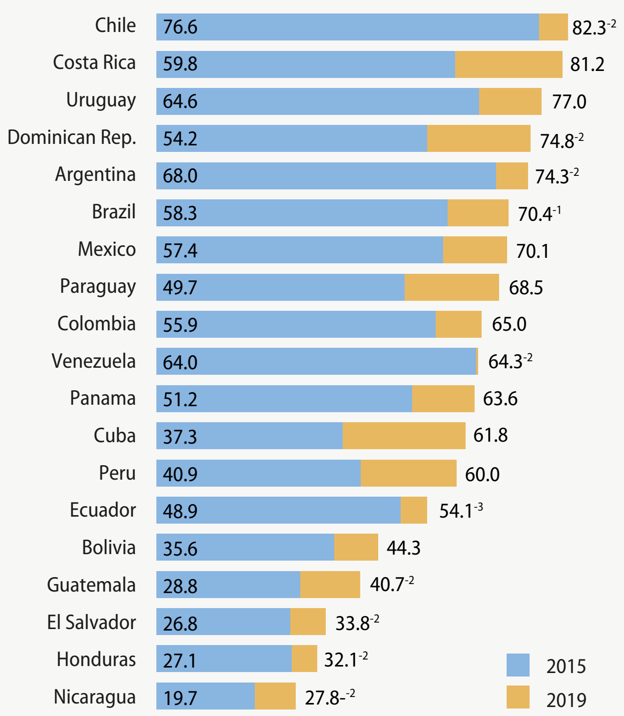
Neither growth pattern is effective in developing innovation, since each fails to establish linkages with domestic suppliers, industries and value chains (Katz and Astorga, 2013; Pérez *et al.*, 2013).

FDI can compensate for a shortage of domestic investment in innovation and high technology but these inflows tend to oscillate more favourably towards the larger economies (Figure 7.1). European and US companies have both raised their level of investment in the region, according to the database of the United Nations Economic Commission for Latin America and the Caribbean (CEPAL).

Top 12 countries for manufactured exports as a share of merchandise exports in Latin America, 2016 and 2019 (%)



Share of population using Internet in Latin America, 2015 and 2019 (%)

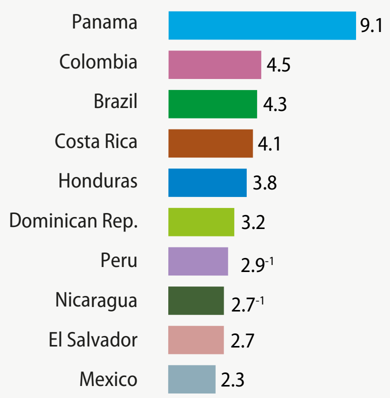


-*n:* data refer to n years before reference year

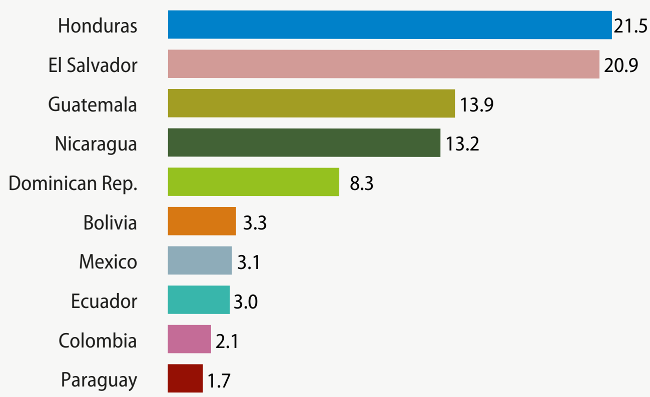
Note: Data are unavailable for Cuba and Venezuela.

Source: World Bank's World Development Indicators, October 2020

Top 10 Latin American countries for FDI inflows as a share of GDP, 2019 (%)



Top 10 Latin American countries for receipt of personal remittances as a share of GDP, 2019 (%)



Chapter 7

The share of total FDI inflows from the European Union (EU) rose from 44% over 2013–2015 to 51% over 2016–2018, while the USA's share increased from 29% to 32%. By some accounts, China is also increasing its investment in the region, particularly as concerns infrastructure development, but data are incomplete (Cuéllar and Bauer, 2019).

The advances of Industry 4.0, such as the emergence of fintech and growing automation, are beginning to steer investment towards products, processes and services that rely on innovation but the impact on employment has yet to be felt. If we take the example of Mexico, it counted 5 700 industrial robots in 2018, ranking ninth worldwide for automation (ProMéxico, 2018). About half of these robots were installed in the automotive sector. Many industrial robots in Mexico have been imported from the USA, Europe and Asia by automobile manufacturers with local assembly plants, such as Chrysler, Ford, General Motors, Honda, Toyota and Volkswagen.

Multinationals focusing on manufacturing

Since 2015, multinational companies with subsidiaries in the region have largely maintained a policy of utilizing existing knowledge, rather than engaging in local research and development (R&D). Those companies that form part of global value chains tend to limit their output in Latin America to manufacturing, which requires little new knowledge and does nothing to promote the development of linkages with scientific institutions.

The regional leaders for high-tech manufactured exports are Mexico and Costa Rica, followed by Brazil, Chile, Colombia and Uruguay. Costa Rican jobs in the software services sector and high-tech exports suffered from the relocation of the Intel plant to Asia in 2014 (Lemarchand, 2015). However, Intel has since opened an Innovation Centre in Costa Rica that employs a much higher ratio of skills than the defunct plant. Moreover, Hewlett Packard opened its own Minnerva innovation centre in Costa Rica in May 2018 to boost company creativity, including through interaction with local organizations and universities.

Multilatinas expanding their influence

In several countries, *multilatinas* are playing a greater role than previously. These Latin American businesses first emerged in the 1960s. In recent years, a growing number have been expanding their reach beyond national borders.

América Economía's 2019 Ranking Multilatinas lists 100 companies with sales exceeding US$ 230 million and operations in at least two foreign countries in 2018.[5] Brazil and Mexico count the most *multilatinas*, followed by Chile, Colombia, Argentina and Peru.

Multilatinas combine their innovation strategies with linkages to local and foreign universities but are not closely connected to the national innovation system (Costa *et al.*, 2015; Aguilera *et al.*, 2017; Ponce *et al.*, 2019).

Integration processes advancing in dispersed order

Trade agreements and integration processes in Latin America could serve as a buffer against the wave of protectionism currently emanating from the USA, by offering wider markets for the region's scientific and technical exports.

In 2017, the USA withdrew its support for the supraregional Trans-Pacific Partnership. It was subsequently revived by the other parties and renamed the Comprehensive and Progressive Agreement for Trans-Pacific Partnership. This trade agreement entered into force in December 2018, after being ratified by six countries, including Canada and Mexico. Chile and Peru are yet to follow suit.

The United States–Mexico–Canada Agreement (USMCA) came into force on 1 July 2020, following lengthy negotiations. It replaces the North American Free Trade Agreement.

Meanwhile, ratification of the free trade agreement negotiated between the EU and the Southern Common Market (Mercosur) has stalled in the face of opposition from European farmers and from indigenous rights and environmental groups concerned about the impact of the deal on the Amazon. This trade agreement had been negotiated in parallel to a rapprochement in science operated by the European Union and ECLAC since 2015. At a joint summit in 2015, the two blocs adopted an action plan for scientific co-operation and researcher mobility, with a view to developing a common research area.

In 2017, the European Commission launched the EU–CELAC Policy Dialogue project to support countries' implementation of *The 2030 Agenda for Sustainable Development*; one pilot project focused on the treatment of biomass waste in Panama, at the initiative of the National Secretariat for Science and Technology (SENACYT).

Joint calls under the Horizon 2020 programme have led to the selection of 27 project proposals that were due to be evaluated in mid-2020. Topics include the impact of transportation on air quality, personalized medicine, the bio-economy and, almost prophetically, the establishment of an international network of research centres in social sciences 'to help address governance and other challenges in the preparedness for, and response to, infectious threats.'

Mercosur itself has been hamstrung by the economic crises affecting Argentina and Brazil between 2016 and 2018. In response to the Covid-19 crisis, the June 2020 session of Mercosur's Specialized Meeting on Science and Technology (RECyt) decided to allocate additional resources to co-ordinating members' response to the pandemic.[6] These funds are to go to the health and information technology sectors, among others, as well as to food, water and energy security and support for small and medium-sized enterprises (SMEs) and start-ups. RECyT has been able to take advantage of the infrastructure built through the Biotech project with the European Union using joint financing (2005–2011). Among the regional projects implemented during Biotech's second phase, several focused on infectious diseases.

SICA has become an active player in scientific co-operation (Box 7.1). In May 2020, the Central American body signed an agreement with Canada's International Development Research Centre for an ambitious project to strengthen the policy-making capabilities of the national research and innovation bodies of SICA's member states.

As for the Union of South American Nations (UNASUR), the majority of its 12 members have withdrawn from this mechanism for regional integration barely a decade after its inception. A new institution took its place in March 2019, the Forum for the Progress and Development of South America (PROSUR).

Regional scientific bodies stepping up to the plate

By ricochet, geopolitical disunity has impeded regional economic and scientific integration over the past five years. Specialized regional bodies are doing what they can to fill the void. The Open Science Forum for Latin America and the Caribbean (CILAC) [Box 7.2] and ECLAC have both been promoting scientific collaboration through regular meetings and conferences.

In Central America, the non-profit Association for Aeronautics and Space (ACAE) has been nurturing scientific collaboration through the Morazan Project. ACAE is developing an early warning system for floods and landslides in a region prone to natural disasters. With many remote areas still deprived of modern telecommunications, Honduras, Guatemala and Costa Rica have joined forces to design and launch a telecommunications satellite. In April 2018, ACAE launched Central America's first satellite, Batsu-CS1, developed by a Costa Rican team.

The Argentine–Brazilian Center for Biotechnology (CABBIO) has plans to become a regional centre. Since Uruguay joined the fold in 2012, CABBIO has become a trinational centre. In 2020, it was undertaking joint activities with Colombia.

Another bottom-up initiative bucking the trend towards reduced multilateral collaboration in Latin America is the Ibero-American Programme of Science and Technology for Development (CYTED). Although CYTED does not fund research, it facilitates the interaction and flow of knowledge

Box 7.1: Greater resilience a focus of Central American integration

For the eight* member states of the Central American Integration System (SICA), regional integration remains a priority. At their Extraordinary Summit of July 2010, they identified the following five pillars of regional integration: democratic security; prevention and mitigation of disasters and the effects of climate change; social integration; economic integration; and institution-building.

One priority of the *Regional Environmental Framework Strategy 2015–2020* developed by the Central America Commission for Environment and Development (CCAD) is the elimination of single-use plastics. Costa Rica has adopted a *National Strategy for the Substitution of Single-use Plastics by Renewable and Compostable Alternatives 2017–2021*. Developed with UNDP support, the strategy includes measurable targets. In Guatemala, meanwhile, some municipalities have banned the use of plastic bags, prompting parliament to consider a national ban. In 2019, Panama became the first Central American country to ban polyethylene bags. A number of companies have espoused this approach.

In December 2019, El Salvador's Minister of the Environment and Natural Resources presented SICA's strategic framework and action plan for achieving carbon neutrality in the agriculture and forestry sectors.

A member of the Carbon Neutrality Coalition, Costa Rica has developed a *National Decarbonization Plan 2018–2050*; by 2020, its electricity network was already 99% carbon emission-free. Costa Rica has supported the development of Honduras' own *National Decarbonization Plan*, which sets the same target of attaining carbon neutrality by 2050.

A focus on challenges related to climate change

CCAD is currently putting the final touches to its *Regional Environmental Framework Strategy 2020–2025*, which will focus specifically on improving resilience to climate change.

Climate change and rapid urbanization are exacerbating the impact of extreme weather events such as tropical storms and hurricanes. Six in ten Central Americans now live in urban areas and the urban population is expected to double by 2050 (World Bank, 2017). Sectors dependent on freshwater (hydropower, agriculture, health, drinking water) and terrestrial, coastal and marine ecosystems are particularly vulnerable.

In 2020, the Co-ordination Centre for Natural Disaster Prevention in Central America and the Dominican Republic (CEPREDENAC), an intergovernmental body operating under the umbrella of SICA, created the Regional Platform for Coordination and Information on Comprehensive Disaster Risk Management. This geographical information system analyses and evaluates countries' exposure to risk and their capacity to tackle these threats under various scenarios. It is also providing information on the Covid-19 epidemic and tracking its evolution.

CCAD runs a programme called Towards a Resilient Central America that has created Centro Clima, a regional platform for information-sharing, and concluded an agreement in 2019 with the US National Aeronautics and Space Administration (NASA) to use geospatial data to combat climate change, among other accomplishments.

In 2020, 12 Central American universities were integrated into the European Space Agency's Copernicus Academy, which bridges the gap between skills and geospatial data use.

The EUROCLIMA+ project has met with some success, especially in the Mesoamerican Dry Corridor. It has also improved co-ordination between SICA's specialized bodies, such as CCAD, CEPREDENAC and the Regional Committee for Water Resources.

Source: compiled by Juan Criado, UNESCO

* The eight SICA members are Belize, Costa Rica, the Dominican Republic, El Salvador, Guatemala, Honduras, Nicaragua and Panama.

Box 7.2: **Steps towards institutionalizing open science in Latin America**

Open science is nothing new to Latin America but it is becoming more mainstream in policy, legal and regulatory documents. An analysis of nine countries by Ramírez and Samoilovich (2018) found that all nine provided open information services, including Brazil and Costa Rica. Four had adopted a legal framework for open science: Argentina, Ecuador, Mexico and Peru. Although four had developed policy documents (Colombia, Ecuador, Mexico and Uruguay), only two had actually adopted an open science policy (Chile and Mexico).

In 2018, the *Panama Declaration on Open Science* was promulgated within the framework of the Open Science Forum for Latin America and the Caribbean (CILAC). The declaration outlines the various components of open scientific practice: open access; open data; open education; citizen science; open, reproducible and replicable research; open evaluation and open peer review; open tools and free software and hardware policies; open infrastructure; and open source innovation.

In Latin America, the most developed and widely implemented of these practices are open access and open data, followed by citizen science (Ramírez and Samoilovich, 2018).

Among initiatives promoting open access at both national and regional levels, one is of particular importance: the Federated Network of Institutional Repositories of Scientific Publications (LA Referencia).

Launched in 2012, LA Referencia is a 'network of open access repositories' that integrates open access scientific material from national 'nodes' into a single platform with interoperability standards. As of January 2020, the platform hosted more than 2 million documents from over 100 universities and research institutes in ten countries, including articles and master's and PhD theses.*

Source: compiled by authors; see also https://forocilac.org and www.lareferencia.info/en/

* The ten countries are Argentina, Brazil, Chile, Costa Rica, Colombia, Ecuador, El Salvador, Mexico, Peru and Uruguay.

between research networks. For more than 15 years, CYTED has issued annual calls inviting researchers to establish ephemeral thematic networks, each of which has a lifespan of three years. Among those highlighted in 2017 were carotenoids in agri-food and health (15 countries), solar thermal concentration systems (7 countries) and interactive digital television as a vehicle of social inclusion (13 countries).

Public scrutiny of the public purse

There is growing awareness that science financed by the public purse should be subject to public scrutiny. This mandate falls to advisory councils. However, many of these bodies are run, wholly or partly, by the government. This concentration of science governance is typical of Latin America, where the same organization may be in charge of both policy-making and policy implementation and even of strategic priority-setting.

In other developments, two new science ministries were established in Chile and Colombia in 2019. These have absorbed the countries' previous agencies, namely, Chile's National Commission for Scientific and Technology Research (CONICYT) and Colombia's Administrative Department of Science, Technology and Innovation (Colciencias).

SUSTAINABLE DEVELOPMENT AGENDA

Countries at different stages of preparedness

The United Nations Economic and Social Council (ECOSOC, 2019) has warned that the world is not on track to achieve the Sustainable Development Goals (SDGs).

In 2016, the Forum of the Countries of Latin America and the Caribbean on Sustainable Development was established to review implementation of *The 2030 Agenda for Sustainable Development*. Since its inception, the forum has produced several reviews.[7]

The incorporation of SDGs objectives and targets is most evident in countries' environmental policies. Some countries have created dedicated platforms to inform progress in SDGs. However, only a few have presented their voluntary national reviews to the United Nations High-level Political Forum on Sustainable Development: Cuba, Chile and Guatemala in 2019 and Colombia, Dominican Republic, Ecuador, Mexico and Uruguay in 2018. Bolivia presented its first review in 2015, the next being due in 2021.

In Colombia, the *Green Book 2030* (Colciencias, 2019) contains the explicit objective of attaining the SDGs by 2030. For its part, Brazil's *National Strategy for Science, Technology and Innovation 2016–2022* sets out to 'strengthen the foundations' of society for sustainable development.

Bolivia, Chile, Costa Rica and Panama make no explicit reference to the SDGs in their strategies but these do emphasize relevant social goals such as better health, energy efficiency or poverty alleviation. Guatemala (UNESCO, 2017) and Mexico, meanwhile, are in the process of adapting their own development plans to the SDGs framework. Mexico presented its *National Strategy for Implementation of the 2030 Agenda* in December 2019; this includes a set of projects at the federal and state levels to attract investment and mobilize resources for sustainable development, as well as the design of sectoral projects, training opportunities and legislative changes.

Gradual convergence of different knowledge systems

A World Bank study (2015) estimates that 42 million Latin Americans are indigenous, representing 7.8% of the region's population. The five countries with the highest percentage are Bolivia (41%), Guatemala (41%), Peru (26%), Mexico (15%) and Panama (12%).

Indigenous and local knowledge has been integrated in the STI policies of some countries, including Bolivia, Panama and, most recently, Mexico. Much attention has centred, so far, on traditional medicine but more could be done to build links with scientific medical knowledge and medical trials.

Indigenous and local knowledge is recognized as being vital to cope with climate change. On behalf of the regional Indigenous Forum Abya Yala, Cerda (2018) proposes a framework for indicators of success in adapting to, and mitigating, climate change. Costa Rica and Bolivia have already begun implementing these tools, such as through Bolivia's Platform of Native Indigenous Nations to Combat Climate Change, which creates a space for dialogue about ancestral practices.

In 2016, Bolivia also introduced a programme at the national level which seeks to facilitate the recovery and use of local and ancestral knowledge. Ecuador has implemented a similar programme to develop a digital repository of ancestral knowledge (Figure 7.2).

These are part of a growing body of programmes in Latin America that promote social or inclusive innovation at the service of excluded and underprivileged communities (Figure 7.2). These programmes have become a landmark in the region.

The Inter-American Development Bank (IDB) has promoted many of the region's social innovation programmes through its I-Lab, which uses virtual platforms and social media to link challenges to demand-driven solutions.

The Digital Culture Centre in Mexico has adopted the use of virtual platforms itself as a vehicle for rethinking policies for creative industries that are being rapidly transformed by digital technologies (Box 7.3).

Research spending stagnating

Since 2015, research intensity in Latin America has remained relatively low, with Brazil (see chapter 8) maintaining its lead for this indicator (Figure 7.3). Research intensity has recently dropped in Argentina, Brazil and Mexico while rising, albeit modestly, in El Salvador, Paraguay and Uruguay.

Despite the Ibero-American and Inter-American Network for Science and Technology Indicators (RICYT) having supported the production of statistics for more than a quarter of a century, several countries do not yet produce regular data. This is true of Bolivia, Guatemala, Honduras and Peru, for instance, as well as most Caribbean countries (see chapter 6). This suggests that the development of STI remains below the radar of some governments.

Box 7.3: **The Digital Culture Centre: an experiment in creative industries**

Established in 2012, the Digital Culture Centre (CCD) is a response to the radical ways in which digital technologies are changing creative content and consumer behaviour in Mexico; it is located within the Mexican Ministry of Culture.

The centre runs youth-oriented programmes on the creative and critical use of digital technologies as tools for economic and cultural transformation.

It also serves as a think tank. There is a need to rethink policies related to creative industries and to adopt policy instruments which nurture innovation and collaboration with other industries. Innovators also need to have access to venture capital funds.

The Creative Compass

In 2018, the CCD launched the Transmedia Map initiative, which has since been renamed the Creative Compass. This pilot project aims to map development of the creative economy in Mexico, drawing on analyses of official data, social networks, quantitative surveys and case studies. The overarching aim is to enlarge the toolbox used to assess cultural industries and offer an instrument for the design of cultural policies.

The Creative Compass is supported by the British Council, as well as by the IDB.

The project is being implemented in collaboration with the Nesta Foundation in the UK, the Metropolitan Autonomous University (Xochimilco) and Parametría.

Taking stock of the creative landscape

In parallel, the CCD is working with the National Institute of Statistics and Geography (INEGI) to incorporate creative industries into the national industrial database.

Initial results* show that 91 000 companies are working in creative industries in Mexico, equivalent to 1.7% of all domestic firms. They employ about 725 000 people. An analysis of social network data** indicates that the most active creative sectors are those in software, design, video games, app development, advertising and marketing. Of the 1 100 communities active in 'technology and business' identified through this social network, two-thirds relate to creative industries.

The Immersion Laboratory

In co-ordination with the Banco Bilbao Vizcaya Argentaria (BBVA) Foundation, the CCD has created the Immersion Laboratory project, 'an open space for experimentation, learning and reflection on immersive technologies'. The project uses a virtual platform for the exchange of knowledge and explores immersive media by engaging artists, innovators and the general public in workshops, its residency programme and its annual Immersive Festival.

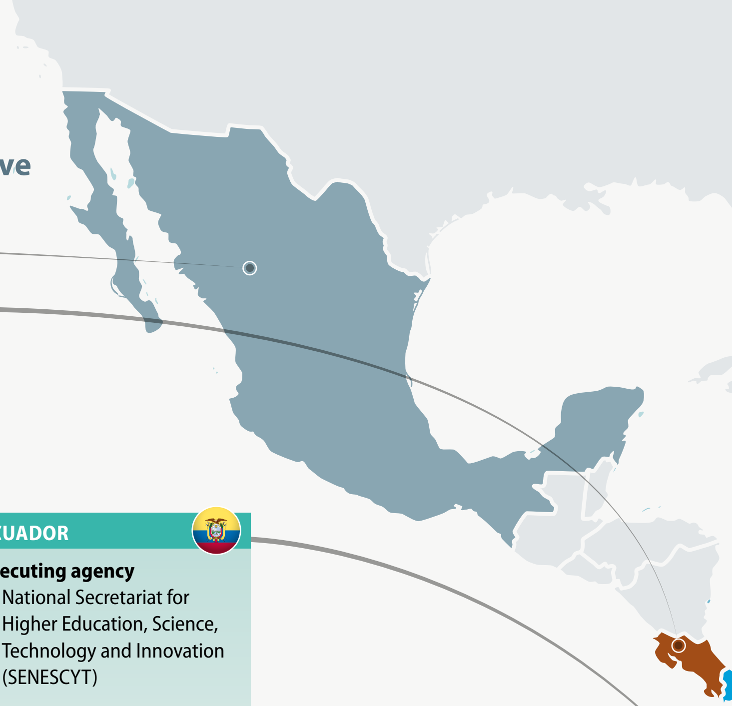
In 2019, the travelling Immersion Laboratory visited the cities of Monterrey, Tlaxcala and Guadalajara, attracting 162 attendees. The same year, the laboratory held 52 workshops, which included do-it-yourself sessions, master classes and exhibitions of items made by participants, such as an experience of virtual reality. In all, there were 6 662 direct and indirect beneficiaries.

Source: https://centroculturadigital.mx/; interviews conducted by authors

* These were identified by the National Statistics Office.

**via www.meetup.com

Figure 7.2: **Instruments promoting social or inclusive innovation in selected Latin American countries**



MEXICO

Executing agency
- National Council of Science and Technology (CONACYT)

Programme
- Technology for Social Inclusion, 2016–2020
  – *postdoctoral scholarships for indigenous women in STEM fields, 2018–2020*
  – *Innovatis: award for national technological innovation promoting social inclusion, 2016–2019*

Executing agency
- CONACYT and Ministry of Welfare

Programme
- Social Economy Promotion Programme, 2015–2020
  – *research projects on public health and food-related issues in agriculture, livestock and manufacturing sectors, 2015–2019*
  – *Study scholarships for indigenous women, 2015–2020*

COSTA RICA

Executing agency
- Ministry of Science, Technology and Telecommunications

Programme
- National Policy for Equality between Women and Men in Training, Employment and Enjoyment of the Fruits of Science, Technology, Telecommunications and Innovation (2018–2027)
  – *research on the barriers faced by women in accessing careers in science and engineering (also with IDB), 2018–2020*
  – *promoted equal enrolment rates between men and women in science and engineering, as well as study scholarships (2018–2020)*

Executing agency
- INCAE business school and its Latin American Center for Competitiveness and Sustainable Development (CLACDS), plus Presidential Council on Competitiveness, Human Talent and Innovation

Programme
- Principles for Responsible Management of Education programme
  – *school provides research and training related to social, eco-friendly development*

ECUADOR

Executing agency
- National Secretariat for Higher Education, Science, Technology and Innovation (SENESCYT)

Programme
- Ancestral Knowledge Co-ordination, 2019–2020
  – *creation of Digital Repository of Knowledge, Research and Innovation in Knowledge Dialogue for public policy management*
- Intercultural Public Policies, 2016– 2018
  – *scholarships for undergraduate and graduate studies for historically excluded groups*
  – *financing for technological R&D projects with a focus on social development*

PERU

Executing agency
- Ministry of Production and Ministry of Social Inclusion and Development

Programme
- Social Innovation Challenges, 2016–2019
  – *challenges associated with water, iron-fortified food, detection of anaemia and protection of areas subject to frost ~3 000 masl.*

CHILE

Executing agency
- Aysén Region, Corporation for the Promotion of Production (CORFO), National Council of Innovation for Development (CNID), with IDB

Programme
- Social Innovation in Aysén, 2014–2020
  – *identification of issues related to youth and environment*
  – *promotion of innovative solutions through its Open Innovation Platform and Contest for Solutions*

Executing agency
- National Commission for Scientific and Technological Research (CONICYT)

Programme
- Seed Capital and Social Innovation Programme, 2008–2018
  – *High-Impact Youth Entrepreneurship Support Fund, 2014–2018*
  – *promoting social innovation to overcome poverty, 2014–2018*

Executing agency
- CNID

Programme
- Local Entrepreneurship Programme, 2012–2020
  – *investment and training subsidies to provide access to new business opportunities and develop skills*
  – *initiatives targeting ventures with a high social impact in underprivileged areas include: Seed Capital Funds, Start-Up Chile Scale, Angels Network and Venture Capital Funds*

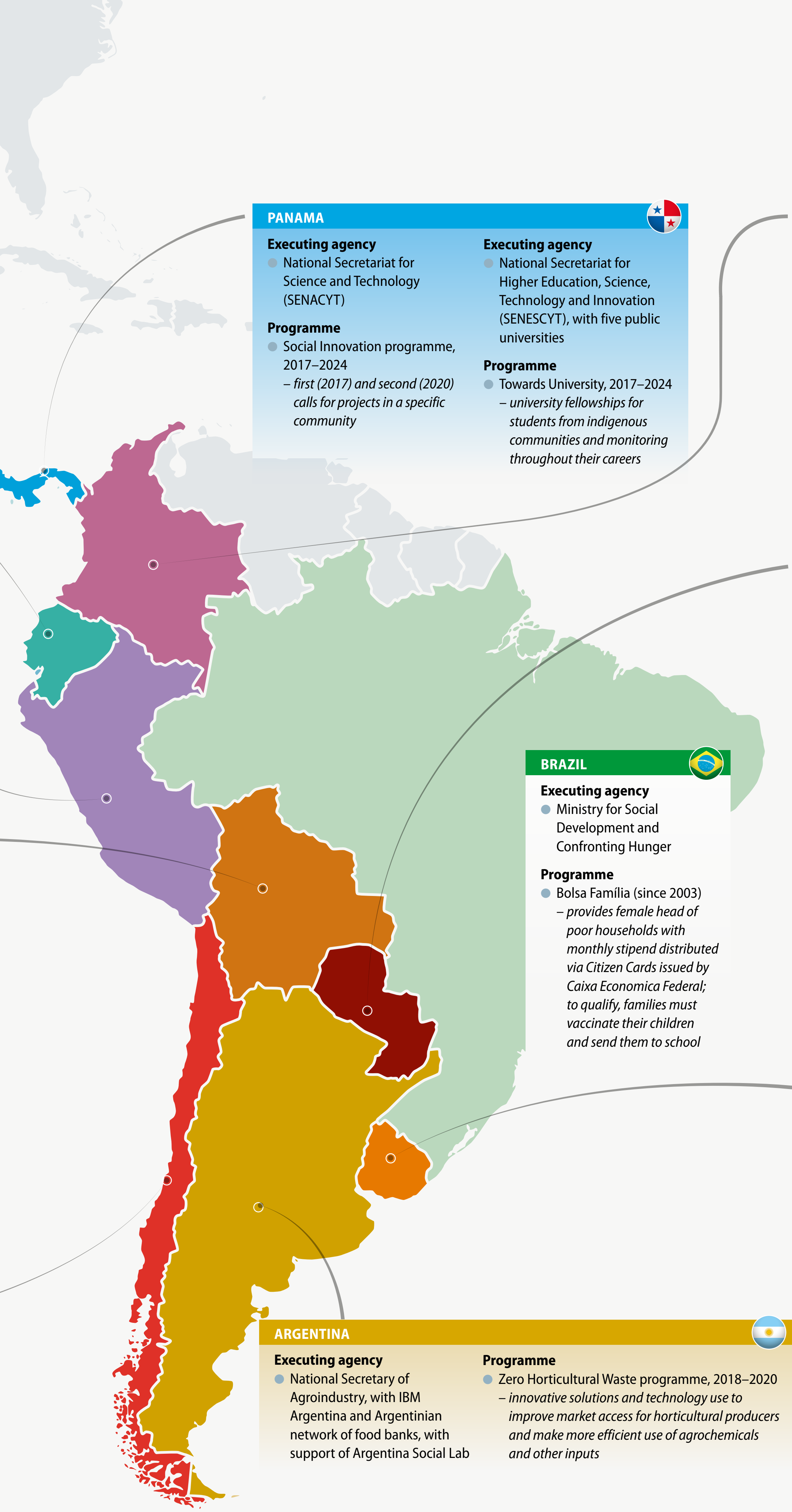
BOLIVIA

Executing agency
- Vice-Ministry of Science and Technology

Programme
- Inclusive Science Culture, 2018–2020
  – *to help build an inclusive knowledge society, through dialogue between different forms of knowledge*
- Local and Ancestral Knowledge, 2016–2020
  – *recovery and use of local and ancestral knowledge based on Framework Law of Mother Earth and Integral Development for Living Well*
- Social Appropriation of Science and Technology, 2018–2020
  – *study of Bolivian hydrological potential*
  – *prospecting for biofuel production*
  – *recovery and systematization of ancestral knowledge for social and productive development*
- Social Inclusion, Production and Sovereign Development, 2018–2020
  – *introduction of technologies for social innovation projects in energy and agriculture*

Executing agency
- Catholic University

Programme
- Carmen Pampa Peasant Unit (since 1993)
  – *awards university-level degrees to rural communities; effectiveness of programme has been recognized by United Nations Subcommittee for the Eradication of Poverty*



PANAMA

Executing agency
- National Secretariat for Science and Technology (SENACYT)

Programme
- Social Innovation programme, 2017–2024
  – *first (2017) and second (2020) calls for projects in a specific community*

Executing agency
- National Secretariat for Higher Education, Science, Technology and Innovation (SENESCYT), with five public universities

Programme
- Towards University, 2017–2024
  – *university fellowships for students from indigenous communities and monitoring throughout their careers*

COLOMBIA

Executing agency
- Colciencias

Programme
- National Strategy for Social Appropriation of STI for the Colombian Regions, 2012–2018
  – *Ideas for Change: issues calls, selects and funds projects proposing solutions for poor communities, with emphasis on water, energy, ecology and ICTs*

PARAGUAY

Executing agency
- National Council of Science and Technology (CONACYT), with National Secretaries of ICTs and Planification, National Commission on Early Childhood and related NGO network

Programme
- I-Lab Paraguay, 2017–2020
  – *social innovation platform involving citizens in identifying and prioritizing problems and inspiring social innovation*
  – *three different challenges launched: Early Years Count, to improve schooling; Rolling Ideas for safe motorbike riding, and Wellness Seeds for rural communities*

BRAZIL

Executing agency
- Ministry for Social Development and Confronting Hunger

Programme
- Bolsa Família (since 2003)
  – *provides female head of poor households with monthly stipend distributed via Citizen Cards issued by Caixa Economica Federal; to qualify, families must vaccinate their children and send them to school*

URUGUAY

Executing agency
- National Agency for Research and Innovation (ANII)

Programme
- Inclusive Innovation programme, 2016–2020
  – *financing projects to improve access to goods and services for excluded groups (health, food, Internet)*

ARGENTINA

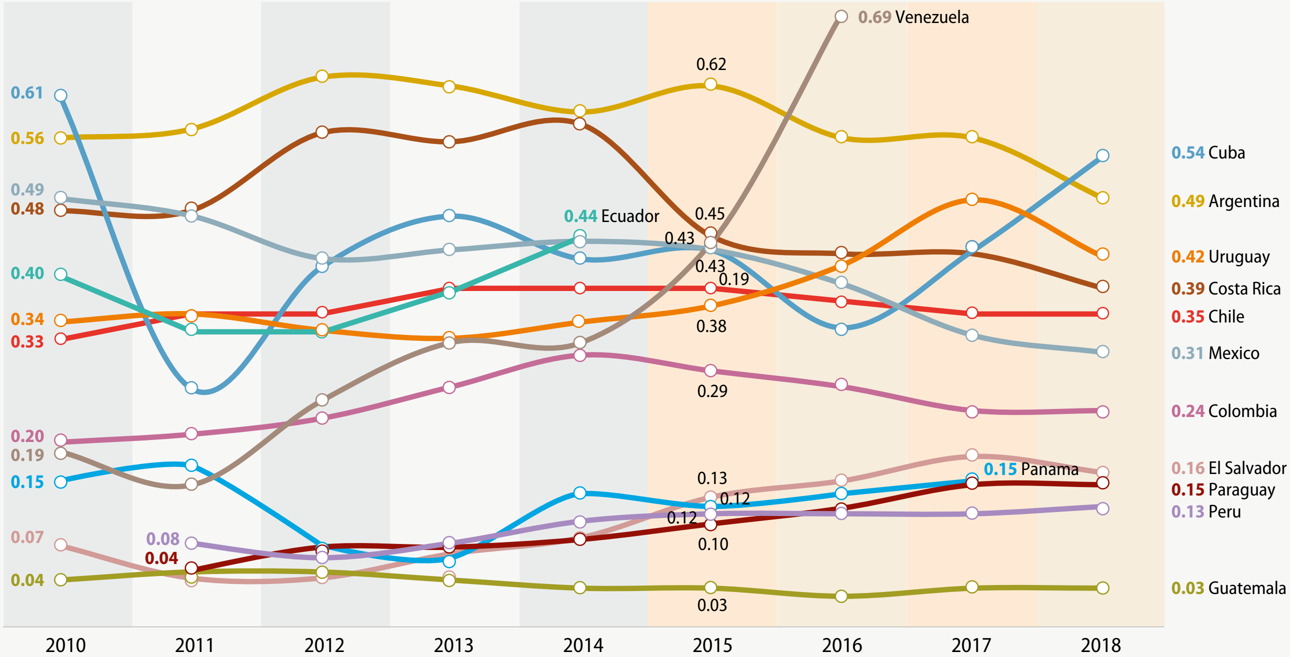
Executing agency
- National Secretary of Agroindustry, with IBM Argentina and Argentinian network of food banks, with support of Argentina Social Lab

Programme
- Zero Horticultural Waste programme, 2018–2020
  – *innovative solutions and technology use to improve market access for horticultural producers and make more efficient use of agrochemicals and other inputs*

UN Disclaimer

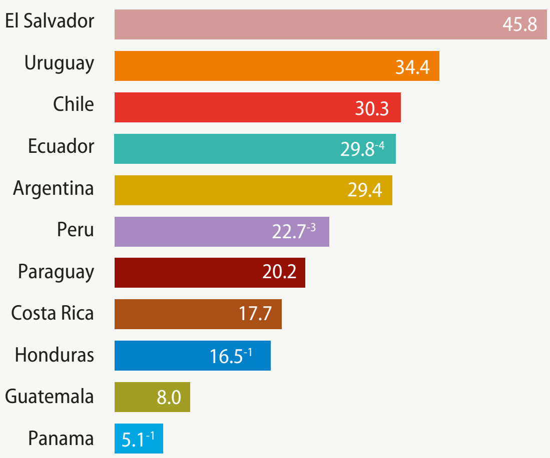
Figure 7.3: **Trends in research expenditure in Latin America**

GERD as a share of GDP in Latin America, 2011–2019 (%)



Note: Honduras invested 0.01% of its GDP in GERD in 2015 and 0.04% in 2017. For GERD in Brazil, see chapter 8.

Share of GERD devoted to engineering and technology in Latin America, 2018 (%)



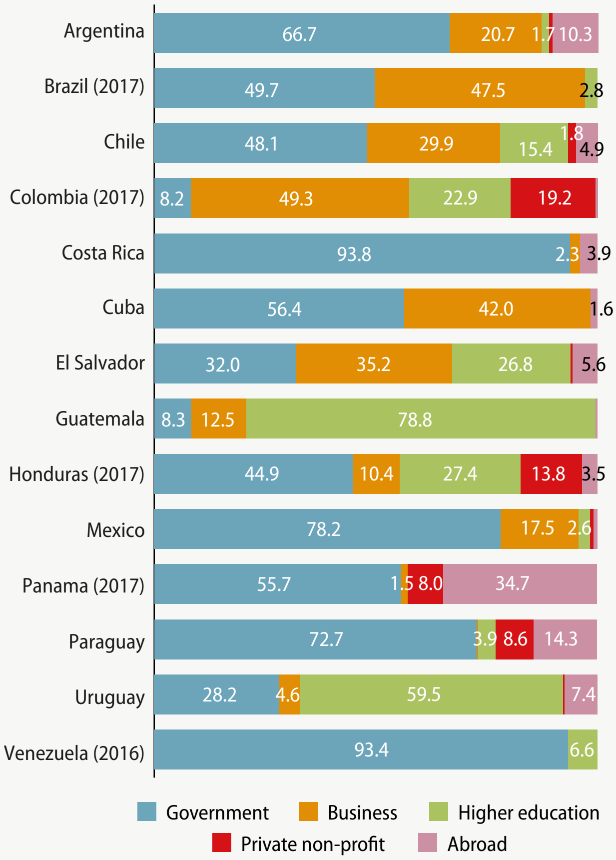
Average research intensity for Latin America and the Caribbean

0.69%
in 2015

0.62%
in 2018

-n: data refer to n years before reference year

GERD by source of funds in Latin America, 2018 or closest year (%)



Note: Data are unavailable for some countries. For the regional average research intensity, data are estimated and include Jamaica, Puerto Rico and Trinidad and Tobago. For El Salvador and Guatemala, data cover only higher education and government sectors; for Mexico, data refer only to federal expenditure on science and technology; for Uruguay, the methodology for calculating GERD changed in 2013, with the introduction of new criteria for calculating private expenditure; Honduras is excluded from the line drawing, as there are only values for 2015 (0.02%) and 2017 (0.04%). For GERD by source of funds, percentages lower than 1% are not labelled on the bar; for GERD in Brazil, see chapter 8.

Source: RICYT

The region is characterized by majority government funding of R&D (58%), which is performed primarily by universities (41%). Government investment levels are too low to provide much of a boost for industrial research. The outsourcing of innovation to other actors is becoming an option for firms but that, alone, does not explain why they only perform 30% of R&D and fund 36% of it. There may be a widespread view among public and most private enterprises that investing in research and innovation is not the best way to enhance their competitiveness and that they are investing more in the national innovation system than they are getting in return.

On average, less than one-quarter (23.4%) of researchers are employed by public and private firms. This shows the low importance accorded to the development of in-house R&D and innovation by most countries. Three countries buck the trend: Brazil (26.1%), Chile (29.5%) and Mexico (37.3%). All three have maintained a more consistent innovation policy in recent years.

Research and innovation surveys are carried out in most Latin American countries.[8] These surveys suggest that statistics on innovation output remain either low or excessively high. The latter trend would imply some degree of misinterpretation on the part of firms responding to the questionnaire, suggesting the need for new tools to collect information on innovation.

According to these surveys, a higher share of manufacturing firms are engaging in forms of innovation other than R&D. More firms are carrying out process innovation than product innovation and just one-tenth of innovative firms are receiving public support for their efforts (Figure 7.7). More than half of manufacturing firms in Argentina, Ecuador and Peru are innovators. These same countries are home to the highest share of businesses investing in R&D but the proportion does not exceed 30% of gross domestic expenditure on R&D (GERD).

Student numbers up but insufficient science graduates

The main challenge facing universities in Latin America, as elsewhere, is to ensure that the supply of advanced skilled professionals keeps pace with the demands of a knowledge economy.

Although there has been an effort to develop master's and PhD programmes, policies are still needed to foster student and academic mobility, as well as to strengthen international research ties. Inadequate advanced training may be one explanation for the gap with other regions in higher education and R&D (OEI, 2019).

Since 2015, the number of students enrolled at Latin American universities has pursued its ascension (Figure 7.4), as universities have ceded to public pressure calling for higher acceptance rates. To cope with the strong demand, a large number of private universities have been established.

The number of PhD graduates is on the rise in Latin America (Figure 7.4). However, a comparison of members of the Organisation for Economic Co-operation and Development (OECD, 2016) reveals that, when it comes to science, mathematics, computer sciences and engineering, 60% of PhDs are obtained in these fields in France, 55% in Canada, 41% in the USA, but only 26% in Mexico.

Even though Argentina, Colombia and Mexico, in particular, have recognized the need to improve advanced training, public expenditure on higher education as a share of GDP has remained inadequate (Figure 7.4).

Threshold crossed for researcher density

In 2014, Latin America crossed a symbolic threshold, that of counting one researcher per 1 000 labour force. Three years later, the regional average was 1.03. Argentina had the largest proportion of researchers (2.91), followed by Brazil, Chile, Costa Rica and Uruguay.

Latin America and the Caribbean is one of the regions that performs best when it comes to gender balance. The following countries have all achieved gender parity in research: Argentina, Cuba, Guatemala, Panama, Paraguay, Uruguay and Venezuela (See chapter 3).

Since 2016, Mexico's Sectoral Research fund for Health and Social Security includes the following mention in calls for proposals: 'When appropriate, proposals that obtain data on living things should […] disaggregate the data by gender and include them in the corresponding analyses, as well as report on the impact on health in men and women.'

Publications rising but impact modest

Between 2015 and 2019, scientific output in mainstream scientific journals increased by 25%. Growth was most significant in Ecuador (171%), followed by the Dominican Republic (98%), Honduras (97%) and Peru (85%). In the case of Ecuador, an improvement in the quality of postgraduate education and policies designed to attract foreign researchers to the country's universities no doubt played a key role. Uruguay increased its own output by 38%, thanks to greater investment and more demand for R&D; higher salaries may also have served as an incentive.

Cuba and Venezuela are among only a handful of countries in the world which have seen a drop in the volume of scientific publications since 2011 (Figure 7.5).

Chile and Uruguay have the strongest publication intensity in the region but Ecuador has shown the strongest growth for this indicator (Figure 7.5).

Spain and the USA are key partners for all countries but there is also considerable co-authorship within the region.[9] Brazil is a top partner for 13 countries, Mexico for 10 and Colombia for four. The largest countries tend to co-author publications more heavily with the USA and Europe (Figure 7.5). Stronger research networks are needed within the region to boost co-authorship further.

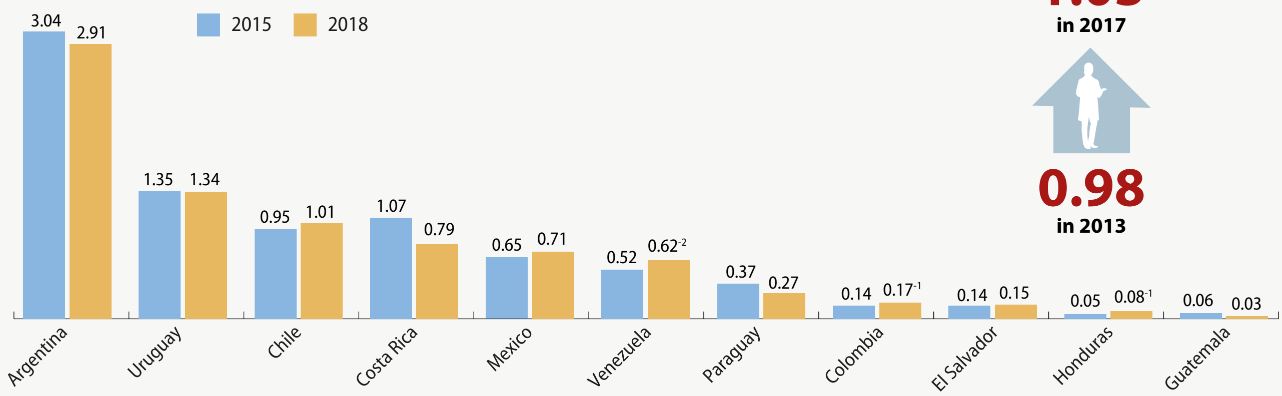
In terms of cross-cutting technologies, there has been strong growth in artificial intelligence and energy-related research since 2011, including in some of the smaller countries like Ecuador (Figure 7.6).

Dynamism in space science and technology

Some of the region's most remarkable contributions to science stem from large projects in astronomy developed in collaboration with foreign research groups. This enables

Figure 7.4: **Trends in human resources in Latin America**

Researchers (FTE) in Latin America per thousand labour force, 2015 and 2018

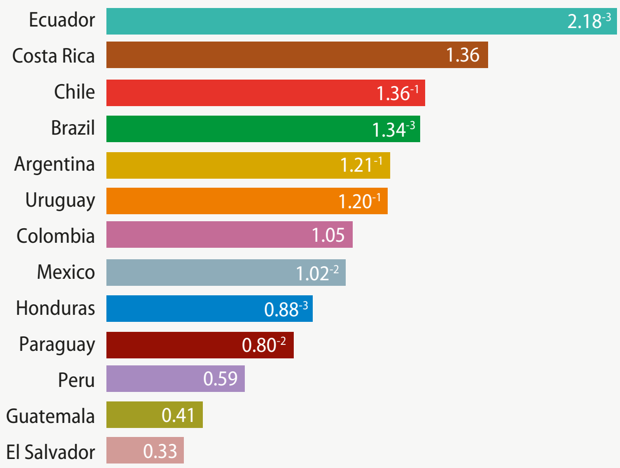


Researchers (FTE) per thousand labour force in Latin America and the Caribbean

1.03
in 2017

0.98
in 2013

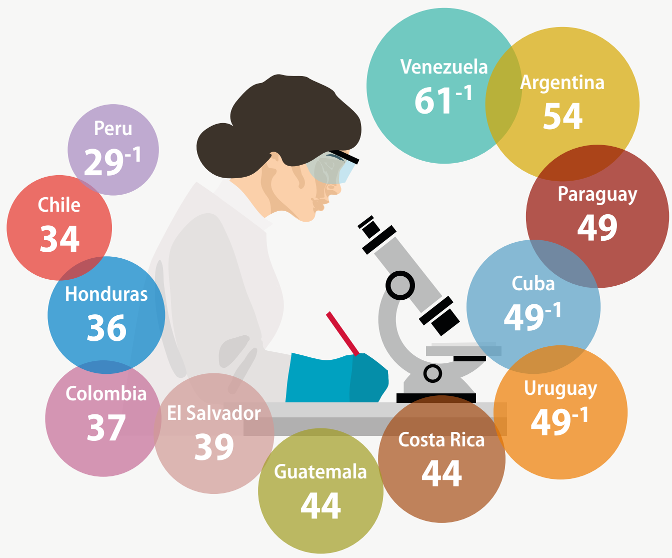
Government expenditure on higher education as a share of GDP, 2018 (%)



0.8%
Share of tertiary students at PhD level in Latin America and the Caribbean, 2017

5.4%
Share of tertiary students at master's level in Latin America and the Caribbean, 2017

Share of female researchers (HC) in Latin America, 2017 (%)



Number of students enrolled in PhD programmes in Latin America, 2012 and 2018

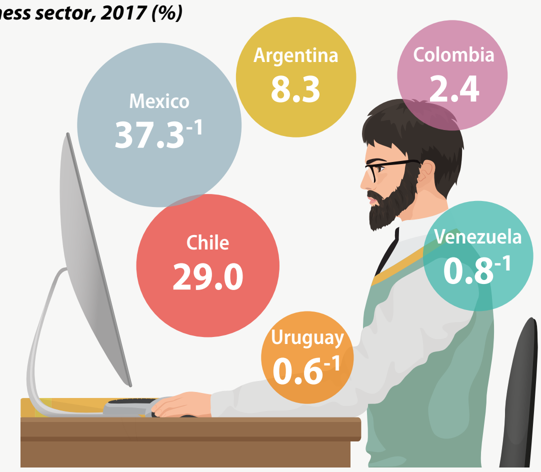
	2012	2018
Argentina	22 787	26 098^{-1}
Brazil	79 478	115 028
Chile	4 328	5 789
Colombia	3 063	6 225
Costa Rica	505	2 805^{+1}
Ecuador	236	315^{-2}
El Salvador	160	63
Guatemala	702^{+2}	881^{-3}
Honduras	30	492^{-1}
Mexico	26 089	43 744
Panama	185	107^{-2}
Peru	–	8 896^{-1}

Students enrolled in higher education in Latin America and the Caribbean

27 967 160
in 2018

26 223 878
in 2015

Share of researchers (FTE) in Latin America employed in the business sector, 2017 (%)



+n/-n: data refer to n years before or after reference year

Source: RICYT and UNESCO Institute for Statistics

Note: The proportion of researchers in unspecified sectors is 5% in Colombia and Uruguay. Costa Rica, El Salvador, Guatemala, Honduras and Paraguay count no researchers (or close to nil) employed in the business sector.

astronomers in the Northern Hemisphere to gain access to the night sky of the Southern Hemisphere.

For example, the European Southern Observatory (ESO) in Chile is supported by 16 European countries. Since 2014, ESO has been building the 39-metre Extremely Large Telescope (ELT) at Cerro Armazones, which will become 'the world's biggest eye on the sky' upon completion in 2025; dozens of cutting-edge European companies are participating in its construction.

As many as 17 countries and nearly 500 researchers are involved in the Pierre Auger Cosmic Ray Observatory in Argentina; this observatory is the fruit of an initiative undertaken by Argentina, Bolivia, Brazil and Mexico in the 1990s. Each contributed substantial funding to get this project off the ground.[10]

One of the most recent additions to Latin America's infrastructure for astronomy is Mexico's Large Millimeter Telescope. Operational since 2013, it was designed by scientists from the National Institute of Astrophysics, Optics and Electronics (INAOE) and the University of Massachusetts (USA). Its overall scientific objective is to contribute to a better and more detailed understanding of the formation and evolution of black holes, galaxies, stars and planetary systems throughout the history of the Universe.

The Large Millimeter Telescope forms part of the collaborative Event Horizon Telescope (EHT). The 2020 Breakthrough Prize in Fundamental Physics was awarded to the EHT for having obtained the first image of a supermassive black hole in the centre of the M87 galaxy through a network of Earth-sized telescopes.

The EHT is a collaboration of 347 scientists from 60 institutions in 20 countries, utilizing eight ultrasensitive radio telescopes strategically placed in Chile, Mexico, the USA and Spain, as well as in Antarctica.

Other infrastructure has been designed to monitor the Earth itself. Two Earth observation satellites developed by the Argentine space agency CONAE with fellow agencies were launched in 2018 and 2020 as part of a constellation that will provide real-time information to monitor soil moisture, plagues of agricultural pests, outbreaks of Denge and Zika, forest fires and climate change, among other applications. The production of local parts for the project has spawned a network of 1 500 high-tech SMEs in Argentina.

New areas of research specialization

Concerns over the state of the planet, coupled with the approaching delivery date for the SDGs in 2030, have made sustainability science a key focus of policy-making and research in Latin America (Aguirre-Bastos *et al.*, 2019; Lemarchand, 2015).

According to a global study commissioned by UNESCO of the priority accorded to 56 research topics related to the SDGs between 2011 and 2019, Latin American scientists publish a higher than average proportion of papers on a range of topics, including support for smallholder producers, traditional knowledge and biodiversity management (Figure 7.5; see chapter 2).

Actual numbers remain modest, however. For instance, on the topic of climate-ready crops, Colombia and Mexico produced 45 and 57 papers, respectively, between 2012 and 2015, compared to 78 and 133 over the period from 2016 to 2019. Ecuador boosted its own output on sustainable transportation from 12 to 92 papers over this period.

Ecuador's specialization in smart-grid technology can be traced back to a series of rolling blackouts in 2009 which prompted the government to prioritize investment in energy infrastructure and the transition from thermal to hydropower and other renewable sources of energy. Many of the projects implemented to this end involved the Corporation of Energy Research, a private non-profit research centre founded in 2002.[11]

With regard to private knowledge creation, Brazil and Mexico account for, by far, the most patents granted by the IP5 offices (Figure 7.7). However, when it comes to resident patent applications per US$ 100 billion GDP, other countries are performing better, including Chile, Colombia and Panama, according to the database of the World Intellectual Property Organization.

Several factors may be at play. Large countries tend to submit patent applications to foreign patent offices to protect, or claim a stake in, large markets. In small countries, there is a higher incidence of resident applications and the activities of a select few high-profile companies can account for a considerable share of patenting activity. Policies designed to boost patenting activity have led to an increase in 'academic patents' but few of these have resulted in commercialization. One exception is the Technological University in Panama, a programme supported by the National Secretariat for Science and Technology (SENACYT) and the Development Bank of Latin America (CAF).

Evidence derived from case studies and field work in Latin America suggests an intense activity of learning processes, adaptation and imitation of other actors (Lerena *et al.*, 2019; Dutrénit *et al.*, 2019). These processes are not being captured by innovation surveys but suggest that innovative processes are occurring.

COUNTRY PROFILES

ARGENTINA

Science paying the price of economic downturn

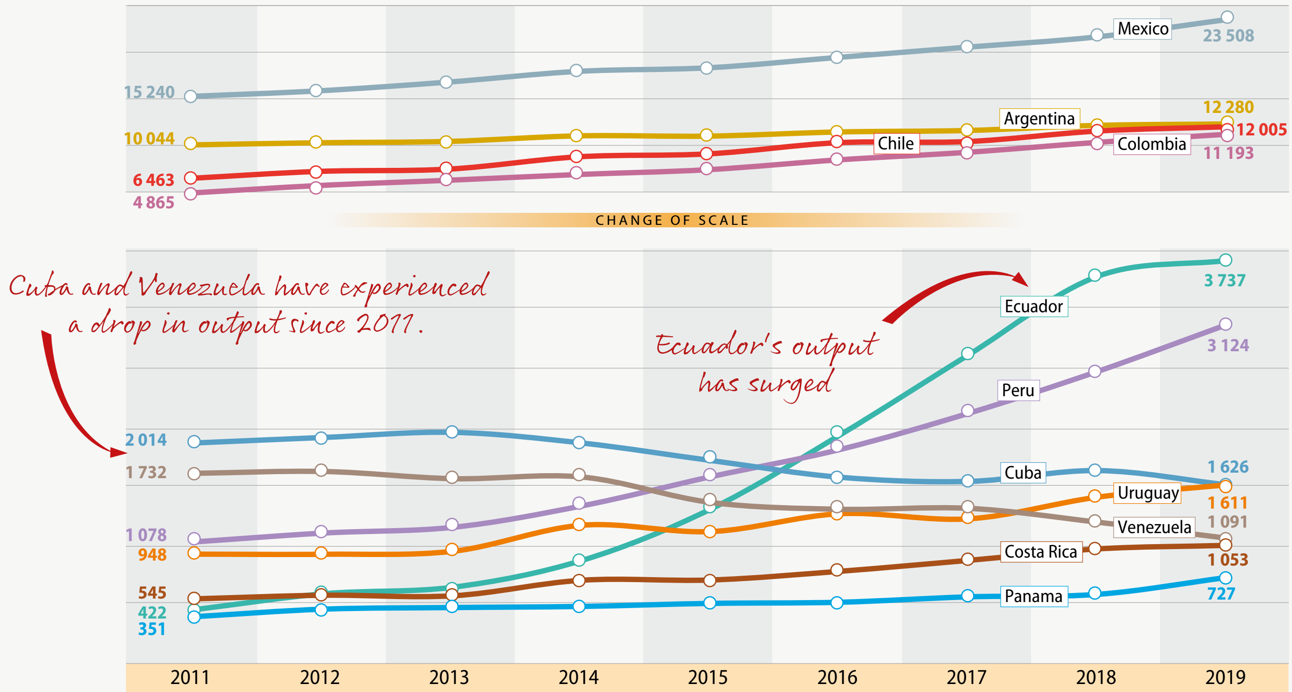
Since 2015, the ongoing socio-economic and political crisis has defined the landscape for STI. The fall in prices for primary goods and exports has led to a contraction in GDP and domestic investment (Figure 7.1). Trade imbalances, a lack of FDI and a high government deficit have engendered a vicious cycle of currency devaluation, higher interest and inflation rates and a drop in real wages.

The real value of scholarships and incentives for graduate students, post-doctorates and academic staff has dropped, as has the purchasing power of scientists' salaries.

Upon taking office in December 2015, the Macri government set out eight goals and 100 priority initiatives to foster socio-economic development. A number of these have links to the SDGs. Accordingly, through the National Council for the Coordination of Social Policies (CNCPS), the government

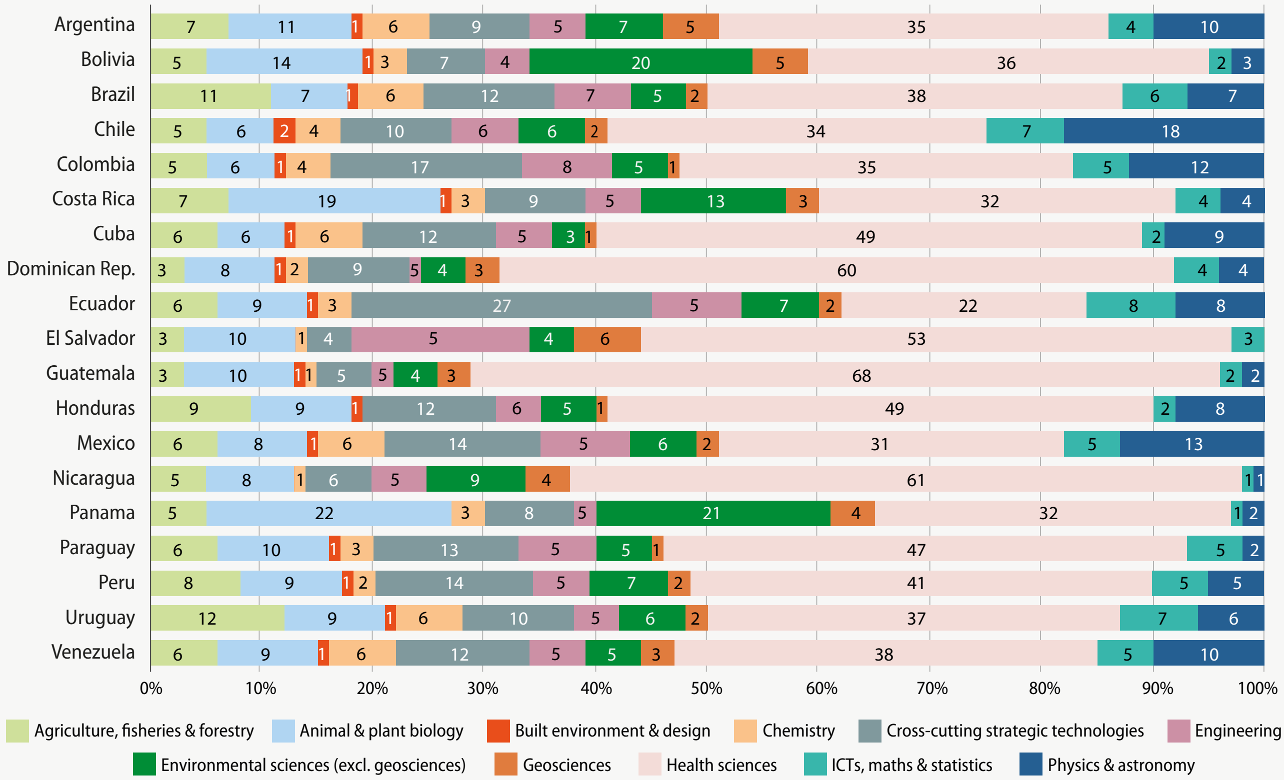
Figure 7.5: **Trends in scientific publishing in Latin America**

Volume of scientific publications from Latin America, excluding Brazil, 2011–2019



	2011	2012	2013	2014	2015	2016	2017	2018	2019
Paraguay	104	118	125	135	197	214	259	226	338
Bolivia	217	210	242	267	275	280	250	307	332
Guatemala	117	167	168	168	220	228	248	242	269
Dominican Rep.	67	73	104	101	117	123	135	161	232
Honduras	66	73	76	68	92	83	118	156	181
Nicaragua	84	99	77	88	95	110	128	124	118
El Salvador	44	52	44	57	76	88	67	92	69

Scientific publications from Latin America by broad field of science, 2017–2019 (%)



40%
Average share of publications with foreign co-authors for Latin America (excluding Cuba), 2017–2019; the G20 average is 28%

0.89
Average citation rate for Latin America (excluding Cuba), 2014–2016; the G20 average is 1.02

How has output on SDG-related topics evolved since 2012?

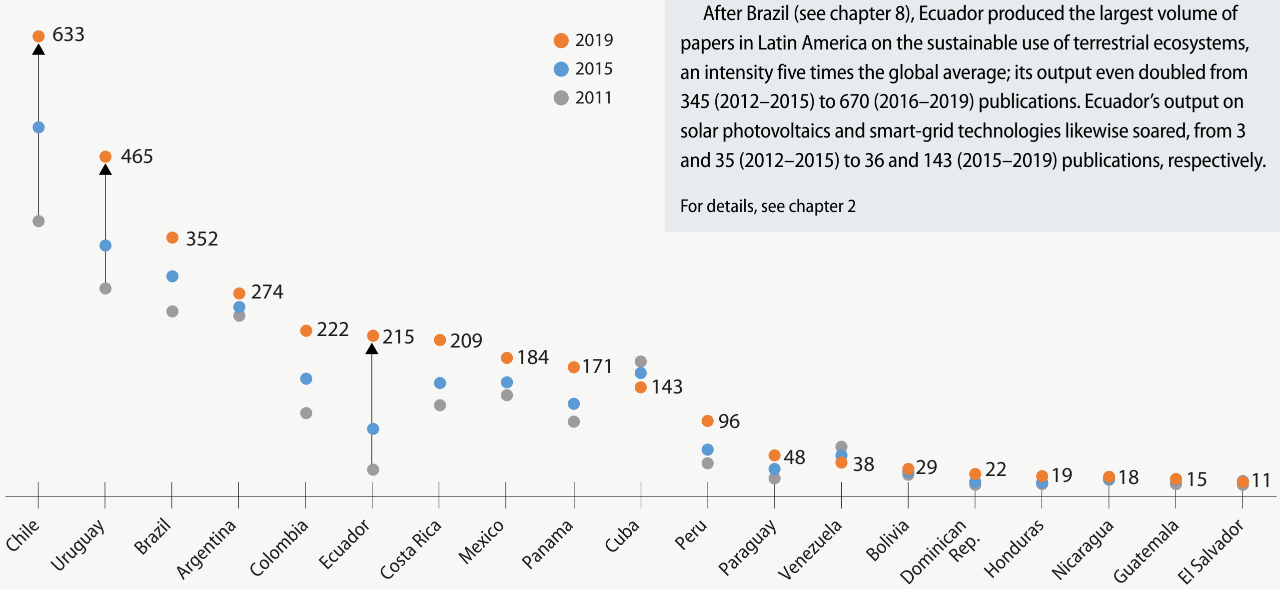
Scientists in Latin America are publishing at least 2.5 times more on the following topics than would be expected, relative to global averages: agro-ecology, tropical communicable diseases, traditional knowledge, help for smallholder food producers, sustainable use of terrestrial ecosystems, the status of terrestrial biodiversity and sustainable management of fisheries and aquaculture. Bolivia's proportion of output on traditional knowledge is even 29 times higher than the global average for this topic.

The volume of publications often remains modest, however. For instance, on the topic of help for smallholder food producers, Colombia and Mexico produced 31 and 42 papers, respectively, between 2012 and 2015, compared to 59 and 86 over the period from 2016 to 2019.

After Brazil (see chapter 8), Ecuador produced the largest volume of papers in Latin America on the sustainable use of terrestrial ecosystems, an intensity five times the global average; its output even doubled from 345 (2012–2015) to 670 (2016–2019) publications. Ecuador's output on solar photovoltaics and smart-grid technologies likewise soared, from 3 and 35 (2012–2015) to 36 and 143 (2015–2019) publications, respectively.

For details, see chapter 2

Scientific publications per million inhabitants, 2011, 2015 and 2019
Data labels are for 2019



Top five partners for Latin America for scientific co-authorship, 2017–2019 (number of papers)

	1st collaborator	2nd collaborator(s)	3rd collaborator	4th collaborator(s)	5th collaborator
Argentina	USA (5 955)	Spain (3 939)	Brazil (3 428)	Germany (2 701)	France (2 541)
Bolivia	USA (262)	Brazil (194)	France (139)	Peru (134)	Spain (132)
Brazil	USA (25 770)	UK (10 880)	Germany (8 757)	Spain (8 695)	France (8 670)
Chile	USA (7 753)	Spain (5 866)	UK (4 127)	Germany (3 758)	France (3 259)
Colombia	USA (5 418)	Spain (4 039)	Brazil (3 347)	UK (2 326)	Mexico (2 236)
Costa Rica	USA (975)	Spain (379)	Brazil (366)	Mexico (342)	Germany (335)
Cuba	Mexico (751)	Brazil (657)	Spain (607)	USA (493)	Ecuador (381)
Dominican Rep.	USA (257)	Spain (135)	Brazil (74)	Mexico (71)	Argentina (62)
Ecuador	Spain (2 506)	USA (1 832)	Colombia (1 030)	Brazil (996)	Mexico (941)
El Salvador	USA (92)	Mexico (54)	Spain (35)	Guatemala/Panama (27)	
Guatemala	USA (409)	Mexico (159)	Brazil (102)	UK (86)	Spain (79)
Honduras	USA (225)	Brazil (99)	Colombia (95)	Spain (92)	Mexico (78)
Mexico	USA (11 478)	Spain (6 051)	UK (3 467)	France (3 371)	Germany (3 063)
Nicaragua	USA (184)	Mexico (71)	Spain (56)	Colombia/Costa Rica (52)	
Panama	USA (1 025)	UK (289)	Germany (244)	Brazil (242)	Spain (215)
Paraguay	Spain (193)	Brazil/USA (187)		Chile (154)	Argentina (133)
Peru	USA (2 188)	Brazil (1 266)	UK (882)	Spain (863)	France (670)
Uruguay	Brazil (831)	USA (783)	Argentina (730)	Spain (599)	Mexico (339)
Venezuela	USA (781)	Colombia (667)	Ecuador (571)	Spain (506)	Brazil (417)

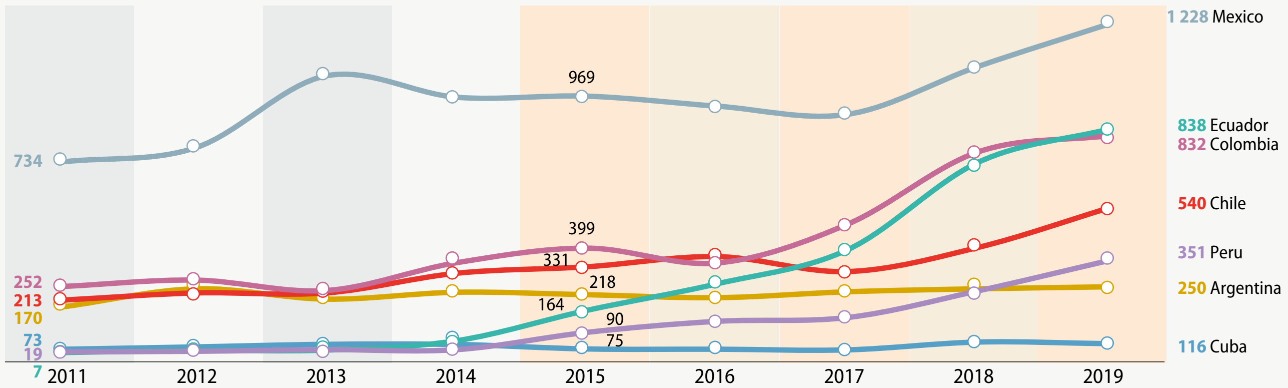
Note: For the volume of scientific publications from Brazil, see chapter 8. For complete bibliometric data for all countries, see the statistical annex, freely available from the *UNESCO Science Report* web portal.

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

Figure 7.6: **Volume of scientific publications from Latin America by cross-cutting strategic technology, 2011–2019**

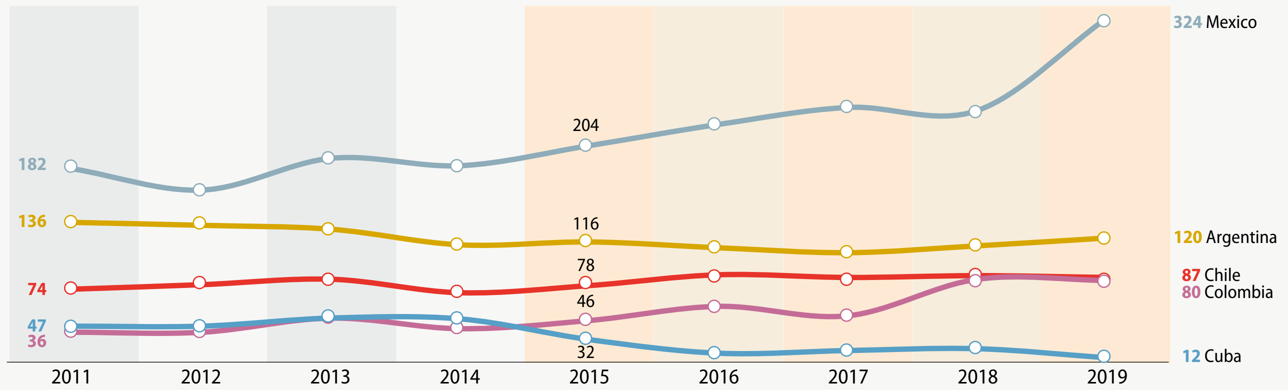
Artificial intelligence and robotics

Among countries with more than 800 publications on this topic over the period under study, excluding Brazil



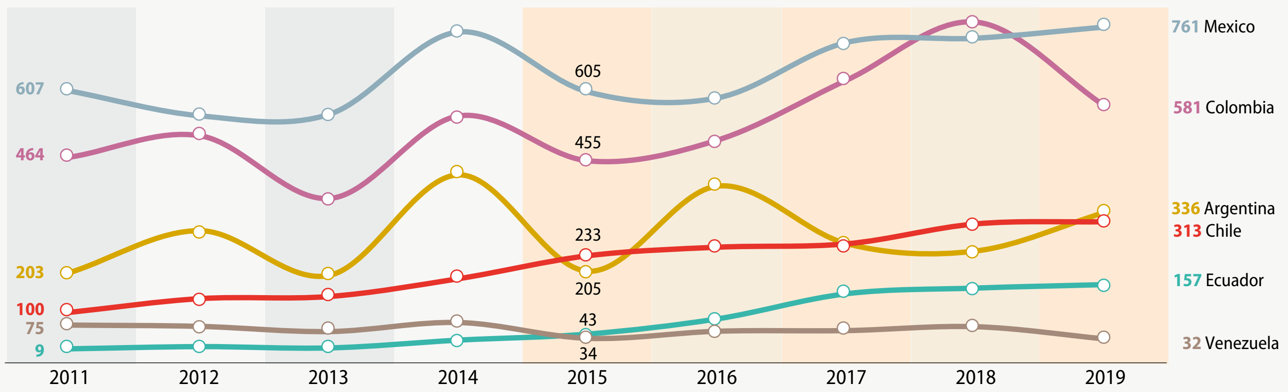
Biotechnology

Among countries with more than 500 publications on this topic over the period under study, excluding Brazil



Energy

Among countries with more than 500 publications on this topic over the period under study, excluding Brazil



7.1%

Share of world publications from Latin America (excluding Cuba) on biotechnology, the largest share of the ten cross-cutting strategic technologies

40 669

Publications from Latin American countries (excluding Cuba) on AI and robotics, the largest subfield of cross-cutting strategic technologies by volume

Note: For data on Brazil, see chapter 8. The three cross-cutting strategic technologies here are part of a wider category that also encompasses bioinformatics, blockchain technology, Internet of Things, materials, nanoscience and nanotechnology, opto-electronics and photonics and strategic, defence and security studies. Output in Latin America was highest for the three technologies shown here. See the statistical annex for complete data for all countries, freely available from the *UNESCO Science Report* web portal.

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

established the National Inter-Institutional Commission for the Implementation and Monitoring of the SDGs, of which the Vice-Ministry of Science and Technology is a member.

A review found that progress had been made by 2018 towards aligning national priorities with the SDGs and in setting up adequate monitoring mechanisms (CNCPS, 2018).

The government budget dedicated to R&D and higher education also supports most of the national research institutes. This budget has decreased since 2015 (Figure 7.3). Although research intensity has dipped only slightly, other signs suggest that a lower priority is being accorded to STI; research and infrastructure projects have been cut back or cancelled in the following areas: the extension of satellite networks and radar; the expansion of the nuclear industry; and support for industrial and agricultural R&D through their respective technological institutes. In 2018, the Ministry of Science, Technology and Innovation was downgraded in the administrative hierarchy to a Secretariat of State under the Ministry of Education.

These quantitative and qualitative changes are likely to have perturbed the growth rate of scientific articles, which has been slow and irregular since 2011 (Figure 7.5).

Meanwhile, sectoral funds remain important programmes in Argentina, particularly FONSOFT, promoting the software industry and FONARSEC, the Argentine Sectoral Fund which focuses on medical, optical and precision instruments, machinery and electrical appliances. These sectoral funds are managed by the National Agency for Scientific and Technological Promotion (ANPCyT), with public and private counterparts.

Agenda: less inequality and a return to growth

Following the elections of December 2019, the new Fernández government promptly sent a bill to Congress targeting fiscal sustainability, more progressive taxation and a more efficient productive sector. The federal bill espouses three ethical imperatives for building a solid, sustainable democracy in Argentina, namely the banishment of hunger, reduction in inequality and a return to growth.

In 2020, the government resurrected the Ministry of Science, Technology and Innovation.

BOLIVIA

A country in transition

In October 2020, Bolivians elected Luis Arce of the Movimiento al Socialismo party to the presidency.

Although these factors are not yet reflected in the data, economic growth is likely to have been affected not only by the Covid-19 pandemic but also by the political crisis over the disputed outcome of the October 2019 election, which had led to a transitory constitutional government.

Over the 2016–2018 period, GDP per capita grew by 5.4%, on average (Figure 7.1). The pace of economic growth has slowed from a high of 6.8% in 2013 to just 2.2% in 2019. This trend is tied to the fall in international prices for commodities and hydrocarbons, coupled with lesser demand from Argentina and Brazil for natural gas.

The *National Science, Technology and Innovation Plan* (2013) fixed ambitious objectives for the first stage of implementation to 2019 for technological development and sectoral projects incorporating new technologies in the food, lithium, energy, agricultural and industrial sectors.

The plan drew attention to indigenous and local knowledge systems, stating that solutions should emerge from the 'convergence of knowledge within the framework of […] dialogue […] between local, ancestral and community practices and knowledge with modern sciences.'

Although the SDG targets do not figure as explicit objectives, the plan also advocates the following 'structural solutions' to the climate crisis: opposition to consumerism; a climate system based on 'responsibility' to Mother Earth and 'humanizing' the economy; the elimination of patents for certain technologies; establishing the International Court for Climate Justice and Mother Earth; and encouraging countries to divert resources from 'military machinery' to climate solutions.

This approach correlates with Bolivia's *Voluntary National Review* submitted to the United Nations in 2015, which set out the concept of *Bien Vivir* (Living Well), defined as 'the civilizational and cultural alternative to capitalism, linked to a comprehensive vision […] in harmony with nature [for a] structural solution to the global climate crisis.' This report fixed the target of increasing the share of alternative and other energy sources (including combined cycle power plants) in total electrical power capacity from 2% in 2010 to 9% by 2030.

Implementation of the *National Science, Technology and Innovation Plan* has been somewhat limited. The planned fund for STI did not materialize and overall research funding has remained low.

As for the Scientific and Technological Information System (SIBICyT) and Bolivarian Innovation System proposed by the *Institutional Strategic Plan 2010–2014* (Lemarchand, 2015), neither would seem to be fully functional today.

Through the Ministry of Education, the transitional government led by interim president Jeanine Añez took steps in February 2020 to revise the 2001 law on science. The government was contemplating the instigation of autonomous mechanisms for governance, research funding and advanced training but this process was interrupted by the Covid-19 crisis.

CHILE

A focus on building better times

Chile registered economic growth of 3.9% in 2018, improving on its average growth rate of 1.8% over the 2015–2017 period (Figure 7.1). This upturn may be linked to the dynamism shown by exports of goods and services, as well as private consumption (CEPAL, 2019c). The upturn has been short-lived, however, as growth has since been affected by social unrest and the Covid-19 crisis.

Research intensity dipped slightly over the 2013–2018 period (Figure 7.3), even as the researcher population surged by 55%, suggesting that the amount of funding available to each researcher has dropped. Publication intensity grew by

25% between 2015 and 2019, a drop from the 35% growth achieved over the period 2011–2015 (Figure 7.5).

Chile's national development plan for 2018–2022, *Let's Build Better Times for Chile,* recognizes the importance of building an innovative and entrepreneurial culture based on the use of new technologies to enable Chile to play an active role in the Fourth Industrial Revolution.

In 2016, Chile established the National Council for the Implementation of *The 2030 Agenda for Sustainable Development*. Led by the Ministry of Foreign Affairs, the council serves as a co-ordinating and monitoring body, as well as an advisory body to the president; it has created several working groups.

CONICYT replaced in far-reaching reform

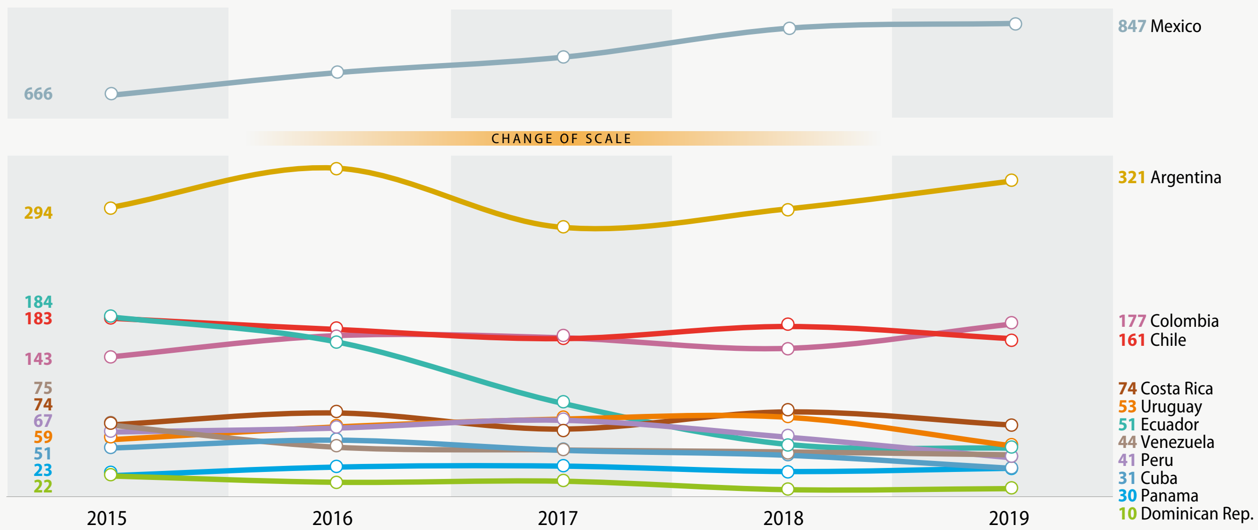
In 2018, the National Commission for Scientific and Technological Research (CONICYT) was broken down, by law, into two new entities, the Ministry of Science, Technology, Knowledge and Innovation and the National Agency for Research and Development (ANID). The ministry became operational on October 2019 and is responsible for policy-making and co-ordination. Its main function is to advise the presidency on the preparation, implementation and monitoring of national policies.

Policy implementation itself falls to ANID, the new decentralized agency. It is attached to the Ministry of Science, Technology, Knowledge and Innovation but has a legal personality of its own and enjoys financial and administrative autonomy. It implements two long-standing programmes, the National Fund for Scientific and Technological Development (FONDECYT) and the Fund for the Promotion of Scientific and Technological Development (FONDEF). It has also inherited Chile's astronomy programme, which used to be implemented by CONICYT.

Figure 7.7: **Trends in innovation in Latin America**

Number of IP5 patents granted to Latin America, excluding Brazil, 2015–2019

For countries with more than 50 patents over the period under study



Share of manufacturing firms in Latin America engaged in innovation, 2017 or closest year (%)

	Innovative firms	Firms that invest in R&D	Firms with formal R&D units	Firms using universities and centres as a source to innovate	Investment in technology adoption	Sales based on new products	Firms with product innovations	Firms with process, organizational or marketing innovations	Innovative firms that received public support
Chile	25.0	9.9	6.1	19.5	55.3	13.5	12.6	22.5	13.4
Colombia	22.9	10.4	5.9	26.4	60.5	8.0	12.2	18.7	4.9
Ecuador (2015)	54.6	29.5	7.4	44.8	80.9	14.7	37.3	49.7	4.6
Paraguay (2016)	45.2	13.8	4.0	21.8	94.3	11.0	22.1	41.8	–
Peru (2015)	6.7	27.4	6.8	63.2	91.7	20.0	47.9	58.6	5.1
Uruguay	41.9	14.8	6.8	64.4	78.3	16.0	24.4	37.9	19.2
Mexico (2016)	22.4	14.3	14.3	10.9	–	–	17.5	19.1	–

Note: Firms that developed at least one innovation project are considered to have engaged in innovation. For data on Brazil, see chapter 8.

Despite this reform, Chile has not abandoned the model of having twin agencies. These have complementary functions. Whereas ANID specializes in support for science-based innovation and entrepreneurship, the second agency, the Corporation for the Promotion of Production (CORFO), is attached to the Ministry of the Economy and specializes in supporting non-science-based innovation and entrepreneurship. Those of its programmes supporting science and technology have been transferred to ANID.

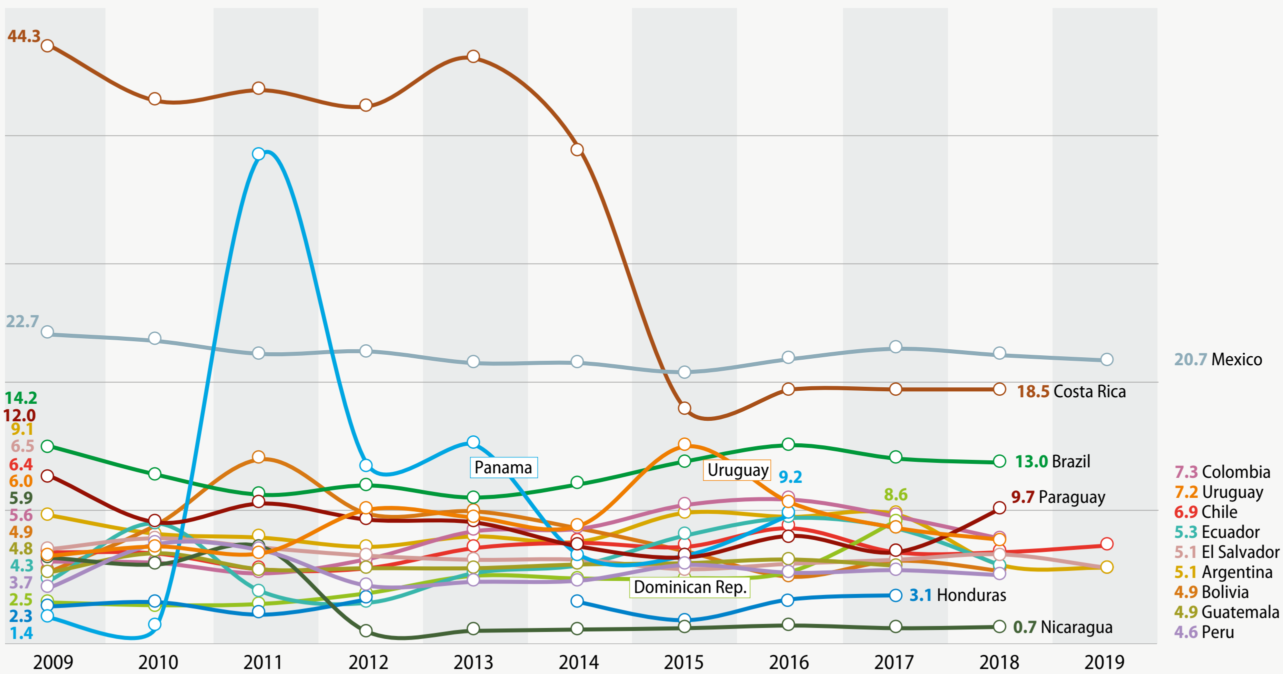
Having two parallel innovation agencies makes co-ordination a challenge. A ministerial committee was set up by the aforementioned law of 2018 to co-ordinate the work of ministries but it has met infrequently, up to now.

The aforementioned law also renamed the National Innovation Council for Development, which is now called the National Science, Technology, Knowledge and Innovation Council for Development, and given it a more consequential role as the advisory body to the presidency on national strategy.

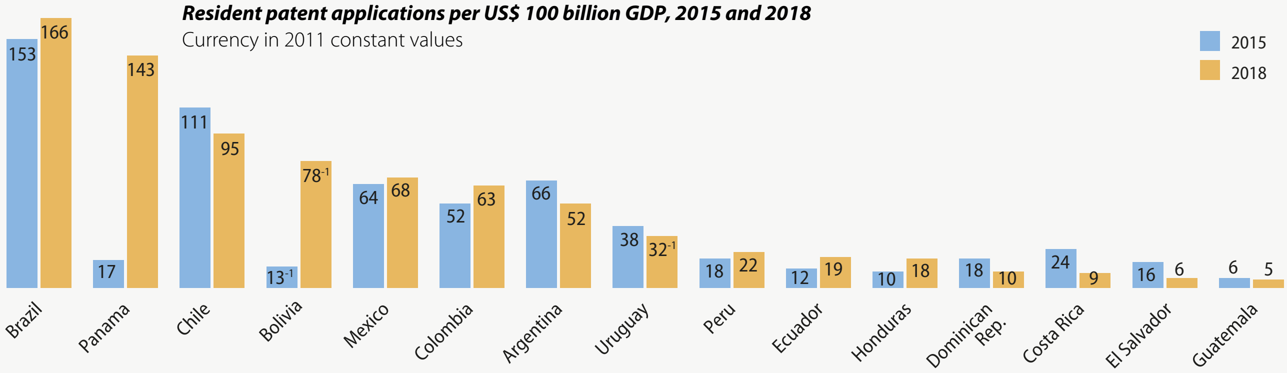
Over the years, CORFO has implemented numerous sectoral programmes, which are distinct from the mission-oriented sectoral funds put in place by Argentina, Brazil, Mexico and others. Since 2015, CORFO has focused on enhancing the competitiveness of a particular sector by improving co-ordination between public and private agents. In 2018, CORFO funded six national programmes for creative industries, sustainable construction, healthy foods, logistics for exports, mining and the solar energy industry. It also funded three mesoregional and 16 regional programmes.

Together with the Ministry of Social Development and Family, CORFO launched the Indigenous Development and Promotion Programme in 2017. It is oriented towards entrepreneurship, providing indigenous groups with state grants to help them fund their business projects. To qualify,

High-tech exports from Latin America as a share of manufactured exports, 2009–2019 (%)



Resident patent applications per US$ 100 billion GDP, 2015 and 2018
Currency in 2011 constant values



Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China. See chapter 8 for Brazil's IP5 patents. Complete data for all countries are freely available from the *UNESCO Science Report* web portal.

Source: for IP5 patents: PATSTAT, data treatment by Science-Metrix; for resident patent applications: World Intellectual Property Organization; for innovative firms: Harmonized Latin American Innovation Surveys dataset, Inter-American Development Bank; for Panama: Universidad Autónoma Metropolitana Database; for Mexico: Mexican ESIDET Database; for high-tech exports: World Bank's World Development Indicators, October 2020 these projects must be economically and socio-culturally sustainable and address one of the designated priority sectors: agriculture, forestry and aquaculture; sources of renewable energy such as solar and wind power; or tourism.

COLOMBIA

Peace deal fostering sustainable development

Colombia's economy slowed at the end of the commodities boom in 2014. Although the drop in demand was partly offset by domestic consumption and investment levels, the growing imbalance between exports and imports still eroded GDP. Accession to the OECD in May 2018 should help Colombia to boost its exports. By 2018, growth had rebounded to 2.5% then 3.3% in 2019 (Figure 7.1).

The most momentous event in Colombia's recent history has been the signing of a peace agreement between the government and the Revolutionary Armed Forces of Colombia–People's Army (FARC–EP) that was ratified by parliament in 2016. This agreement will contribute to the fulfilment of the SDGs, through the following initiatives:

- Science and ICTs for Peace, developed by Colciencias together with the Ministry of Information Technologies and Communication, seeks to promote innovative solutions for the victims of the armed conflict.
- The Colombia Bio programme promotes the conservation, management and sustainable use of biodiversity in Colombian territories; the project was initially led by Colciencias, in partnership with national and regional institutions.

By the end of 2019, 22 bio-expeditions had been undertaken in different regions as part of Colombia Bio, to enrich the scant taxonomic record. Colombia Bio is supporting bioprospecting to foster the development of products and services with high added value. It is also analysing the entire value chain as a preamble to making recommendations for how to mainstream the sustainable use of biodiversity at the institutional level. In parallel, the project is striving to develop a 'biodiversity culture' to ensure popular support for the conservation and sustainable use of biodiversity.

In 2019, the government created the Ministry of Science, Technology and Innovation to replace Colciencias. Colciencias had been in charge of policy-making and evaluation. Since it had also fulfilled the vital role of implementation agency, the ministry established an autonomous unit in December 2019 in charge of implementation. In 2020, the government was contemplating establishing an independent implementation agency.

The new ministry has taken over all of Colciencias' portfolios, including those mentioned above and the Health Research Fund (FIS). The latter is a sectoral fund benefiting from a permanent source of income in the form of government revenue from casinos and lotteries.

Regional pacts targeting equity

Colombia's modest research intensity has slipped further since 2015 but numbers of researchers are on the rise (Figures 7.3 and 7.4). Although these dual trends have reduced the amount of funding per researcher, the country's scientific output actually grew by 52% over the 2015–2019 period (Figure 7.5).

The *National Development Plan 2018–2022*: *Pact for Colombia, Pact for Equity* is structured by regional 'pacts' that seek to nurture the strengths of each region. These pacts are essentially cross-cutting agreements on strategic issues that include sustainability, peacebuilding, digital transformation, decentralization and STI. All the pacts are aligned with, or at least related to, the SDGs.

In December 2019, the International Mission of the Wise established by the government delivered its final report on how to place knowledge at the heart of Colombia's sustainable development. The report made recommendations on three key topics: biodiversity; productive sustainable development; and social equity. It also recommended raising domestic investment in R&D.

COSTA RICA

The world's first pact for the SDGs

Costa Rica has shown impressive socio-economic growth, even if the pace slowed slightly in 2019 (Figure 7.1). This robust economic health is generally attributed to Costa Rica's outward-looking approach to development, its openness to foreign investment and gradual trade liberalization (Dempsey, 2019). However, the country has also accumulated a large fiscal imbalance, suggesting that the current model is not sustainable.

When Intel closed its manufacturing plant in 2014, the share of high-tech goods in manufactured exports shrank by half the following year to 17% (Figure 7.7). However, in 2016, Intel opened a Mega Laboratory and Global Services Center in Costa Rica, which employs 2 000 people and works with 11 universities to turn out new goods. As a result, Costa Rica now counts 28% of high-tech products among its manufactured exports and ICT services make up 7% of total exports (Global Innovation Index, 2019). In March 2020, Intel announced plans to move manufacturing operations back to Costa Rica.

For decades, Costa Rica has been a world leader in conservation and environmentalism, as testified by its network of protected areas. More than half (52%) of its terrestrial territory is part of the UNESCO World Network of Biosphere Reserves, which group communities who are committed to sustainable development.[12] The government hopes to establish a new transboundary biosphere reserve between Cocos Island, currently a World Heritage site, and the Galápagos Biosphere Reserve by 2022.[13]

In 2016, Costa Rica became the first country in the world to establish a national pact for the fulfilment of the SDGs. This pact was signed by the executive, legislative and judicial branches, as well as by public universities, local governments and the private sector. Signatories undertook to mobilize the requisite resources to reach the SDGs and remain accountable to citizens (MNPEP, 2017). An official website covering all SDG-related issues in Costa Rica has since been launched with development actors as an interactive tool[14] and the government has increased the budget and technical staff of the National Institute of Statistics and Census to bolster its capacity to monitor implementation of the SDGs (ODS-MIDEPLAN, 2017).

In 2017, Costa Rica adopted a *National Strategy for the Substitution of Single-use Plastics by Renewable and Compostable Alternatives 2017–2021* (Box 7.1).

Several institutions have developed supportive strategies for reaching the SDGs. The University of Costa Rica has launched Preventec, for instance. This programme collects and processes information to provide advance warning of disasters, including floods, landslides and eruptions, and mitigate their potential impact.

The University of Costa Rica has also designed bespoke tutoring programmes for students from indigenous communities to enable them to attend its own campus and other state universities. By the 2019/2020 academic year, 500 students from indigenous territories had taken part in this programme, 140 of whom were currently enrolled.

An ambitious digital agenda

In 2012, the Ministry of Science and Technology absorbed the telecommunications sector. Three years later, the government approved the *National Plan for Science, Technology and Innovation* (2015–2021) and *National Development Plan for Telecommunications* (2015–2021), both of which build on the wider *National Development Plan* (2015–2018).

These strategic plans set out a vision for a more competitive country, better connected to global networks, in which the state assumes a more active role in enhancing productivity and human development, with close linkages to the private sector and civil society.

The *National Plan for Science, Technology and Innovation* (2015–2021) has identified the following strategic areas for the development of an inclusive knowledge economy: education, health, environment and water, energy, food and agriculture. The plan highlights skills training, entrepreneurship and the development of online digital services for community use.

The Ministry of Science, Technology and Telecommunications runs a national programme called Intelligent Community Centres (CECI), which strives to narrow the digital divide in rural communities and foster the social appropriation of knowledge. Each learning centre is equipped with computers and Internet access and provides online courses in computing, English and other areas.

These centres have been equipped by Sutel, Costa Rica's telecommunications regulator, using the national telecommunications fund FONATEL. The programme is narrowing the digital divide in rural areas through three projects: connected homes, equipped public spaces and connected public spaces. By 2019, 130 000 people on a modest income had been given free access to the Internet and a laptop, according to a statement issued by Sutel. By this time, the connected public spaces programme had also equipped public centres with 36 000 computers. The third project had, meanwhile, provided schools, clinics and communities in 103 rural communities with free Internet connectivity, approaching its target of 125 communities.[15]

One central focus of the *National Plan for Science, Technology and Innovation* (2015–2021) are convergent technologies: biotechnology, nanotechnology, cognitive sciences and digital technologies. It is planned to develop two smart cities which will serve as a blueprint for the transition from traditional urban planning to sustainable metropolises.

The *Institutional Strategic Plan 2019–2025* supports the plan by prioritizing inclusive access to ICTs and a strong knowledge base.

A key test for the government's digital agenda will be the effectiveness of policy implementation. In 2020, a bill was being debated in parliament which proposes creating a national innovation agency modelled on the Costa Rican Investment Promotion Agency (CINDE), which is managed by the private sector.

CUBA

Science has become collateral damage

The thawing of relations with the USA in 2014 brought in a flood of visitors and remittances, while accelerating investment in infrastructure.

The thaw was to be short-lived. In 2017, the economic and commercial blockade imposed by the USA tightened its grip once more, compounded by the crisis in Venezuela, Cuba's main trading partner (CEPAL, 2019a).

In order to relieve economic hardship and improve productivity, the Cuban government had launched a process in 2011 to update the country's socialist socio-economic model by rehabilitating private entrepreneurship. Restrictions on the size of a company were removed and foreign investors were offered more favourable terms. The government also authorized Cubans with passports to travel abroad.

This new model was revised shortly before the government launched its *National Plan for Economic and Social Development* in April 2016. The plan outlines five strategic foci: a socialist, effective, efficient and socially inclusive government; productivity and integration in the international community; human potential and STI; natural resources and the environment; and human development, equity and social justice.

As Cuba updates its economic model, innovation is increasingly coming to the fore as a priority issue. Launched in 2014, Cuba's flagship policy instrument, the Financial Fund for Science and Technology (FONCI) has released annual calls for research proposals since 2015. By 2018, 194 ongoing projects had received financial support (CITMA, 2019).

Cuba's efforts to reform its mode of governance have reconfigured the country's main economic and political actors, opening spaces for private sector participation. There have been some notable successes, including the rise of self-employment and the emergence of small privately owned firms. These and other measures have increased monetary–mercantile relations within the economy, offering a more complex domestic market. However, Cuba's strong dependence on exports and its difficulties in participating in trade since the USA blockade was restored in 2017 are holding the country back.

The deterioration in US–Cuban relations since 2017 has impinged on resources for R&D. One of the Cuban government's strategies for avoiding brain drain, upon lifting restrictions on international travel in 2012, was to raise scientists' salaries but it was initially unable to honour this pledge. Scientific output has, accordingly, declined steadily since 2013 (Figure 7.5).

The country's first science parks

There were two important science policy changes in 2019. Firstly, the government adopted the National Nanoscience and Nanotechnology Programme to promote the development of new products and technologies with a potential economic impact. The main expression of this programme is the Center for Advanced Studies, founded in 2019 to serve as the national hub for research in nanoscience and nanotechnologies.

Secondly, the government approved new legal directives to stimulate R&D and curb high emigration rates among the highly skilled. These directives covered the following: economic incentives for researchers, like the long-awaited salary increases for researchers and academic teaching staff; the creation of Cuba's first science and technology parks, as well as interface firms; and the establishment of several high-tech firms.

By 2020, the first two science and technology parks had emerged on the university campuses in Havana and Matanzas. They specialize in ICTs.

DOMINICAN REPUBLIC

A focus on sustainable production and consumption

Poverty levels dropped over the 2015–2018 period when economic growth averaged 6.3%. The modest slowdown to 4.8% in 2019 is partly due to the economic performance of the Dominican Republic's main trading partner, the USA (CEPAL, 2019a).

The main drivers of growth since 2015 have been private consumption; mining (gold and silver); exports; tourism; free-zone exports, especially of medical devices; and remittances.

The relative weight of manufacturing in the economy has diminished from 14.7% in 2015 to 14.1% in 2018, however. According to manufacturers, the sector has, nevertheless, increased its aggregate value by raising the technology content of exports. Mining and tourism have become the main currency-generating sectors. The country's dependence on tourism has made it highly vulnerable to restrictions on international travel since the onset of the Covid-19 pandemic. Fortunately, the economic impact of Covid-19 on tourism has been mitigated by higher international prices for gold exports.

Although much of the economy remains informal, it now carries less weight, thanks to incentives to establish official ties with SMEs through public procurement programmes such as the school meals programme, which operates at national level. As the informal economy has shrunk, more firms have been paying taxes. Moreover, since the introduction of measures to raise taxes on income, profits, capital gains and consumption, public expenditure has grown.

In 2012, the Dominican Republic approved by law its *National Development Strategy 2010–2030*, which has four thrusts: a 'social and democratic' legal framework; equal rights and opportunities; a sustainable, inclusive and competitive economy; and environmentally sustainable production and consumption patterns adapted to climate change.

The most significant progress has been made on the fourth thrust. In 2018, the Dominican Republic submitted its *Voluntary National Review*, which notes that efforts to align the *National Strategy* with *The 2030 Agenda* include identifying five accelerators. The government has decided to focus on two of these: multidimensional poverty reduction and sustainable consumption and production patterns.

Investment prioritizing higher education

In developing the country's nascent national innovation system, the government is prioritizing higher education. The national innovation system is co-ordinated by the Vice-Ministry of Science and Technology within the Ministry of Higher Education, Science and Technology (MESCyT). Governance rests with the National Council of Higher Education, Science and Technology (CONESCYT).

Over the period covered by the *Strategic Plan for Science, Technology and Innovation 2008–2018*, the government mobilized about US$ 53 million in funding for research projects proposed by universities and public and private research centres, through the National Fund for Innovation and Scientific and Technological Development (FONDOCYT).

In May 2020, the government issued a presidential decree (#175) which is expected to kickstart the formulation of a national innovation strategy by 2030.

A triple helix space on campus

One of the most significant advances since 2010 for the national innovation system has been the creation of 24 Centro Pymes (literally, SME centres) across the country. These centres operate on university campuses as a 'triple helix space.' Half of funding is provided by the government, through the Ministry of Industry, Commerce and Micro-, Small and Medium-sized Enterprises. The other half is provided by universities and the business sector.

Each Centro Pyme serves as a mentor for budding entrepreneurs and SMEs, providing them with financial and technical advice and access to funding sources. They also serve as a liaison point between young start-ups and more mature enterprises. In less than a decade, the Centro Pymes have been credited with the creation of 10 000 direct jobs in more than 600 micro-enterprises and SMEs and the mobilization of around US$ 320 million in investment funds from public and private banks.

ECUADOR

Progress through social innovation

Since 2015, Ecuador's economy has alternated recession and lethargic growth (Figure 7.1). Aggregate demand has fallen, driven by a slowdown in household consumption and net investment. Although exports grew slightly from 2017 to 2018, productivity remains low. Moreover, the high cost of financing external loans in a context of volatile global oil prices has been challenging the government's fiscal consolidation policies (CEPAL, 2019a).

The *National Development Plan 2017–2021: Toda una Vida* (An Entire Life) provides a roadmap for 'humaniz[ing] indicators and chang[ing] the face of vulnerable groups, as a state policy.' The plan sets aside an investment of US$ 25.6 million for the five-year period. All eight objectives are closely related to the SDGs but the first of these objectives stands out for devoting 60.3% of the total investment to 'guarantee[ing] a decent life with equal opportunities for all.'

The National Secretariat for Higher Education, Science, Technology and Innovation (SENESCYT) is responsible for elaborating and implementing policy, including ancestral knowledge. SENESCYT co-ordinates the National Knowledge Dialogue Project, which is striving to ensure that ancestral knowledge co-exists alongside scientific and technical knowledge.[16]

In 2019, elaboration of the *National Plan for Science, Technology, Innovation and Ancestral Knowledge to 2030* got under way, with the participation of researchers, innovators, students, entrepreneurs, teachers, professors, technical specialists and other social and state actors.

Launched in 2018, SENESCYT's Inédita programme funds both institutional and collaborative scientific research projects. Its Network Knowledge programme aims to build academic, research, cultural and social innovation networks through events and scientific publications. To promote innovation and entrepreneurship, SENESCYT grants seed capital to social innovation projects through its Bank of Ideas programme.

A first business survey

One notable initiative seeks to connect the private sector better with the country's development needs. In a first for Ecuador, the government programme *Ecuador 2030* surveyed 800 businesses, in order to establish a *Business Agenda to 2030* in 2019. This programme is mentoring companies to help them develop business models that will equip them to seize the opportunities offered by the Fourth Industrial Revolution while embracing sustainable development.

Between 2012 and 2019, the country's output on the theme of artificial intelligence (AI) and robotics grew annually by 9%, one of the highest rates in the world. Scientists produced 248 publications between 2012 and 2015 and 2 208 between 2016 and 2019 (Figure 7.6).

For the past decade, the government has prioritized investment in energy infrastructure and the transition from thermal to hydropower and other renewable sources of energy, following a series of rolling blackouts in 2009. This focus is reflected in Ecuador's growing specialization in smart-grid technology (Figure 7.6). Ecuador has seen the strongest growth in scientific publications of any Latin American country since 2015 (152%).

Efforts to attract high-level scientists

The Prometheus Project, an initiative of former president Rafael Correa, sought to strengthen research capacities at public institutions by persuading high-level foreign researchers and the diaspora to move to Ecuador. From 2010 until it was wound up in 2017, the project attracted a total of 884 researchers but it is not known whether these researchers have remained in the country.

Yachay Tech University in Urcuquí was destined to become the jewel in the crown of another project designed to boost research capacity, the Yachay City of Knowledge (Lemarchand, 2015). Founded in 2012, the university sought to attract high-level foreign researchers. It was to be the country's first research-intensive hub but has since become primarily a teaching institution, according to the former Vice-Chancellor (Reichhardt, 2019).

EL SALVADOR

A focus on reducing poverty

El Salvador's economy grew by 2.4% in 2019 (Figure 7.1), driven by a moderate increase in remittances, exports and public-sector investment. Exports grew by 4.2%. The main growth sectors have been construction, electricity and financial and insurance services, with some input from the manufacturing industry. These figures were being extensively reviewed in 2020, in light of the Covid-19 crisis.

El Salvador has made great strides in reducing food insecurity, chronic malnutrition, poverty and inequality since 2015 (WFP, 2017). However, food insecurity and malnutrition, natural disasters, gender inequality, high public debt and a rampant homicide rate remain persistent challenges.

Since coming to power in 2019, the Bukele government has made sustainable development a priority of the *National Development Plan* for 2019–2024 (*Plan Cuscatlan*). This plan aims to foster a stable business climate, attract FDI and facilitate trade. It creates a social development team and provides guidelines for environmental management that are inspired by the SDGs.

Plan Cuscatlan also advocates using technology to create a new governance system. It proposes replacing the Ministry of Education, Science and Technology with a Ministry of Higher Education, Science and Technology and creating a Ministry of Innovation and Modernization of the State.

The new plan advocates using technologies to introduce a new form of governance; it proposes establishing a task force of specialists in industry, production and technology to advise the government on how to adopt open-access strategies, support start-ups and create smart cities.

In the section on innovation and technology, the plan outlines a strategy consisting of three programmatic strands: eGOES, which is intended to bring about the full digitalization of government services, among other targets; a technology programme that includes a series of measures to reduce the digital divide; and an innovation programme advocating the creation of technological spaces, such as bootcamps, hackathons and makerspaces.

These projects are all at an early stage of implementation and have yet to be tested by the real-life conditions of the Covid-19 crisis.

GUATEMALA

Development plan aligned with SDGs

Guatemala is one of three Latin American countries which recorded growth of well over 3% in 2019 (Figure 7.1). The main driver has been private consumption, fuelled by an increase in remittances and easier access to credit, along with greater public investment. Among the most dynamic sectors are construction; communal, social and personal services; and retail, restaurants and hotels (CEPAL, 2019a). There is full employment (2.4% unemployment in 2018) but the economy remains largely informal.

Since it took office in January 2020, the incoming government has not introduced any major shift in economic policy but it has embarked on a national competitiveness programme to boost exports of manufactured goods.

In 2014, Guatemala approved its *National Development Plan K'atun: Nuestra Guatemala 2032*. Two years later, it integrated 99 goals from *The 2030 Agenda for Sustainable Development* into the plan and defined ten national priorities: poverty reduction and social protection; access to health services; access to water and natural resources management; food and nutritional security; employment and investment; economic value of natural resources; institutional strengthening, security and justice; education; comprehensive tax reform; and territorial planning.

Shortly thereafter, the government adopted a *National Climate Change Policy* (2016) and updated its 2011 *National Strategy for Risk Reduction 2018–2022*. A number of municipalities have since banned single-use plastics (Box 7.1).

Guatemala will need to diversify its research focus, if it is to further its development agenda. It has the highest concentration of publications in a single discipline of the entire region: 65% are in health sciences.

At 0.03% of GDP in 2017, Guatemala's research intensity is the lowest in the region (Figure 7.3). This corresponds to an annual investment of just US$ 21.2 million from the public purse.

A pivot towards innovation and entrepreneurship?

Another challenge will be to develop more postgraduate programmes. Guatemala has a small pool of people with bachelor's or postgraduate degrees in science and engineering. This reflects the small number of postgraduate programmes available, which, in turn, helps to explain why Guatemala has such a small pool of researchers (UNESCO, 2017). There were just 360 full-time equivalent (FTE) researchers in 2015. The number of researchers even declined by 34% in the two years to 2017 (Figure 7.4).

On the basis of the diagnosis and recommendations made by UNESCO (2017), the government has announced its intention of expanding the focus of the *National Development Plan K'atun: Nuestra Guatemala 2032* to embrace innovation, entrepreneurship and the study and dissemination of ethnomedicine.

These recommendations have yet to be fully implemented. However, the incoming government has adapted the plan to include economic growth, competitiveness and prosperity as a pillar of its own development agenda. Within this new framework, the National Secretariat for Science and Technology (SENACYT)[17] concluded an agreement with the United Nations Development Programme and the Taiwan Province of China in 2020 to use digital technologies to foster inclusion and poverty reduction, as well as industrial development and innovation.

HONDURAS

Investment in renewable energy

In 2019, economic growth dipped below 3% for the first time since 2013 (Figure 7.1), despite volatile global oil prices over this seven-year period. This stability has boosted investor confidence. Honduras has managed to reduce its dependence on banana and coffee exports by diversifying its export base towards industries such as apparel and automobile wire-harnessing. Greater productivity has not followed suit, however, and growth has not had a marked impact on living standards.

Honduras reported in its *Voluntary National Review* (2017) that it had integrated the SDGs into the country's planning, oversight and assessment system, including by defining appropriate indicators to permit monitoring and evaluation, such as the multidimensional poverty index.

In its second *Voluntary National Review* (2020), Honduras reported having extended access to electricity from 74.0% to 83.1% of the population and having raised the share of renewable sources from 44.3% to 55.6% of the energy mix between 2015 and 2019.

A number of related projects have been developed since the adoption of the Law for the Promotion of Public–Private Partnerships (2010), including the Patuca III hydro-electric dam, a solar park in the south of the country and wind farms in Francisco Morazán and Choluteca.

Entrepreneurship to combat youth unemployment

One concern highlighted by the 2020 *Voluntary National Review* is the proportion of young people between the ages of 15 and 24 years who are neither in work, nor studying. This proportion even progressed from 27.0% to 28.1% between 2015 and 2019. To tackle this problem and foster entrepreneurship, the Honduran Institute of Science, Technology and Innovation (IHCIETI) introduced the Honduras Start-up Programme in 2016. Each year, it selects digital projects for seed funds in areas that include software and mobile app development, video-game creation, automation and robotics.

IHCIETI is the executing agency for the National Secretariat for Science, Technology and Innovation (SENACIT), which is headed by a Secretary who serves as advisor to the President of the Republic. Both bodies were set up in accordance with the Law for the Promotion and Advancement of Science, Technology and Innovation (2013). This law also established the National Council for the Promotion of Science, Technology and Innovation (CONFOCIT) and the National Fund for Financing Science, Technology and Innovation (FONAFICIT). In 2020, the law's regulatory norm was being discussed.

A national plan in the pipeline

A national survey in 2017 found GERD to amount to just 0.04% of GDP (Figure 7.3). Scientific output, while still low, grew by 97% over the 2015–2019 period (Figure 7.5). Research with a focus on agriculture has notched up some successes, such as a study on banana packing conducted by the Zamorano Pan-American Agricultural School.

The IDB has approved a technical co-operation project to Support the Strengthening of the National System for Science, Technology and Innovation of Honduras. This project is funding preparation of the national plan for science, technology and innovation.

This process got under way in January 2019 and is due to conclude in 2020. It should be informed by the Observatory of Long-term Planning established in 2018 as a dedicated unit of IHCIETI. The process will follow the *Guidelines for the Formulation and Approval of Public Policies* issued by the Secretariat for the General Coordination of Government.

MEXICO

A shift in development model

Since the change in government in December 2018, Mexico's socio-economic policy has pivoted towards a new development model with a focus on social programmes. The government has introduced new instruments to redistribute income. This has contributed to a change in the structure of public expenditure, both in terms of consumption and investment.

Mexico has been affected by the America First doctrine of its northern neighbour and main trading partner, which materialized in a long negotiation for the signing of the USMCA. As a result, Mexico has departed from its previous growth pattern of around 2% per year. In 2019, the economy shrank by 0.1%, although full employment was preserved, with just 3.4% of the population being unemployed at the time.

A focus on social and local challenges

There is, as yet, little evidence that Mexico's economy will undergo deep structural changes overnight. The absence of any industrial policy suggests that the Mexican economy will remain dependent on oil and manufactured exports associated with global value chains, as well as remittances.

Mexico's main targets, as outlined in the *National Development Plan for 2019–2024*, relate to national challenges such as poverty, inequality, employment and education. Mexico submitted a *Voluntary National Review for the High-level Political Forum on Sustainable Development* in 2018 and the current government has linked the *National Development Plan* to *The 2030 Agenda for Sustainable Development*.

The government is working to connect science better with local challenges. Its new initiative, entitled Strategic National Programmes (PRONACES), allocates funding to research projects with a focus on societal issues at local level. Programmes include: contaminating processes and the socio-environmental impact of toxins; the promotion of literacy as a strategy for social inclusion; and the sustainability of socio-ecological systems.

PRONACES is co-ordinated by the National Council of Science and Technology (CONACYT). In 2019, PRONACES accounted for just 1.1% of CONACYT's budget but recent changes suggest that resources may be reassigned to this new programme. Since 2019, the government has reverted to a linear view of innovation that minimizes the vital role played by the business sector in innovation. One consequence of this policy shift has been that CONACYT no longer funds private business ventures, although it does still engage in other forms of public–private partnership like with the Querétaro Aerospace Cluster (Box 7.4).

The end of the road for sectoral funds

Since 2019, the government has been gradually winding down the sectoral funds programme, as part of the curb on allocating resources to promote business innovation. In 2019 and 2020, CONACYT did not issue any calls for project proposals, meaning that only those projects having received funding in previous years remain operational.

The Law on Science and Technology (2002) stipulates that CONACYT is entitled to sign agreements with various ministries and other government bodies to cofinance each sectoral fund. Technical committees were set up to assign public resources to priority economic sectors. By 2005, there were 17 of these mission-oriented funds in sectors that included agriculture, energy, environment and health.

The amount of resources allocated to the sectoral funds has always been modest; by 2019, these amounted to 2.1% of CONACYT's budget.

In 2020, the government decided to eliminate sectoral funds altogether without undertaking any robust evaluation to justify their disappearance.

Putting the brakes on the slide in research intensity

Research intensity has been declining steadily. In 2018, it hit a low of 0.31% of GDP. In 2020, parliament approved a rule prohibiting any further drop in public research expenditure until the 1% target laid out in the Law of Science and Technology is attained.

In 2018, the public sector financed nearly 80% of GERD (Figure 7.3). To promote basic science, the López Obrador administration has established a new programme called Frontier Science that is co-ordinated by CONACYT.

A far-reaching bill

A draft bill on science, technology and innovation was presented to the president in December. The bill proposes moving from a governance system in which the scientific, technical, academic and business communities at federal and state levels all participate in decision-making bodies towards a concentration of power in CONACYT. Some other normative documents already approved by parliament reflect this gradual centralization of decision-making power and resources in CONACYT. For instance, the new *CONACYT Statutes* approved in 2020 have eliminated the autonomous character of the body responsible for ensuring linkages between the public sector and the scientific, technical, academic and business communities, the Scientific and Technological Consultative Forum.

Box 7.4: **The Querétaro Aerospace Cluster: a winning formula**

Located in the centre of the country, Querétaro is one of the most densely populated states in Mexico. It is home to the Querétaro Aerospace Cluster, the fastest-growing hub for aerospace in the country, according to the Secretariat for the Sustainable Development of Querétaro (SEDESU).

In 2012, eight years after the inauguration of the city's Intercontinental Airport, a group of multinational corporations that included Airbus, Delta and Bombardier joined forces with local entrepreneurs, research centres and educational institutions to form an innovation cluster. One of these institutions was the University of Aeronautics of Querétaro (UNAQ), the country's sole university specializing in the aerospace industry, founded in 2007.

A number of factors have contributed to the cluster's growth: the provision of education targeting the development of competencies; the internationalization of markets; the presence of local suppliers; joint ventures; and the promotion of innovation and technological development. For example, companies based within the cluster have concluded agreements with UNAQ to develop training programmes tailored to the needs of their technicians (see photo, p. 200).

Government agencies have played a key role in the cluster's success by fostering innovation through public policies, subsidies and infrastructure development. CONACYT, for instance, has supported the Red Temática Nacional de Aeronáutica, a network of researchers, entrepreneurs and students who collaborate on project development.

CONACYT has also supported the Laboratory for Testing and Aeronautical Technology (LABTA), which evaluates the durability of components and materials used in aircraft, through three of CONACYT's research centres: the Centre for Research and Technological Development in Electrochemistry (CIDETEQ), the Centre for Engineering and Industrial Development (CIDESI) and the Centre for Advanced Technology (CIATEQ).

Since 2019, the Querétaro Aerospace Cluster has hosted FAMEX, the biggest aerospace fair in Latin America.

Mexican exports of aerospace products progressed by 14% per year between 2010 and 2016. Over the same period, FDI inflows cumulated at about US$ 1.3 billion and the number of aerospace companies in Mexico rose from 241 to 330. Of these, 40 are based at the Querétaro Aerospace Cluster.

Source: adapted from Muñoz-Sanchez *et al.*, 2019; www.queretaro.gob.mx/sedesu

Should these changes be approved, three levels of policy-making (strategic, policy and implementation) will become intertwined under CONACYT leadership, with the potential to generate conflicting objectives and problems of accountability and capture by certain actors.

NICARAGUA

Plan's implementation perturbed

In 2019, Nicaragua's economy contracted for the second year in a row (Figure 7.1). Political and social unrest since April 2018 has had serious repercussions for economic sectors that include construction, commerce, tourism and hospitality (CEPAL, 2019d).

Unrest has also affected the university sector. According to the National Forum on Education, in 2018, enrolment dropped by 40% at public universities and by 50% at private universities.[18]

The *National Human Development Plan* for 2012–2016 had two thrusts. The first was to use STI and entrepreneurship to modernize the productive economy and ensure adaptation to climate change. This was to be achieved through a series of programmes proposing new university curricula with a strong emphasis on climate science, the collection and analysis of statistics on STI and greater investment in STI. The second thrust was to build capacities for e-governance through the GOBeNIC programme.

Some elements of the *National Human Development Plan* 2012–2016 have been implemented, despite a challenging social and political context. Since 2014, talks, seminars and conferences on nanotechnology have been held at various universities. The Nicaraguan Institute of Agricultural Technology (INTA) has also run several workshops in agro-nanotechnology since 2017 which bring together researchers, technicians, students and producers from around the country.

Implementation of the *National Human Development Plan 2018–2021* has also been perturbed by the crisis. These delays prompted the National Academy of Sciences to issue a declaration in 2019 in support of the country's research, academic and civil society communities.

The National Human Development Plan 2018–2021 has been designed to converge with the SDGs. The ninth of its 19 objectives is to 'build resilient infrastructure, promote inclusive and sustainable industrialization and promote innovation', which is aligned with SDG9. The aim is to promote linkages between the national government, universities, technical and vocational training institutions, producers and the private sector. This is to be achieved through the extensive use of ICTs and the promotion of technology transfer through such means as technology transfer offices on university campuses and FDI, as well as advanced training programmes in fields such as nanotechnology, biotechnology, convergent technologies and renewable energy.

Despite static investment in R&D, scientific output in academia has surged in the past five years (Figure 7.5).

The National Council for Science and Technology (CONICYT) is responsible for implementing the successive *Human Development Plans*. Attached to, and chaired by, the Vice-Presidency of the Republic, CONICYT is made up of representatives of the business, government, academic and civil society sectors.

In 2019, Nicaragua adopted a *National Policy for Mitigation and Adaptation to Climate Change*. This policy provides CONICYT with a framework for promoting research in renewable energy and biodiversity, training and awareness with regard to the protection of natural resources and the dissemination of knowledge about risk management and climate change. CONICYT's budget remains extremely modest, however.

PANAMA

A roadmap to 2040

Panama is one of three high-income countries in Latin America, along with Chile and Uruguay. Enlargement of the Panama Canal, completed in 2016, has attracted high levels of FDI, as has the modernization of the country's electricity and telecommunications infrastructure. Despite this, poverty and inequity remain prevalent.

Between 2015 and 2019, the National Secretariat for Science, Technology and Innovation (SENACYT) conducted a foresight exercise entitled *Panama 2040*, in consultation with public and private socio-economic actors. The study established a roadmap for transforming Panama into an ICT hub and a fully sustainable and inclusive society by 2040.

To this end, the *Strategic Plan 2019–2024* (2020) proposes doubling GERD to 0.33% of GDP by 2024, augmenting patenting and following a smart specialization approach to defining territorial agendas for innovation. The emphasis will be on dialogue and social innovation (SENACYT, 2018). In July 2019, Panama became the first Central American country to ban single-use plastics (Box 7.1).

Since the establishment of SENACYT in the late 1990s, there have been successive five-year national strategic plans. A review of the fourth plan covering the period to 2019 pinpointed a high degree of structure and coherence among programmes (UNCTAD, 2019). These plans have been considered ambitious and even visionary, as they have sought to harness research to problem-solving and have led to prospective studies on frontier technologies. One foresight exercise also examined potential outcomes of policy implementation.

In 2015, SENACYT launched an extensive programme to provide rural and urban communities with greater Internet access. Over the past five years, Infoplazas AIP has established over 275 such access points at different locations identified by local authorities, such as schools and other public buildings. In 2019, the programme was transformed into a legal entity with functional autonomy, the Agency of Public Interest.

More researchers

In the period since 2015, the number of researchers has increased to 800 (in head counts), a large proportion of whom hold doctoral degrees (42%).

The presence of three prestigious research institutions specializing in biodiversity, biotechnology and biomedicine (Institute for Scientific Research and High Technology Services, INDICASAT), tropical medicine (Gorgas Memorial Laboratory) and tropical research (Smithsonian Institution) ensure a good citation rate, even if output at the national level is low (Figure 7.5).

PARAGUAY

A carbon-neutral economy by 2050?

Since 2016, climatic phenomena have affected the primary and energy sectors, contributing to a fall in agricultural prices. The government has been obliged to take fiscal measures to compensate for the drop in public revenue. In 2019, the economy stalled (Figure 7.1).

In September 2016, the government established the Inter-Institutional Coordination Commission; it is responsible for implementing and monitoring international commitments made within the framework of *The 2030 Agenda for Sustainable Development*. The commission plans its activities on an annual basis and solicits the participation of both public- and private-sector organizations.

The Ministry of Education is working with the Centre for Sustainable Development at Columbia University in the USA to design and implement a nation-wide reform to help Paraguay achieve a carbon-neutral economy by 2050. As part of this project, the centre is helping the government to implement a fiscal reform to close the 'green finance' gap in Paraguay. The project also plans to add other renewable energy sources such as wind and solar power to complement electricity production by the Itaipú Binational Hydro-electric Dam, which Paraguay shares with Brazil.

The country's first science policy

Although Paraguay's national innovation system is still in its infancy, it already has a well-established institutional and policy framework. In 2013, there was no budget at all for R&D. By 2018, research intensity amounted to 0.15% of GDP and there were 0.27 researchers per 1 000 labour force.

The National Council of Science and Technology (CONACYT) published the country's first *National Science, Technology and Innovation Policy 2017–2030* in 2017. It focuses on developing a competitive productive sector to support socio-economic and environmental development. The main policy instruments are PROCIENCIA and PROINNOVA. The first of these programmes aims to strengthen national capacity for research and technological development through four main prongs: promotion of scientific research (competitive funds, infrastructure projects); strengthening human capital for R&D (national scholarships, a 'linking programme'); developing the researcher system; and supporting social appropriation of science and technology. The second, which is better funded at US$ 10 million over 2017–2022, promotes investment in applied research and innovation through individual projects and incubation services, among other things.

Some three-quarters of funding targets applied research (CONACYT, 2019). In 2018, CONACYT issued a call to public and private bodies for research project proposals with a science, technology and society focus. Projects could either target education (public perception of science, stimulation of a vocation for science, educational innovation, etc.) or social innovation in areas such as health, energy, agriculture and transportation.

One-third of research expenditure is allocated to natural sciences, engineering and technology. A little more than half goes to agriculture, health and the environment and another

15% to the advancement of knowledge in non-academic institutions (UNESCO, 2018). Scientific output grew by about 72% between 2015 and 2019 (Figure 7.5).

PERU

Several poverty reduction targets reached

Since 2015, growth in Peru has fluctuated. After dipping in the aftermath of heavy rains and flooding tied to the 2017 El Niño phenomenon, the economy grew by 4.0% in 2018, fuelled by domestic demand. This has enabled the government to raise the minimum wage and launch a new cycle of investment in the mining sector (CEPAL, 2019a).

To provide a framework for the country's implementation of *The 2030 Agenda for Sustainable Development*, the National Centre for Strategic Planning (CEPLAN) formulated the *National Development Strategic Plan* (PEDN) in 2011. The plan's output is being monitored by the National Institute of Statistics and Information Technology.[19]

The *National Development Strategic Plan*'s objectives for poverty reduction are closely related to the SDGs. Many of the targets will have to be revised in the next edition of the plan, however, to reflect the impact of the Covid-19 pandemic.

A special regime for researchers

The *National Competitiveness and Productivity Policy* and its corresponding *Action Plan* (2019–2030) is a multisectoral proposal articulated by the National Competitiveness and Formalization Council. The *Action Plan* focuses on nine priority areas: infrastructure; human capital; innovation; financing; the labour market; business environment; foreign trade; institutions; and sustainability.

The third objective of the *Action Plan* concerns innovation and technology transfer. There are five overarching strategies for developing a culture of research and innovation and accelerating the absorption of digital technologies, in particular: a stronger regulatory environment, including as concerns intellectual property protection; a larger pool of qualified experts; higher levels of public and private investment in innovation; a better articulation of public and private actors to adapt innovation to market needs; and a regular review of the innovation policy mix.

One of the most important measures in the *National Action Plan for Competitiveness and Productivity by 2030* is the establishment of a special regime for outstanding researchers. The first step towards this regime was accomplished with the enactment of the Law for the Promotion of Scientific Researchers in May 2019. Researchers selected for this special regime will be divided into three categories according to their research focus and academic training; a fourth category will target postdoctoral researchers.

In 2019, the National Council for Science, Technology and Technological Innovation (CONCYTEC) solicited feedback from the national scientific community on the draft regulations for the special regime.[20]

This special regime for researchers is a first for Peru. Other countries have similar instruments providing pecuniary and non-pecuniary incentives for researchers, including Colombia, Mexico and Uruguay.

CONACYT is one of the two main drivers of science in Peru. In addition to supporting postgraduate training and research, it formulates key policy documents. It was responsible for drafting the *National Strategic Plan for Science, Technology and Innovation for Competitiveness and Human Development 2006–2021*. This plan has sought to build bridges between the actors of the national innovation system and ensure that technological demands are met in seven priority productive sectors: agriculture and the agrifood industry; fishing and aquaculture; mining and metallurgy; forestry; energy; telecommunications; and tourism. The plan has also been prioritizing four social and environmental sectors: health; education; environment; and housing and sanitation.

A newcomer: Innovate Peru

The second main driver of science in Peru is a relative newcomer, the National Innovation Programme for Competitiveness and Productivity, better known as Innovate Peru. Established in 2014, it operates under the Ministry of Production.

Innovate Peru runs a number of competitive funding programmes, such as Fincyt 3, built upon an IDB loan; the research and development fund for competitiveness (FIDECOM); the framework fund for innovation, science and technology (FOMITEC); and a fund for SMEs. Innovate Peru has sought to ensure that the funds complement one another in terms of the type of instruments used, the size and profile of companies and degree of development.

In parallel, the Ministry of Agriculture has administered the National Agrarian Innovation Programme (PNIA) since 2014. This six-year programme sought to foster a more inclusive and sustainable agriculture sector by improving the competitiveness and profitability of smallholders and medium-sized producers. PNIA was funded jointly by the Peruvian government, the World Bank and IDB. It had the twin objective of improving both supply and demand for innovation services, notably by strengthening the capacity of the National Institute of Agricultural Research (INIA) to deliver quality services and by developing a market for these.

A second programme has been implemented since 2017. The National Innovation Programme for Fisheries and Aquaculture (PNIPA) is being implemented by a special unit under the Ministry of Production and funded jointly by the government and the World Bank.

The fact that the aforementioned agencies and programmes all depend on different ministries makes it difficult to work in a co-ordinated manner. This prompted parliament to table a bill in August 2020 reforming the science system. The main changes proposed are the creation of an Interministerial Commission at the strategic level, an advisory council and a Secretariat for Science and Technology as a special unit within the Presidency of the Council of Ministers. The latter body would co-ordinate the two national implementing agencies, one for science and the other for innovation and entrepreneurship, absorbing Innovate Peru and CONCYTEC's implementation agency, FONDECYT. Existing programmes such as PNIPA, Fincyt 3 and FIDECOM would also be absorbed. CONCYTEC itself would disappear.

URUGUAY

Foreign investment in infrastructure

After hitting a low of 0.4% growth in 2015, Uruguay's economy rebounded before stalling once more in 2019 (Figure 7.1).

The coalition government in place since March 2020 faces a number of challenges. Exports of primary goods have been affected by a drop in demand and there have been cutbacks in public expenditure. According to World Bank data, central government debt has risen from 4.9% (2015) to 8.4% (2020) of GDP, inflation is hovering above the target range and the unemployment rate remains unsatisfactory, at 7.5% in 2015 and 8.8% in 2020.

Low domestic investment contrasts with high FDI stemming largely from a US$ 3 billion agreement signed by the government in November 2017 with UPM, a Finnish consortium specializing in paper manufacturing.

Under the 50-year agreement, the Paso de los Toros paper pulp mill is being built on the Black River in the centre of the country. The choice of site has led environmentalists to express concerns about potential pollution of the river, particularly since nearby paper mills polluted the Uruguay River more than a decade ago.

The incoming government has endorsed the agreement, under which UPM will invest in electrical infrastructure at the mill and finance roadworks and possibly a railtrack to enable a greater volume of timber to be transported from the mill in Paso de los Toros to Montevideo's port for export. This should produce positive spillovers for both cities. There should also be a ripple effect in terms of personnel training.

Great strides in renewable energy

Uruguay has made great strides towards its renewable energy targets since adopting a *National Energy Policy* to 2030 (2008). By 2017, wind turbines were producing 32% of the country's electricity, up from just 1% in 2013. When combined with hydropower and solar power, renewable sources accounted for 90% of Uruguay's power generation by 2017, compared to 57% in 2012 (IEEFA, 2018).

To train personnel for the new sector, the government established the country's first Centre for Training in the Operation and Maintenance of Renewable Energies (CEFOMER) in 2018 in the town of Durazno (Proaño, 2018).

Policy-makers have focused on three strategies for mainstreaming renewable energy: auctions, fiscal incentives and net metering, by which consumers sell excess electricity to the grid.

These incentive measures have been costly for the government; they correspond to an annual investment of 3% of GDP each year. The privatization of electricity provision has also resulted in Uruguay having the highest electricity prices in South America.

Other social advances since 2016 include the implementation of a system offering wide health coverage and a drop in extreme and relative poverty levels, through the following means. Under a public–private partnership, the government pays for patients to receive private care, in line with a list of tariffs agreed with the service provider. There has also been a sizeable increase in real wages through a process of collective bargaining involving trade unions, firms and government and a social policy has focused on integrating populations living on the margins of society.

Transforma Uruguay taking a systemic approach

In 2016, the government established the National System of Productive Transformation and Competitiveness (Transforma Uruguay) to improve co-ordination between a constellation of government agencies and the private sector.[21] Transforma Uruguay was enshrined in law in 2017.[22] Its workplan has four main thrusts: promoting the business and investment climate; internationalization of SMEs; innovation; and capacity-building. By November 2018, 17 of the 52 projects implemented under this workplan had been completed, according to the *National Plan for Productive Transformation and Competitiveness* published in 2019. As of June 2020, the incoming government has not yet appointed anyone to head Transforma Uruguay's Secretariat, nor issued any programmatic guidelines.

Uruguay established its first science and technology park, Pando Science and Technology Park, in 2008 and its first *Strategic National Plan for Science, Technology and Innovation* (PENCTI) in 2010. It is planning to update the latter document, according to its 2019 *Voluntary National Review*. This document also cites plans to raise investment in R&D, create interdisciplinary centres of advanced studies and develop more science and technology parks through public–private partnerships.

A national climate policy

Uruguay has had a National Climate Change Response System since 2009. In 2017, the government approved the *National Climate Policy* by executive decree, following an inclusive consultation process. The policy serves as a framework for implementation of its commitments under the *Paris Agreement* (2015).

In 2017, the National Secretariat for Science and Technology (SYNCYT) was established and placed under the presidency. SYNCYT is responsible for co-ordinating policy planning and implementation with the following bodies: the National Agency for Research and Innovation (ANII),[23] the National Council for Innovation, Science and Technology (CONICYT) and the Honorary Commission of the National System of Researchers.

In October 2019, the scientific community reiterated 'the importance of continuing to strengthen capacities' in STI and 'its use for national development' in a joint statement by CONICYT, the University of the Republic and the National Academy of Sciences (CONICYT *et al.*, 2019).

VENEZUELA

A haemorrhage of human capital

The Bolivarian Republic of Venezuela is going through what could turn out to be the most serious inflationary process in the history of Latin America and the Caribbean. By 2016, inflation (in consumer prices) had reached 255% and was on an upward trajectory, according to the World Bank. According to CEPAL (2019a), in the first three quarters of 2018, the economy contracted by 19.5%, the fifth consecutive fall in GDP in as many years.

According to the United Nations High Commissioner for Refugees (UNHCR), there are more than 4.6 million refugees and migrants from Venezuela worldwide; this represents the largest exodus of a single population in the region's recent history. In 2019, Venezuelans migrated primarily to Colombia (1.63 million), Peru (863 613), Ecuador (385 042) and Brazil (224 102) [UNHCR, 2019]. Many of these migrants are professionals, including scientists, resulting in a huge loss of human capital for Venezuela and a boost for its neighbours' scientific capacities.

According to data collected by the non-governmental organization Sinergia (2019), the situation with regard to poverty, nutrition and health is deteriorating.

Science and technology for citizen's needs

The *Plan de la Patria 2025* (2019–2025) is Venezuela's second socialist socio-economic development plan after the years 2013–2019. The *Plan de la Patria 2025* establishes a national objective of developing scientific and technological capacities linked to citizen's needs. The *National Science, Technology and Innovation Plan 2005–2030*, subtitled *Building a Sustainable Future*, has fixed the following strategic objectives:

- to promote scientific and technological independence, in order to build an endogenous model of environmentally sustainable development;
- to support social inclusion in science and technology, whereby policies are developed by and for Venezuelan citizens; and
- to develop human resources, scientific infrastructure and technological platforms.

Scientific publishing has been steadily declining in Venezuela, with a drop of 24% observed over the 2015–2019 period (Figure 7.5).

CONCLUSION

Time for more dialogue, funding and foresight

Latin America is characterized by a strong heterogeneity in the scale, level of development and policy direction of national innovation systems. For decades, policy-making in the region has largely fallen into two camps: policy frameworks that adapt instruments from abroad tailored to other realities; and policies that involve experimentation and trialling of new instruments, designed by and for the region, which strive to reflect local problems (Crespi and Dutrénit, 2014; Navarro *et al.*, 2016). Bolivia and Panama have recently joined the latter category, which also groups Argentina, Brazil, Colombia, Costa Rica, Mexico, Peru, Paraguay and Uruguay.

Since 2015, there has otherwise been little change of note in the governance of national innovation systems. New institutions designed to consolidate these systems have not managed to thrive in the face of political instability. Research budgets have been shrinking.

STI policies are not being constructed with sufficient public participation and dialogue. The lack of consultation, coupled with the low financial commitment to science, not only affects the relevance of policies; it also influences perceptions of the relevance of research and innovation in the collective imagination (Dutrénit *et al.*, 2018). These factors are at the root of the somewhat erratic policy-making we observe in attempting to link STI to national challenges (Casas and Mercado, 2016).

Policy processes in Latin America and the Caribbean should be grounded in deeper foresight work, to provide a more solid foundation for policy-making. In 2015, Argentina became the second Latin American country after Brazil to host an institution specializing in strategic foresight studies (Lemarchand, 2015). Five years on, the Interdisciplinary Centre for Studies in Science, Technology and Innovation (CIECTI) in Argentina and the Centre of Management and Strategic Studies (CGEE) in Brazil remain the only specialized centres on the continent, although Honduras did establish an Observatory of Long-term Planning in 2018 as a dedicated unit of IHCIETI.[24]

Given the modest level of research expenditure, it is hardly surprising that scientific output has grown at a modest pace in most countries. Argentina, a country with strong scientific and technical capacities, has performed comparatively weakly in the past few years against most related indicators.

Likewise, Cuba and Venezuela, which have traditionally had strong scientific bases, are seeing a worrying erosion in knowledge production.

Of note is that the group of countries with small or emerging national innovation systems are slowly moving towards consolidation: the Dominican Republic, El Salvador, Guatemala, Honduras and Paraguay.

A number of emerging developments, including political shifts in Mexico, Argentina and Uruguay and political crises in Bolivia, Chile, Ecuador and Nicaragua, are likely to affect their national innovation systems in unpredictable ways. When a new government takes the country in a radically new direction, this creates uncertainty for private-sector actors, undermining investor confidence.

Even when new instruments are introduced to stimulate innovation and experimentation, private actors can be hesitant to seize the extended hand, for fear that it may be snatched away again.

Lemarchand (2015) has likened the absence of long-term planning in Latin America to the Sisyphus trap. 'How often has a new party or group come to power in a Latin American country,' he writes, 'and immediately set about putting a new set of rules and policies in place? Like Sisyphus, the national innovation system sees the original policy roll back down the hill, as the country takes a new policy direction.'

Sustainable development higher on the agenda

One positive trend is the emergence of sustainable development as an overall policy objective. Even when policy documents make no explicit reference to *The 2030 Agenda for Sustainable Development*, their own goals tend to be aligned with this agenda. For instance, the Colombia Bio programme seeks to mainstream the sustainable use of biodiversity at the institutional level.

The scientific community has, itself, been receptive to this discourse, as reflected in the high growth rate for articles on renewable energy and other areas related to sustainability and the environment.

However, STI policies are not yet fully coherent with sectoral policies, especially in light of the SDGs framework. For instance, there should be greater articulation between industrial and STI policies, both to devise effective stimuli for innovation, such as instruments for public procurement, and to support the country's sustainable development agenda. For instance, industrial support will be vital to the success of Costa Rica's *National Strategy for the Substitution of Single-use Plastics by Renewable and Compostable Alternatives 2017–2021*.

Across the region, ties to industry need consolidating. Although innovation has penetrated the discourse of politicians, the media and the social fabric and the concept of an innovation system has now been widely incorporated into STI policy-making, demand for knowledge in the productive sector remains weak; large companies, be they subsidiaries of multinationals or *multilatinas*, still have very limited interaction with local knowledge networks.[25]

Poverty and inequality simultaneous challenges

One point clearly emerges from the analysis of 18 countries in the present chapter, the particular difficulty they encounter in strengthening national innovation systems and promoting knowledge production while grappling, simultaneously, with high levels of poverty and inequality. There is already a wealth of social innovation in Latin America but STI policies could be more strongly oriented towards fostering gender equality and providing solutions for the specific needs of indigenous peoples.

Science must find new ways of generating knowledge, based on teamwork and the integration of different types of knowledge. Although some countries have recognized local and indigenous knowledge as being key to building knowledge systems and incorporated this imperative in social innovation policies, for most countries, policies designed to identify, promote and consolidate this knowledge are still in their infancy (United Nations, 2019). Much remains to be done to systematize local and indigenous knowledge, build transdisciplinary bridges across codified disciplines and exploit a holistic knowledge system to solve local and national problems.

It will be necessary to rethink the region's development model by paying greater attention in STI policy to social equity and environmental sustainability. Society, for its part, must be willing to develop social innovation based on greater solidarity.

The health emergency associated with the Covid-19 pandemic has sent shockwaves across Latin America, taking tens of thousands of human lives and plunging the region into an economic recession. All Latin American forecasts indicate that the pandemic will exacerbate levels of poverty and inequality.

However, the pandemic has also provided a window of opportunity for the region to see STI in a more positive light. Since the outbreak, governments everywhere have been turning to science for solutions. This has opened their eyes to the potential of science for problem-solving.

KEY TARGETS FOR LATIN AMERICA

- By 2030, Bolivia aims to raise the share of alternative and other energy sources (including combined cycle power plants) in total electrical power capacity from 2% (2010) to 9%.
- Paraguay plans to achieve carbon neutrality by 2050.
- The Dominican Republic intends to formulate a national innovation strategy by 2030.
- Panama is seeking to become an ICT hub and a fully sustainable and inclusive society by 2040.
- Panama intends to double its GERD/GDP ratio from 0.16% to 0.33% by 2024.

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ENDNOTES

1 For coverage of Belize, Guyana and Suriname, see chapter 6.
2 See (in Spanish): https://es.unesco.org/fieldoffice/montevideo/cienciaresponde/paisesresponden
3 See (in Spanish): observatoriocts.oei.org.ar
4 See: https://bidlab.org/es/map-LAC-innovators-Covid-19
5 See: https://www.americaeconomia.com/negocios-industrias/multilatinas/estos-son-los-resultados-del-ranking-multilatinas-2019
6 See: https://www.recyt.mercosur.int/
7 See: www.foroalc2030.cepal.org
8 These surveys cover product and process innovation, as well as organizational and marketing innovation. They are increasingly based on various iterations of the Oslo Manual.
9 Several agreements have laid the foundations for publishing with foreign co-authors in Latin America, including the Foreign Fulbright Student Program (USA), the Ibero-American Programme of Science and Technology for Development (CYTED) and agreements made by the Latin American Council of Social Sciences (CLACSO).
10 The project was co-ordinated by UNESCO and is named after the French scientist Pierre Auger, who headed the UNESCO Division of Mathematical and Natural Sciences from 1948 to 1958.
11 See: http://energia.org.ec
12 For details of the UNESCO World Network of Biosphere Reserves, see: https://en.unesco.org/biosphere/wnbr
13 In 2019, Costa Rica committed to the High Ambition Coalition for Nature and People to protect at least 30% of land and ocean, within the framework of the Post-2020 Global Biodiversity Framework due to be submitted to the 15th Meeting of the Conference of the Parties to the Convention on Biological Diversity in 2021.
14 See: http://www.ods.cr/
15 See: https://www.bnamericas.com/en/news/costa-rica-achieves-3-of-4-objectives-to-end-digital-divide
16 See (in Spanish): https://www.educacionsuperior.gob.ec/proyecto-nacional-de-dialogo-de-saberes
17 In Guatemala, the National Secretariat of Science and Technology (SENACYT) implements the decisions adopted by the National Council for Science and Technology (CONACYT), which is chaired by the vice-president.
18 See: https://redclade.org/noticias/nicaragua-foro-informe-examen-periodico-universal/
19 See: http://ods.inei.gob.pe/ods/
20 CONCYTEC sent the proposal for the special regime for researchers to vice-chancellors of Peruvian universities for internal consultations, interviewed researchers and university staff and posted the draft regulations on its portal.
21 These agencies include the National Agency for Research and Innovation (ANII), the National Institute for Agricultural Research (INIA), the Technological Laboratory of Uruguay (LaTU) and the Investment, Export and Country Brand Promotion Agency.
22 The creation of the National Training Institute was also enshrined in this law.
23 ANII dates from 2005. It has the particularity of managing sectoral funds both for scientific research projects (digital inclusion, health, sustainable agro-environmental platforms, etc.) and for promoting innovation (energy, animal health, creative industries, logistics, etc.).
24 Cordeiro (2016) has accounted for extensive work by 13 countries in Latin America, as well as by Spain, to conduct foresight exercises of national, sectoral and regional scope in the past ten years.
25 Policy analysts should investigate the possibility of developing new metrics to assess STI performance, as argued by Radosevic and Yoruk (2016), since conventional indicators tend to be better suited to mature systems. Conventional indicators do not adequately convey the progress made or setbacks endured by national innovation systems in a heterogeneous region at varying stages of development.

AT A GLANCE

In May 2017, a multidisciplinary team interacts with a girl born with microcephaly, at the Hospital de Apoio a Criança in Brazil. Between 2015 and 2018, health authorities were overwhelmed by the surge in cases of microcephaly which has been associated with the mosquito-borne Zika virus. As of April 2018, Brazil was second only to the USA for the volume of scientific publications on Zika, accounting for 15% of global output.

- There is a growing uptake of digital technologies, including in the health, banking and agriculture sectors. A geostationary satellite now provides the most remote regions with broadband access.
- Sirius, one of the world's most sophisticated synchrotron light sources, is nearing completion.
- Indicators related to graduate education and academic research have shown steady progress. However, outlays by federal funding agencies for research have fallen.
- Although regional disparities in graduate education are narrowing, research-intensive companies remain concentrated in the south.
- Several indicators are flashing a warning for the national innovation system, with the downturn in business expenditure on R&D, industrial patent filing and the intensity of high-tech exports.
- Brazil has one of the world's cleanest energy matrices but is vulnerable to ecological disasters.
- Science, technology and innovation has been hampered by policy volatility and the lack of critical evaluation processes.

8 · Brazil

Hernan Chaimovich and Renato H. L. Pedrosa

INTRODUCTION

Economic downturn has hampered business innovation

After a relatively long period of economic growth and political stability since the mid-1990s, Brazil entered recession in 2015. This downturn was followed by a lukewarm recovery, with accumulated growth of just 3.8% over the 2017–2019 period (Figure 8.1).

Since the economy was still in convalescence in 2018–2019, it is highly likely that domestic expenditure on research and development (GERD) will contract further in 2020, even if a lower GDP may boost the GERD/GDP ratio. Indicators for research and development (R&D) in both the government and business enterprise sectors were already down in 2017, the last year for which data are available (Figure 8.2).

The economic downturn since 2014 has hampered the private sector's ability to innovate. The data released in 2020 by the Brazilian Institute of Geography and Statistics (IBGE) following its national *Survey of Innovation 2017* show a steep drop in research expenditure by Brazilian businesses. This survey covers all public and private firms in transformative industries, primarily, but also firms in extractive industries and the services sector, as long as their work involves technology.[1] Between 2014 and 2017, the number of firms in the transformative sector reporting in-house R&D grew but their in-house expenditure declined. In the services sector, the situation was reversed (Figure 8.2).

This latter trend may be a reflection of the services sector's greater participation in the economy; it accounted for 74% of GDP in 2017, up from 68% of GDP in 2010. Overall, the participation of industry dropped from 27% to 21% of GDP over the same eight-year period; the transformative subsector was no exception, its share of GDP having dipped from 15% to 12% over the same period (IBGE, 2020).

The Covid-19 pandemic has plunged Brazil into recession once more, with GDP forecast to contract by between 5.0% and 5.8% by the end of 2020, according to projections by the Central Bank of Brazil (BCB, 2020) and International Monetary Fund (IMF, 2020), respectively. There has been a concurrent drop in 2020 in a number of key economic indicators, including those for inflows of foreign direct investment (FDI) and the public debt-to-GDP ratio (Figure 8.1).

As of early April 2021, Covid-19 has claimed more than 340 000 Brazilian lives, according to the Johns Hopkins Coronavirus Resource Center; this corresponds to a mortality rate of 161 per 100 000 inhabitants, the eighth-highest ratio in the world. Policy disagreements over how to contain the spread of the pandemic have led to the resignation of two health ministers. Having a centralized e-health system has made it easier to adapt health care services to the pandemic (Box 8.1).

SUSTAINABLE DEVELOPMENT AGENDA

More tenuous policy linkages

The IBGE[2] and the Secretary of Government, a cabinet-led federal ministry directly linked to the Office of the President, are jointly responsible for generating and administering indicators to monitor progress towards Brazil's Sustainable Development Goals (SDGs[3]) to 2030. However, neither IBGE nor the Secretary of Government has any responsibility for developing related policies and programmes, which are discussed later.

In mid-2020, the Ministry of Science, Technology and Innovations[4] published its *Strategic Plan 2020–2030*, which replaces the *National Strategy for Science, Technology and Innovation 2016–2022*.[5] Even though the new plan mentions sustainable development as an overarching objective, there are few socio-economic and no environmental targets included in the map of indicators and related targets.[6]

The *National Strategy for Science, Technology and Innovation 2016–2022* had been influenced by *The 2030 Agenda for Sustainable Development*. It comprised twelve volumes on: water and ocean; biotechnology; agriculture; Antarctica; the bio-economy; biomass; science; climate; social inclusion; science education and dissemination; food; and health.

In 2018, a general outline of the draft National Strategy for Economic and Social Development (ENDES) was shared online for public consultation (ENDES, 2018). Many of the document's listed topics derived directly from *The 2030 Agenda for Sustainable Development*. As of October 2020, there has been no further action on ENDES and the government webpages devoted to this document have been taken down.

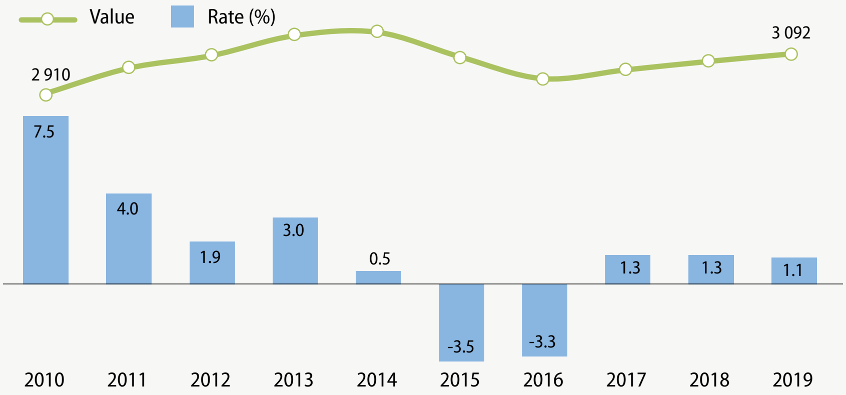
Such abrupt revisions of science, technology and innovation (STI) policy and planning are symptomatic of a systemic problem in Brazil. The practice of fixing overambitious goals and targets, only to replace them every few years (Chaimovich and Pedrosa, 2015) can only be a futile exercise. Policies need time to be effective because the actors on the ground need long-term stability to implement real change.

Policy volatility is compounded by the absence of clear provisions holding those responsible for policy implementation to account, or of any critical assessment of why certain objectives may not have been reached, in order to overcome these shortcomings in the design of future policies.

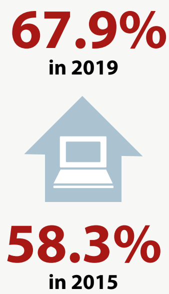
Recent developments also suggest a weakening of ties between science and technology, on the one hand, and socio-economic innovation policies and programmes, on the other. These linkages had been one of the strengths of the Brazilian innovation ecosystem. We shall present some evidence of this trend in the next section.

Figure 8.1: **Socio-economic trends in Brazil**

GDP value and growth in Brazil, 2010–2019
In PPP$ billions (constant 2017 values) and change (%)

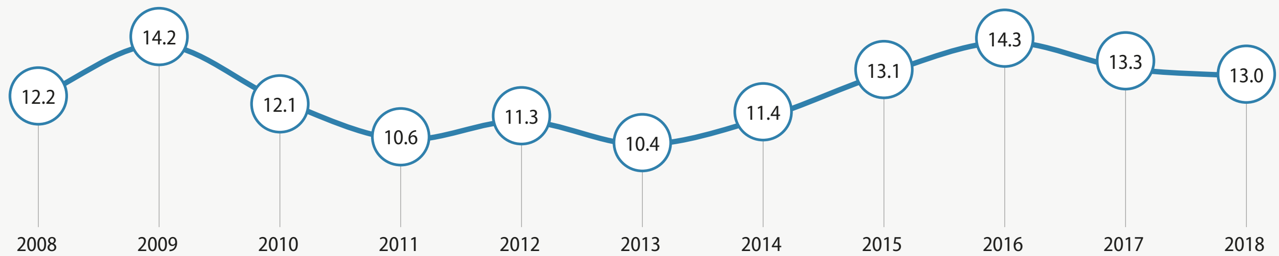


Share of Brazilian population using the Internet

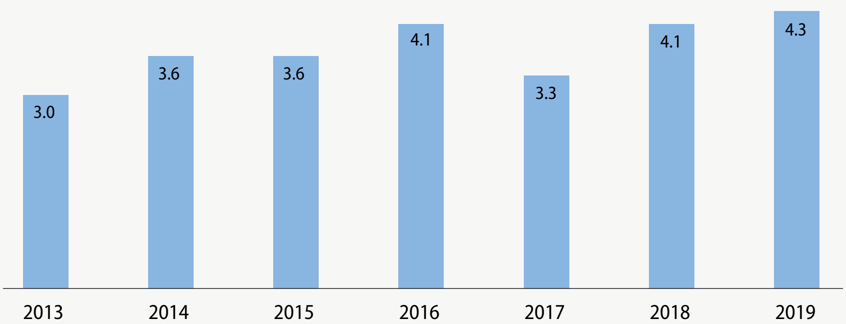


Total electricity generation is projected to grow by 7.4% between 2020 and 2024 but solar power should grow by 43%.

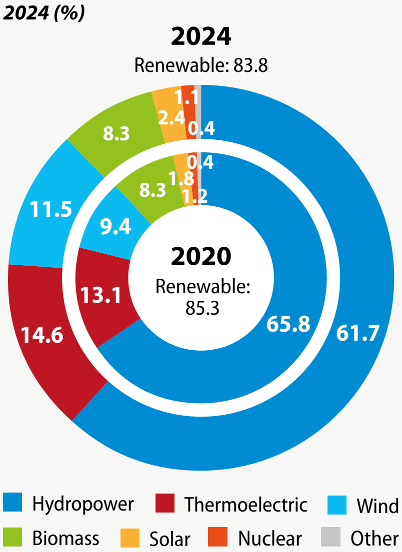
Brazilian high-tech exports as a share of manufactured exports, 2008–2018 (%)



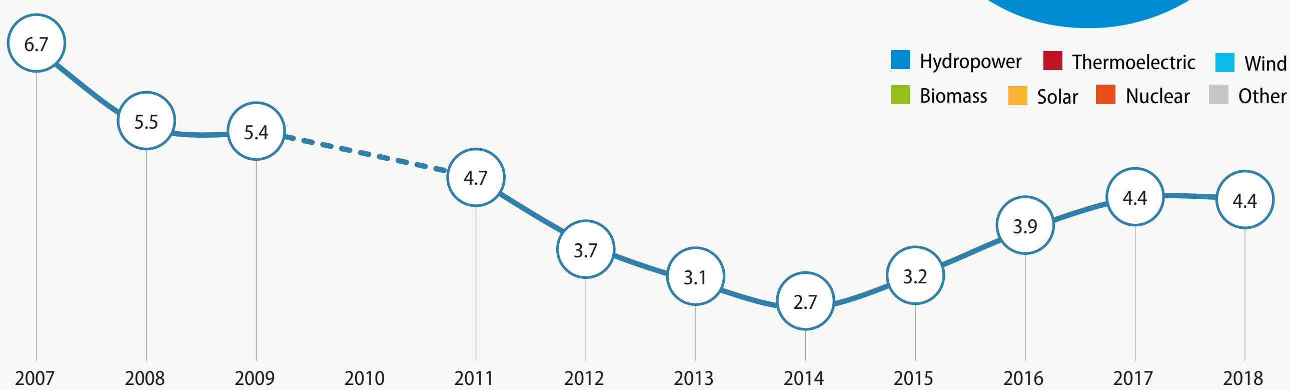
FDI flows to Brazil as a share of GDP, 2013–2019 (%)



Installed capacity for electricity generation in Brazil by source, 2020 and projection to 2024 (%)



Share of the Brazilian population living on PPP$ 1.90 or less a day, 2007–2018 (%)
In constant 2011 values



Source: World Bank's World Development Indicators, October 2020; for Internet penetration: ITU World Telecommunication/ICT Indicators Database; for energy: National System Operator

Social innovation rudderless

With the proposed National Strategy for Economic and Social Development seemingly discarded, this leaves no policy document to bridge scientific and socio-economic innovation. This integrated approach had been one of the strengths of Brazil's innovation planning and policy-making. Most notably, it had driven rapid progress for multiple indicators of social inclusion (Chaimovich and Pedrosa, 2015).

There are signs that Brazil is now slipping backwards in terms of social inclusion. For example, Brazil had managed to reduce extreme poverty and food insecurity,[7] leading the Food and Agriculture Organization of the United Nations

Box 8.1: **E-health system making a difference in Brazil during Covid-19 pandemic**

The digital transformation of the Brazilian health sector moved into high gear in 2017 with the publication of the *E-Health Strategy* by the Ministry of Health. The adoption of information technology is being encouraged to improve the Unified Health System (SUS). Medical big data and artificial intelligence are being used to develop prediction models and new drugs, as well as protocols for diagnosis and treatment. Virtual reality and remotely controlled robots are being used to train surgeons.

Hospital staff are using a range of mobile phone apps to improve patient management and care. Patient records on paper are gradually being replaced by their digital equivalent, placing a patient's X-rays, prescriptions and medical history at the physician's fingertips. Patients living in remote areas may also consult a doctor through telemedicine, a real advantage for a country as vast as Brazil.

Since February 2019, the Empresa Brasileira de Serviços Hospitalares (EBSERH) has been contributing to this digitization drive, in line with the *E-Health Strategy* and World Health Organization guidelines. Attached to the Ministry of Education, EBSERH is a state-owned company responsible for managing 40 federal university hospitals across the country. These hospitals offer free services to the local population and training for health care providers. EBSERH is the only network of federal university hospitals among the 3 526 public hospitals in Brazil.

EBSERH is also Brazil's largest network of public hospitals, with 55 000 employees and an annual budget of over US$ 7 billion. Each year, these hospitals register about 7 million medical appointments, 300 000 surgeries and 400 organ and tissue transplants. EBSERH funds internships for 4 000 medical students and residency programmes for 10 000 new doctors and other health care professionals annually.

Hospitals sharing a common communication network

The 40 federal university hospitals managed by EBSERH share a common communication network infrastructure and a single central information system, the Electronic Health Record and Hospital Management Software (AGHU), which, in April 2019, became the only management system operating in all 40 university hospitals. It provides 18 modules, including an e-register for patients, prescriptions and medication control, information pertaining to staff, the supply chain, civil registration, vital statistics and health financing, as well as on the management of equipment, drugs and other medical supplies. The AGHU database centralizes patient information from participating hospitals. It allows for big data analysis and visualization to support decision-making, including the monitoring of epidemiological trends like Covid-19.

The database is also being used to recruit patients for research projects and clinical tests, to develop prediction models, conduct patient safety tests with regard to infections and extend telemedicine to the general population. In 2020, EBSERH was in the process of integrating the AGHU database into the Ministry of Health's National Health Data Network (RNDS). Created in 2019, RNDS will, ultimately, group information on 110 million patients and 15 million monthly procedures. Prior to RNDS, there was almost no data-sharing among public hospitals.

Covid-19 extending national telemedicine network

The Covid-19 pandemic has provided an opportunity to extend the telemedicine services provided by federal university hospitals through the National Network for Telemedicine (RUTE), which was set up by the Ministry of Science, Technology and Innovations in 2006. It provides communication infrastructure in public universities and their university hospitals, health institutions and certified teaching and research hospitals. This has enabled the creation of around 140 telemedicine and e-health centres, providing virtual consultations and remote monitoring of patients' health. All EBSERH university hospitals are part of this network. The law on telemedicine adopted on 15 April 2020 (#13.989) has made it possible to extend this service to rural areas and remote towns. It is expected that riverside and indigenous populations in the Amazon could soon be within reach (Box 8.3).

Having a centralized system has made it possible to put contingency plans in place during the Covid-19 pandemic to cope with the demand for new intensive-care beds and personal protective equipment. Virtual infrastructure and systems have been enhanced to enable administrative teams to work from home and to accelerate the extension of telemedicine, such as through the use of call centres and chatbot robots to track cases of Covid-19 and monitor the health of patients with chronic diseases.

The global Covid-19 pandemic has shown that digital tools are no substitute for functioning health systems. However, they can strengthen health management and extend health care to vulnerable populations.

Source: Simone Scholze, Director of Information Technology at EBSERH, and Claudia Brandão, EBSERH Advisor for Information Technology Planning

(FAO) to declare Brazil a hunger-free nation in 2014. FAO now considers this status to be in jeopardy (Beraldo, 2020) as a consequence of the growth in poverty levels in recent years, combined with the negative effects of the Covid-19 pandemic on the economy and key SDG goals (Sumner *et al*., 2020; FAO *et al*., 2020).

In 2018, 4.4% of the population was living in extreme poverty, up from an all-time low of 2.7% in 2014 (Figure 8.1). Extreme poverty is higher among the Black segment of the population; it concerned 8.8% of Blacks in 2018, more than double the rate for Whites (3.6%) [IBGE 2019].

Of note is that the reversal in the decline of extreme poverty has been a consequence of the economic crisis of 2015–2016 and lacklustre recovery of 2017–2018. This reversal in trend demonstrates how important it is for Brazil to take a systemic approach to co-ordinating social planning and innovation.

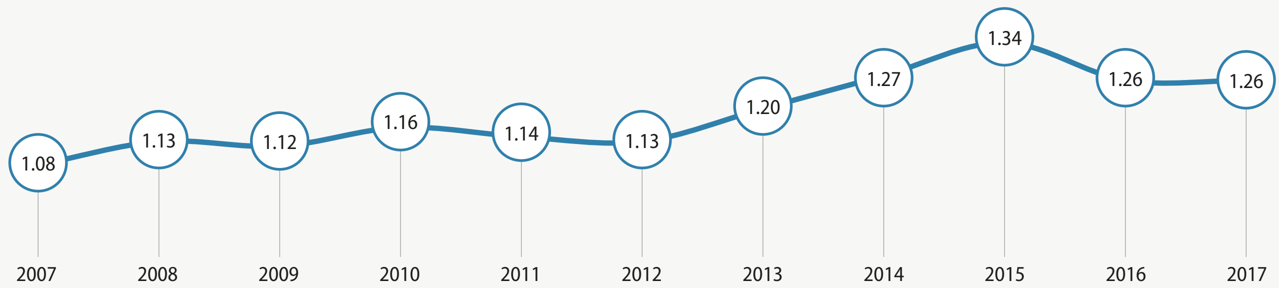
With the Covid-19 pandemic threatening to exacerbate the problem, the government introduced the Emergency Aid programme in April 2020. Funded to the end of 2020 to the tune of R$ 330 billion (*ca* PPP$ 147 billion), it has transferred monthly instalments of R$ 600 (*ca* PPP$ 266) directly to vulnerable groups, such as existing welfare beneficiaries and workers in the informal economy. The programme has been implemented via two mobile apps. Brazilians may use one (Auxílio Emergencial) to apply to the programme and the other (Caixa Tem) to receive the funds directly. By June 2020, both apps had been downloaded more than 80 million times, corresponding to about 40% of the population. By October, funds had reached more than 65 million people (MC, 2020; ITS Rio, 2020).[8]

The government plans to introduce a new direct allowance scheme in January 2021 called Renda Cidada (Citizen Income), which will replace the Bolsa Família scheme introduced in 2003 for poor families (see Figure 7.2).

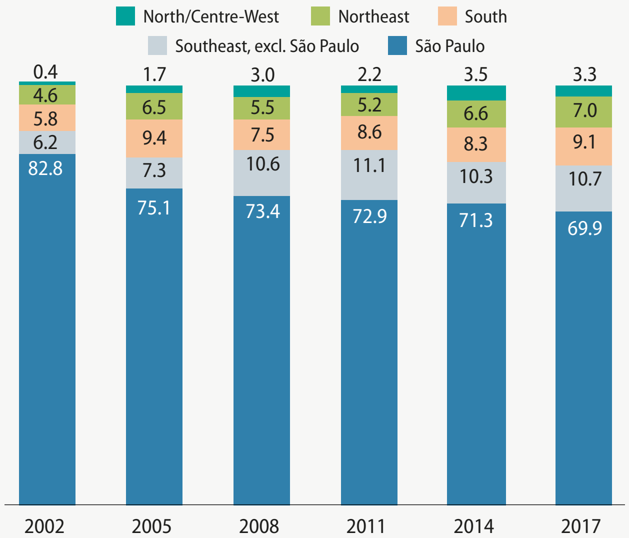
Figure 8.2: **Trends in research expenditure in Brazil**

GERD in Brazil as a share of GDP, 2007–2017 (%)

Between 2015 and 2017, Brazil's R&D expenditure dropped by 16%.

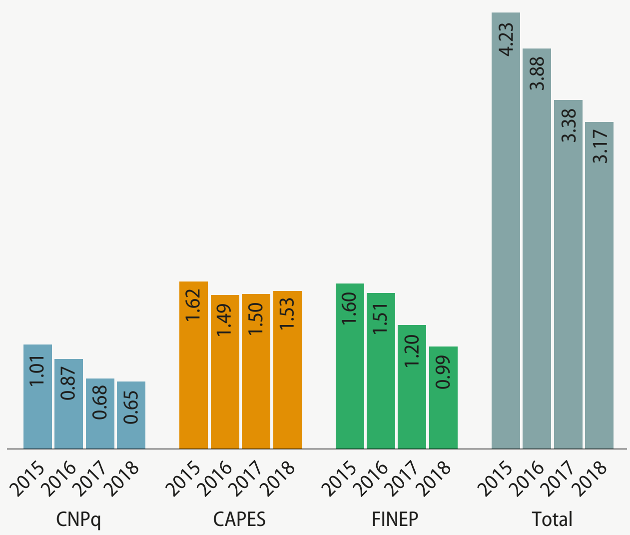


Share of state government R&D expenditure in Brazil by region, 2002–2017 (%)



The total outlay by federal agencies shrank by 21% over 2015–2018, from US$ 4.4 to 3.5 billion.

Outlays by Brazilian federal research funding agencies, 2015–2018
In PPP$ billions, constant 2017 values



Note: These data do not include outlays in undergraduate scholarships under the Science without Borders programme, which extended funding to 75 000 undergraduate students between 2011 and 2015 to enable them to spend a semester abroad. Inclusion of expenditure under this programme would have increased the outlays by CNPq and CAPES in 2015 and, to a lesser degree, in 2016, making the registered decrease in outlays for the period in the graph even larger than shown.

Reducing inequalities in higher education, primarily, had been another cornerstone of Brazilian educational policy since the early 2000s. The eighth goal of the law establishing the *National Plan for Education 2014–2024* was to guarantee twelve years of schooling for those living in poverty and rural areas, with emphasis on equality between Blacks and non-Blacks (Chaimovich and Pedrosa, 2015). This target was replicated in the Ministry of Education's *Institutional Strategic Plan* for 2015–2018, which outlined numerous policy instruments, including monitoring of the quota system for underprivileged and Black students at federal universities. This target is missing from the *Institutional Strategic Plan* for 2020–2023, however.

A shift in environmental policy

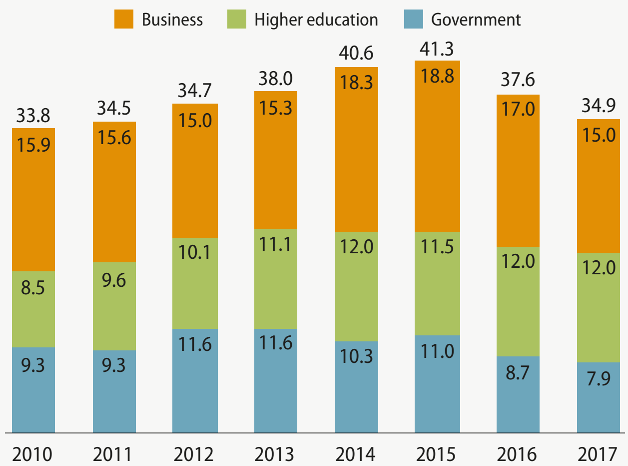
In recent decades, Brazil has been active in climate diplomacy. It had hosted the first Earth Summit (1992), which produced the first global agreement on climate, the *United Nations Framework Convention on Climate Change* (1992); this agreement, in turn, laid the groundwork for the *Kyoto Protocol* (1997) and the *Paris Agreement* (2015). Brazil also hosted the third Earth Summit in 2012. Over the years, Brazilian scientists have contributed to the regular monitoring reports of the Intergovernmental Panel on Climate Change. Brazil has also monitored climate change at the national level through the National Institute for Space Research (INPE).

However, since the current administration took office in early 2019, there has been a policy shift. This has translated into the relaxation of environmental laws and regulations. The administration has publicly questioned the scientific basis for the anthropogenic origin of climate change.

The decision to relax environmental legislation is all the more relevant in that Brazil has seen a string of ecological disasters in recent years. For example, in November 2015, the Fundão dam collapsed, sending more than 56 million m³

GERD in Brazil by sector of performance, 2010–2017

GERD in PPP$ billions (constant 2011 values)



Number of Brazilian firms in the transformative sector reporting in-house R&D

5 930
in 2017

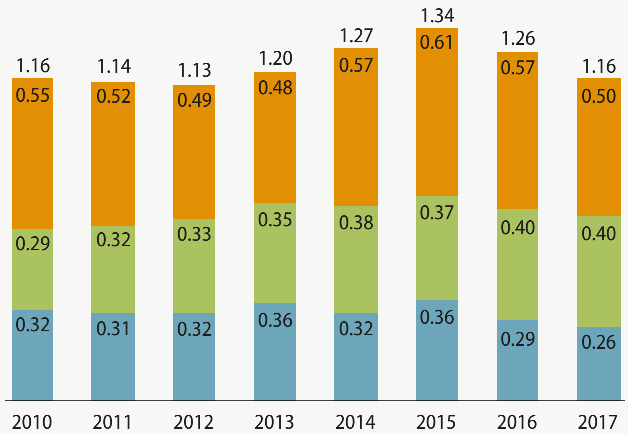
5 877
in 2014

In-house R&D expenditure by Brazilian firms in the transformative sector

US$ 10.1 billion
in 2014

US$ 8.5 billion
in 2017

GERD as a share of GDP (%)



Number of Brazilian firms in the services sector reporting in-house R&D

1 682
in 2014

1 394
in 2017

In-house R&D expenditure by Brazilian firms in the services sector

US$ 3.74 billion
in 2017

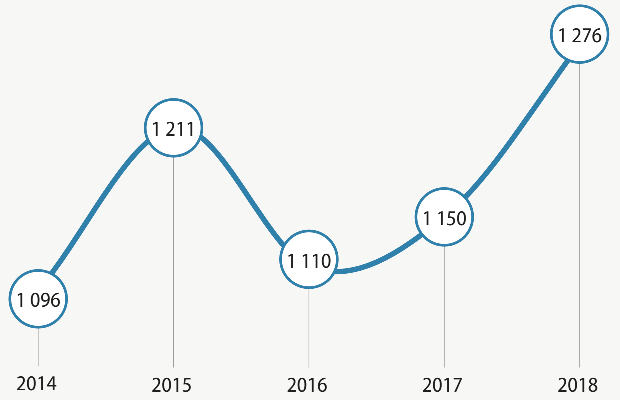
US$ 3.55 billion
in 2014

Note: 'Government' includes expenditure performed or deployed by government organizations from public funds, including science/technology funding agencies, except that performed by businesses. Higher education includes only General University Funds, for public and private institutions. Business includes all R&D performed or contracted by enterprises, including those funded by government.

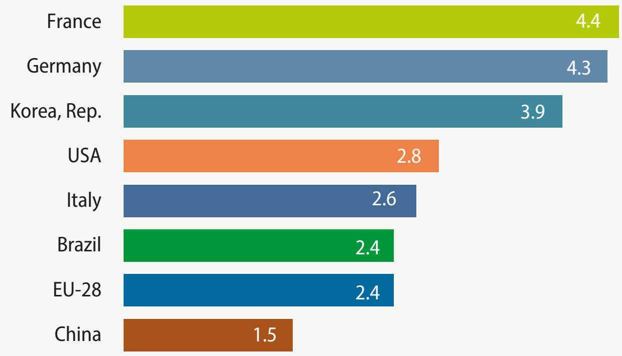
Source: for GERD as a share of GDP: UNESCO Institute for Statistics; for GERD by sector: Ministry of Science, Technology, Innovation and Communications, World Bank, data for 2017 for businesses processed by authors from IBGE (2017); for share of expenditure by region: Ministry of Science, Technology, Innovation and Communications´ ST&I indicators; for federal agencies: DadosAbertos/Ministry of Science, Technology, Innovation and Communications (CNPq/FINEP) and Geocapes/CAPES/Ministry of Education, processed by FAPESP's Group of Studies; for research expenditure by Brazilian firms: IBGE (2017)

Figure 8.3: **Trends in innovation in Brazil**

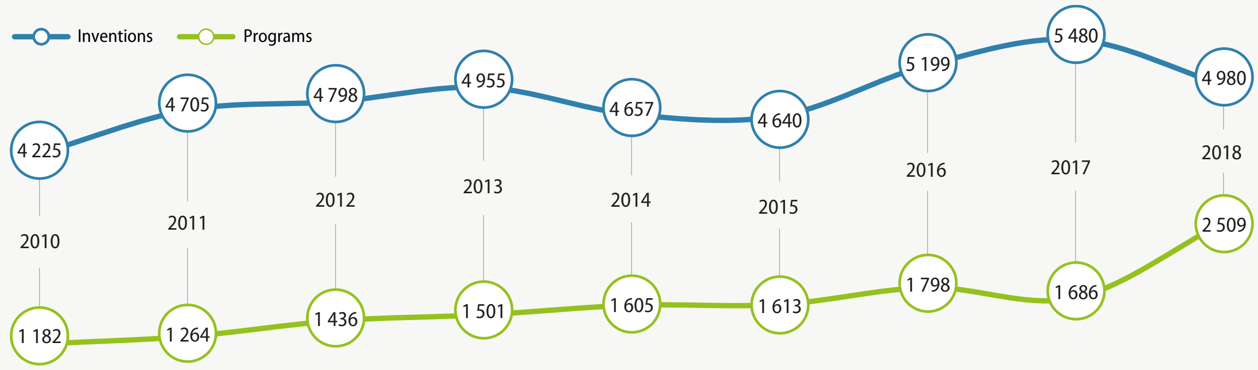
Number of IP5 patents granted to Brazil, 2014–2018



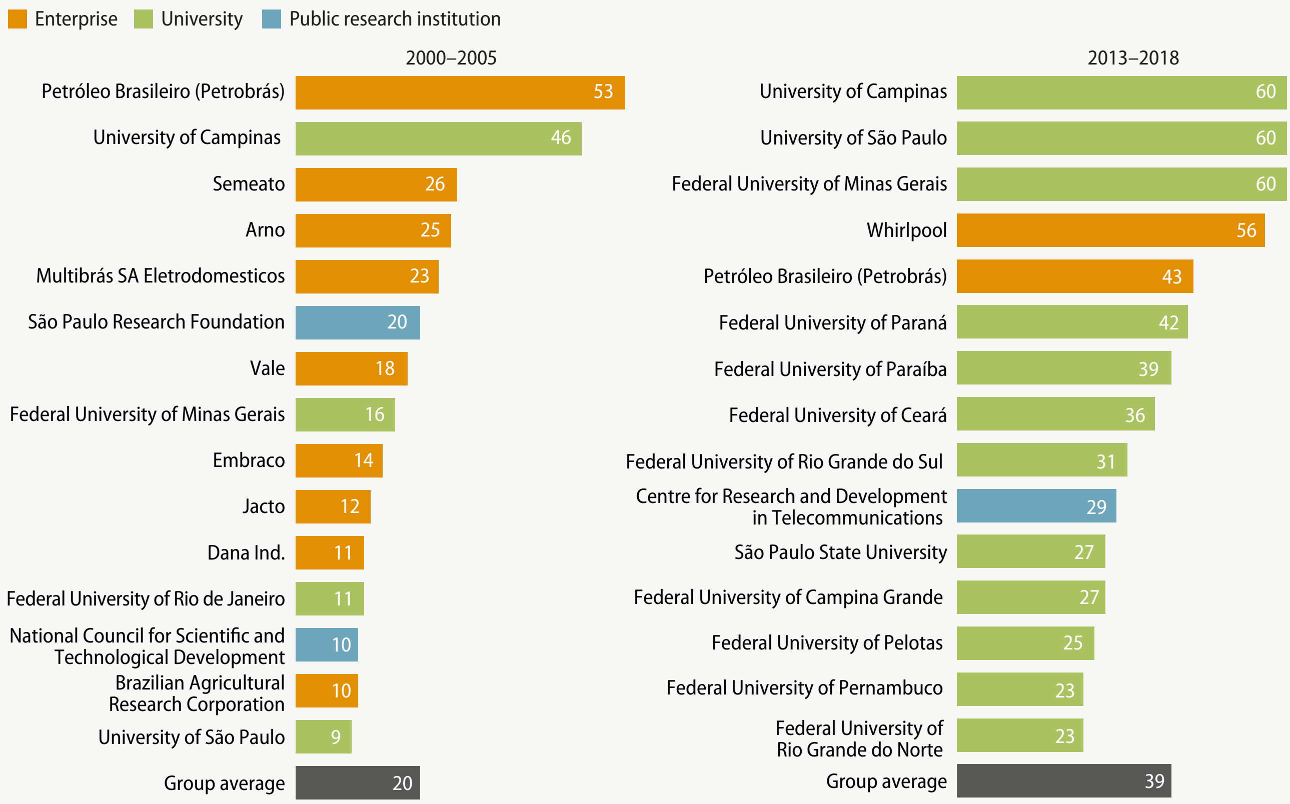
Share of scientific publications resulting from university–industry collaboration in Brazil, 2015–2017 (%)
Other countries and regions are given for comparison



Patents for inventions and software programs filed at the National Institute of Industrial Property (INPI) of Brazil, 2010–2018



Leaders in patent applications to INPI among residents of Brazil, 2000–2005 and 2013–2018



Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China.

Source: INPI Statistics; for IP5 patents: PATSTAT, data treatment by Science-Metrix; for the share of publications with co-authors from universities and businesses: Brito Cruz (2019) of toxic waste from an iron mine into the Carmo River, an affluent of the Rio Doce. In January 2019, the collapse of a tailings dam at Brumadinho in southeast Brazil poured tonnes of mud and iron ore into the Paraopeba River, boosting the concentration of heavy metals and destroying swaths of the biodiversity-rich Atlantic Forest. In both cases, the lives of tens of thousands of people were durably affected by the widespread pollution (de Oliveira Andrade, 2020).

An annual report by the National Agency for Water and Sanitation warned, in 2018, that 45 Brazilian dams were at a high risk of failure, including five retaining mining tailings (Alves, 2018). The same year, the government announced the end of megahydropower projects in the Amazon, citing environmental concerns. These dams had been financed largely by the Brazilian National Bank for Economic and Social Development (BNDES).

Satellite data from INPE reveal a 34.4% rise in deforestation in the Amazon in the twelve months to July 2019, the highest level since 2008.[9] Wildfires have placed another important biome under severe stress, the Pantanal, the world's largest tropical wetland. From January to October 2020, these fires devastated an area of 4.1 million ha, more than doubling the figure for the same period in 2019 (1.7 million ha). About 27% of the entire biome had been affected as of 18 October, a record proportion (LASA, 2020). Given the key role that these two biomes play in regulating the climate of Brazil and the wider subcontinent, there is a need for emergency measures to protect both the Amazon and the Pantanal.

A steering committee for the ocean decade

With its long coastline, Brazil is particularly invested in ocean issues. In 2018, the government launched a UNESCO Chair on Ocean Sustainability at the University of São Paulo's Oceanographic Institute. In November 2019, Rio de Janeiro hosted the South Atlantic Workshop, a regional consultation organized by UNESCO's Intergovernmental Oceanographic Commission to prepare countries for the United Nations Decade of Ocean Science for Sustainable Development (2021–2030); in 2020, the government created a national steering committee for the Decade.

One of the world's cleanest energy matrices

A water-rich country, Brazil has one of the world's cleanest energy matrices (Box 8.3). Historically, Brazil has depended upon hydropower for electricity generation. However, the share of wind and solar energy, biofuels and biomass in Brazil's installed capacity for electricity generation rose from 14.7% in 2015 to 19.5% in 2020 and is projected to reach 22.1% by 2024. If one adds hydropower to the mix, this means that the contribution of renewable sources to electricity generation increased from 80% to 85% between 2015 and 2020. This proportion should remain stable to 2024 (Figure 8.1).

This makes Brazil one of only a handful of countries drawing more than 80% of its capacity for electricity generation from renewable sources.[10]

Moreover, the use of biofuels in transportation is growing, with hydrated ethanol sales jumping from 13.0 million m^3 to 22.5 million m^3 over 2014–2019. Although most biofuels are based on ethanol, they increasingly include other types, such as biodiesel (ANP, 2020).

As much as R$ 1 billion (*ca* PPP$ 440 million) is projected in new investment in biofuels alone between 2020 and 2030 (EPE, 2019). This is being encouraged by RenovaBio, a national programme established in 2018–2019 which has adopted a regulatory framework for a decarbonization credit system (CBIO) in Brazil (ANP, 2019), in accordance with the *Paris Agreement* (OECD/FAO, 2020).

Over 170 small businesses and start-ups have made use of knowledge or technology developed by the ongoing BioGen research programme of the São Paulo Research Foundation (FAPESP), resulting in 17 patent filings. Since its inception in 2008, BioGen has invested R$ 170 million (*ca* US$ 78 million) in projects in bio-energy science and, especially, biofuels, involving more than 300 scientists from Brazil and abroad (BioGen, 2020a and 2020b).

TRENDS IN TECHNOLOGICAL INNOVATION

Tech innovation hubs: a success story for academia

The *National Strategy for Science, Technology and Innovation 2016–2022* fixes a series of targets to 2022 (Table 8.1) which complement those of the *National Plan of Graduate Education* adopted in 2014 (Table 8.1).

The *Plans of Action* provide further details of the *National Strategy for Science, Technology and Innovation 2016–2022*, while adding fresh targets and objectives for technological innovation to 2022. The basic document contains a large section on tech and innovation hubs and parks. It proposes developing more technological innovation hubs *(núcleos de inovação tecnológica*) at universities, among other measures.

Existing technological innovation hubs are a consequence of the Innovation Law of 2004 (Chaimovich and Pedrosa, 2015). This law required every scientific institution in the country to establish a technological innovation hub. Each of these centres was mandated to facilitate the transfer of technology to businesses and other organizations, help its own researchers with intellectual property registration and develop incubators for innovative start-ups. This policy partly explains the heady growth ever since in registration filings for patents and software programs. The law has also made it easier for faculty to collaborate on projects with firms. Previously, public employment rules in place at universities had imposed severe restrictions on this type of collaboration.

There is evidence that the technological innovation hubs have had a positive impact on innovation in academia, especially as concerns patents and scientific collaboration with industry (Box 8.2). According to a study by Brito Cruz (2019), Brazilian research-intensive universities show similar levels of collaboration with industry to those of other countries (Figure 8.3). Moreover, this form of interaction has expanded rapidly over the past two decades. This suggests that the technological innovation hubs have been effective.

Businesses filing fewer patents

Business innovation has been less dynamic in recent years, as testified by the drop observed in patent filing by industry (Figure 8.3). This has followed the slump in business expenditure on R&D during the 2015–2016 recession. In fact, business investment is declining across the board, along with the share of industrial output in GDP and Brazil's participation in foreign trade, especially with regard to exports of high-tech manufactured products (Figure 8.1).

The number of invention patents filed at the National Institute of Industrial Property (INPI) dropped by 9% between 2017 and 2018. This is most likely a delayed effect of the lesser investment by transformative industries. The services sector has done the opposite, raising its own investment in R&D. This led to a surge (+49%) in patent filings of software programs, possibly reflecting the growing digitalization of Brazilian society (Figure 8.3), including industry itself.

Despite getting off to a slow start, the uptake of digital technologies by the government and business sectors is picking up. To improve connectivity across the country, the Ministry of Defence deployed the Geostationary Defence and Strategic Communications Satellite in 2017 (Box 8.3). Digital technologies are being introduced into sectors as varied as health (Box 8.1), banking (Box 8.4) and agriculture (Box 8.5).

Table 8.1: **Progress towards the targets to 2022 of the Brazilian *National Strategy for Science, Technology and Innovation***

Indicator	Situation in 2014	Situation in 2017	Target to 2022
GERD/GDP ratio (%)	1.27	1.16	2.00
Private expenditure on R&D as a share of GDP (%)	0.60	0.63	1.00
Public expenditure on R&D as a share of GDP (%)	0.67	0.53	1.00
Federal government expenditure on R&D as a share of GDP (%)	0.45	0.39	0.80
Innovation index of businesses (%)	36.0	33.6	50.0
Number of enterprises active in R&D	5 600	5 500	10 000
Share of innovative businesses using government support programmes for STI (%)	39.9	26.2	40.0
Number of researchers and technical staff (FTE) involved in industrial R&D	105 452	89 689	120 000
Number of researchers per million inhabitants	888	–	3 000
Undergraduate degrees in engineering as a share of total degrees (%)	6.6	10.0^{+1}	12.0
Number of doctorate degrees conferred	17 286	$22\,894^{+1}$	$28\,987^{-2}$

-n/+n: data refer to n years before or after reference year

Note: The great majority of private research expenditure comes from the business sector. Private universities contributed just 0.03% of GERD in 2014. Public expenditure covers research organizations, which contributed 0.35% of GERD in 2014, and includes general university funds. Federal government expenditure covers federal research institutions and includes the general university funds spent by federal institutions, which contributed 0.19% of GERD in 2014.

Source: Ministry of Science, Technology, Innovation and Communications (2016) *National Strategy for Science, Technology and Innovation 2016–2022*; IBGE (2014 and 2017); National Institute of Educational Studies and Research Anísio Teixeira and Ministry of Education (2014) *Higher Education Census*; National Institute of Educational Studies and Research Anísio Teixeira and Ministry of Education (2018) *Higher Education Census*; GEOCAPES database; Co-ordination for the Improvement of Higher Education Personnel and Ministry of Education (2014) *National Plan of Graduate Education 2014*; for private expenditure on R&D: Ministry of Science, Technology and Information and Communications

Box 8.2: **Technological innovation hubs in Brazil: the case of Inova Unicamp**

The first patents filed by the University of Campinas (Unicamp) in the State of São Paulo date from 1984 when the university was less than 20 years old. Its innovation agency, Inova Unicamp, started out as a technology transfer office in 1989 before assuming its current structure in 2003.

The university was the co-leader for the number of patents filed in Brazil over the 2013–2018 period (Figure 8.3) and had accumulated 1 087 patents by 2019, second only to Petrobrás, the giant state-controlled oil company. Unicamp has 131 current licenses in place (INOVA, 2020).

Some 717 companies may be considered as spin-offs of the university, having been founded either by alumni or faculty members. Of these spin-offs, over 50 started their development at the university incubator, Incamp. Over a twelve-month period from 2018 to 2019, these companies almost doubled their revenue to US$ 3.9 billion, by which time they were directly employing more than 31 000 staff.

Two of these start-ups qualify as 'unicorns', namely, start-ups with a market value of over US$ 1 billion. One had its origins in one of the university's 'junior enterprises', where undergraduate students develop projects with help from faculty and more experienced students. These projects tend to be small in scope and are developed under a contract with an outside business.

The spin-offs specialize in the following fields, in decreasing order: information technology; consultancy; engineering; health and well-being; and other services.

Patents and licensing cover all areas of knowledge, with a preponderance of specialization in chemistry, engineering and health.

Source: compiled by authors

In December 2019, Brazil hosted the UNESCO Regional Forum on Artificial Intelligence in Latin America and the Caribbean, which attracted ministers and private companies from across the region, as well as international bodies. In 2020, UNESCO assisted the government in mapping best practices around the world, as a prelude to the formulation of a national AI strategy.

The downward trend in patent filing by industry is nothing new. Growth has been driven primarily by universities. In fact, in 2018, Brazilian businesses accounted for only 29% of invention patents and 37% of software programs filed at the INPI by residents. Research institutes, universities and other non-profit organizations accounted for more than 30% of

Box 8.3: **The Geostatic Defence and Strategic Communications Satellite: expanding digital integration across Brazil**

In 2017, the Ministry of Defence deployed the Geostationary Defence and Strategic Communications Satellite, which has been designed for both military and civil applications and cost R$ 2.8 billion (*ca* US$ 1.4 billion).

Although the satellite covers the whole country, it is especially relevant for Brazil's vast Amazon region. Covering an area of 5 million km^2 (59% of the Brazilian territory), the region was home to 20 million people at the time of the last census of the Brazilian Institute of Geography and Statistics (IGBE) in 2010. This translates into a population density of just 4 persons/km^2.

The Geostationary Defence and Strategic Communications Satellite was developed by the Franco-Italian company, Thales Alenia Space, under a contract with Visiona Tecnologia Espacial, a joint venture between Embraer, the Brazilian aircraft manufacturer, and Telebrás, the state-run telecommunications company set up in 2012 for the specific purpose of being the satellite programme's prime contractor.

Thanks to the training and technology transfer component of the contract with Thales Alenia, Visiona Tecnologia Espacial has gradually been able to develop its own projects. For instance, it provided the communications security arrangements for the 2016 Olympic Games in Rio de Janeiro.

Visiona Tecnologia Espacial has also designed and built the first Brazilian high-resolution satellite with applications for meteorological stations and projects that use the Internet of Things. With INPE, Visiona Tecnologia Espacial has developed early warning systems for natural disasters and nanosatellites; with Tesera Systems, a Canadian company, it has developed technology for making forest inventories.

Source: compiled by authors

Box 8.4: **Brazil embraces open banking, instantaneous payments and AI**

The term open banking refers to the ways in which customer data and other information are shared between banks, including via instantaneous payment systems. The Central Bank of Brazil began discussing this concept in early 2018 (Damaso, 2019) before approving general guidelines for an open banking system in April 2019 (BCB, 2019).

Relevant legislation has since been passed, including to establish norms for data-sharing and consumer rights, to clarify rules for fintech companies and to pave the way for a free national instantaneous payment system.

A ten-second service

On 12 June 2020, the Central Bank established the Instantaneous Payment System and Instantaneous Payment Account (BCB, 2020), which now goes by the name of PIX. Once fully operational, this system will provide a free real-time system (within ten seconds) for individuals and businesses wishing to make bank transfers and payments anywhere across the national territory.

The Central Bank opened PIX for registration on 5 October 2020. Within five days, almost 25 million registrations had been filed (Agência Brasil, 2020). This shows just how much interest the initiative has sparked. It also shows a high level of public confidence in digital banking services.

The seeds were sown decades ago

The digital transformation of the Brazilian banking system over the past three decades has been one of the few positive consequences of the highly protectionist national Informatics Law in place during the 1980s and early 1990s. Despite restricting access by industry and firms in the services sector to the most advanced computer technology available internationally, making it hard for Brazilian industry to compete in the global arena (Chaimovich and Pedrosa, 2015), the law incited the large national private banks to become directly involved in establishing hardware and software firms.

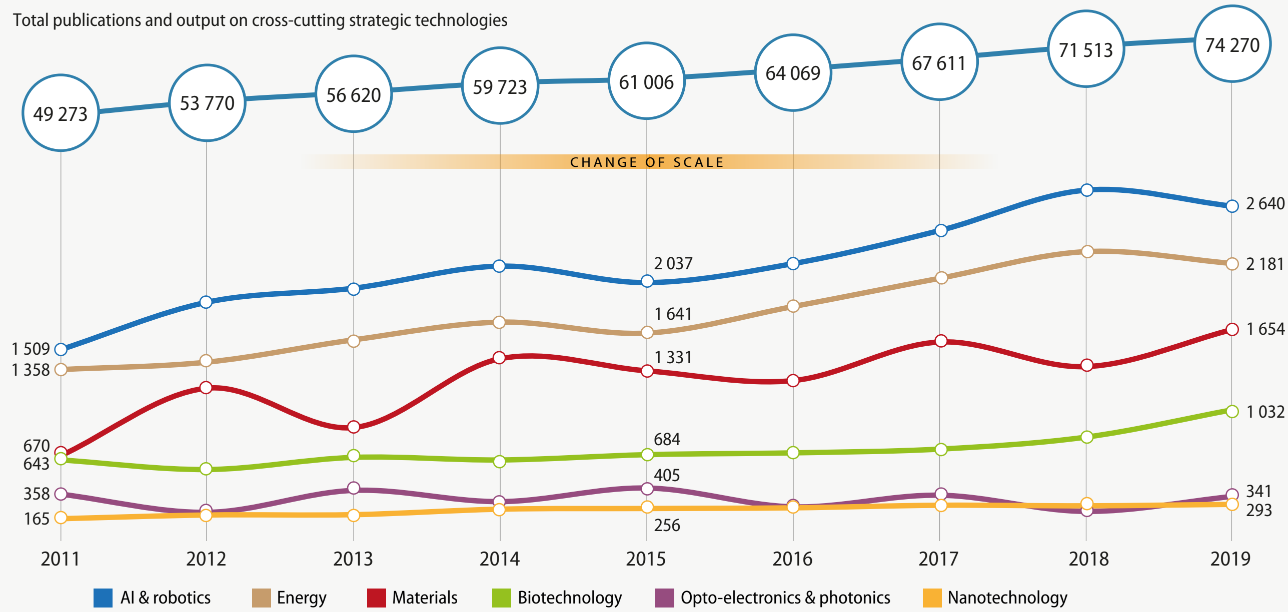
When Brazilian markets were opened to international competition in the 1990s, only a handful of the local computer hardware firms survived. However, their acquired experience of information technology would, later, help banks to develop their online platforms and, more recently, AI-based services. This has been accompanied by extensive communication technology and infrastructure, now used by the new instant payment service. For example, Bradesco, one of the country's two largest private banks, has been at the forefront of the digital revolution in Brazil, thanks to its establishment of a Digilab back in 1979. Bradesco was the first Brazilian bank to have an AI interface. Developed by IBM and launched in 2016, this chatbot can recognize spoken Brazilian Portuguese, thanks to Banco Bradesco's expertise in this area.*

*Marcelo Frontini, Head of Digital Channels at Banco Bradesco's AI project conveyed this information to the authors in an interview in February 2020.

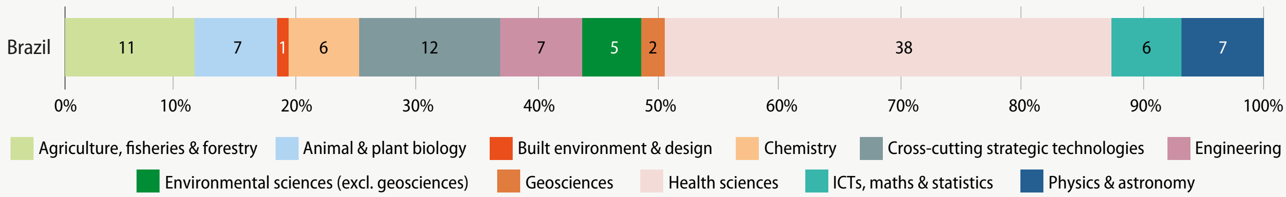
Source: compiled by authors

Figure 8.4: **Trends in scientific publishing in Brazil**

Volume of scientific publications in Brazil, 2011–2019



Scientific publications in Brazil by broad field of science, 2017–2019 (%)



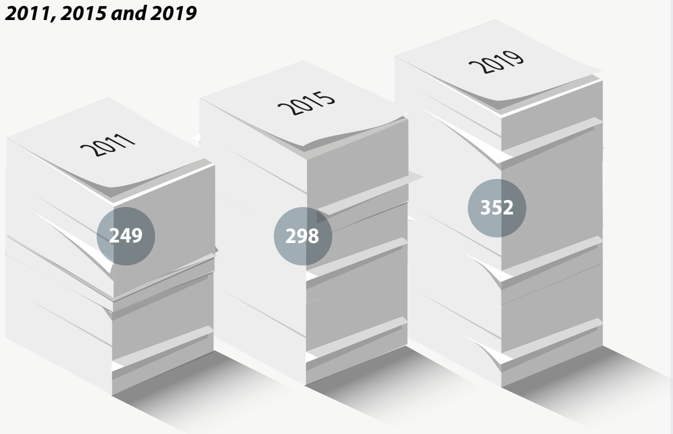
0.91

Average of relative citations for Brazil, 2014–2016; the G20 average is 1.02

34%

Share of publications with foreign co-authors in Brazil, 2017–2019; the G20 average is 25%

Scientific publications per million inhabitants in Brazil, 2011, 2015 and 2019



How has output on SDG-related topics evolved since 2012?

Brazilian scientists are publishing at least three times more than the global average proportion on the following topics: traditional knowledge, help for smallholder food producers, the sustainable use of terrestrial ecosystems and the status of terrestrial biodiversity. Brazil's output on agro-ecology is even 4.5 times the global average.

In health research, the intensity of output is 4.2 times the global average for tropical communicable diseases. Moreover, the number of publications on new or re-emerging viruses that can infect humans increased by 250% from 643 (2012–2015) to 1 605 (2016–2019), in the context of the Zika epidemic. Despite this scientific expertise, the WHO Covid-19 Dashboard reported in October 2020 that Brazil had the third-highest national caseload of this coronaviral disease after the USA and India.

Brazil produces less than the global average proportion on the clean energy topics under study, with the exception of hydropower (double the average intensity): 827 (2012–2015) and 1 191 (2016–2019) publications, and on biofuels and biomass (2.4 times the global average): 2 433 (2012–2015) and 3 222 (2016–2019).

For details, see chapter 2

Brazil's top five partners for scientific co-authorship, 2017–2019 (number of publications)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Brazil	USA (25 770)	UK (10 880)	Germany (8 757)	Spain (8 695)	France (8 670)

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

Box 8.5: **Digital agriculture: connectivity for food and biofuel production in Brazil**

The past five years have seen a rapid expansion of digital technology in agriculture. This is a vital economic sector for Brazil, the third-biggest producer (after China and the USA) and second-biggest exporter (after the USA) of agricultural products.

One of the main uses of digital technology is to connect and integrate equipment used to labour the fields, such as tractors (Zaparolli, 2019). There are two types of solution, one using the available telecommunications infrastructure and the other employing local radio frequency systems.

An example of the first type is ConectarAGRO; it uses broadband access to Internet and involves a Telecom Italia subsidiary in Brazil called TIM, as well as several Brazilian companies specializing in agricultural equipment and others specializing in automation, software and connectivity (Tiago, 2019).

A notable example of the second type of solution is the partnership between CPqD, a non-profit research institute based in Campinas which is, currently, the largest software registering organization in Brazil, and Usina São Martinho, one of the largest sugarcane producers in the world. They have developed an Internet of Things system which uses a radio frequency to connect agricultural equipment in the field without recourse to public telecommunications infrastructure. This approach has since been adopted by other agricultural businesses; it has also been licensed to equipment companies such as John Deere (Zaparolli, 2019).

Source: compiled by authors

patent applications and 42% of software program filings, the remainder being filed by individuals (FAPESP, 2017).

This means that non-profit organizations (excluding individuals) accounted for more than half of patents and software programs filed by Brazilian residents in 2018. This compares with 30% in 2012 and just 7% in 2000. The latter ratio is close to that observed in other regions. For example, European universities and other non-profit organizations accounted for only 6% of patent filings to the European Patent Office over the 2012–2016 period (FAPESP, 2017).

A comparison of the 2000–2005 and 2013–2018 periods reveals that industry has almost vanished from the top ten organizations for invention patent filing in Brazil. Only the Brazilian state-run oil company, Petrobrás, made it into the top ten for 2013–2018, in fourth place (with 54 filed patents); moreover, only the Brazilian branch of Case New Holland, a Dutch conglomerate, made it into the top 25 Brazilian entities, in twelfth place (with 30 filed patents), along with 21 universities and two research institutes (Figure 8.3). For comparison, just four universities had made it into the top 25 between 2000 and 2005.

In addition, there has only been a modest increase in the number of patents filed over these twin periods, well below the pace of patent filing by many other emerging economies, especially those in Asia. This is another sign of stagnation in technological innovation in Brazil.

Targets to boost industrial innovation

The *National Strategy for Science, Technology and Innovation 2016–2022* fixes specific targets to 2022 for industrial innovation, such as to:

- increase by 20% the number of enterprises and people employed in science and technology parks;
- support 250 projects in research and innovation by new enterprises installed in these parks;
- support the establishment of 1 000 new high-growth innovative enterprises (start-ups) in technological parks and innovation hubs; and
- expand from 11 to 30 the number of laboratories associated with a national programme supporting prototyping labs.

The *National Strategy* recommends greater co-operation between federal government agencies and state science funding agencies, in order to expand support for small businesses and foster collaboration on collecting data and developing indicators (p. 34).

Targets related to patents and scientific publications, on the other hand, are conspicuous by their absence from both the *National Strategy for Science, Technology and Innovation* and the *National Plan of Graduate Education*. The focus here is primarily on input indicators, such as expenditure, the number of enterprises active in innovation and the number of researchers.

TRENDS IN SCIENTIFIC PUBLISHING

Scientific community has risen to the challenge

Even as patent filing by industry has tended to stagnate, indicators related to graduate education and academic research have shown steady progress. This dynamism has spawned some interesting developments, such as the rapid responses to the Zika and Covid-19 crises in 2016 and 2020, respectively (Box 8.6). Brazilian scientists and engineers have also designed and built Sirius, a highly sophisticated synchrotron light source which will be invaluable for basic research (Box 8.7).

Although the volume of scientific publications has ballooned since 2011, there has been less progress in important areas such as environmental and energy research. There has been little focus on energy generation despite localized efforts like the BioGen programme. Between 2012 and 2019, Brazilian publications on the development and use of sustainable means of transportation amounted to just half (0.53) the global average intensity on this topic. Brazilian scientists have also published more on hydropower than other types of renewable energy, despite biomass and wind and solar energy playing a greater role in electricity generation. The number of Brazilian publications on hydropower is double the global average intensity (Figure 8.4).

Box 8.6: Brazilian scientists rise to the challenge of Zika and Covid-19

In 2015, scientists at the Federal University of Pernambuco in Recife were the first to link a rise in the incidence of newborns displaying an abnormally small head and resultant brain damage (microcephaly) with an outbreak of Zika, transmitted to their mothers by mosquitoes.

A study conducted by FAPESP found that, as of April 2018, Brazil was second only to the USA for the volume of scientific publications on Zika, accounting for 15% of the total (Figure 8.5). In the first and third positions were two Brazilian institutions with a tradition for research on tropical diseases, the Oswaldo Cruz Foundation (Fiocruz) and University of São Paulo. The US Centre for Disease Control and Prevention had the second-largest tally.

Among publications with 100 or more citations, Brazilian scientists authored 28%, a share that increased to 45% when the subject included microcephaly.

Vaccine development for Covid-19

By the end of July 2020, there were already close to 21 000 publications on the topic of Covid-19 in the Web of Science database. Brazilian scientists had authored 584 of those, placing them eleventh worldwide, ahead of countries with strong scientific research systems such as Switzerland, the Netherlands, Japan and the Republic of Korea.

Scientists from the University of São Paulo had authored in 142 publications (42nd place worldwide), ahead of the University of California San Francisco (130) and Cornell University (135) and behind Stanford (156) and Yale Universities (158) in the USA. Fiocruz counted 40 publications.

One joint Brazilian–UK study found that the city of Manaus in the Brazilian Amazon had attained herd immunity, after about 66% of the population was infected with Covid-19 between March and September 2020. The researchers estimated the fatality ratio at 0.28% in a population where only 6% are older than 60 years of age (Buss *et al.*, 2020).

FAPESP has launched calls for research proposals on Covid-19 and, by July 2020, had invested over PPP$ 100 million in new and converted projects, including seven related to vaccine development. One such project is being led by Jorge Kalil at the School of Medicine within the University of São Paulo. The proposed vaccine should be cheap to produce and provide genetically and ethnically diverse populations worldwide with immunity.

The Federal University of São Paulo and Fiocruz are co-ordinating third-phase clinical trials on 5 000 Brazilian volunteers of the vaccine developed jointly by Oxford University in the UK and the British firm AstraZeneca.

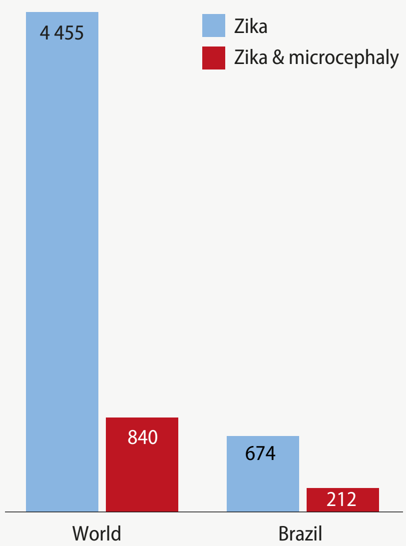
The Butantan Institute in São Paulo was doing the same for the Chinese Sinovac vaccine until the government halted the trial in November 2020.

Both Fiocruz and the Butantan Institute have a long history of developing and producing vaccines for various diseases.

Source: compiled by authors

Figure 8.5: Trends in Brazilian publications on Zika and related microcephaly

Volume of Brazilian publications on Zika and related microcephaly and global total, 2014–2018



Top institutions for publications on Zika and related microcephaly, 2014–2018

	All publications, 2014–2018		Publications with at least 100 citations*	
	Zika	Zika & microcephaly	Zika	Zika & microcephaly
Oswaldo Cruz Foundation, Rio de Janeiro	218	69	11	8
Centers for Disease Control and Prevention (USA)	202	34	10	3
University of São Paulo	155	38	8	7
University of Texas, Medical Branch, Galveston (USA)	105	24	5	5
Harvard University (USA)	10	22	4	3
Johns Hopkins University (USA)	97	28	5	5
University of London (UK)	91	33	2	2
Emory University (USA)	73	17	5	3
INSERM (France)	73	14	4	–
Federal University of Rio de Janeiro	72	27	6	2

*as of April 2018

Source: Pesquisa FAPESP (2018) Dados: publicações científicas sobre zika e microcefalia. Collation of the Web of Science core collection, all types of publication, CC-VY-NC-ND. See: https://tinyurl.com/yyvwkg6u

Box 8.7: **Sirius: the most complex scientific infrastructure ever built in Brazil**

Sirius is the largest and most complex scientific infrastructure ever built in Brazil and one of the first fourth-generation synchrotron light sources in the world.

It has been designed by Brazilians who have spent the past six years building the synchrotron in Campinas with a federal investment of about US$ 500 million. It will have 40 beam lines by the time it becomes fully operational in 2021.

Sirius is part of the Brazilian Synchrotron Light Laboratory, which has been operational since 1997. It is part of the National Centre for Research in Energy and Materials (CNPEM), the first Brazilian Social Organization.* CNPEM also runs laboratories in the areas of biosciences, nanotechnology and bioethanol.

One of the biggest challenges in building Sirius has been to maintain the synchrotron's thermal and vibrational stability as it accelerates electrons around the storage ring at phenomenal speeds to produce light.

In December 2019, Sirius produced its first X-ray microtomographs showing extremely detailed images of minerals and the heart of a mouse.

Industrial applications of Sirius will include developing ways to break down asphaltenes to allow the pumping of high viscosity oil; explaining the elementary process of catalysis in the production of hydrogen from ethanol; and understanding the interaction between plant and pathogen for the control of citrus diseases.

Source: compiled by authors

* Social organizations are private, non-profit organizations developed and financed primarily under government contract. CNPEM operates under a contract with the Ministry of Science, Technology, Information and Communications. For more background on social organizations, see Chaimovich and Pedrosa (2015).

TRENDS IN RESEARCH EXPENDITURE

Research expenditure down since recession

The *National Strategy for Science, Technology and Innovation* has recommended that each of the government and private sectors increase their research expenditure to 1.0% of GDP by 2022.

This target will not be reached, as GERD had fallen back to the 2010 level of 1.26% of GDP by 2017, after peaking at 1.34% in 2015 (Figure 8.2). On the contrary, in light of Brazil's economic performance in 2018–2019 and fallout from the Covid-19 pandemic in 2020, the outlook looks bleak for research expenditure in terms of absolute value. Despite a projected drop in GDP, business investment in R&D as a share of GDP is expected to shrink.

It must be said that the level of business research expenditure is a relatively weak predictor of technological innovation for countries like Brazil, as the bulk is invested in adapting existing technologies. However, there has been a concurrent deterioration in indicators of industrial output in patent filing for inventions and high-tech trade in consumer goods since the previous *UNESCO Science Report* (Chaimovich and Pedrosa, 2015).

Higher education is the only sector to have seen a rise in research expenditure since 2015 (Figure 8.2). This trend may be short-lived. Both public and private tertiary institutions have seen a cut in revenue since 2017 and the year 2020 is shaping up to be worse.

Cutbacks by federal agencies

There are signs that graduate education, the crown jewel in the Brazilian innovation ecosystem, may be entering a period of stagnation. The period between 2015 and 2018 witnessed a sharp drop in budget outlay by both the National Council for Scientific and Technological Development (CNPq), which irrigates public research, and the Funding Authority for Studies and Projects (FINEP), which nurtures business research. For CNPq, the drop was 36% and, for FINEP, 38% (Figure 8.2).

Recent data show a drop in the number of doctoral scholarships granted by the body responsible for funding, accrediting and assuring the quality of post-graduate programmes, the Co-ordination for the Development of Higher Education Personnel (CAPES), implying a reduction in outlay by CAPES for 2019 and, likely, for 2020 (CAPES, 2020).

Overall, the budget outlay by federal agencies decreased by 25% from 2015 to 2018. Given the drastic drop in federal revenue in the wake of the economic recession caused by the Covid-19 pandemic, it is expected that 2020 data will show further reductions for all three agencies.

These cutbacks will eventually be reflected in the number of postgraduate degrees and scientific publications, as well as in terms of technological innovation: patents, software, new products, etc.

Moreover, since many states depend almost exclusively on federal funds for research and innovation, especially graduate education and scientific research, the current trend may eventually exacerbate the disparities between southern and southeastern states, especially the State of São Paulo, on the one hand, and states in the centre-west, northern and northeastern regions, on the other.

TRENDS IN HUMAN RESOURCES

More doctorates but an uncertain future

The vast public university system has always been the backbone of Brazilian science. In turn, it relies on the bedrock of a strong and diversified graduate education system. There has also been robust growth in the number of doctorates conferred; the target to 2022 for 29 000 new degrees could be reached (Table 8.1), if the average pace of yearly growth of 6.3%, seen over 2015–2019, is maintained (CAPES, 2020). Undergraduate education, on the other hand, is more dependent on the private sector (Chaimovich and Pedrosa 2015). The target of having 12% of all undergraduate degrees conferred in engineering by 2022 stands a good chance of being reached.

From 2010 to 2015, the number of doctoral scholarships granted by CAPES almost doubled. After progressing at 14% per year until 2015, the pace of growth slowed to just 4% for the cumulative three-year period to 2018 (Figure 8.6). As doctoral programmes take at least four years to mature, the effects of these trends will only be reflected in the number of degrees being granted in 2020 and beyond.

Women making inroads in higher education

Women have made faster progress than men in educational attainment in recent decades, reflecting a general trend in Brazil that is more closely linked to changing social attitudes than any specific government policy. Women have formed the majority of new degree-holders since 2005. In 2017, they accounted for 54% of graduates.

Only the fields of engineering and exact and Earth sciences were dominated by male graduates (66%) in 2017. Women dominated degrees in health sciences (67%) [CAPES, 2020].[11]

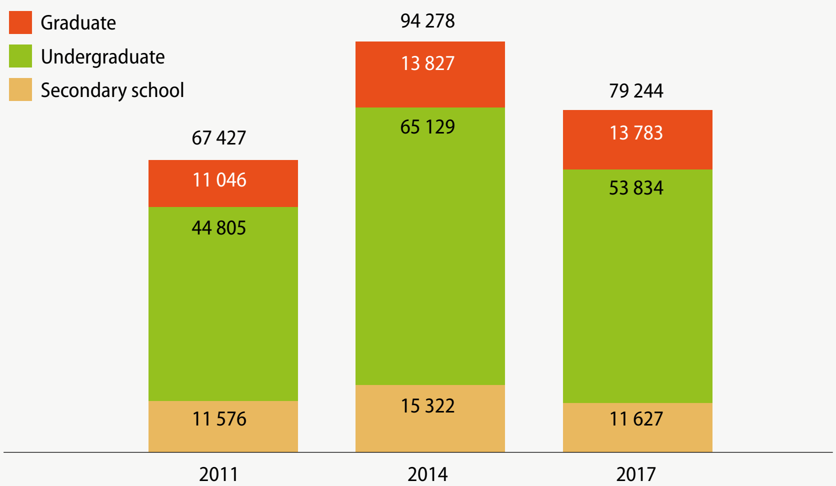
Slow growth in number of researchers

The Ministry of Science, Technology and Innovations has not updated its aggregate data on the number of researchers

Figure 8.6: **Trends in human resources in Brazil**

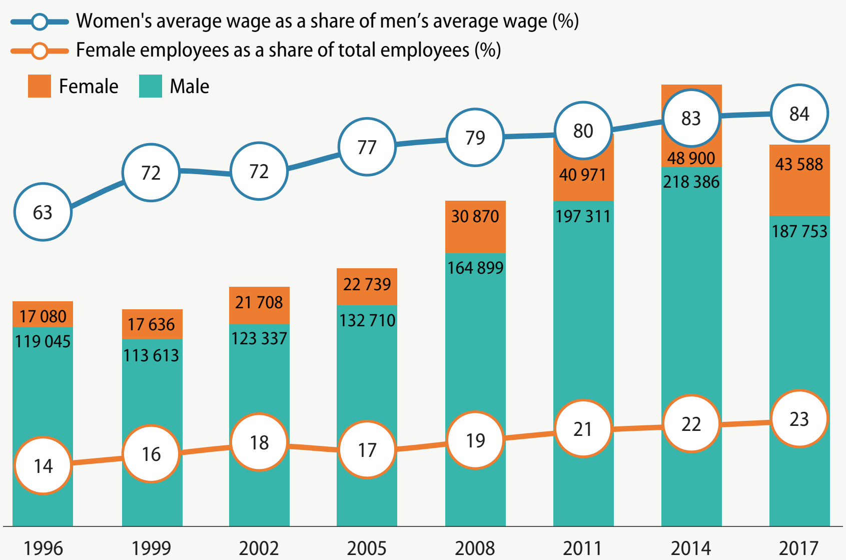
Researchers (HC) employed in business enterprise sector in Brazil, 2011, 2014 and 2017

By highest level of education



The share of researchers without a university degree decreased from 17.2% in 2011 to 14.7% in 2017.

Employment in engineering in Brazil, 1996–2017



A smaller proportion of female (11%) than male (14%) engineers lost their jobs in the 2014–2017 period marked by recession.

Researchers (HC) in Brazil

316 822
in 2014

Academic researchers (HC) in Brazil

66 026
in 2017

61 197
in 2015

Doctoral scholarships provided by CAPES

43 327
in 2019

42 779
in 2015

21 941
in 2010

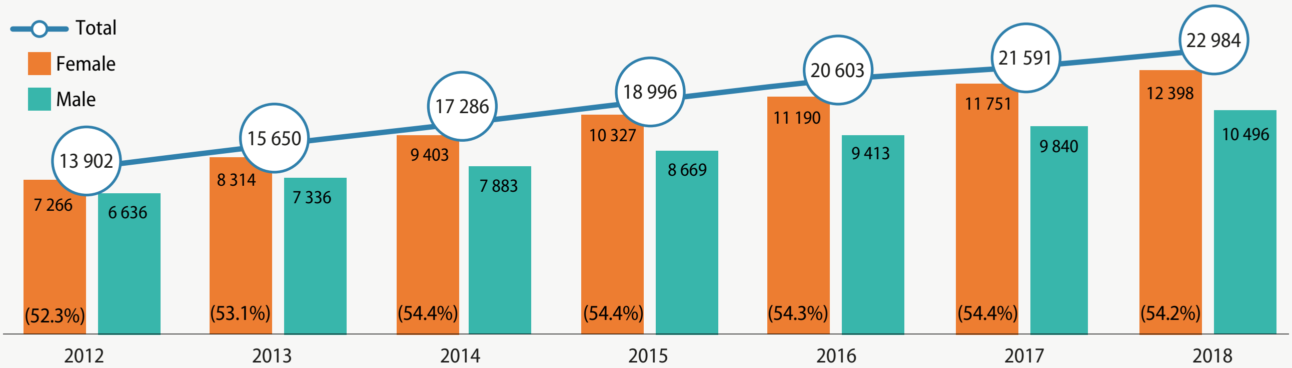
The number of doctoral scholarships granted by CAPES has decreased for the first time in a decade, declining by 2.7% between 2018 and 2019.

nationwide since 2014. However, there are ways of getting around this obstacle, at least partially. Thanks to IGBE's 2017 Innovation Survey and CAPES' data on enrolment in graduate education programmes at the country's universities and some research institutes, a proxy for the number of researchers taking part in academic research, we can draw some conclusions as to the status of the research community in Brazil.

From 2015 to 2017, the number of researchers progressed by 3.9% per year. Although the pace of growth has been slower than for either the period from 2005 to 2010 (5.8%) or that from 2010 to 2015 (6.1%), graduate education has not been hit as hard by the recession of 2015–2016 as other areas of science and technology (Figure 8.6).

If we look at research personnel as a whole, including technicians and support staff, we see that the expansion which accompanied the economic boom up until 2014 has since gone into reverse. Most affected by budget cuts between 2014 and 2017 were research personnel having completed secondary education. One-quarter of them (24%) lost their jobs, compared to 17% of research personnel with undergraduate degrees and 0.3% of those with postgraduate degrees.

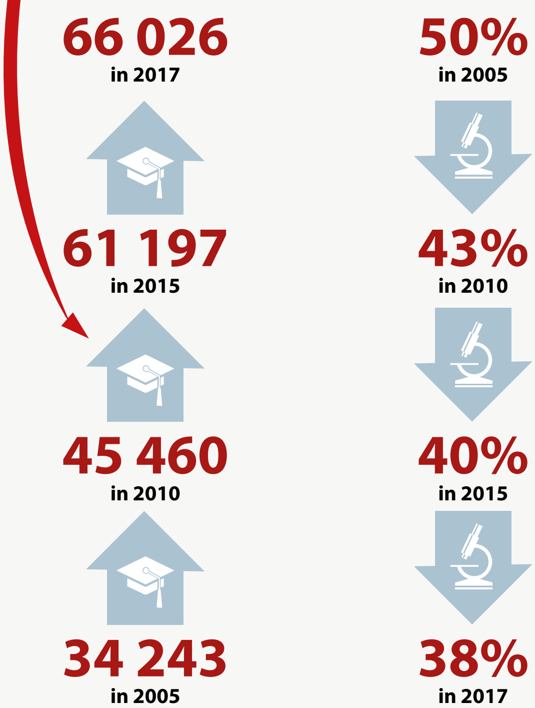
Number of doctorates awarded in Brazil by sex, 2012–2018



The 2010–2015 period witnessed the fastest pace of growth in graduate education since 2005.

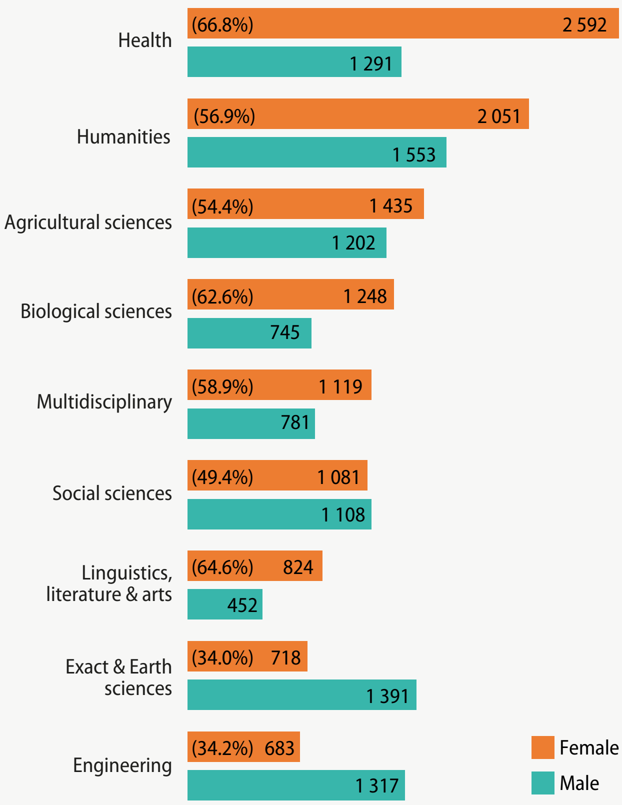
Number of Brazilian students enrolled in graduate education

Share of researchers among faculty members at the Universities of São Paulo and Rio de Janeiro



Doctorates granted in Brazil by field of study and sex, 2017

Share of women is given between parentheses



Source: For academic researchers: CAPES (2020); for researchers in business: IBGE (2011, 2014 and 2017); for employment in engineering: Ministry of Labor and Employment's (MTE) Annual List of Social Information (RAIS), data processed by authors; for doctorates: GEOCAPES database and Plataforma Sucupira

The data for 2014 and 2017 include the totals for female employees but without reference to educational attainment. Women made up 21% of research personnel (19 660) in 2014 and 24% (18 673) in 2017, suggesting that women were less affected by budget cuts than their male counterparts. From this, we can surmise that more women than men working in the field of research had reached the higher echelons of education. We find the same pattern in engineering.

Gender pay gap narrowing

One goal of the *National Strategy for Science, Technology and Innovation 2016–2022* has been to improve the participation of women in science and engineering professions. State and federal policies initiated prior to 2015 have led to a notable improvement in this area. For instance, the pay gap between men and women has narrowed to historical levels.

Despite the recession in 2015, women engineers have maintained their upward trajectory of the past 20 years. By 2017, they accounted for 23% of Brazilian engineers (Figure 8.6). Over the three years to 2017, 14% of male engineers lost their jobs, compared to 11% of their female colleagues.

Female engineers still earn only 84% as much as their male colleagues, even though the pay gap is gradually narrowing (Figure 8.6). Women also tend to have a higher level of educational attainment than men: 12.0% of female engineers held a postgraduate degree in 2017, compared to 7.4% of their male colleagues.

The discrepancy in educational attainment persists for women who identify as Black: 9.0% hold a postgraduate degree, compared to 5.8% of Black men. Overall, Blacks account for one in five Brazilian engineers: 21% of men and 22% of women.

At least in engineering, the gender pay gap in Brazil is more closely associated with a person's sex than with their ethnicity. The average salaries of Black (R$ 12 071) and White men (R$ 12 949) were similar in 2017 and the same can be said for women (R$ 10 563 for Whites, R$ 10 161 for Blacks).

TRENDS IN REGIONAL DISPARITIES

Policies starting to bear fruit

The *National Strategy for Science, Technology and Innovation 2016–2022* has fixed the objective of reducing regional disparities in science and engineering. Federal and state policies implemented prior to 2015 are now beginning to bear fruit.

Brazil has managed to reduce the historical concentration of graduate education in the States of São Paulo and Rio de Janeiro, home to the country's largest and more traditional public universities. In 2005, these two states accounted for 68% of doctorates. By 2010, this share had dropped to 59% then to 49% (2015) and 45% (2018) [CAPES, 2020].

This trend towards decentralization is likely to continue, albeit at a slower pace, since it is partly a consequence of the expansion of the federal system of universities between 2005 and 2012, which has now been completed.

Although it would be beneficial for the younger group of federal universities and some newer state systems to expand graduate education in the coming years, this may not materialize, in light of the cutback in the number of graduate scholarships adopted by the incoming administration in 2019, as well as existing restrictions on investment.

In terms of the regional distribution of faculty members, the States of São Paulo and Rio de Janeiro have the greatest concentration but their combined shares have decreased over the years, as faculty numbers have risen elsewhere. These two states accounted for about 50% of research faculty in 2005, 43% in 2010, 40% in 2015 and 38% in 2017.

Regional disparities in business innovation

Despite some efforts by central and local governments, the states in southeast and south Brazil still host about 90% of research-intensive companies.[12] In fact, the State of São Paulo alone maintained a 49% share of in-house research expenditure by industry in 2014 and 2017. To put this in context, the State of São Paulo accounted for 22% of the Brazilian population and 32% of national GDP in 2017.

Thus, there remain yawning differences between north and south where business innovation is concerned, despite some progress since the early 2000s in decentralizing the Brazilian economy during a time when states in the northeast experienced faster growth than elsewhere.

Regional disparities in state research funding

There are also wide regional disparities in state funding of R&D, despite some progress in the past two decades, especially since the government expanded the federal system of universities in some states.

However, the State of São Paulo accounts for an even larger share of public research expenditure by state than it does for business expenditure on R&D, if one excludes federal funding (Figure 8.2). Since 2014, there has been very little change in this indicator.

The State of São Paulo's pre-eminence in state-funded R&D can be put down to a potent combination of strong public universities (University of São Paulo, Unicamp, Unesp) and sustainable research funds administered by FAPESP. The foundation enjoys operational autonomy, thanks to funding in the form of an annual 1% share of state sales taxes, under a provision inscribed in the State Constitution. The Constitution also stipulates that only 5% of FAPESP's budget may be used for administrative purposes, thereby limiting potential misuse (Chaimovich and Pedrosa, 2015).

Up to now, disparities in state funding of science have been compensated by the outlays of federal agencies but, as we have seen, their capacity to fund STI has been compromised in recent years.

CONCLUSION

Notable scientific and social achievements

The quality and quantity of Brazil's scientific output has progressed considerably since 2011, as witnessed by publication trends. Brazilian scientists have risen to the challenge of two successive epidemics, Zika in 2015 and Covid-19 in 2020. In the latter case, Brazilian researchers and organizations have joined international efforts to produce vaccines against Covid-19.

Brazilian scientists and engineers are also on the verge of completing Sirius, one of the world's most sophisticated synchrotron light sources. This is an admirable achievement.

Likewise, Brazil has launched a new geostationary satellite capable of providing the most remote parts of the country with broadband, with positive socio-economic spillovers.

Digital technologies like AI are starting to be used by government departments and in the more innovative and competitive economic sectors such as banking and agriculture. The Central Bank's new instantaneous payment system promises to revolutionize financial transactions in Brazil, one of the first such initiatives in the world. In the food and biofuel production businesses, AI systems and the Internet of Things are being developed and deployed.

Another success story are the technological innovation hubs on university campuses. These have boosted patent generation, scientific collaboration with industry and the incubation of tech-based start-ups.

There has also been progress in reducing regional disparities in science and graduate education. In engineering, women have been less affected by budget cuts than their male colleagues, in a reflection of their higher levels of educational attainment – and perhaps also the gender pay gap, even if the latter has dropped to a historically low level.

With regard to environmental policies, there are positive initiatives like the decarbonization credit system (ANP, 2019), which is in step with the *Paris Agreement* (2015). Brazil remains one of the rare countries that can lay claim to having over 80% of electricity generated by renewable sources. The RenovaBio programme and the 2020–2030 investment plan in biofuels (EPE, 2019) suggest that biofuels will increasingly drive transportation and electricity generation, enabling Brazil to remain a leader in this field.

A resurgence in social inequality

That is the good news. Other trends are less encouraging. In recent decades, Brazil's social policies had successfully chipped away at poverty and inequality levels. This positive trend was already under stress in 2015, as Brazil entered recession (Chaimovich and Pedrosa, 2015). The subsequent economic recovery over 2017–2019 proved too modest to prevent a resurgence in social inequality.

Over the past couple of years, this issue has received insufficient policy attention, judging from the growing numbers of people sliding back into extreme poverty. With the Covid-19 pandemic having inflicted great hardship on a broad segment of the population, this issue must be prioritized to ensure the coherence of Brazil's sustainable development agenda.

The government has also shown little interest in affirmative action policies, despite the fact that these can improve the accessibility of public higher education and careers to Black and minority ethnic groups.

A need for greater environmental monitoring

In the field of environmental protection, even in times of robust legislation and regulatory statutes, it had been difficult to translate this legal framework into concrete action. The situation has deteriorated in the past couple of years, as legislation and control mechanisms have been rolled back. Serious environmental crises, involving dam failures and the growing incidence of wildfires in the Amazon forest and in the Pantanal region, attest to an insufficient monitoring and prevention system.

A drop in patent filing by industry

One key policy concern should be the drop in patent filing by industry. Business expenditure on R&D has declined steeply. This is part of a broader trend. Business investment overall is declining, as is the share of industrial output in GDP and Brazil's participation in foreign trade, especially with regard to exports of manufactured products. These are warning signs, for these are all indicators of an innovative economy. The slow pace of digital transformation by industry is an obvious consequence of this lack of innovation by the industrial sector.

Even graduate education, the jewel in the crown of the national innovation system, appears to be entering a period of stagnation, or worse, with outlays by the federal agencies funding research having declined since 2015, sometimes to a remarkable extent.

A need for greater policy evaluation

The aforementioned negative trends may be impeding implementation of the *National Strategy for Science, Technology and Innovation 2016–2022*, which had been influenced by *The 2030 Agenda for Sustainable Development*, or of its revised version, the *Strategic Plan 2020–2030*.

More broadly, the successive national plans for science, technology and innovation tend to set lofty goals but more long-term policy instruments are needed to achieve their quantifiable targets. There is also a need for a thorough assessment of the reasons for the non-attainment of certain goals and targets, so that newer plans can adopt more realistic goals and more effective policy instruments to achieve these.

Also desirable would be a return to the model of close integration between science and socio-economic innovation planning and implementation that has served the country so well in the past.

Available indicators suggest that the Brazilian innovation system has arrived at a crossroads. Many of the gains of the previous decades will be eroded, if these key indicators cannot be rapidly turned around.

KEY TARGETS FOR BRAZIL

Brazil plans to:

- raise the research intensity of the government and private sectors to 1% each by 2022;
- award 29 000 new doctoral degrees in one year by 2022;
- confer 12% of all undergraduate degrees in engineering by 2022.

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ENDNOTES

1 Extractive industries such as mining, oil and gas are also consulted by the national Survey of Innovation 2017, as are firms in the services sector, as long their work involves technology. For instance, telecommunications and Internet providers are included, as well as electric power and gas facilities.

2 IBGE is in charge of developing and producing indicators for the SDGs, in partnership with other ministries and federal agencies, such as the Ministry of Science, Technology and Innovations, the Ministry of Environment, the statistics body of the Ministry of Education and the Ministry of Health.

3 See (in Portuguese): https://odsbrasil.gov.br/

4 In 2016, the government added the portfolio for communications to the Ministry of Science, Technology and Innovation (via Law No. 13 341), which was, consequently, renamed the Ministry of Science, Technology, Information and Communications. Four years later, the Bolsonaro administration restored the Ministry of Communications, thereby reviving the Ministry of Science, Technology and Innovation.

5 Since the most recent data available cover the period to 2018, the authors refer to the *National Strategy for Science, Technology and Innovation 2016–2022* when discussing objectives, goals and targets for science and technology, rather than the more recent document.

6 See: https://tinyurl.com/STI2020-2030

7 Extreme poverty corresponds to a daily income of less than PPP$ 1.90.

8 In September 2020, the federal government announced that the value of the monthly instalments would be reduced to R$ 300, with four further instalments planned to December 2020.

9 The National Institute for Space Research (INPE) reported the loss of 10 129 km^2 of rainforest between August 2018 and July 2019, an area close to the size of Lebanon.

10 Among the 36 countries which produced at least 100 TWh of electricity in 2019, Brazil came second only to Norway (98%) for the share of renewable sources of energy. The average was 38% for Europe, 30% for China and 17% for the USA (OWID, 2020).

11 In the Brazilian system, medicine is an undergraduate degree, whereas doctorates in health science are all academic, unlike in some other countries. The same is true of law, which is part of the social sciences in the grouping shown.

12 Data for regions and states in IBGE's Innovation Surveys are only available for the mineral/oil and transformative industries. As those industries accounted for 69% of the total internal R&D by businesses in Brazil, the shares for total R&D expenditure by businesses by state should not vary greatly from that for the industrial sector.

The Rubjerg Knude lighthouse in Denmark is wheeled back from the cliff edge in October 2019. Back in 1900, the lighthouse had been situated about 200 m from the North Sea coast. By the time it was moved, the eroding coastline had narrowed that distance to just 6 m, placing the lighthouse in danger of tumbling into the sea. The new *European Green Deal* is championing the target of carbon neutrality by 2050, to accelerate the pace of climate change mitigation and adaption within the bloc. © Hans Ravn

AT A GLANCE

- Brexit will not change the essence of the European project, which is tending towards closer integration.
- The European Green Deal is Europe's new growth strategy. It is accompanied by innovative industrial and digital strategies.
- European firms are less likely than US firms to have adopted digital technologies but more likely to invest in climate change mitigation and adaptation.
- The European Union plans to spend € 1.8 trillion in public funds between 2021 and 2027, 30% of which is to be invested in countries' dual green and digital transition.
- Within the Horizon Europe research programme to 2027, twin engines of this transition will be smart specialization by regions and new mission-oriented policies.
- A Just Transition Mechanism will help vulnerable countries weather the transition, such as job losses tied to the phasing out of a polluting industry.
- The European Union intends to reinforce its strategic autonomy and soft power in the coming years, including through its trade, digital and defence policies.

9 · European Union

Luc Soete, Sylvia Schwaag Serger, Johan Stierna and Hugo Hollanders

INTRODUCTION

Covid-19: will the EU ever be the same?

Like other parts of the world, the European Union (EU) has been hard hit by the Covid-19 pandemic.

Having been at the epicentre of the pandemic in the spring of 2020, it then endured a more severe second wave in the autumn that has continued well into 2021. This double dip has exposed the institutional limits of European health governance when confronted with a global pandemic.

The Covid-19 pandemic has reinforced the national context as the dominant policy framework for science-based health policies in Europe.[1] This evolution has been visible from the first outbreak in northern Italy to the onslaught of the second wave in Belgium, France, the Netherlands, Spain and the United Kingdom (UK), as well as in countries largely spared by the first wave, such as the Czech Republic, Germany, Ireland and Sweden.

If the Covid-19 pandemic has reinforced national approaches to health policy, it has had the opposite effect on scientific research communities specializing in molecular biology and immunology, which have become globalized. Medical researchers have become frontrunners in the use of open access, rapid-fire international sharing of data and the exchange of information on clinical testing of candidate vaccines. It is true that this reaction had also been observed during previous pandemics, such as the outbreak of the first severe acute respiratory syndrome (SARS) in 2003, but on a much smaller scale. Scientific facts and evidence have become the basis for public trust in the face of disinformation campaigns. This is a dream scenario for scientists in many non-medical fields like climate science who have been up against disinformation campaigns for decades.

This common scientific framework did not prevent national health advisors from applying a myriad of different lockdown policies across Europe at the start of the outbreak in March 2020 that have sown disorder at the European level.[2] Yuval Noah Harari's characterization of the Covid-19 pandemic over 2020 as 'a scientific triumph coupled with a political fiasco' appears particularly relevant in the European context.[3]

It was only in response to the second wave that common European health policies were discussed and attempts made to implement these. Examples are the transfer of patients across borders within the EU, to prevent hospitals from becoming overwhelmed with national Covid patients; the design of a European gateway to ensure the interoperability of tracing apps across the EU; or the speedy validation at the EU level of rapid antigen tests to provide results more quickly than the standard molecular kits based on a polymerase chain reaction.

The main response at the EU level has been the formal approval and allocation across European member states of vaccines approved by the European Medicines Agency, starting with the vaccine developed by the German firm BioNTech and its US partner Pfizer on 21 December 2020.[4] These vaccines were acquired ahead of their development through supply deals with various global pharmaceutical firms.

However, as the formal approval process for other vaccines took longer than expected, vaccination campaigns across the EU slowed down after Pfizer announced delays in the production of its own vaccine. Further uncertainty was injected by the emergence of multiple variants of the Covid-19 virus in Brazil, South Africa and the UK, which were more contagious than the original virus.

From a historical perspective, the Covid-19 health crisis is a unique phenomenon for the EU. It appears likely to have longer-term ramifications than the financial crisis of 2008, often termed the Great Recession to reflect its far-reaching, albeit temporary economic impact. The Covid-19 crisis raises broader, more fundamental questions than the Great Recession, such as with regard to the role of the state in the economy, the organization of work or the value of proximity. The crisis has highlighted the need for new ways of doing business such as teleworking, virtual meetings, distance learning or the reshoring of supply chains. In the case of the EU, the bloc will also need to find new ways of organizing governance in a more complementary way between the various complex, multilevels of European, national and regional-cum-local decision-making. For instance, the EU needs to find a way to ensure strategic access to health infrastructure and equipment such as a minimum stock of intensive-care units and breathing aids, testing materials and medical masks in reserve (ESIR, 2020).

In Europe, the post-Covid world will probably look nothing like the pre-Covid world. Even the typically conservative *Financial Times* has advocated radical reforms to forge 'a society that will work for all', including a greater role for governments in the economy and an injection of funding for public services (Editorial Board, 2020).

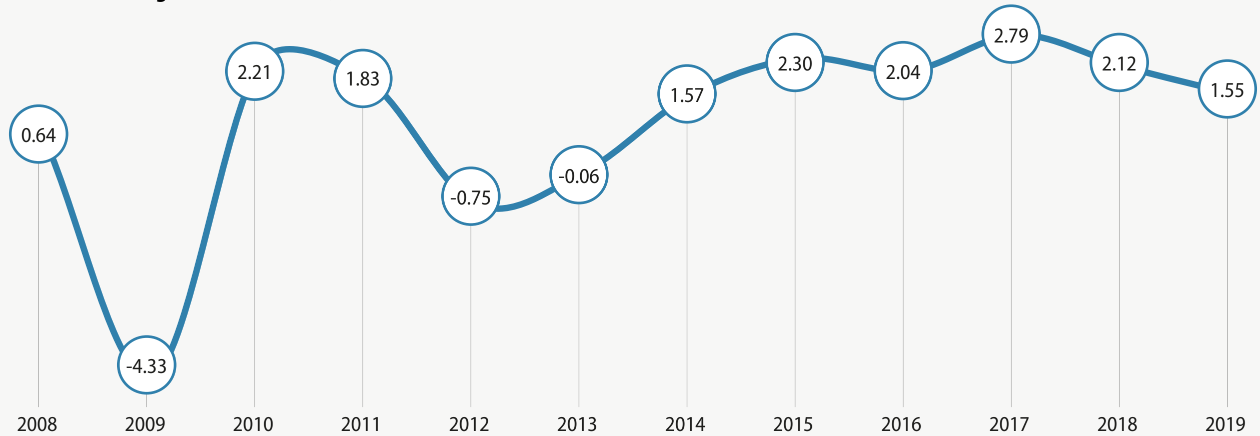
Brexit: changing the EU's outer skin but not its essence

The second major challenge facing the EU has been the UK's formal departure from the bloc on 1 January 2021. Overnight, the external contours of the EU have shifted with the departure of one of the bloc's largest and wealthiest countries, taking with it the fifth-highest nominal GDP in the world, second only to that of Germany in the EU, along with 67 million Europeans.

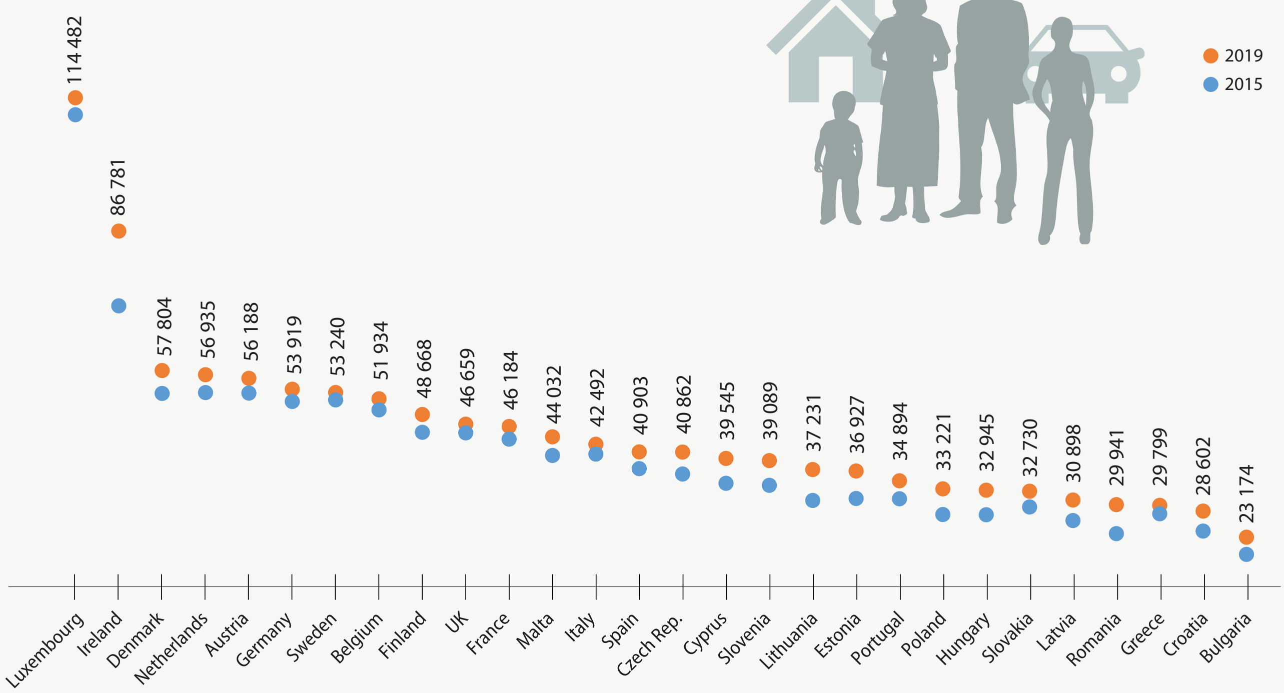
The bloc's total volume of GDP will shrink from PPP$ 23.0 trillion, prior to the British exit (Brexit), to PPP$ 21.1 trillion (Table 9.1 and Figure 9.1). Since the UK devotes 1.72% of GDP to research and development (R&D), the bloc's average research intensity will mechanically rise

Figure 9.1: **Socio-economic trends in the European Union**

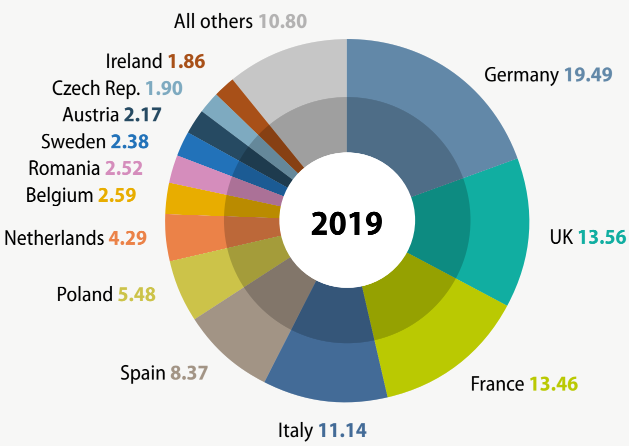
Rate of economic growth in the EU28, 2008–2019 (%)



GDP per capita in the EU28, 2015 and 2019
In constant 2017 PPP$, data labels are for 2019



Contribution by individual countries to the GDP of the EU28, 2019 (%)



GDP per capita in the EU28, in constant 2017 PPP$

44 170
in 2019

41 471
in 2015

Total volume of GDP in EU28, in constant 2017 PPP$

23.0 trillion
in 2019

21.1 trillion
in 2015

Note: The EU28 refers to the 28 member states of the European Union as of December 2019, which include the UK.

Source: World Bank's World Development Indicators, December 2020 from 2.03% to 2.18% of GDP (Table 9.1 and Figure 9.2). Researcher density, however, will drop (Table 9.1 and Figure 9.3).

Above all, the UK's loss will be felt in terms of scientific output, as the UK has the highest publication intensity in the EU (Table 9.1); in 2018, it overtook the more populous Germany to lead the bloc for the sheer volume of output (Figure 9.4). At the same time, the mutual benefit derived by the UK and the 27 remaining EU members (EU27) from past interaction provides solid grounds for both parties to maintain close scientific ties, now that the UK has become a 'third country' (Box 9.1).

The UK's decision to withdraw from the bloc has been an unprecedented development for a region built on the concept of expansion, rather than contraction. In the past, it was the successive waves of enlargement which caused an often short-lived reduction in the average economic wealth of the EU, as the level of development of member states joining the bloc tended to be well below the EU average. The next wave of EU enlargement is likely to involve countries in Southeast Europe that are already integrating EU legislation into their own national body of law in preparation for membership of the bloc (see chapter 10).

Rather than undermining the bloc's values and purpose, the UK's departure appears to have reinforced the view within the EU that further integration in particular fields may be warranted to defend and strengthen the bloc's core values, as in the case of digital technologies, individual privacy and democracy.

There is also growing awareness that the current system of obtaining unanimous approval of decisions in areas like international taxation hinders the EU from acting for the benefit of all and makes it less responsive to changing circumstances.

Similarly, the combination of the Trump administration's emphasis on America First (see chapter 5), the economic expansion of China (see chapter 23) and the Covid-19 outbreak has given rise to discussions within the EU27 on the possible need for greater European technological sovereignty in strategic areas, in light of the increasingly complex geopolitical situation. The need for a common defence policy, a common foreign policy and for large-scale investment in infrastructure, in order to ensure that the EU27 can form a coherent, independent pole next to China and the USA, are all becoming the subject of intense reflection.

In short, despite Brexit, the EU will continue to be a major player in setting the global science, technology and innovation (STI) agenda.

Sustainable development: a desire to lead by example

The third defining challenge revolves around the EU's ambition of leading by example by resolutely embarking on a more sustainable development path, in line with the United Nations' Framework Convention on Climate Change, the *Paris Agreement* (2015) on climate action and *The 2030 Agenda for Sustainable Development* (2015).

This ambitious path has been laid out in the EU's Multi-annual Financial Framework, the European Commission's budget for the period stretching from 2021 to 2027, which covers the next framework programme for research and innovation, Horizon Europe, and other large investment streams for STI such as InvestEU and Structural Funds.

The InvestEU programme builds on the *Investment Plan for Europe* (or *Juncker Plan*) adopted in 2015, which sought to mobilize public and private investment (Hollanders and Kanerva, 2015). InvestEU brings under one roof the European Fund for Strategic Investments (est. 2014) and 13 other financial instruments, while seeking to match projects to potential investors via its portal.[10]

Designed to foster balanced development across regions within countries,[11] the EU's Structural Funds have two components: the European Social Fund and the European Regional Development Fund.

The Multi-annual Financial Framework reflects the six priorities championed by the Commission's president, Ursula Von Der Leyen (2019a), namely:

- a European Green Deal (green transition);
- an economy that works for people;
- a Europe fit for the digital age (digital transition);
- protecting the European way of life;
- a stronger Europe in the world; and
- a new push for European democracy.

Using the crisis to foster a green, digital transition

The anticipated negative economic impact of the Covid-19 pandemic on individual European member states led to the negotiation, in mid-2020, of a unique new funding programme called NextGenerationEU. With a budget totalling € 750 billion, this programme brings to the fore Europe's potential for solidarity and mutual engagement in a crisis.

When NextGenerationEU is combined with the standard Multi-annual Financial Framework, this means that the European Commission will dispose of its largest-ever budget over the seven years to 2027 (€ 1.8 trillion), corresponding to about 2% of the gross national income of EU member states.

Through NextGenerationEU, the European Commission is authorized, for the first time, to borrow money on financial markets and distribute about half of it as grants and subsidies (€ 390 billion) to member states hardest hit by the pandemic and the remainder as loans. These funds will be distributed by the Recovery and Resilience Facility established for the purpose, which individual member states are already translating into national plans.

Thanks to the anticipated boost in private investment and support for afflicted companies, the EU expects to emerge from the Covid-19 crisis stronger than before. Key EU programmes will be reinforced, back-to-back with national resilience and recovery plans, to strengthen the Single Market and accelerate the twin transitions to green and digital societies.[12]

A moment of truth for European 'soft power'

The final defining challenge for the EU in the coming decade will be the extent to which it is prepared to embrace its role as a global leader for 'soft power'.

Can the EU reposition itself in a post-coronavirus world as a leading multilateral actor in STI, setting global standards with respect to the environment, digitalization and consumer rights, not to mention access to science and the sharing of research results?

Can the EU stem the rising tide of isolationism, at a time when global collaboration is needed more than ever? How will the EU address issues of international co-operation, technological sovereignty and the blurring of lines between scientific, commercial, nationalist and military agendas?

What is the EU's policy with regard to mergers and acquisitions of technology by foreign multinational corporations? How will it handle the threats posed by some digital technologies to privacy, integrity and human rights? How will the EU respond to the geopolitical tensions between

Box 9.1: The European Union's post-Brexit relationship with the UK

Under the *Trade and Cooperation Agreement* announced by the UK and EU on 24 December 2020, the UK will no longer operate under the European Economic Area regulations for cross-border trade in goods and services and will have to pay to remain within the European Research Area.

Implications for trade in tech and services

The trade deal exempts British companies from paying tariffs on exports of goods to the EU from 2021 onwards* but erects non-tariff barriers: British exporters are required to provide paperwork for customs proving that their goods meet rules of origin.[5] Although it is part of the UK, Northern Ireland will remain in the Single Market for goods, in order to avoid a hard border with the Republic of Ireland.

Some 43% of British exports of goods and services went to the EU in 2019. The top six categories for goods were: petroleum products (11.8%), road vehicles (10.2%), other transport equipment (5.8%),[6] miscellaneous manufactured goods (5.5%), medicinal and pharmaceutical products (5.4%) and electrical machinery and appliances (4.0%). More than half of UK imports (52%) came from the EU (House of Commons, 2020).

The UK services sector accounts for about 80% of GDP. Under the trade deal, the UK no longer benefits from passporting rights, which had given the services sector automatic access to the EU market. These companies will now need to negotiate bilateral agreements with each EU country, including those in fintech and other digital industries, which may impede their access to the EU's Digital Single Market. Business and financial services accounted for respectively 33.1% and 20.5% of all services exported to the EU in 2019 (House of Commons, 2020).

New institutional arrangements

In a speech on 2 March 2018, the UK prime minister affirmed the government's intention of remaining part of EU agencies 'that are critical for the chemicals, medicines and aerospace industries,' in order to ensure that newly developed products need only undergo one series of approvals.

The government has also, repeatedly, affirmed the importance of co-operation on defence and security, which would normally mean participation in the European Defence Agency.

Since a third country may not host an EU agency, the European Medicines Agency has already moved its headquarters from London to Amsterdam.

However, the UK's refusal to be subject to the European Court of Justice will also exclude it from membership of EU agencies. Without membership, British companies will need to respect both UK and EU rules for their goods if these parallel systems' regulations diverge, in future.

In July 2020, the UK withdrew its April 2018 ratification of the agreement for a Unified Patent Court (2013). Participation is linked to membership of both the EU and the European Court of Justice, as the common court will apply EU law once the last two member states agree to be bound by the protocol.

The UK's membership of the European Space Agency will not be affected by Brexit, as it is not an EU body. The same applies to the European Organization for Nuclear Research (CERN).

The UK will be reimbursing the £ 23 million it received from the European Regional Development Fund towards construction of the National Graphene Institute at Manchester University in 2013. This fund is part of the Structural Funds which help to ensure even-handed development across the EU by investing in regions where the need is greatest. The UK plans to replace the EU's Structural Funds with a new UK Shared Prosperity Fund, as outlined in the Internal Market Act which received royal assent in December 2020 (Institute for Government, 2020).

The British government has pledged to raise gross domestic expenditure on R&D (GERD) from 1.7% to 2.4% of GDP by 2027 to maintain domestic competitiveness post-Brexit.

An associate member of Horizon Europe

As a third country, the UK will need to negotiate a separate agreement with the EU to participate in Horizon Europe (2021–2027) as an associate member.

The UK has left the European Atomic Energy Community (Euratom)[7] but has come to an agreement with the EU regarding its continued participation, as a Fusion Energy partner, in Euratom's Research and Training Programme and in the International Thermonuclear Experimental Reactor.[8]

The UK will also continue to participate in the Copernicus Earth Observation programme but not in the Galileo space navigation programme, which is developing an alternative to the US Global Positioning System.

The Royal Society has urged the government to participate in both the European Research Council (ERC) and the new European Innovation Council (RS, 2020). However, the UK will be excluded from the European Innovation Council, as its withdrawal from the EU automatically ended its membership of the USA and China over what is, at heart, a question of technological supremacy and power?

The EU has always been a reference for the use of soft power to achieve its goals. In line with the bloc's founding values, the EU has wielded science diplomacy not only to enhance collaboration in science and innovation but also to combat the weakening of democracy, rising inequality and growing tensions between economic, social and environmental sustainability. How the EU manages to play this role in an increasingly polarized environment both within and beyond the bloc represents one of its most fundamental challenges for the coming decade.

the European Investment Bank, which can no longer invest in UK companies. The Council has an accelerator fund that offers companies grant funding of up to € 2.5 million, as well as the option of equity investments of up to € 15 million backed by European Investment Bank funds (Kelly, 2020a).

That leaves the ERC. UK scientists will be entitled to compete for ERC grants, in return for an upfront financial contribution, but will no longer have the right to influence the shape of the ERC's research programme.

Under Horizon 2020, the UK received one-fifth of ERC grants, a greater share than any other country. Each ERC grantee employs, on average, six researchers. In 2020, there were 840 ERC grantees in the UK, 43% of whom were British and 37% from the EU (Institute for Government, 2020).

Implications for scientific and student mobility

The trade agreement relegates Mutual Recognition of Professional Rights to the past; this means that the qualifications of specialists such as doctors, scientists, engineers and architects are no longer automatically recognized. Europeans wishing to work in the UK will only obtain a work permit if they score highly on a points-based scoreboard. In January 2020, 9.1% of hospital doctors in the UK were EU citizens (Baker, 2020).

The UK has opted to pull out of the EU's Erasmus+ scheme, which allows students to study in other European countries. The UK plans to create a replacement scheme named after British mathematician Alan Turing to ensure that its citizens can still study abroad but without UK universities hosting any European students themselves.

In 2018/2019, around 18 000 students and trainees from the UK participated in Erasmus+, compared to around 30 000 continental Europeans who studied in the UK.** In December 2020, the Irish foreign affairs minister pledged to finance Erasmus+ grants for students from Northern Ireland.

From now on, Europeans studying in the UK will pay the same fees as other international students (*ca* £ 18 000 per year), about double the current amount. More than half of postgraduate students (54%) in the UK are foreigners (Institute for Government, 2020).

Already less scientific co-operation with the EU

The UK is highly invested in international scientific collaboration: the share of publications with a foreign co-author rose from 58% to 65% between 2015 and 2019 (see chapter 1).

Between 2014–2016 and 2017–2019, the UK's top scientific partners remained the USA, Germany, France, Italy and China but China moved up from fifth to third place (Figure 9.4).

Between 2015 and 2018, UK applications for research funding under Horizon 2020 (2014–2020) fell by 40%.[9]

Over the same period, there was a 35% drop in the number of scientists coming to the UK on the EU's Marie Sklodowska-Curie Fellowships. Around half (48%) of academics who left British universities to work or study overseas in 2018 were non-British EU citizens (RS, 2020).

Source: compiled by Susan Schneegans

*Tariff-free trade relies upon adherence to the principle of a 'level playing field' for open and fair competition. Both the EU and UK have the right, subject to arbitration, to 'take counter measures if they believe they are being damaged by measures taken by the other Party in subsidy policy, labour and social policy or climate policy' (Govt of UK, 2020). These countermeasures could include tariffs or quotas.

**Both the incoming and outgoing mobility of students and trainees under the Erasmus scheme has been lower for the UK than for France, Germany and Spain. See: https://tinyurl.com/Erasmus-incoming-outgoing

Table 9.1: **Impact of Brexit on the European Union, 2019**

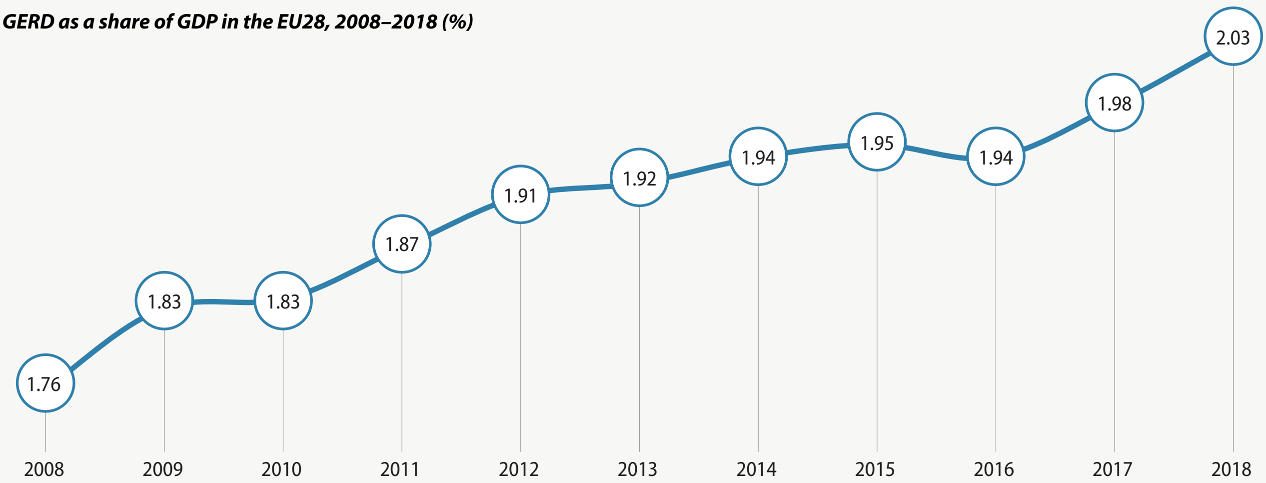
	Population, 2019 (millions)	GDP (PPP$ trillions), 2019	GDP per capita, 2019 (PPP$)	Total GERD, 2018 (PPP$ billions)	GERD/GDP ratio, 2018	Researchers, 2018 (FTE, in thousands)	Researchers (FTE) per million inhabitants, 2018	Volume of scientific publications, 2019	Volume of IP5 patents, 2019
EU27 + UK	514.3	23.0	44 170	330.8	2.03	2 081.7	4 069	752 472	172 266
Change (%)	-13.0 ↓	-15.1 ↓	+0.6 ↑	-12.2 ↓	+7.9 ↑	-14.8 ↓	-2.0 ↓	-14.3 ↓	-11.7 ↓
EU27	447.5	21.1	44 436	290.6	2.18	1 772.7	3 988	644 547	152 164

Note: The EU27 refers to the 27 member states of the European Union as of February 2020.

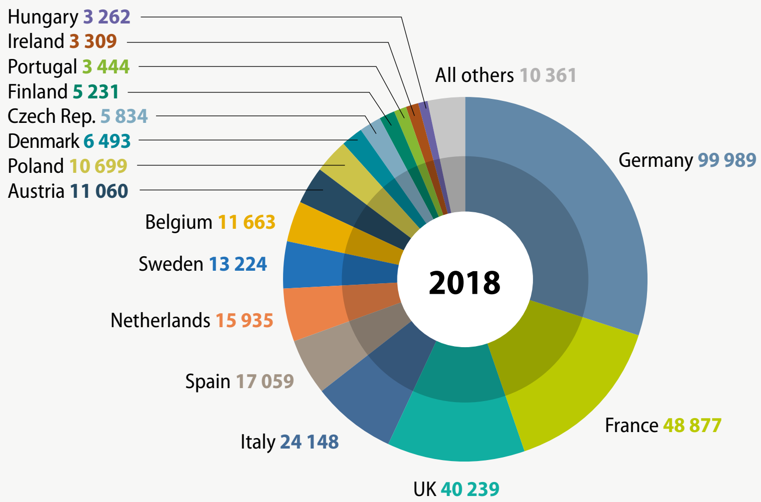
Source: UNESCO Institute for Statistics; for population and GDP (in constant 2017 PPP$): World Bank's World Development Indicators, January 2021; for publications: Scopus (Elsevier), excluding Arts, Social Sciences and Humanities, data treatment by Science-Metrix; for IP5 patents: see Figure 9.10 for details

Figure 9.2: **Trends in research expenditure in the European Union**

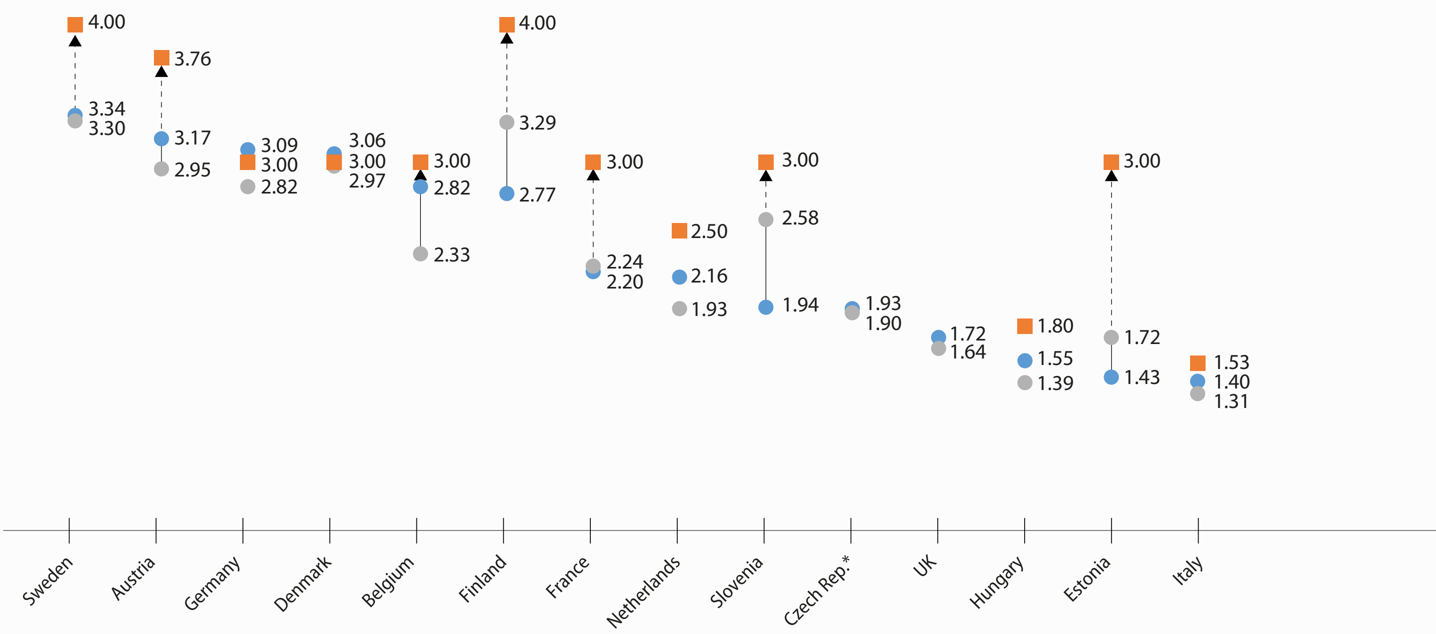
GERD as a share of GDP in the EU28, 2008–2018 (%)



GERD in the EU28, 2018
In PPP$ thousands, constant 2005 values

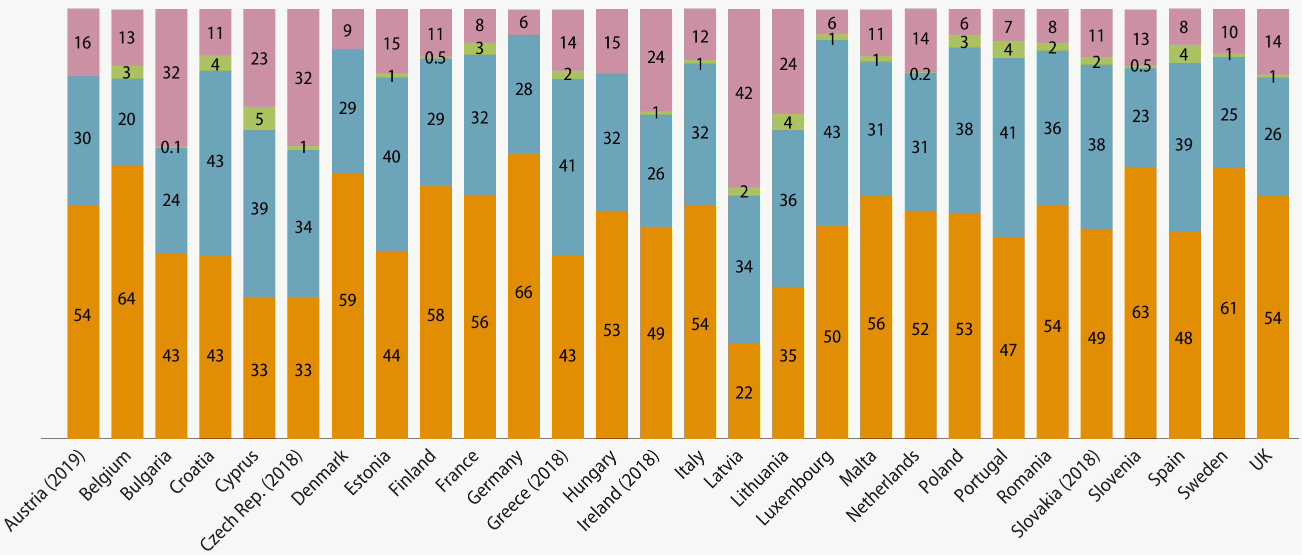


GERD as a share of GDP in the EU28, 2013, 2018 and targets to 2020

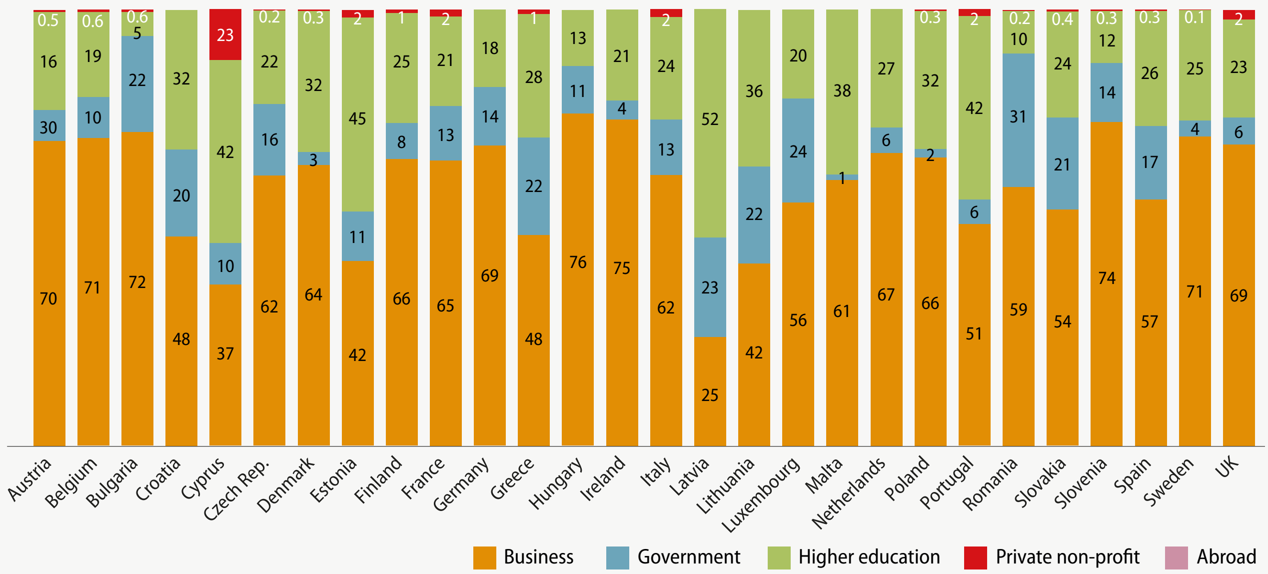


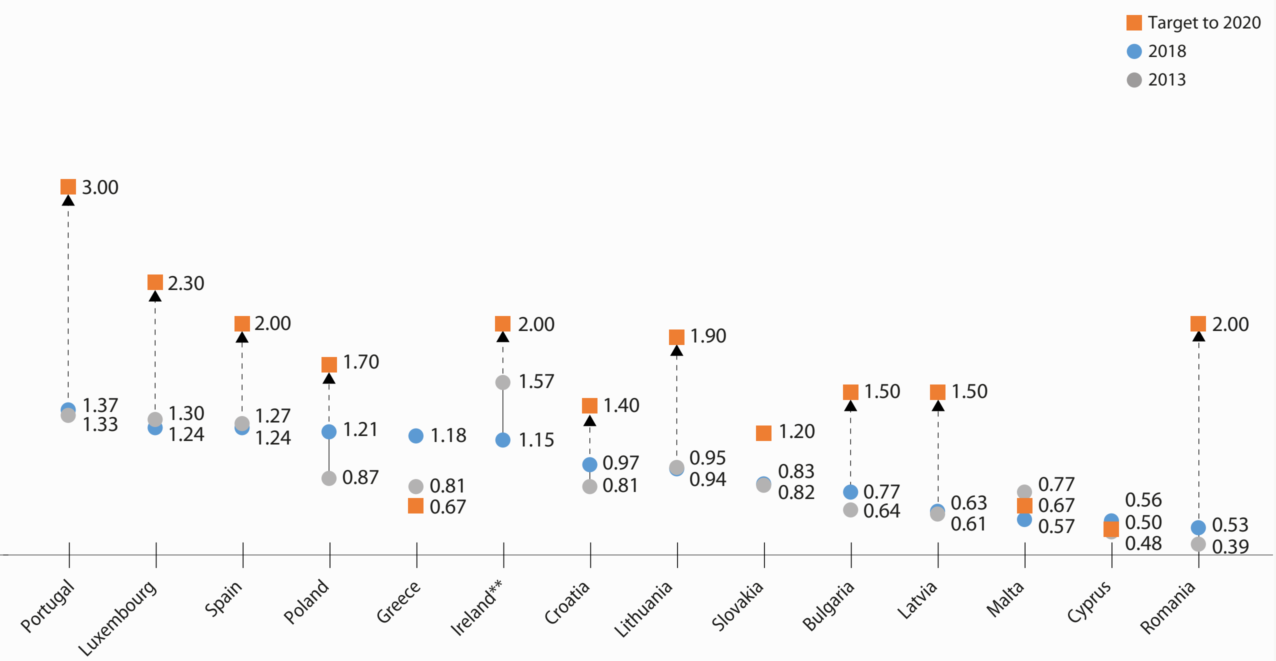
*a target of 1% is available only for the public sector **the national target of 2.5% of GNP has been estimated to equal 2.0% of GDP

GERD by source of funds in the EU28, 2017 or closest year (%)



GERD by sector of performance in the EU28, 2018 (%)



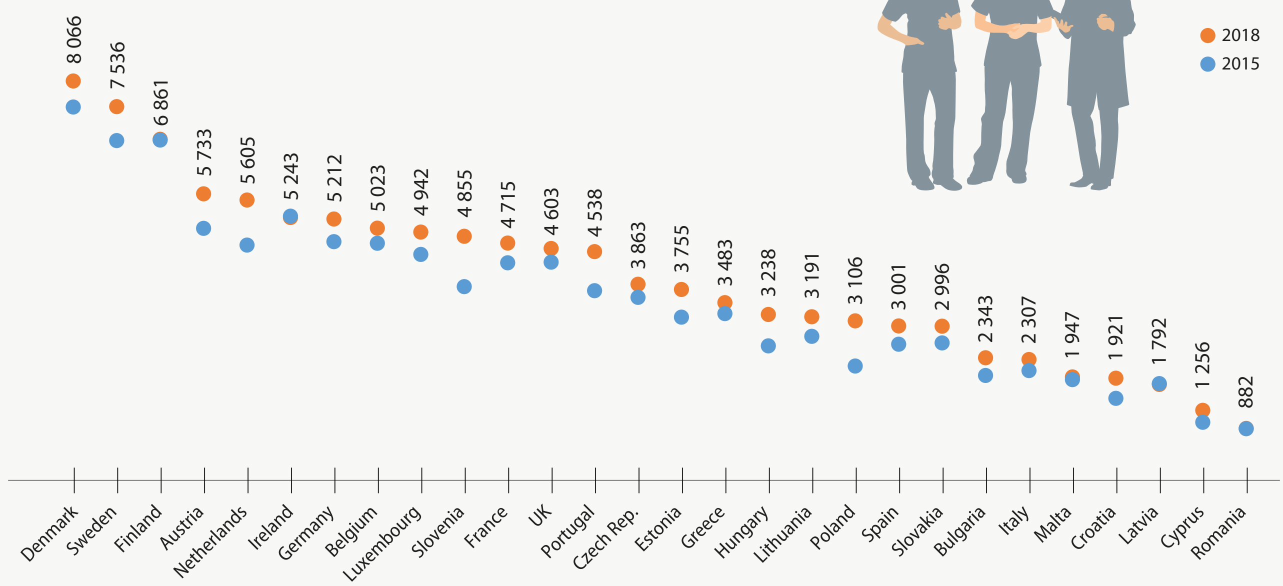


-n: data refer to *n* years before reference year

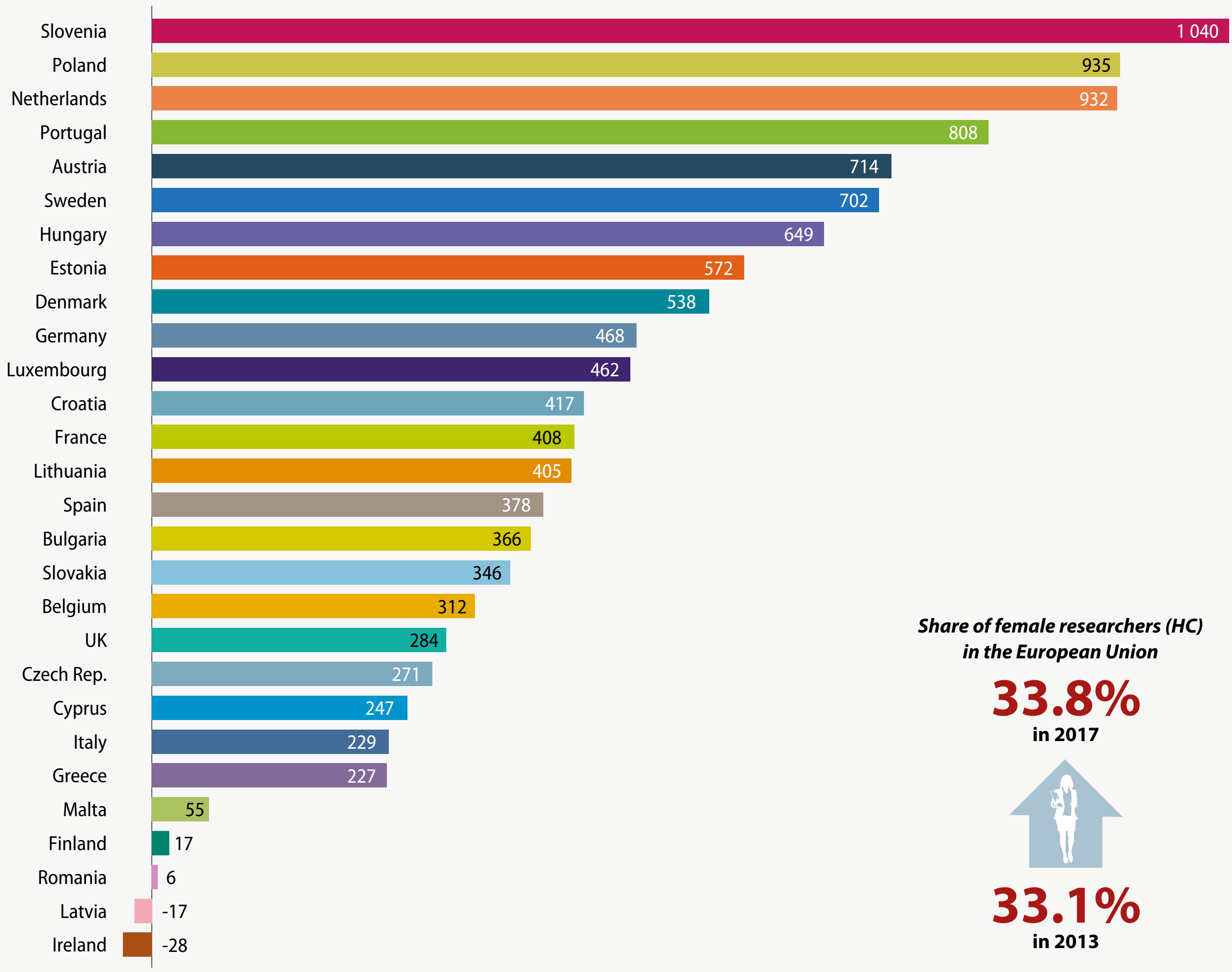
Source: UNESCO Institute for Statistics; for GERD/GDP: Organisation for Economic Co-operation and Development's Main Science and Technology Indicators; for research intensity targets: Eurostat

Figure 9.3: Trends in researchers in the European Union

Researchers per million inhabitants (FTE) in the EU28, 2015 and 2018
Data labels are for 2018



Change in the number of researchers (FTE) per million inhabitants in the EU28, 2015–2018



Share of female researchers (HC) in the European Union

33.8%
in 2017

33.1%
in 2013

Note: The share of female researchers is based on 2017 data for all countries except the Czech Republic (2018), Slovakia (2018) and the UK (2016); for details, see chapter 3. The EU28 refers to the 28 member states of the European Union as of December 2019, which include the UK.

Source: UNESCO Institute for Statistics

RESEARCH TRENDS

Leaders in innovation transitioning fastest

The large differences in size between the individual countries that make up the EU have always been part of the rationale for the free mobility of goods and services, workers and citizens, not to mention knowledge flows. The common view has always been that all countries benefit from a borderless Europe, even if some may benefit more than others.

Between 2013 and 2018, the EU's average research intensity rose from 1.94% to 2.03% of GDP (Figure 9.2). The stability of the bloc's research intensity is mainly due to its economic structure, with a predominance of medium-tech industrial sectors. A successful industrial positioning of EU firms in accelerating the transition to green, digital economies would probably increase the bloc's knowledge intensity in terms of intellectual property.

There is a close correlation between the research intensity of a country and its innovative performance. Those EU countries which are leaders in innovation have, on average, a research intensity close to, or above, 3%; they are also the most advanced in terms of their transition to green and digital economies. Since 2013, Denmark and Germany have passed the 3% threshold to join Sweden, the leader for this indicator. Finland, on the other hand, has seen its own research intensity dip below 3%. Slovenia's own research intensity has dipped beneath 2% (Figure 9.2).

A host of other countries remain far from their 2020 target intensity, including Bulgaria, Estonia, France, Ireland, Latvia, Lithuania, Luxembourg, Poland, Romania and Spain (Figure 9.2).

Share of industrial research funding up in many countries

There remain large differences in both funding and spending patterns among EU countries (Figure 9.2). In 2018, the business sector was the largest funding sector in 22 member states, with shares in Belgium, Germany, Slovenia and Sweden at 60% or more. Finland (from 61% to 58%) and Denmark (from 60% to 59%) have left this group since 2013, whereas Sweden has joined it (57% in 2011).

Since the last edition of the *UNESCO Science Report* (Hollanders and Kanerva, 2015), the government share has declined significantly for many countries, most spectacularly for Cyprus (from 66% to 39%). Funding from abroad was the most important source for Bulgaria and Lithuania in 2013 but this is no longer the case (Figure 9.2). The explanation lies in the surge in business funding of R&D, which has mechanically reduced the government share in these three countries.

The business enterprise sector is also the largest spending sector in 24 EU countries, including the UK. More than two-thirds of gross domestic expenditure on R&D (GERD) is performed by businesses in Austria, Belgium, Bulgaria, Germany, Hungary, Ireland, Netherlands, Slovenia, Sweden and the UK. In Cyprus, Latvia and Lithuania, it is the higher education sector which performs the largest share of GERD (Figure 9.2).

The general pattern in the EU is that the business sector spends more money on performing research than it finances. This is the case for all but Estonia. The trend is particularly marked in Bulgaria, the Czech Republic, Hungary and Ireland, where the difference exceeds 20 percentage points (Figure 9.2).

In most countries, the business enterprise sector also relies on government funding and funding from abroad. The higher education sector is heavily dependent on government funding in the EU27 and, in the UK, on tuition fees.

Scientific output and collaboration up

Between 2015 and 2019, scientific productivity rose by 7% across the bloc (Figure 9.4). Only in France did output dip slightly (-0.4%). Growth was most rapid in Bulgaria, Cyprus, Denmark, Latvia and Malta, although the small size of most of these countries may partially explain the steep curve. Growth was also notable among the more populated countries of Spain (13.2%), the UK (12.9%), Italy (12.7%) and Poland (11.7%). German output grew by 5.6%.

For the EU as a whole, the share of scientific publications with foreign co-authors progressed from 41% to 47% between 2015 and 2019. This ratio is well above the average of 34% (2019) for members of the Organisation for Economic Co-operation and Development (OECD).

For all but seven EU countries, at least half of publications had foreign co-authors. Smaller countries are more likely to collaborate internationally, as their smaller research base forces researchers to look abroad for possible co-authors. For this reason, the relatively low rate of international collaboration for Poland (31% in 2015 and 36% in 2019) by EU standards, with its population of almost 40 million, stands out.

Poland had the EU's lowest citation rate for both the 2014–2016 (0.95) and 2016–2017 (1.02) periods. By this measure, the quality of scientific publications was highest (1.83 or more over both periods) in Cyprus, Estonia, Luxembourg and Malta, all small countries with more specialized universities. All but Poland scored higher than the EU average (1.13 in 2016–2017).

Poland's lower level of international scientific collaboration, compared to its neighbours, may explain its score. International co-publications have, on average, higher citation rates than publications written by authors from a single country. For example, publications from 2016–2017 involving authors from at least three EU countries had an average citation rate of 2.24, compared with 1.03 for articles involving authors from a single country. About 18% of the EU's scientific publications from 2016–2017 involved authors from at least two EU countries. A further 4% involved authors from at least three EU countries (Figure 9.4).[13]

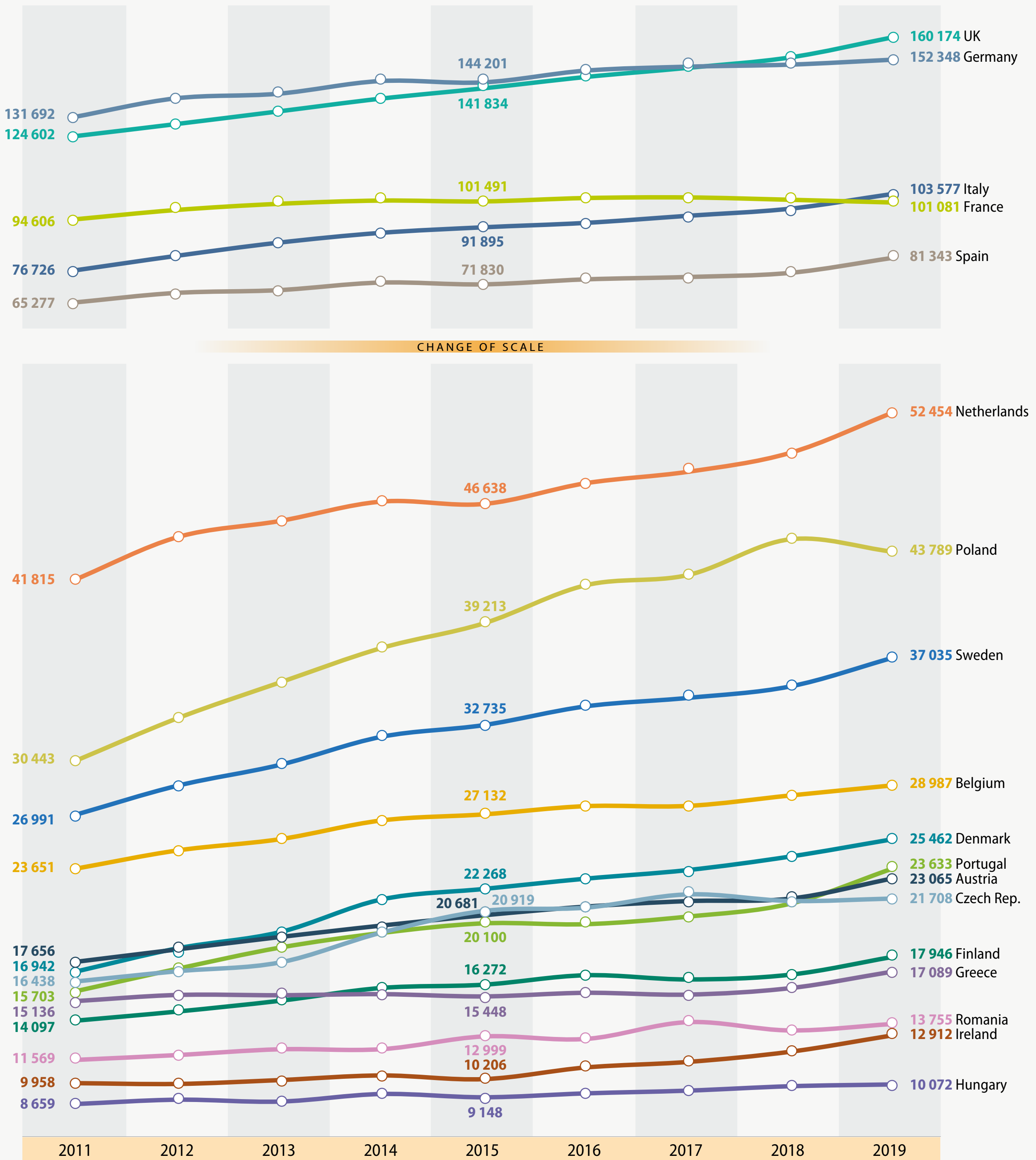
Brazil, Russia and China among top collaborators

Given the sheer volume of scientific output by the USA, Germany, the UK, France and Italy, it is only natural that scientists working in these countries should feature most frequently as partners (Figure 9.4).

Geographical proximity also matters. The Netherlands is a top collaborator for neighbouring Belgium, for instance, Poland for Lithuania, Greece for Cyprus, Spain for Portugal and the Czech Republic for Slovakia.

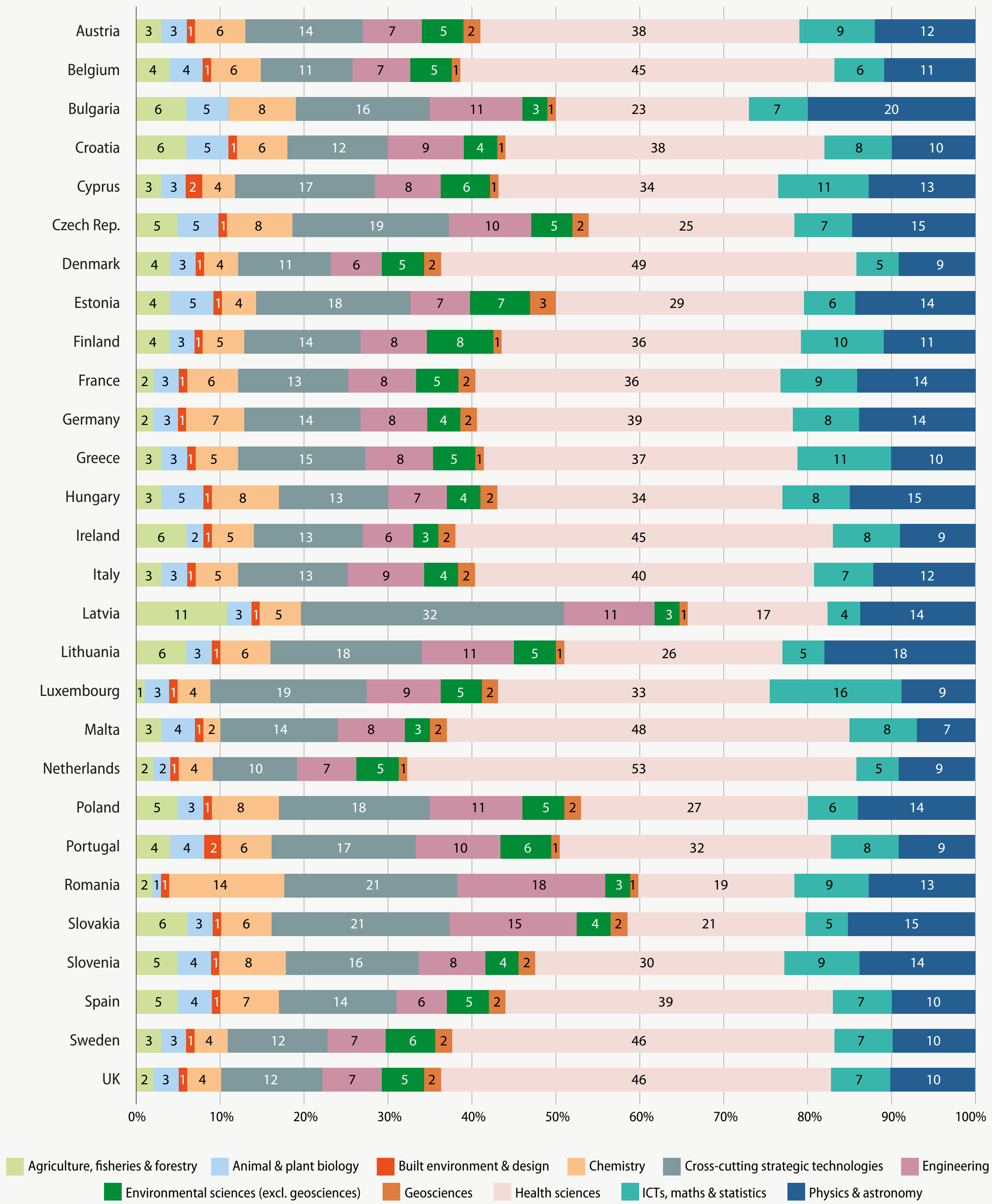
Figure 9.4: **Trends in scientific publishing in the European Union**

Volume of scientific publications in the EU28, 2011–2019



	2011	2012	2013	2014	2015	2016	2017	2018	2019
Slovakia	4 962	5 429	5 520	6 284	6 291	6 833	7 199	6 887	6 831
Croatia	5 330	5 456	5 219	5 207	5 221	5 262	5 637	6 035	5 804
Bulgaria	3 496	3 727	3 763	3 790	3 665	3 898	4 256	4 946	5 180
Slovenia	4 554	4 650	4 666	4 635	4 863	4 787	4 857	4 952	5 151
Lithuania	2 649	2 501	2 566	2 812	2 855	2 765	3 019	3 054	3 291
Estonia	1 910	2 100	2 157	2 413	2 345	2 468	2 578	2 632	2 958
Cyprus	1 166	1 340	1 518	1 453	1 543	1 801	1 974	2 154	2 485
Latvia	1 514	1 428	1 496	1 455	1 842	1 824	2 164	2 029	2 016
Luxembourg	1 006	1 088	1 300	1 526	1 473	1 550	1 579	1 703	1 798
Malta	275	357	413	452	521	565	627	713	707

Scientific publications in the EU28 by broad field of science, 2017–2019 (%)



14.3%
Share of EU28 publications (co-)authored by UK researchers, 2019

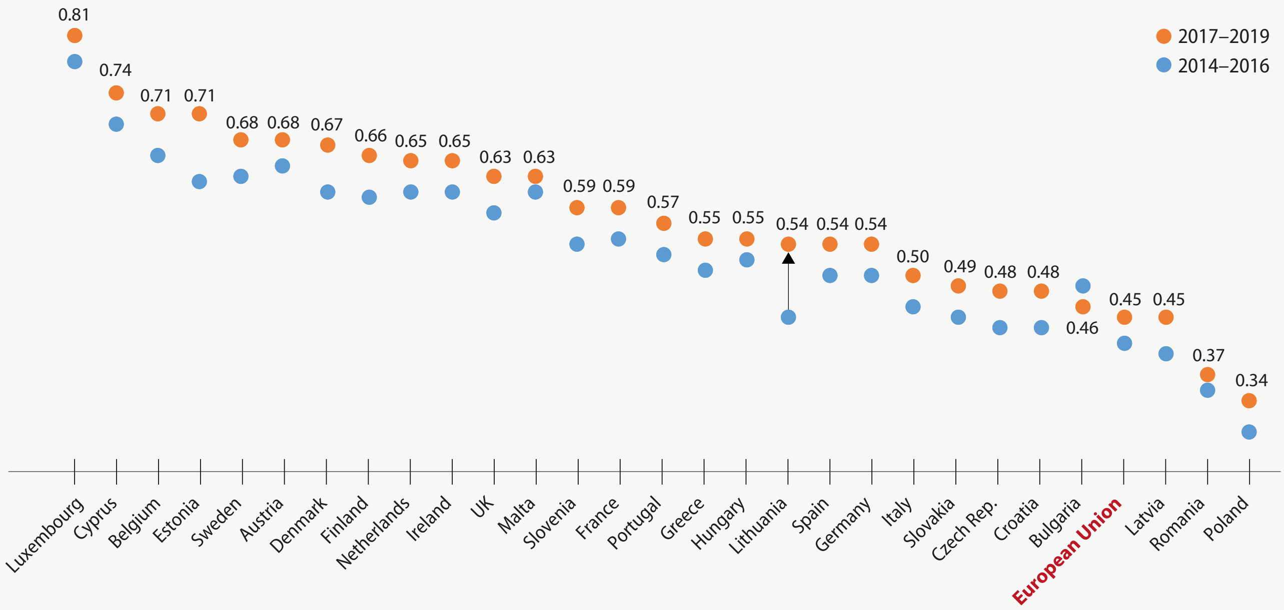
1.14
Average of relative citations for EU28 countries, 2014–2016; the OECD average is 1.11

45.2%
Share of publications with foreign co-authors in EU28 countries, 2017–2019; the OECD average is 34%

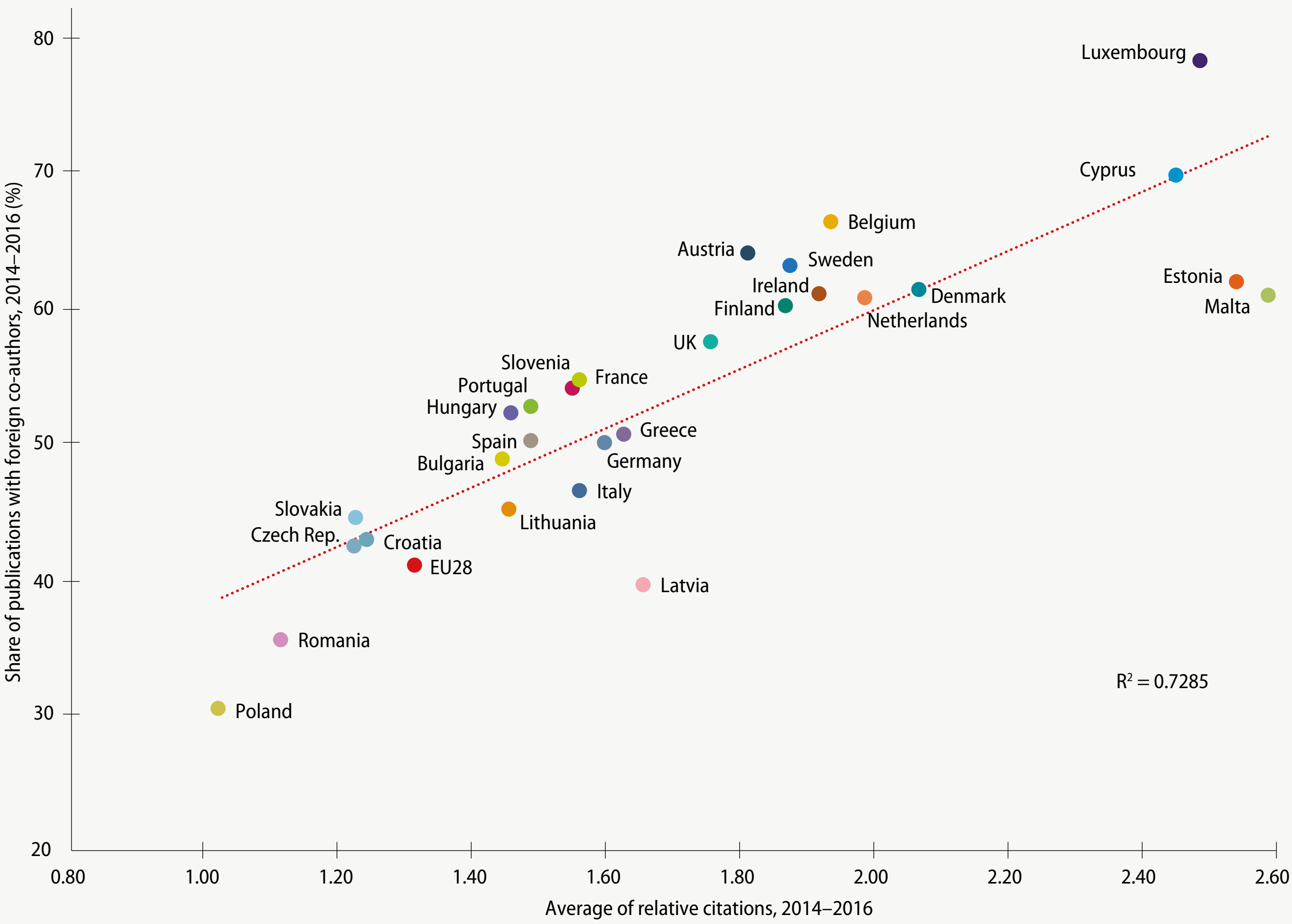
Chapter 9

Figure 9.4: Trends in scientific publishing in the European Union... *continued*

Average citation rate in the European Union, 2014–2016 and 2017–2019



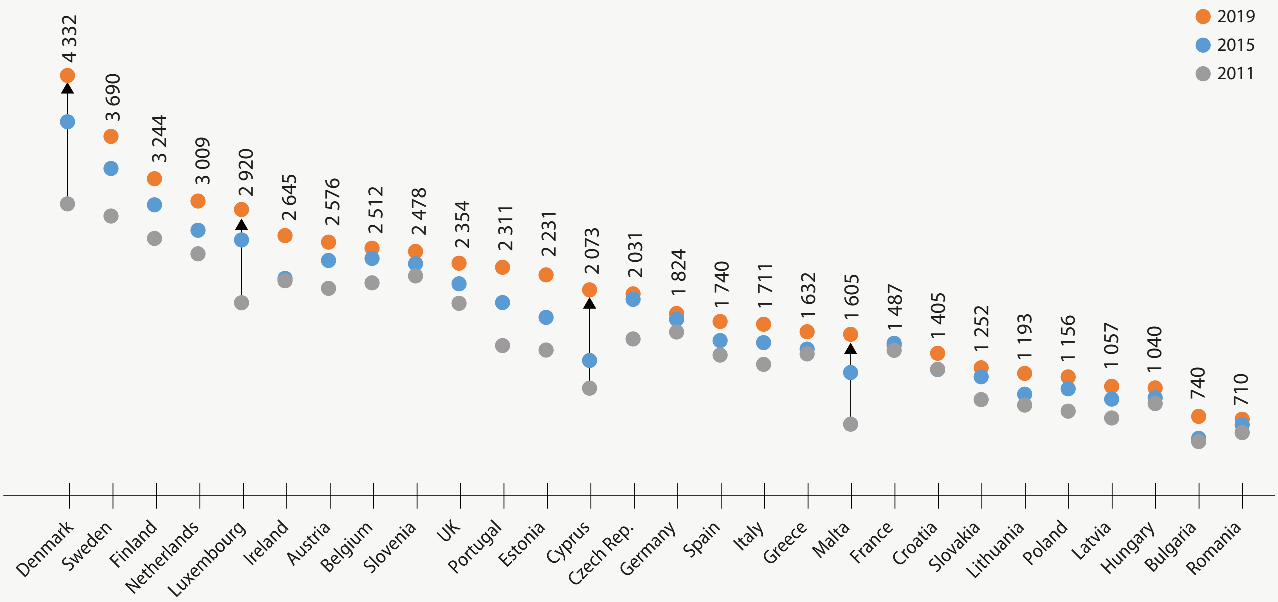
International collaboration and impact of scientific publishing in the European Union, 2014–2016



Note: International collaboration for the EU reflects collaboration with non-EU member countries. The dotted line represents a linear regression where $R^2 = 0.729$, a correlation coefficient of 0.85.

Source: Scopus, excluding Arts, Humanities and Social Sciences; data treatment by Science-Metrix

Scientific publications per million inhabitants in the EU28, 2011, 2015 and 2019
Data labels are for 2019



Top five partners for the EU28 for scientific co-authorship, 2017–2019 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator(s)	4th collaborator	5th collaborator
Austria	Germany (17 902)	USA (11 685)	UK (8 723)	Italy (7 628)	France (6 506)
Belgium	USA (15 177)	UK (14 054)	France (13 763)	Germany (12 810)	Netherlands (12 019)
Bulgaria	Germany (1 994)	Italy (1 717)	USA (1 666)	UK (1 486)	Russian Fed. (1 381)
Croatia	Italy (2 322)	Germany (2 302)	UK/USA (2 014)		France (1 758)
Cyprus	Greece (1 863)	UK (1 518)	USA (1 232)	Italy (1 143)	Germany (1 109)
Czech Rep.	Germany (7 412)	USA (6 889)	UK (5 567)	France (5 001)	Italy (4 904)
Denmark	USA (14 544)	UK (12 059)	Germany (10 548)	Sweden (7 809)	Netherlands (6 484)
Estonia	Germany (1 672)	Finland (1 649)	UK (1 622)	USA (1 524)	Italy (1 262)
Finland	USA (8 609)	UK (7 642)	Germany (7 049)	Sweden (6 440)	France (4 592)
France	USA (45 675)	UK (32 518)	Germany (31 902)	Italy (26 818)	Spain (20 449)
Germany	USA (69 443)	UK (45 561)	France (31 902)	Italy (28 675)	Switzerland (26 969)
Greece	UK (8 272)	USA (7 471)	Italy (6 181)	Germany (6 094)	France (4 852)
Hungary	Germany (4 896)	USA (4 849)	UK (4 062)	France (3 132)	Italy (3 127)
Ireland	UK (8 966)	USA (6 364)	Germany (4 239)	Italy (3 490)	France (3 487)
Italy	USA (41 375)	UK (32 974)	Germany (28 675)	France (26 818)	Spain (22 367)
Latvia	Germany (898)	Russian Fed. (840)	UK (755)	Poland (749)	Lithuania (728)
Lithuania	Germany (1 319)	USA (1 197)	UK (1 196)	Poland (1 195)	Italy (1 145)
Luxembourg	Germany (1 238)	France (941)	UK (798)	USA (714)	Italy (631)
Malta	UK (547)	Italy (527)	Germany (287)	Spain (270)	France (252)
Netherlands	USA (29 970)	UK (26 538)	Germany (24 994)	Italy (14 639)	France (14 380)
Poland	USA (10 851)	Germany (10 587)	UK (8 391)	Italy (7 443)	France (7 191)
Portugal	Spain (9 826)	UK (7 784)	USA (7 123)	Brazil (6 886)	Germany (5 907)
Romania	France (3 465)	Germany (3 352)	Italy (3 284)	USA (3 161)	UK (2 649)
Slovakia	Czech Rep. (3 987)	Poland (1 982)	Germany (1 790)	USA (1 520)	Russian Fed. (1 386)
Slovenia	Italy (2 301)	Germany (2 122)	USA (1 912)	UK (1 814)	France (1 591)
Spain	USA (30 910)	UK (25 679)	Italy (22 367)	Germany (21 935)	France (20 449)
Sweden	USA (20 923)	UK (16 701)	Germany (15 303)	France (9 214)	Italy (9 168)
UK	USA (83 678)	Germany (45 561)	China (41 732)	Italy (32 974)	France (32 518)

Note: The EU28 refers to the 28 member states of the European Union as of December 2019, which include the UK.

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

There have been some shifts in the relative weight of countries as partners between 2014–2016 and 2017–2019. Within the EU, France has slipped a little in the table, whereas Italy and Poland now feature more prominently as scientific collaborators.

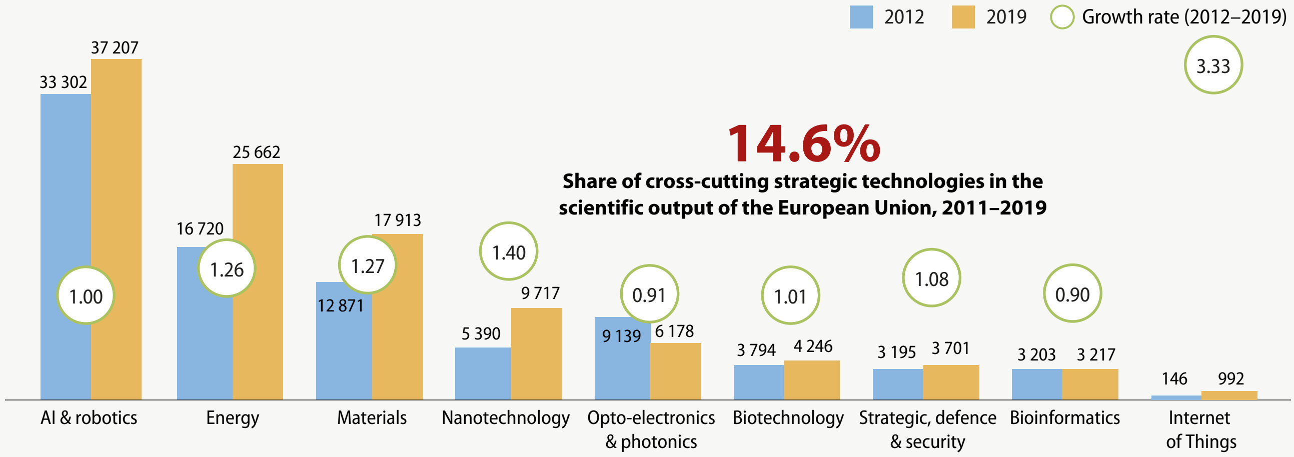
Among non-EU partners, there has been a slight decrease in the USA's importance as a partner, even as emerging economies have moved up the table. The Russian Federation is now a top partner not only for Latvia but also for Bulgaria and Slovakia. Brazil has moved up from fifth to fourth place among Portugal's top collaborators and China up from fifth to third place for the UK.

Stagnation in scientific output on AI and robotics

European scientific output on what may be considered strategic, cross-cutting technologies has been highest since 2012 in the field of artificial intelligence (AI) and robotics, followed by energy and materials (Figure 9.5). Of note is that the bloc's publication intensity on AI and robotics stagnated over the 2012–2019 period.

Figure 9.5: **Trends in publishing on cross-cutting strategic technologies in the European Union**

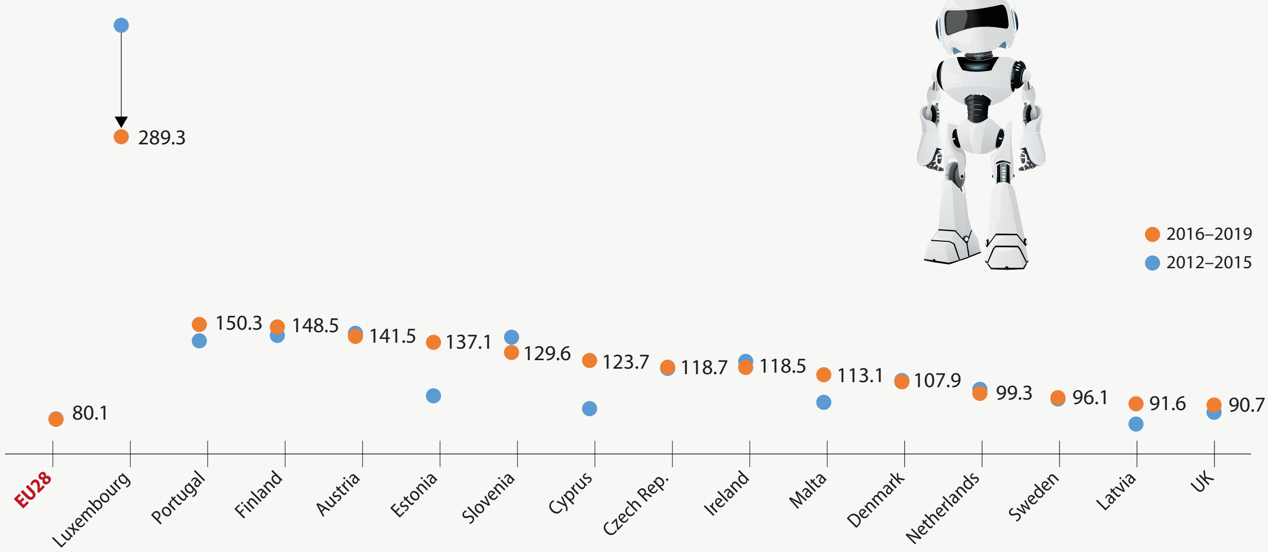
Volume of scientific publications on cross-cutting technologies in the EU28, 2012 and 2019



Five EU members feature among the top ten countries globally for publications on cross-cutting tech per million inhabitants: Luxembourg, Sweden, Finland, Estonia and Slovenia.

From 2011 to 2019, Germany (20%) and the UK (17%) accounted for the largest shares of publications on cross-cutting strategic technologies among the EU28.

Top 15 EU28 countries for publication intensity on AI & robotics, 2012–2015 and 2016–2019
Publications per million inhabitants, data labels are for 2016–2019

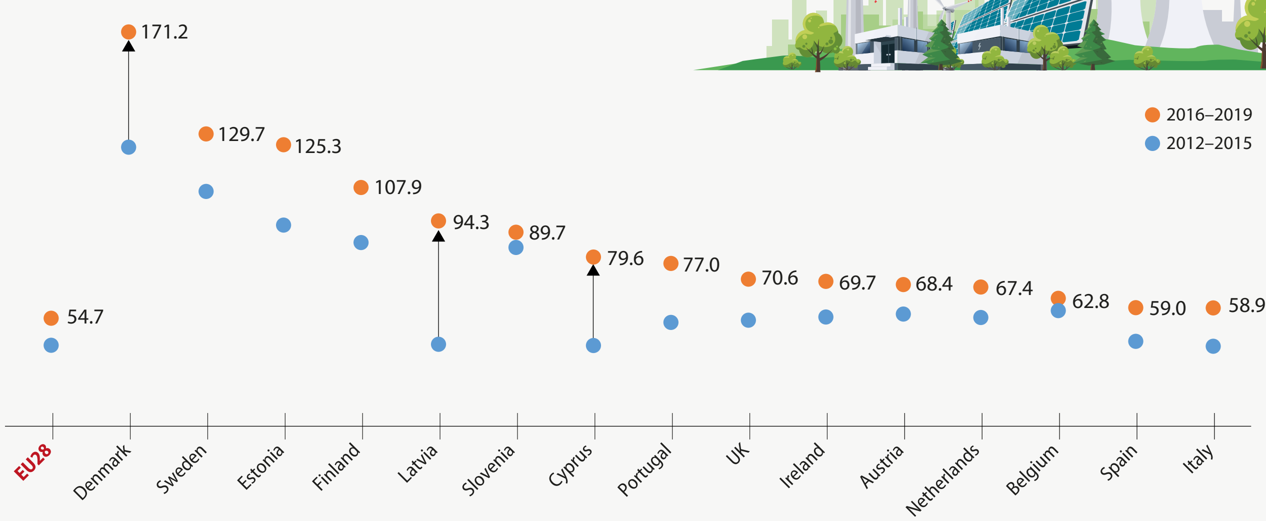


Apart from the UK, it is the smaller countries which dominate the table for publication intensity in these three fields. Italy and Spain make it into the top 15 for research on energy and Germany and Poland for materials science. The low output on the Internet of Things suggests that this field may be too recent a development to be producing a high volume of publications (Figure 9.5).

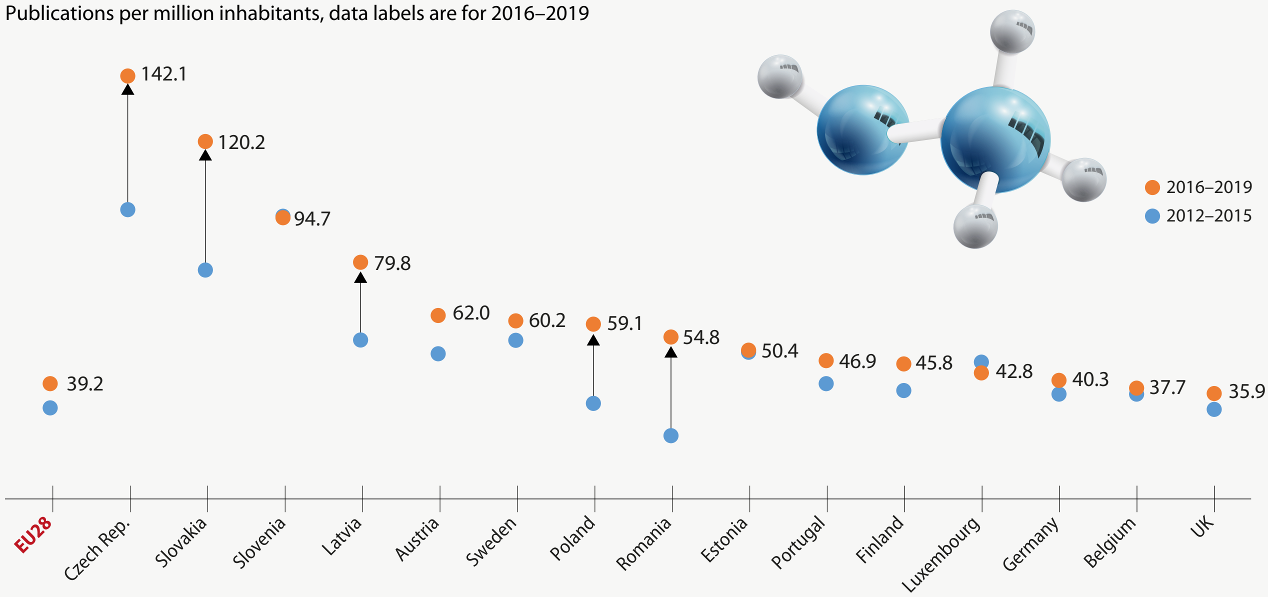
UNESCO analysed scientific publications on 56 research topics of relevance to the Sustainable Development Goals over the 2011–2019 period. The study found research related to climate change to figure among five of the top ten topics with the fastest growth rate in the EU, along with greater battery efficiency, which will be essential for low-carbon technologies such as solar photovoltaics and electric vehicles (Figure 9.6).[14] This finding tallies with the EU's stated goal of achieving carbon neutrality in the next 30 years.

A separate study by SciVal and Elsevier for the European Commission found the volume of EU research output on affordable and clean energy (SDG7) to be second only to that on health (SDG3) between 2015 and 2019. Climate-related research (SDG13) figured third (Figure 9.7).

Top 15 EU28 countries for publication intensity on energy, 2012–2015 and 2016–2019
Publications per million inhabitants, data labels are for 2016–2019



Top 15 EU28 countries for publication intensity on materials science, 2012–2015 and 2016–2019
Publications per million inhabitants, data labels are for 2016–2019



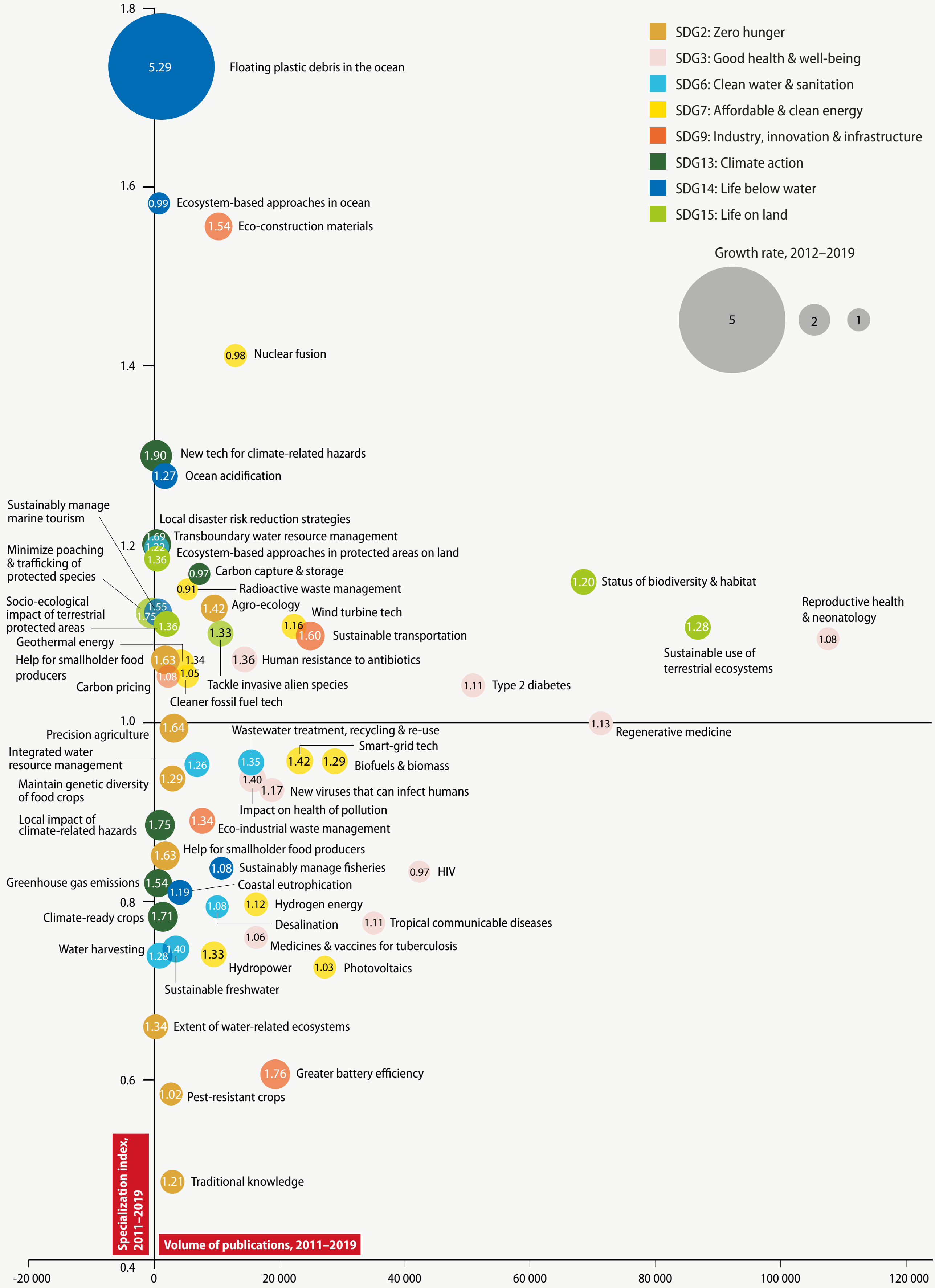
Note: Countries produced the greatest output on three cross-cutting strategic technologies: AI and robotics, energy and materials science. The growth rate was calculated as the number of publications during 2016–2019 divided by the number of publications during 2012–2015 to buffer the variability among individual years. See the statistical annex for complete data for all countries, freely available from the *UNESCO Science Report* web portal.

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

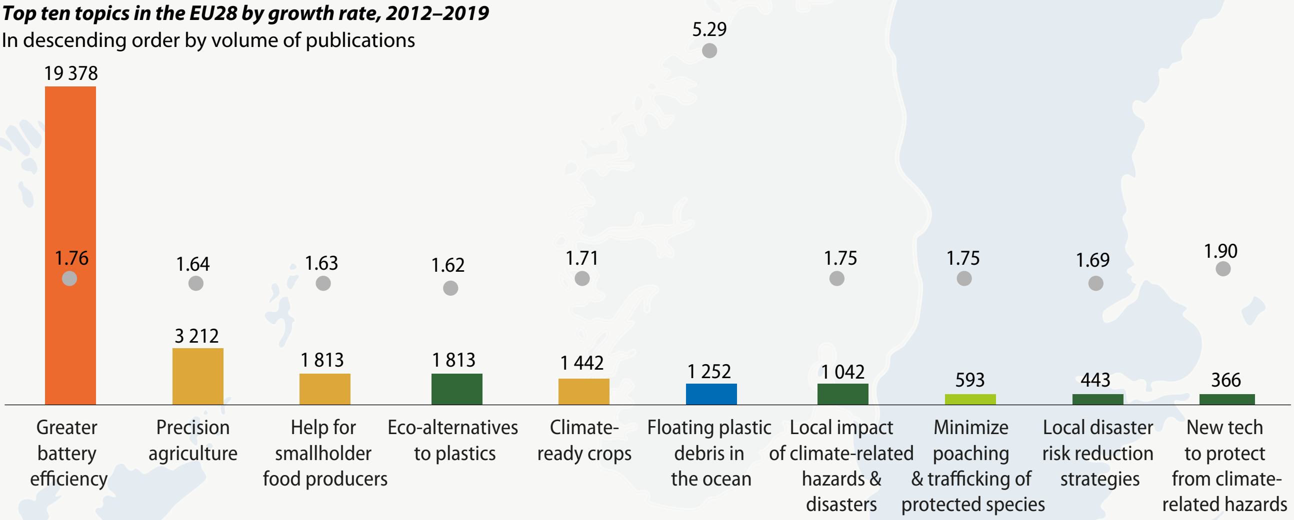
Figure 9.6: **Trends in scientific publishing on SDG-related topics in the European Union**

Scientific publications in the EU28 on 56 topics related to the SDGs, 2011–2019

The size of the bubble is proportionate to the growth rate



Top ten topics in the EU28 by growth rate, 2012–2019
In descending order by volume of publications



Top five topics by growth rate for selected EU28 countries, 2012–2019
For topics generating over 100 publications between 2011 and 2019
Specialization index given within brackets

UK	Growth rate, 2012–2019	Publications, 2011–2019
Floating plastic debris in the ocean (2.07)	4.65	307
Greater battery efficiency (0.47)	2.33	3 113
Geothermal energy (0.60)	2.12	567
Precision agriculture (0.44)	2.06	322
Eco-alternatives to plastics (0.42)	1.96	157

Germany	Growth rate, 2012–2019	Publications, 2011–2019
Floating plastic debris in the ocean (1.42)	4.82	224
Local impact of climate-related hazards & disasters (0.57)	2.13	153
Eco-alternatives to plastics (0.64)	1.99	223
Help for smallholder food producers (0.93)	1.97	378
Greater battery efficiency (1.02)	1.81	5 935

France	Growth rate, 2012–2019	Publications, 2011–2019
Floating plastic debris in the ocean (1.28)	4.23	159
Local impact of climate-related hazards and disasters (0.67)	2.38	120
Smart-grid technologies (0.52)	1.55	1 785
Sustainable transportation (0.92)	1.49	2 904
Geothermal energy (0.85)	1.48	496

Italy	Growth rate, 2012–2019	Publications, 2011–2019
Floating plastic debris in the ocean (2.28)	5.90	215
Local impact of climate-related hazards and disasters (0.55)	2.65	86
Sustainably manage marine tourism (1.47)	2.45	117
Help for smallholder food producers (0.52)	2.35	144
Eco-alternatives to plastics (1.65)	2.27	350

Spain	Growth rate, 2012–2019	Publications, 2011–2019
Floating plastic debris in the ocean (1.96)	5.63	159
Sustainably manage marine tourism (2.30)	1.92	152
Eco-construction materials (1.42)	1.88	933
Greater battery efficiency (0.54)	1.84	1 830
Geothermal energy (0.74)	1.63	298

Note: The growth rate is calculated as the number of publications from 2016–2019 divided by the number of publications from 2012–2015. The specialization index reflects the intensity of focus on a research topic relative to the global average share of publications (set at 1.00).

Source: Scopus (including Arts, Humanities and Social Sciences); data treatment by Science-Metrix

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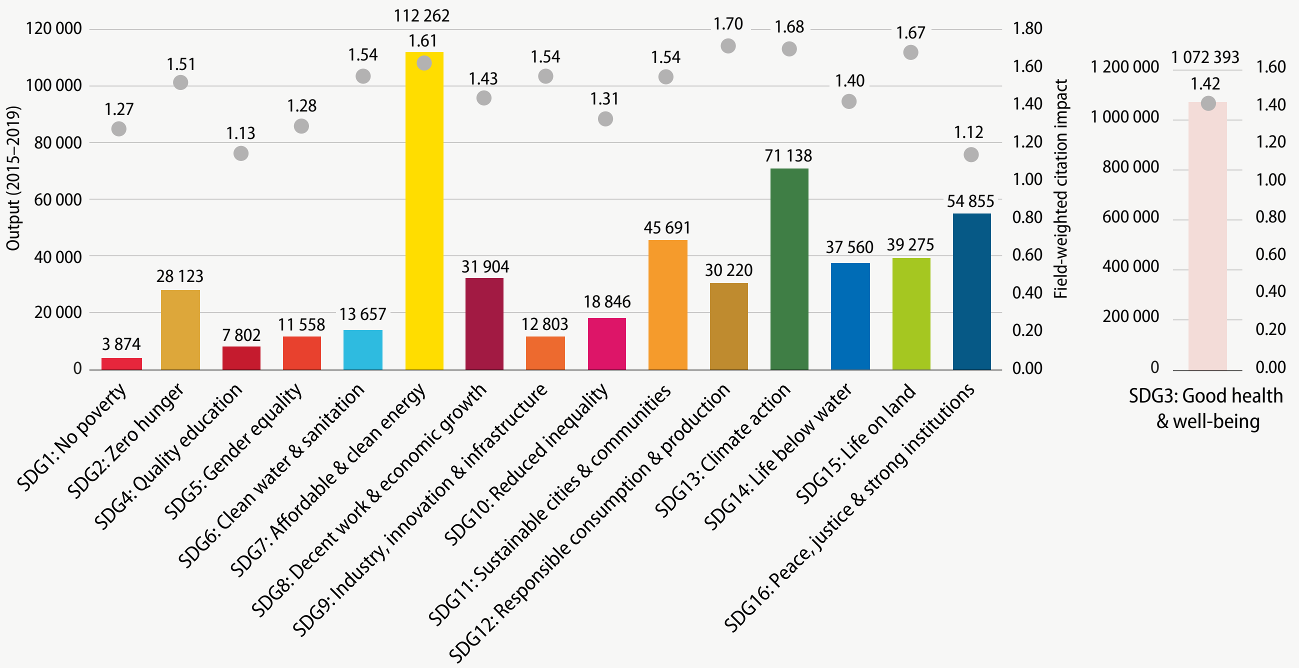
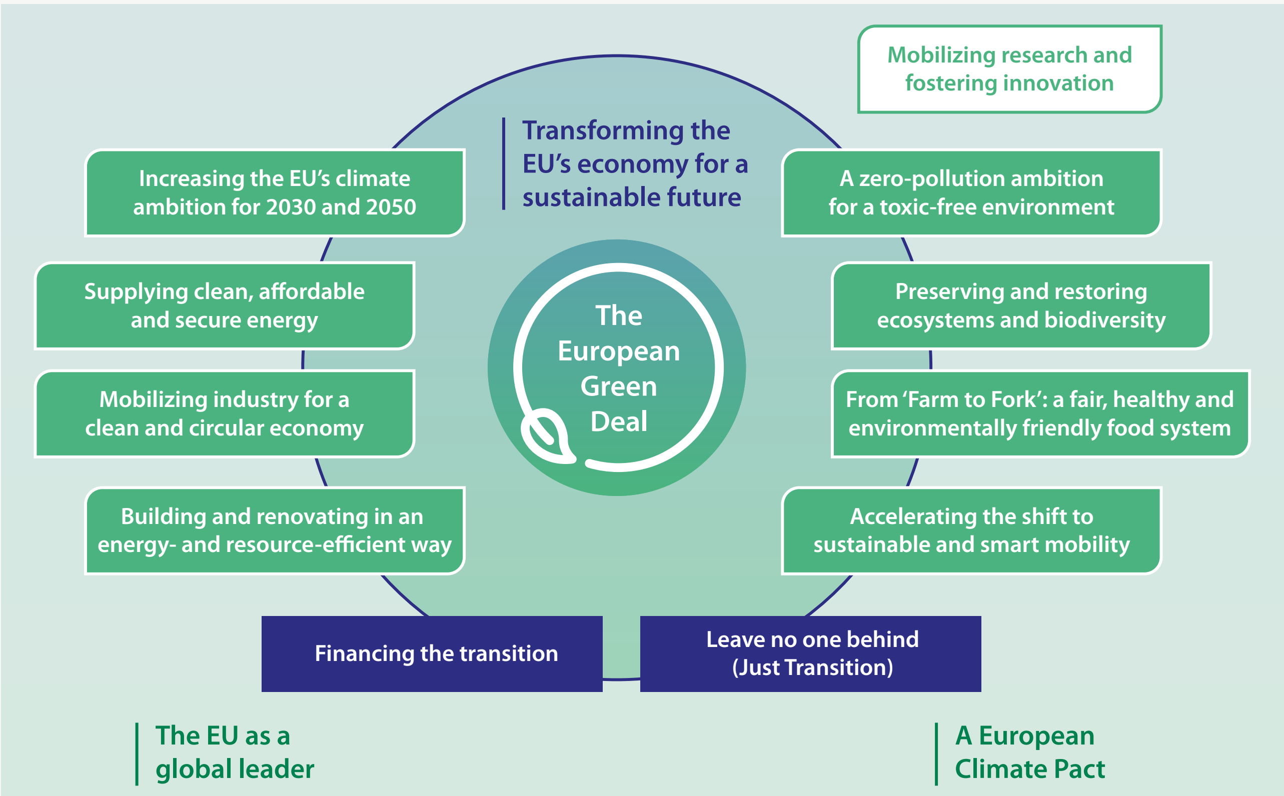
Figure 9.7: **Volume of EU28 publications on 16 SDGs, 2015–2019**



Source: data prepared for the European Commission by SciVal, Elsevier

Figure 9.8: **The European Green Deal**



Source: European Commission

POLICY TRENDS

Europe's new growth strategy: the Green Deal

'The *European Green Deal* is Europe's new growth strategy'. This is how the President of the European Commission, Ursula von der Leyen, presented the EU's overarching policy in December 2019, in her speech to the 25th Conference of the Parties to the United Nations Framework Convention on Climate Change (EC, 2019a).

At the time, she stressed the innovative nature of the *European Green Deal*, which will determine the overall direction of EU policy for the next decade. Accompanied by a smart industrial growth strategy, the drive for sustainability will take Europe on a transformative journey which should see it become 'the world's first climate-neutral continent' no later than 2050 (Von der Leyen, 2019b).

This policy shift signals the EU's receptiveness to the growing chorus of concerned scientists who had been sounding the alarm for years prior to the adoption of the *Paris Agreement* on climate action in 2015. Scientists warn that the transgression of planetary boundaries is leading to irreversible environmental harm.[15] In 2017, 1 700 independent scientists, including the majority of living Nobel laureates, published their *World Scientists' Warning to Humanity: a Second Notice*, an open letter stating that humanity was 'pushing Earth's ecosystems beyond their capacity to support the web of life' (Ripple *et al.*, 2017). If we are to succeed in mitigating climate change, we must accelerate the pace (Roberts *et al.*, 2018).

The Intergovernmental Panel on Climate Change's special report on how to achieve *Global Warming of 1.5°C* (2018) states that five socio-economic systems are responsible globally for 90% of carbon dioxide (CO_2) emissions, namely:

- the energy system, with a penetration of 21.7% of renewables in 2017 (25% of global emissions);
- the agrifood system (24%);
- the manufacturing system (21%);
- the transportation system, with a penetration of just 3.4% by renewables (14%); and
- the buildings–housing system, with a penetration of 10.3% by renewables (6%).

Across Europe, all five socio-economic systems are currently undergoing a transition driven by innovation, at a pace that varies from one country to another (EC, 2018a).

The challenge for the new *European Green Deal* will be to accelerate this transition in all five socio-economic systems simultaneously, in order to steer countries towards overall fulfilment of the Sustainable Development Goals, while taking into account different national contexts and making sure that jobs lost in one industry can be recreated elsewhere (EC, 2019b). Since inclusiveness is central to the EU's values, the bloc's approach sets out to limit the turbulence engendered by transitioning to green and digital societies, such as by safeguarding the transparency of personal data and preserving the purchasing power of vulnerable segments of the population.

In early 2020, the European Commission launched several important policy initiatives to translate this policy vision into action. In January, it presented the European Green Deal's *Sustainable Europe Investment Plan* mobilizing public and private investment to a cumulative total of at least € 1 trillion. This initiative comes with tailored resources in the form of the Just Transition Mechanism, oriented towards those countries and regions within countries that will be most vulnerable to changes wrought by the green, digital transition (EC, 2020d), such as widespread job losses through the phasing out of a polluting industry.

These policy initiatives reflect the Commission's systemic, comprehensive approach to the *European Green Deal,*[16] which entails simultaneously pointing resource mobilization and regulatory and other reforms in the same direction, to ensure a credible commitment to the 2050 target (Figure 9.8). Credibility is important to citizens but also to firms.

With this approach, the Commission aims to trigger a 'crowding-in effect', whereby higher government spending boosts investment by the private sector. We know from experience that the probability of a crowding-in of private investors increases, if the scale and the scope of public resources, regulatory changes and reforms all point towards the same target.

The *European Green Deal* is also comprehensive, in terms of its ambition to integrate the green and digital transition in the framework of a common industrial policy. Industrial transformation and corresponding support for corporate innovation emerge at the interface of green and digital technologies.

The EU's digital strategy, *A Europe fit for the Digital Age* (2019), strives to accelerate the development and deployment of digital technologies in the EU but also to shape their uptake and use to be consistent with European values. The challenge will be to synchronize supply- and demand-side policies, while fostering economies of scale and scope through this multilevel European industrial policy (Box 9.2).

In parallel, the rolling EU reform agenda, dubbed the 'European semester', will integrate the United Nations' Sustainable Development Goals in economic policy, placing sustainability and the well-being of citizens at its heart (EC, 2019a).

Over the 2021–2027 period, the EU will invest more than € 1.8 trillion in public funds, out of which at least 30% must focus either on accelerating the green transition or adapting to climate change. Given that part of this investment will be channelled through national recovery and resilience plans and through EU Structural Funds, the EU investment will, by law, be topped up by national and regional co-investment.

This implies that total public investment in the green transition across the EU will amount to around € 100 billion annually for seven years. To this must be added the crowding-in of private investment.

In order to increase the credibility of the new EU policy, in March 2020, the Commission proposed a European Climate Law enshrining the 2050 climate-neutrality objective in the EU regulatory framework. This law is expected to be approved in April 2021. In December 2020, the Commission adopted the target of a 55% reduction in carbon emissions by 2030 over 1990 levels.

Throughout the 2020–2024 period, new regulations and revisions to existing ones will be sensitive to enhancing sustainability. The challenge will be to ensure that countries transpose these regulations into domestic law. For example, the Directive on the Reduction of the Impact of Certain Plastic Products on the Environment (#904), adopted by the European

Box 9.2: **Revisiting Europe's industrial strategy**

The EU adopted its revamped industrial policy in March 2021. It rests on three drivers capable of transforming European industry: the green transition, supported by the *European Green Deal*; the digital transition, supported by the EU's digital strategy; and global competitiveness that will leverage the Single Market to set global social and environmental standards.

Within this policy framework, the EU is launching several concrete initiatives in 2020 and 2021. One of these is the new European Innovation Council (Box 9.3). It will identify next-generation technologies, accelerate their commercial application and help them to support the rapid scale-up of start-ups.

The following are other examples.

New markets for climate-neutral and circular products

The circular economy reduces waste and re-uses and recycles industrial products. To modernize and decarbonize energy-intensive industries, the *European Green Deal* sets the objective of creating new markets for climate-neutral and circular products, such as steel, cement and basic chemicals. For instance, the European Commission will support clean steel breakthrough technologies leading to a zero-carbon steel-making process by 2030.

Use will be made of the EU Emissions Trading System Innovation Fund created in 2019 to help deploy other large-scale innovative projects, to support clean products in all energy-intensive sectors.

The world's largest carbon-pricing system

The EU Emissions Trading System is currently the world's largest carbon-pricing system. Between 2020 and 2030, it will provide revenue through its own Innovation Fund. The European Commission announced the creation of this new investment programme for low-carbon technologies on 26 February 2019.

The EU Emissions Trading System Innovation Fund will be replenished primarily by auctioning 450 million allowances over the period to 2030. The fund will improve risk-sharing for projects by allocating funding in a more flexible way through a simpler selection process. It is open to projects from energy-intensive industries.

A new sustainable product policy framework will establish sustainability principles for all products. Priority will be given to high-impact product groups, including initiatives on the common charger, a circular electronics initiative, sustainability requirements for batteries and new measures in the textiles sector. Europe also needs to address the sustainability of construction products and improve the energy efficiency and environmental performance of built assets.

Incentivizing investment in sustainability

Investment towards competitive sustainability will be incentivized throughout the financial system. The recent agreement on an EU taxonomy and the certainty provided by the European Climate Law (March 2020)[23] are big steps in the right direction.

Building on this progress, the stakeholder consultation on a Renewed Sustainable Finance Strategy in May 2020[24] has put in place clear rules to guide investors towards sustainable forms of investment.

Private investment and public finance will be mobilized for the large-scale deployment of innovative technologies. One concrete tool is Important Projects of Common European Interest (IPCEIs). Building on experience with recent IPCEIs, the Commission will explore ways to combine national and EU instruments to leverage investment across the value chain, in full respect of relevant financial and competition rules. To help make the most out of this tool, the Commission will put in place revised State aid rules for IPCEIs in 2021.

A new European Clean Hydrogen Alliance will be launched and alliances on industrial clouds and platforms, low-carbon industries and raw materials should follow once ready.

Towards a 'right to repair'

The European Commission will propose ways to improve consumer rights and protection, including by working towards a 'right to repair' for consumers, including a right to update obsolete software.

This will empower consumers to play a more active role in the circular economy by providing them with trustworthy information on how to choose re-usable, durable and repairable products.

Investment in strategic technologies

The EU will develop Quantum Communication Infrastructure for deployment in the next ten years, based on quantum key distribution, to protect key digital assets of the EU.

The EU will also support the development of key enabling technologies that are strategically important for Europe's industrial future. These include robotics, micro-electronics, high-performance computing and data cloud infrastructure, blockchain, quantum technologies, photonics, industrial biotechnology, biomedicine, nanotechnologies, pharmaceuticals, advanced materials and technologies.

Source: European Commission, communication of New Circular Economy Action Plan on 10–11 March 2020

Parliament and Council of the European Union in June 2019,[17] intends to eliminate ten single-use pollutants (straws, takeaway food containers, etc.) and to require producers of other pollutants, such as single-use plastic bags, to cover the costs of waste collection and treatment. According to a coalition of national and international environmental organizations, 'one year after the entry into force of the directive, the transposition of the legislation into domestic law has stalled in most European countries' (Seas at Risk, 2020).

A Europe fit for the Digital Age

A Europe fit for the Digital Age (2019) outlines the European Commission's strategy for achieving the digital transformation while helping to make Europe climate-neutral by 2050.

This strategy for the coming decade follows the adoption of the Digital Single Market (2015), itself an outcome of the *Europe 2020 Strategy* adopted in 2010 (Hollanders and Kanerva, 2015), which initiated a *Digital Agenda for Europe 2020*.

The Commission's stated aim is to strengthen Europe's digital sovereignty and set standards, rather than follow those of others, with a clear focus on data, technology and infrastructure.

This strategy builds on recent regulatory reform. In 2016, the EU adopted a General Data Protection Regulation (#679) to protect citizens' right to data privacy in the EU and the wider European Economic Area. The directive also tackles the transfer of personal data beyond the EU for commercial or other purposes. Digital companies must now obtain authorization from Internauts visiting their website for their personal data to be harvested.

The Covid-19 pandemic has accelerated the spread of digital communication to Europeans from all walks of life. However, there is a lack of harmonization among EU member states in many areas of digital services and an absence of large Internet companies, as noted in the previous *UNESCO Science Report* (Hollanders and Kanerva, 2015). This has prompted the European Commission to make it a top policy priority to reinforce the Digital Single Market and improve connectivity, while securing high cybersecurity standards. At the same time, the way in which the Covid-19 pandemic has boosted the profits of many foreign tech giants has highlighted their global and European dominance across most online markets, sowing doubts as to the adaptability of the EU's current competition policy.

As a result, the EU's digital strategy is likely to become even more prominent in the years to come, not only because it shares common goals with the *European Green Deal* but also on account of the now widely perceived urgency for the bloc to reinforce its strategic autonomy in digital services. The top two priorities will be to streamline the functioning of the Digital Single Market and strengthen the regulation of Internet platforms, the latter through legislation that will include a Digital Markets Act and Digital Services Act.[18]

Differences in national regulation alone do not explain the EU's weakness when it comes to creating and expanding commercial Internet platforms. Consumer habits and broader cultural differences are likely to play a preponderant role. From this perspective, shifting the focus from consumer-to-consumer (C2C) markets to industrial digital interactions (business to business, or B2B) might prove to be a more rewarding digital strategy for the EU. On 14 December 2020, the European Commissioner for the Internal Market, Thierry Breton, remarked in an interview with the radio station France Inter that current Internet giants such as Facebook or Google harvested personal data, whereas the next wave of Internet giants would specialize in industrial data, a sphere in which European companies showed strengths.

Complementary national and regional AI strategies

In 2018, the European Commission adopted its *Artificial Intelligence for Europe* strategy, followed by a co-ordinated implementation plan prepared with member states. The plan advocated closer co-operation between member states, Norway, Switzerland and the Commission in four key areas: increasing investment in AI; making more data available; fostering talent; and ensuring trust by developing ethical, trustworthy AI.

Judging investment levels for AI in the EU to be 'low and fragmented, compared with other parts of the world such as the USA and China', the plan foresees greater co-ordination of public and private investment in AI to improve synergies.

The 2018 strategy for AI also included the launch of a so-called Quantum Technologies Flagship with ten-year funding of some € 1 billion;[19] through calls for research project proposals, the flagship will bring together European research institutions, industry and public funders with the aim of developing quantum Internet in Europe where quantum computers, simulators and sensors are interconnected via quantum communication networks.

The Commission has pledged to increase total investment in AI (public and private funds combined) to € 20 billion per year by the end of 2020. This will translate into a greater number of ERC grants for research on AI, greater funding from the European Innovation Council (Box 9.3) for innovators and small and medium-sized enterprises (SMEs) specializing in AI and, hopefully, a boost in private investment in AI through the Public–Private Partnerships (PPP) programme under Horizon Europe. Through the PPP, the Commission will invest at least € 1.5 billion to trigger an expected € 2.5 billion investment in AI by the private sector.

At the same time, the Digital Europe Programme launched in 2021 is focusing on supercomputing, AI, cybersecurity, advanced digital skills and the widespread deployment of digital technologies across the EU, including via digital innovation hubs. The latter have been established as part of the Digitising European Industry Initiative adopted in 2016.

According to the European Commission, only about one in five EU companies are digitalized. It has also observed that about six out of ten large industries and more than 90% of SMEs are lagging behind in digital innovation.[20] Digital innovation hubs allow companies of all sizes to 'test before they invest' in digital technologies, using competitive funding initially provided under Horizon 2020.[21]

The European Commission expected all member states to have national AI strategies in place by 2019. As of February 2020, 16 countries had published national strategies, five had produced an advanced draft and the remainder were in the process of developing one (JRC, 2020).

The European Commission plans to create common data-sharing spaces, in compliance with the *General Data Protection Regulation* of 2016. It has singled out the health sector for its potential as a major beneficiary of AI. The Commission is supporting the development of a common health database containing anonymous scans donated by patients, so that algorithms can be used to improve cancer diagnoses and treatments.

Last but not least, with the *Digital Education Action Plan 2021–2027*, the European Commission has engaged in a major rethink of education. In order to prepare the workforce for the digital economy of tomorrow, greater emphasis will be laid on lifelong learning. 'We should create education aimed at adults, not simply a few retraining sessions scattered over the course of a career,' it proclaims. 'We should give young people the capacity to learn, rather than feeding them with technical knowledge that can quickly become obsolete.'[22]

HORIZON EUROPE

Two new features

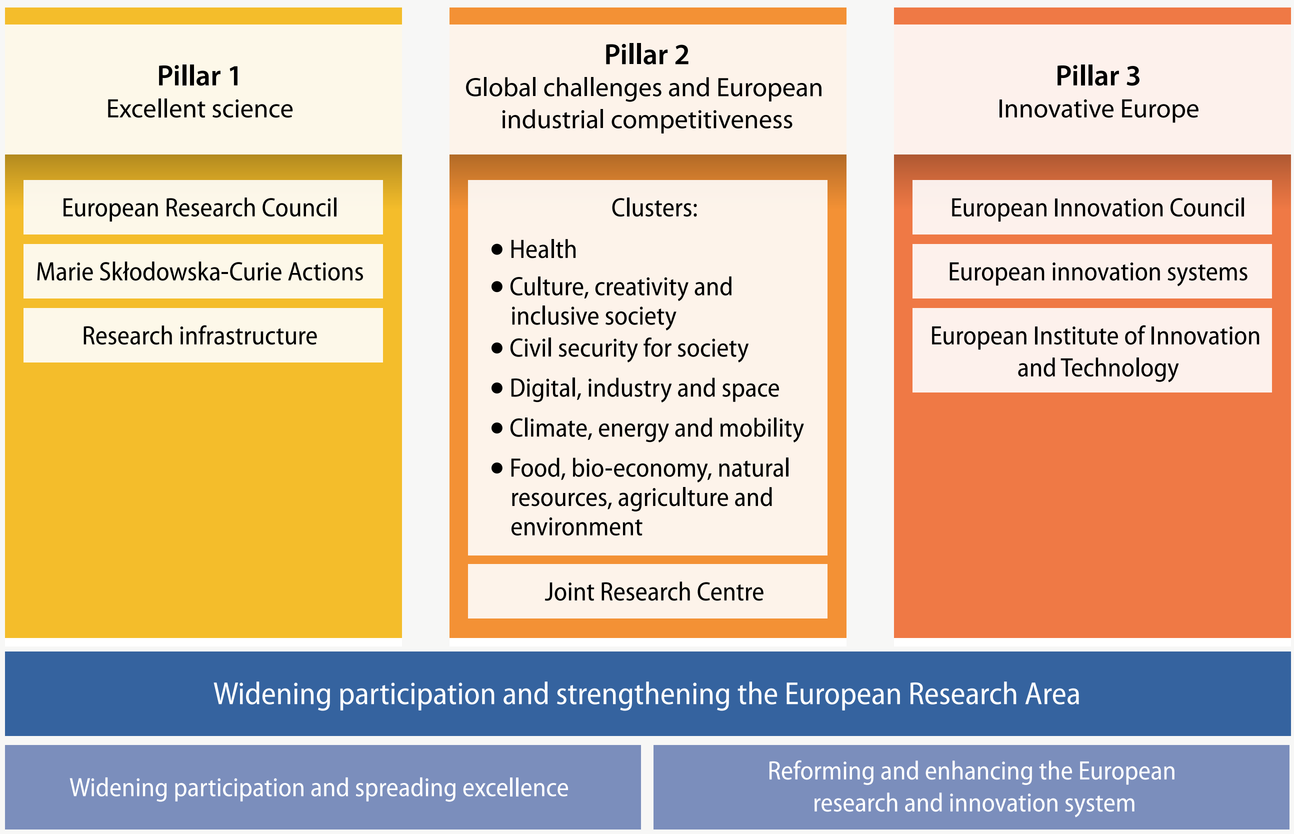
Horizon 2020, the previous EU framework programme for research and innovation, was the biggest ever, with around € 77 billion of funding available over the seven years to 2020. It focused on breakthroughs, discoveries and world-firsts by taking good ideas from the laboratory to the market. Horizon 2020 contributed to the overall EU policy, *Europe 2020* (2010), and, in particular, to one of its key components, the *Innovation Union* (Hollander and Kanerva, 2015).

Horizon 2020 has been succeeded by Horizon Europe, the EU's ambitious research and innovation programme to 2027. Horizon Europe ensures a seamless transition from Horizon 2020, with a similar structure built on three pillars: scientific excellence, societal challenges and innovation (Figure 9.9). However, it introduces two new features: the European Innovation Council (Box 9.3) and, secondly, a mission-oriented approach to societal challenges, as a contribution to the overall EU policy for the transition to green, digital societies (Box 9.4).

Horizon Europe rests on the following three pillars:

- The **Excellent Science** pillar supports frontier research projects designed and driven by researchers through the European Research Council. It also funds fellowships and researcher mobility through Marie Skłodowska-Curie Actions and invests in world-class research infrastructure through the European Regional Development Fund.
- The **Global Challenges and European Industrial Competitiveness** pillar supports research into societal challenges, reinforces technological and industrial capacities and sets EU-wide missions with ambitious

Figure 9.9: **Preliminary structure of Horizon Europe**



Source: European Commission

Box 9.3: **The new European Innovation Council**

The European Innovation Council became fully operational in 2021. Its role is to fill the financing gap for innovative start-ups and small and medium-sized enterprises (SMEs), in full alignment with the European Commission's recommendation for the establishment of a private public fund specializing in initial public offerings of SMEs.

This gap is particularly acute when it comes to disruptive and breakthrough innovation where technology and market risks are high. The Council will complement member states' own support for innovation. It is expected to give a significant boost to innovative start-ups and SMEs in Europe, creating a pipeline of promising projects for InvestEU and venture capital and, thereby, giving Europe a leading position in future tech-based markets.

In 2017, the Commission launched the first pilot phase for the future European Innovation Council. Since then, 2 078 projects have received funding totalling over € 893 million. Building on this, an enhanced pilot phase was launched in March 2019.

This latter phase has enabled the Commission to test the main changes brought in under Horizon Europe. For instance, Horizon Europe introduces targeted calls for future and emerging technologies under the European Innovation Council's Pathfinder Pilot, which employs external programme managers to ensure flexible management of the portfolio of projects.

Horizon Europe also provides scope for innovators to apply for blended finance (combining grant funding and equity) under the European Innovation Council's Accelerator Pilot. A total of € 1 billion will be allocated under Horizon 2020 over 2019–2020, of which at least € 100 million will be in the form of equity.

The European Innovation Council's Accelerator will target cases where there is strong potential for upscaling but the risks are too high for private investors, such as in highly disruptive, deep-tech areas.

In line with the provisions outlined in Horizon Europe, a specific entity will be established to manage equity investments and crowded-in investments from private investors. In 2020, this entity was still in the process of being set up, with support from the European Investment Bank Group.

Source: EC (2019b)

goals tackling some of the EU's biggest challenges related to health, climate change, clean energy, mobility, security, digital, materials, etc. This pillar will also support partnerships with member states, industry and other stakeholders to work jointly on research and innovation.

- The **Innovative Europe** pillar aims to use the European Innovation Council to make Europe a frontrunner in market-creating innovation and support for SMEs. In parallel, the European Institute of Innovation and Technology (est. 2008) will continue to foster the integration of business, research, higher education and entrepreneurship.

Pillars 1 and 3 of the Horizon Europe programme focus on a free-thinking, bottom-up approach with the European Research Council (pillar 1) being to breakthrough science what the European Innovation Council (pillar 3) is to market-creating innovation. Both build on the principle of open international competition for funding based on the sole criterion of excellence. After a positive assessment, the European Research Council benefitted from an increased budget over 2015–2020.

In parallel to the quest for scientific excellence, there has been a growing policy concern over the low level of private investment in high-growth or high-risk tech companies in the EU. Venture capital is bigger in the USA, favoured by the larger market potential.[25] According to the European Commission, the EU counts only 8% of the world's start-ups that have managed to raise € 1 billion in funding ('unicorns'), far less than the USA, which counts almost 50% of unicorns, and Asia.

In comparison with the USA, Europe's venture capital market remains underdeveloped at all stages of enterprise development: inception, growth and scale-up, seed-capital, start-up and later-stage development funding (EC, 2019b). European start-ups often move to the USA to tap into the resources available there. For instance, in the USA, there is 14 times more later-stage capital than in Europe.

This deficit was the rationale behind setting up the European Innovation Council as a flagship initiative under pillar 3 of Horizon Europe (Box 9.3).[26]

A mission-oriented approach

The second pillar of Horizon Europe addresses societal challenges, with the introduction of two novelties. The first of these is a broader clustering of societal challenges that had already been addressed by Horizon 2020 as part of an overall strategy to foster a transsectoral, multidisciplinary approach to research and innovation. The second novelty is a stronger transformative approach to innovation policy which draws inspiration from mission-oriented research and innovation.[27]

In 2017, the Directorate-General for Research and Innovation began exploring how the policy design applied by the USA's classic Moonshot mission within the Apollo programme (1961–1975) could be applied to solving societal challenges on Earth. The European Commission launched several studies scanning similar policy initiatives around the world that were more recent and mainly technological in nature. It also amassed opinions from academic experts in Europe and beyond. This rich evidence base was ventilated in an open reflection involving policy-makers responsible for innovation in EU member states (Mazzucato, 2018; RISE, 2018; EC, 2018b; EC, 2018c).

The final outcome was included in the Commission's Horizon Europe proposal in 2018, which introduced a mission-oriented programme design expressed through five concrete missions (Box 9.4):

- Adaptation to climate change;
- Cancer;
- Climate-neutral and smart cities;
- Healthy oceans, seas, coastal and inland waters; and
- Soil, health and food.

The focus of the new EU policy on the green, digital transition opens up fresh opportunities for STI policy which have not yet been fully grasped. The EU policy experimentation with smart specialization and its more recent mission-oriented policy are a snug fit in a systemic and transformative innovation policy. The policy challenge for the coming years will be to bring these two approaches closer together at the right level of granularity and with the proper multilevel governance to turn Europe's cultural diversity into greater economic value.

SMART SPECIALIZATION

A place-based industrial policy

Besides Horizon Europe, the EU is orienting investment towards research and innovation through its Structural Funds, in general, and the European Regional Development Fund, in particular.

Box 9.4: The five characteristics of the EU's mission-oriented research and innovation policy

The EU's new mission-oriented approach can be summarized by five principles: target-setting, a systemic mobilization of policy instruments, programme design, experimentation and multilevel governance.

Target-setting serves as the basis for determining in which direction the EU wishes to go, or, in other words, its directionality. The policy objective here is to achieve traction. For this, the mission must be meaningful to citizens, ambitious yet credible, measurable and, lastly, must contain the right level of granularity.

A good illustration of granularity is the proposed mission of achieving 100 climate-neutral cities in the EU by 2030; this mission is aligned with the overall target of a climate-neutral EU by 2050, while covering a different level of granularity, in that it avoids being too prescriptive. The mission does not specify any particular industrial sector, nor specific scientific disciplines or technologies. Achieving the target requires innovation in several sectors and even across sectors, such as by combining new solutions for transportation, digital management and electric vehicles. The mission of achieving 100 climate-neutral cities is also a target with a capacity for traction by having meaning for local policy and identity. The target is place-based, enabling different solutions and pathways to be chosen in different cities that will mobilize different combinations of policy instruments. In other words, the target leaves room for entrepreneurial discovery.

The second characteristic of a mission-oriented policy is its systemic nature. Many cities in the EU are mobilizing both supply- and demand-side instruments to improve local climate or air quality. Investment in public infrastructure, urban planning and transport systems is being combined with energy-efficient procurement in public buildings, public-sector innovation, local public monitoring of pollution levels or science parks for local start-ups specializing in clean technology. Cities are joining forces and sharing best practices through national, European or broader international networks.

The third characteristic is policy design and, in particular, the way in which public STI investment programmes are structured and implemented. The European Commission's proposal for Horizon Europe has been inspired by best practices from many national programmes. The last *European Green Deal* call of Horizon 2020 has already put this principle into practice. Calls for proposals are less prescriptive in technical terms, leaving a broader opportunity for applicants to propose innovative solutions combining technological and non-technological elements.

Moreover, the calls are open to a broader range of applicants ranging from producers to users and funding is available not only for the development of innovation but also its deployment and diffusion. In addition, projects are managed to a greater extent as part of a portfolio, to maximize synergies and spillover effects between projects. In short, a mission-oriented policy requires a revision of the criteria for participation, eligibility and management of STI funding programmes.

The fourth characteristic is policy experimentation and a system of continuous learning. A mission-oriented policy starts with the final target without prescribing the pathway for getting there. Since it is not possible to know beforehand which way is best, there has to be a system of continuous experimentation and learning, combined with flexibility in policy design. All actors are encouraged to participate in this learning process, in particular those with a stake in seeing the mission accomplished, including users and citizens.

The fifth characteristic of a mission-oriented policy is the need for pro-active governance and effective multilevel governance. No ambitious mission will be achieved without engagement at all levels of governance, from the large-scale traction of investment and regulations at the EU level to strategies and investment at national, regional and municipal levels. Everyone will strategically seek their own comparative advantage, so, in this sense, synergies with smart specialization strategies are obvious.

Source: compiled by authors; for details, see: https://tinyurl.com/EU-missions-Horizon-Europe

In this policy area, the 2014–2020 period was characterized by the roll-out of an innovative approach to place-based innovation, the so-called smart specialization strategies. This concept was first proposed by a group of economic advisers to EU Commissioner Janez Potocnik in the context of the *Lisbon Agenda*, as the EU's policy for 2000–2010 came to be known (Foray *et al.,* 2009). The objective of the *Lisbon Agenda* was to make the EU the most knowledge-intensive economy in the world by 2010 by raising the bloc's research intensity to 3% of GDP, which has proved to be a stubbornly elusive target.

Foray *et al.* (2009) argued that a place-based industrial policy should replace a one-size-fits-all approach. It was felt that smaller countries and regions keen to make an impact should concentrate their scarce resources by investing only in technologies and innovation[28] that were relevant to their particular local industry. The choice of technologies was to be 'bottom-up' and fall to local entrepreneurs in an 'entrepreneurial process of discovery'. The subsequent technological upgrading of local firms, they argued, would increase their competitiveness in market niches by capitalizing on the productive assets and the comparative advantage of the regional economy. Across Europe, this process would increase diversity among regions and favour technology diffusion from the 'leader regions' to the 'follower regions' by allowing the latter to apply technologies generated by the 'leader regions' to their existing industrial process.

The European Commission retained this policy proposal. The development of smart specialization strategies was set as an *ex ante* conditionality for regions receiving resources from the European Regional Development Fund over the 2014–2020 period. Today, EU member states and regions within each country have developed over 120 smart specialization strategies mobilizing over € 65 billion in public investment, two-thirds of which has come from the EU budget (EC, 2017).

Regions with a similar specialization profile co-operate within thematic platforms.[29] To date, three thematic platforms link over 100 regions specializing in industrial modernization, energy and agrifood. The great majority of regions have chosen sustainable energy as one field for their smart specialization strategy. Research is particularly intense in this area in Poland (Figure 9.10).

The European Commission has set up an overall smart specialization platform which advises member states and regional authorities on how to design and implement their smart specialization strategies. For example, member states are advised to select priority sectors on the basis of interaction between policy-makers and the private sector, in a process known as enterpreneurial discovery.

There is growing interest in this place-based approach to STI policy from countries beyond the EU (see chapter 10). This has led the European Commission to collaborate with the United Nations on integrating this concept into implementation of the Sustainable Development Goals.

Six years on, the assessment by regional and local actors of this policy experiment in smart specialization has been broadly positive, although there is room for improvement. A recent evaluation of the process of entrepreneurial discovery by Cvijanovic *et al*. (2020) found that smart specialization had improved the governance of local innovation systems through strategy-setting and better public–private co-operation. The study also identified shortcomings when it came to ensuring a continuous process of entrepreneurial discovery and involvement by civil society.

For the period from 2021 onwards, the EU is placing greater emphasis on sustainability. The *European Green Deal* and the *New Industrial Strategy for Europe* (2020) recognize the importance of place-based innovation and of supporting the industrial transition to digital, green societies.

In this context, the challenge for smart specialization will be to combine an overall directionality to competitive sustainability with bottom-up strategies and entrepreneurship.

A EUROPEAN HIGHER EDUCATION AREA

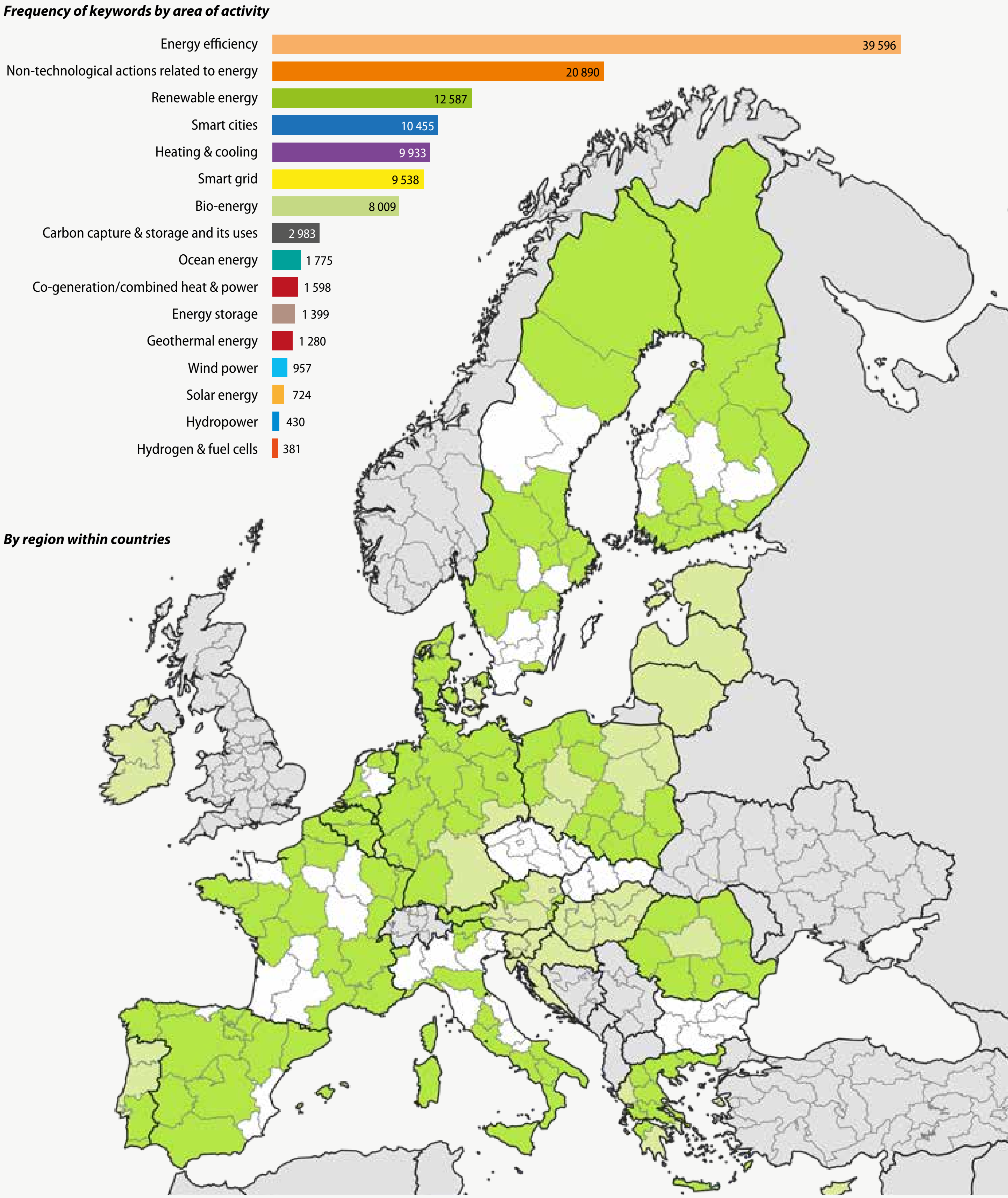
Creating a future European identity

A skilled and highly educated labour force will be an essential component for the transition towards a green and digital economy. However, with the EU's rapidly ageing population and low birth rates in many member states – Bulgaria is even the fastest-shrinking country in the world, followed by Lithuania and Latvia – maintaining the same level of qualifications and skills in the European population will take a supreme effort. For the highly developed, wealthy members of the EU, a tug of war for talent is likely to become a hidden factor in future migration strategies, as countries vie to attract talent in fast-evolving Industry 4.0 fields such as AI and circular engineering.

As in the case of health, education in Europe is, first and foremost, a national prerogative. As a result, there is a wide variety of norms with respect to school age, language of instruction, curricula, the share of public versus private funding of education, etc. However, under pressure from student mobility schemes like the EU's Erasmus programmes (today Erasmus+), which now extend to citizens beyond the bloc, the EU has attempted to harmonize education systems through institutional reforms like the European Credit Transfer and Accumulation Scheme and the alignment of the structure of bachelor's and master's degrees. These reforms have been instrumental in boosting student mobility among European universities. Between 2014 and 2020, Erasmus+ gave 3.7% of young Europeans the opportunity to study, train, volunteer or gain professional experience abroad. The budget for Erasmus+ in 2019 amounted to € 3.37 billion.

The ultimate aim is to create a European (Higher) Education Area, analogous to the European Research Area. It is hoped that this will forge a European identity in future generations but there is a very real prospect that the heightened mobility of skilled youngsters could also lead to brain drain for some countries and brain gain for others. This has made it a political priority to create European networks in higher education that extend beyond the top-ranking universities in some of the richer member states (Box 9.5).

Figure 9.10: **Level of priority accorded to sustainable energy and renewable sources in smart specialization strategies in the European Union, 2017**



Note: Territories shaded in a darker green have a stronger focus on R&D than those shaded in a lighter green. Data are unavailable for the UK.

Source: European Structural and Investment Funds Energy Tool, Smart Specialisation Platform, Joint Research Centre in Seville, January 2021

UN Disclaimer

EUROPE IN THE NEW GLOBAL LANDSCAPE

A global leader in green innovation

According to the European Investment Bank, the EU has been a global leader in green innovation. In 2017, the bloc registered 50% more patents in green technologies than the USA and the gap was even wider (76%) for patents combining green and digital technologies (Figure 9.12) [EIB, 2021].

Although the top global companies for digital innovation are largely American, the top innovators for technologies that combine green and digital elements tend to be European. European firms are less likely than US firms to have adopted digital technologies but more likely to invest in measures for mitigating or adapting to climate change. The share of firms that make green investments and are also digital adopters was also marginally higher in 2019 in Europe (32%) than in the USA (28%) [EIB, 2021].

Technological sovereignty: a new concept for the EU

The strained relations between the USA and China over trade, technology and, ultimately, ideology, power and influence threaten to usher in an era of reduced flows of global knowledge and technology, interlinkages and co-operation. Both the USA and China are increasingly emphasizing the need to reduce their intertwinement not only with one another's markets but also with one another's research and innovation systems. The resulting decoupling of the world's largest economies and scientific powerhouses will have widespread ramifications for the rest of the world, including Europe.

In line with the government policy of reducing dependence on foreign technology (see chapter 23), China's exposure to the world in terms of trade, technology and capital has been declining (McKinsey, 2019). This trend is also illustrated by the significant drop between 2006 and 2016 in the share of foreign co-inventors among Chinese patents registered through the Patent Cooperation Treaty. According to this measure, China's participation in international technological co-operation has declined considerably, even as this form of co-operation has risen in the EU and the USA. Consequently, China's share of total technological production is now considerably lower than that of the EU or USA (EC, 2020a, pp. 401–402).

The looming decoupling and confrontation over technology between the USA and China might force Europe and other parts of the world to choose between two increasingly separate realms of technology, such as with regard to telecommunications, digitalization, AI and the Internet. Alternatively, the rest of the world could decide to safeguard its participation in both realms but this would be an extremely costly and inefficient option.

Decoupling, growing conflicts over technological superiority and a progressive retrenchment from international collaboration in science and technology – driven, again, primarily by the USA and China – have also given rise to a related concept, that of technological sovereignty.[30]

In a recent report, the European Commission highlighted the importance of safeguarding Europe's technological sovereignty and strategic interests in trade and technology in areas like AI and related digital technologies and infrastructure (EC, 2020a, pp. 21–24, 452 and 504). Recognizing that the strained relations between China and the USA have reshaped the geopolitical landscape, it cautions that '[i]nternational technological co-operation policies need to be put into a wider perspective of changing global approaches to trade and technological sovereignty' (EC, 2020a, p. 391).

The President of the European Council has emphasized the importance of European strategic autonomy, arguing

Box 9.5: The European Universities Initiative: developing a sense of belonging

The current ambition of building a European Education Area by 2025 is rooted in the Bologna Process launched by the EU in the eponymous Italian city in 1999, which set out to harmonize standards for university qualifications across Europe.

In September 2020, the European Commission laid out a pathway for taking this process to the next level in a *Communication on the European Education Area*. In addition to qualifications being recognized across the EU, the vision is for everyone to be able to access a high-quality education, for study abroad and the knowledge of at least two foreign languages to become the norm and for Europeans to identify as such through a strong sense of belonging and familiarity with Europe's cultural heritage and diversity.

It was in this context that the European Commission launched the European Universities Initiative, in line with the conclusions of the EU's Gothenburg Summit on education and culture in December 2017.

The aim of the initiative is to create networks of tertiary institutions to boost student mobility between EU countries and develop joint curricula. The European Universities Initiative has been co-developed by universities, student bodies, member states and the European Commission.

The ultimate goal is to create a European inter-university campus, whereby students will be able to obtain a degree by combining their studies in several EU countries.

So far, the European Commission has launched two calls which have led to 41 European University alliances involving more than 280 institutions, each of which has received up to € 5 million.

Although the initial funding was clearly earmarked for education and student, teacher and administrator mobility, these alliances have also benefitted from preferential or targeted funding for joint research and research infrastructure.

Source: compiled by authors; see: https://tinyurl.com/ycb2zzta that it was 'goal number one for our generation' (European Council, 2020). The current debate on how to ensure strategic autonomy has embraced the defence sector (Box 9.6).

Moreover, a foresight report published by the European Commission has identified dependence on certain imported products like microprocessors and on imported raw materials for key technologies, such as borates, heavy rare earth elements and light rare earth elements, as potential threats to Europe's economic sovereignty (EC, 2020a, pp. 17–19).

In parallel, foreign acquisitions of European high-tech companies are fuelling concerns that Europeans may be losing strategic assets. Examples are the American chipmaker Nvidia's purchase of British chip-designer Arm in 2020 and Chinese appliance-maker Midea's acquisition of German robotics company Kuka in 2016.[31] In recent years, there has been a surge in Chinese acquisitions of, and strategic investments in, high-tech European companies, with Chinese firms targeting particularly robotics, next-generation information technology, new materials, energy-saving and new-energy vehicles. Germany has attracted the greatest share of these investments (EC, 2019d).

Growing concern over foreign strategic takeovers of European firms, particularly by China, resulted in a report by the European Court of Auditors (2020) on how Europe should respond to 'China's state-driven investment strategy' and in an EU regulation on Foreign Direct Investment Screening, which came into effect in October 2020 (Box 9.7).[32]

In sum, numerous testimonials and reports point to an increasingly complex balancing act for Europe as it strives to protect itself from overreliance on foreign technology, while continuing to champion the global enterprise of science [see, for example, SFIC (2020)].

Europe as a soft power for responsible openness

The EU is, by essence, more about engaging internationally than decoupling. The Covid-19 crisis has highlighted the advantages of such a culture of sharing. Europe's seven-year framework programmes for research and innovation are one of the most ambitious means of promoting cross-border scientific collaboration among European countries and beyond. This culture is reflected in the much higher ratio of international scientific co-publications in the EU than in China, Japan, the Republic of Korea or the USA (EC, 2020a, p. 408).

In recent years, the EU has increasingly called for more reciprocity in opening up its research system, programmes and access to data, in messaging addressed to China, in particular (Kelly, 2020b).

The size and strength of its consumer market, combined with an ability and willingness to enforce regulations, has allowed the EU to exercise considerable global influence, or 'soft power' in a number of realms in recent years (Bradford, 2020a). Examples include data protection and privacy through the General Data Protection Regulation, raising the global bar for antitrust or market-distorting behaviour, environmental, and consumer health and safety regulations (Bradford, 2020b; Barthelemy, 2019).

As set out in a recent iteration of the European industrial policy (EC, 2020b):

> *At the same time, the EU needs to be able to strengthen its strategic interests abroad through economic outreach and*

Box 9.6: **The European Defence Fund**

In March 2019, the European Commission launched the European Defence Fund to support a competitive defence industry capable of contributing to the EU's strategic autonomy.

The fund will co-finance joint defence industrial projects worth up to € 500 million, with an additional € 25 million to support collaborative defence research projects.

The focus will be on drone technology, satellite communications, early warning systems, artificial intelligence, cyberdefence and maritime surveillance.

The idea is also to build an integrated defence industrial base across the EU, investing in European defence industrial value chains and dynamic supply chains that include small and medium-sized enterprises and new entrants.

Stronger integration of defence capabilities

Europe relies on two pillars for its defence, the North Atlantic Treaty Organization (NATO) and the EU. As only 22 EU member states are also NATO members, some EU member states are excluded from the defence pact.

Moreover, over the past decade or so, the USA has urged NATO members in Europe to assume greater responsibility for assuring their own defence: as of 2019, only the three Baltic States, Greece, Poland, Romania and the UK devoted more than 2% of GDP to their defence sector.

This state of affairs led the EU to create an obligation, in 2009, for member states to come to one another's assistance in the event of armed aggression on their territory, through the Treaty of Lisbon on European Union.

This treaty laid the groundwork for strengthening the EU's Common Foreign and Security Policy by creating the Permanent Structured Cooperation (PESCO) in 2017 to pursue structural integration of the national armed forces.

Under PESCO, member states commit, *inter alia*, to raising their investment in the defence sector, including as regards R&D; to participating in identifying military needs and in deploying units; and to developing the European Defence Technological and Industrial Base.

This has, in turn, led to the creation of the European Defence Fund.

Source: compiled by authors; see: https://tinyurl.com/EU-defence-fund

Box 9.7: **An EU framework to screen foreign direct investment**

At the global level, the EU is the main destination for foreign direct investment (FDI). FDI stocks held by third-country investors in the EU amounted to € 6 441 billion in December 2017.

To protect EU strategic interests related to foreign direct investment, the EU issued a regulation (#452) in March 2019 which creates a screening mechanism that enables member states and the European Commission to exchange information and, if necessary, raise concerns about specific investments in the EU.

This allows the Commission to issue opinions when an investment poses a threat to the security or public order of more than one member state, or when an investment could undermine a project or programme of interest to the entire EU, such as Horizon 2020 or Galileo.

It allows the EU to observe non-discrimination and strong confidentiality requirements.

It also establishes certain core requirements for member states which maintain or adopt a screening mechanism at national level on the grounds of security or public order.

Lastly, it encourages international co-operation on investment screening, including the sharing of experience, best practices and information on issues of common concern.

The EU framework for screening FDI has been fully operational since 11 October 2020.

The European Commission considers that this new framework will be instrumental in preserving Europe's strategic interests while keeping the EU market open to investment.

Source: compiled by authors; see: Šefčovič (2020); https://tinyurl.com/EU-regulation-2019-452; https://tinyurl.com/EU-trade-FDI-press-release

diplomacy. The EU must leverage the impact, the size and the integration of its single market to set global standards. Being able to forge global high quality standards which bear the hallmark of Europe's values and principles will only strengthen our strategic autonomy and industrial competitiveness.

Soft power in digital policy

A further illustration of the EU's use of its soft power is to be found in the digital policy realm. EU's digital policy, *A Europe fit for the Digital Age* (2019), aims to assert digital leadership in new-generation technologies like AI that are linked to the digital transition (Box 9.8).

However, the EU's digital policy agenda also embraces a second dimension, that of ensuring that the new digital society respects European values and standards. 'We must ensure that the European way is characterised by our human and ethical approach. New technologies can never mean new values' (Von der Leyen, 2019c).

One concrete EU policy initiative that aligns with this way of thinking is the upcoming Digital Services Act, which makes

Box 9.8: **Artificial Intelligence: the EU's global approach**

Artificial intelligence (AI) offers a concrete illustration of the EU's new industrial policy, whereby the EU proposes a regulatory- and investment-oriented approach with the twin objectives of promoting the uptake of AI and, simultaneously, addressing the risks associated with certain uses of this new technology (EC, 2020c).

The European Commission defends the principle of international co-operation on AI and argues for an approach based on the respect of fundamental human rights, including human dignity, pluralism, inclusion, non-discrimination and protection of privacy and personal data. The Commission perceives the responsible development and use of AI as being a driving force in achieving the Sustainable Development Goals to 2030.

The EU aims to build alliances around shared values and to promote the ethical use of AI. It was closely involved in developing the OECD Council's Recommendation on Artificial Intelligence adopted by member states of the Organisation for Economic Co-operation and Development (OECD) in May 2019. The G20 subsequently endorsed these ethical principles in its June 2019 Ministerial Statement on Trade and Digital Economy.

At the United Nations, the EU is involved in follow-up to the report of the High-Level Panel on Digital Cooperation, including its recommendation on AI. The EU is also involved in developing the Recommendation on the Ethics of Artificial Intelligence, which is due to be submitted to UNESCO member states for adoption in November 2021.

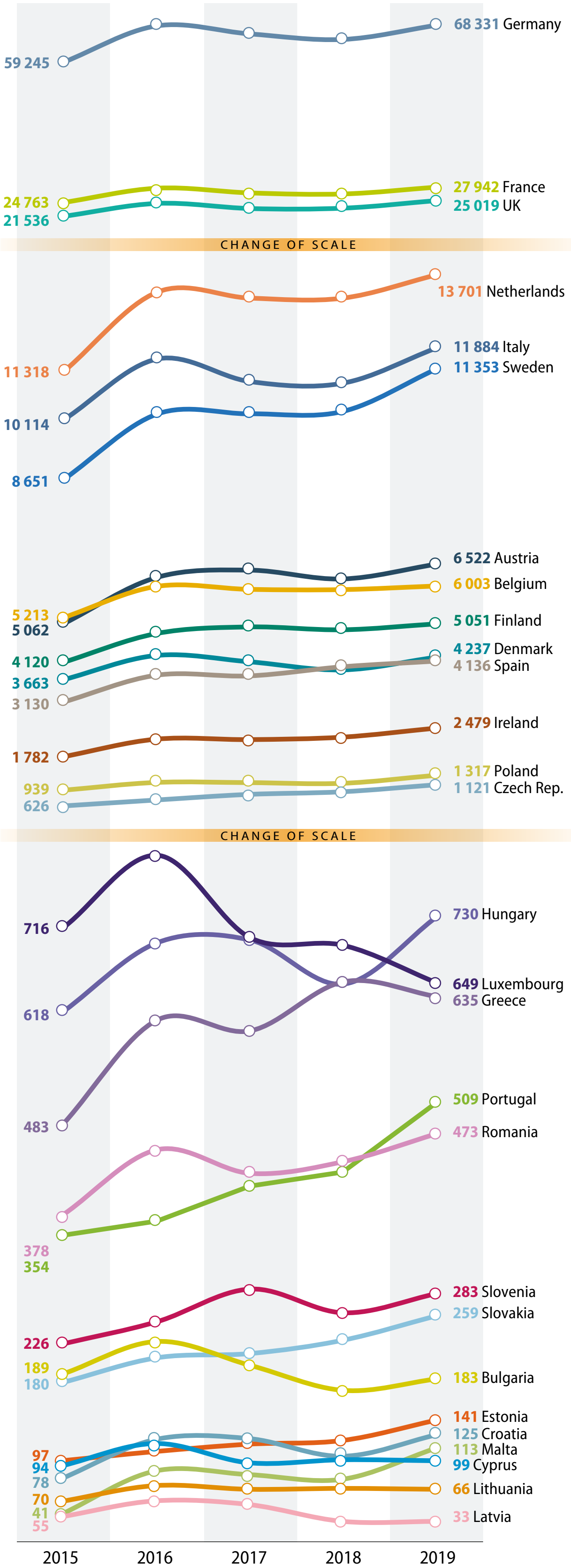
The EU continues to co-operate on AI with like-minded countries and global players, on the basis of EU rules and values, such as support for upward regulatory convergence, open access to key resources like data and generally creating a level playing field.

The European Commission monitors policies of third countries that limit data flows and will address undue restrictions that do not respect the Findable, Accessible, Interoperable and Reusable (FAIR) principles for data.

The EU is also promoting ethical AI through bilateral trade negotiations and in the context of its interaction with the World Trade Organization.

Source: compiled by authors; see: European Commission Expert Group (2018) Final Report and Action Plan on FAIR data: https://tinyurl.com/EU-FAIR-data

Figure 9.11: Number of IP5 patents granted to inventors from the EU28, 2015–2019



Source: PATSTAT; data treatment by Science-Metrix

provision, *inter alia*, for upgrading the EU's liability and safety rules for digital platforms, services and products.

The European Commission had already introduced a strong open access and open data mandate for Horizon 2020. It has included potentially stricter requirements for Horizon Europe. Research data must be open by default, there must be mandatory data management plans and FAIR principles for data are being mainstreamed. The Commission is also supporting citizen involvement in research (citizen science) [EC, 2020a, p. 404].

Since January 2021, all publications must be open access for any research grantee funded by cOAlition S, a group encompassing European national research agencies and foundations, as well as international organizations. The European Commission also launched Open Research Europe in 2021, an open-access peer-reviewed publishing platform for projects funded under the Horizon 2020 and Horizon Europe programmes (see The Time for Open Science is Now, p. 12).

Another initiative concerns digital taxation, a policy ambition to find a consensus at the international level by the end of 2020 on a tax regime for multinational digital companies, which can have a minimal physical presence in a country, while incurring low costs and generating high profits.

The European Commission considers today's international corporate tax rules to be ill-suited to doing business in the digital world. Since 2018, it has proposed adopting new tax rules to capture these digital profits. Such a proposal would enable member states to tax profits that are generated in their territory, even if a company does not have a physical presence there. The new rules would ensure that online businesses contribute to public finances at the same level as traditional 'brick-and-mortar' companies. The European Commission has given the OECD time to come up with a global solution but, failing that, has expressed its intention of imposing a digital tax on foreign companies at the European level in 2021.

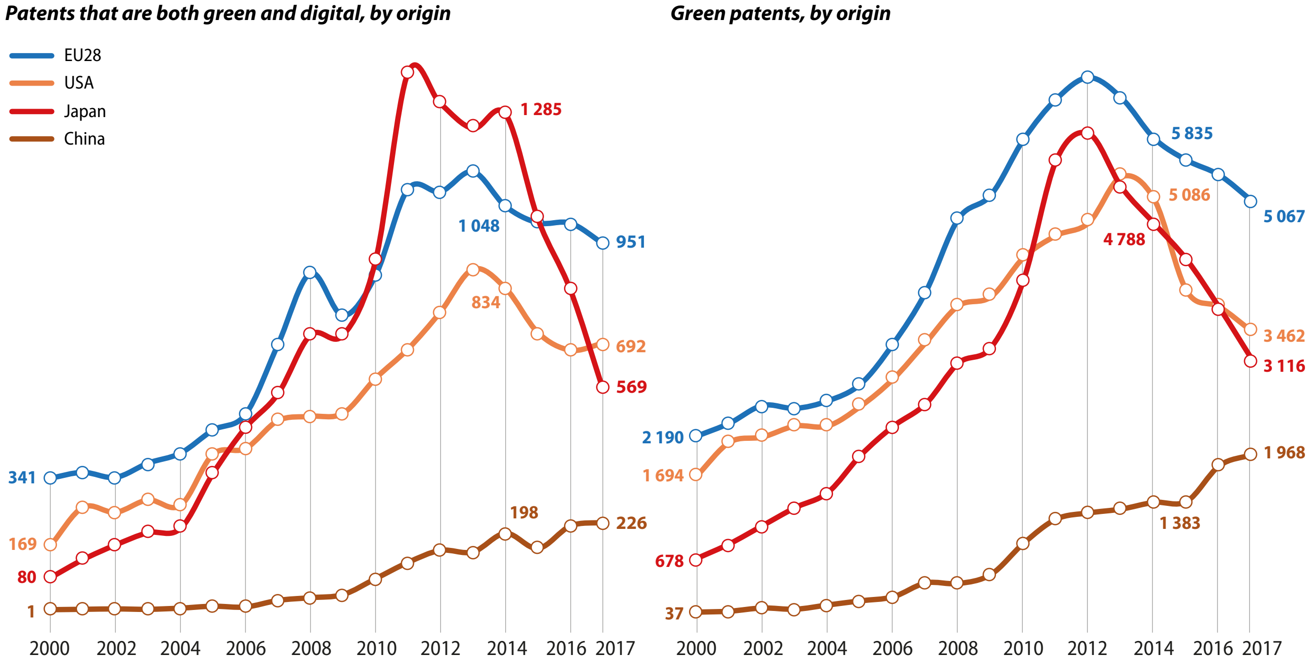
Soft power through trade policy

The EU's soft power is most visible in its trade policy, where it is able to capitalize on the size and purchasing power of the EU internal market, which still is the largest consumer market in the world.

Above all, EU trade policy is a major tool for promoting sustainable development. Through trade agreements, complemented by special incentives for developing countries, EU trade policy fixes standards for products and services that reflect social justice, respect for human rights and high labour and environmental standards.[33]

More concretely, EU trade agreements with Canada, Central America, Colombia, Peru, Ecuador, Mexico, Mercosur (see chapter 7), Japan, the Republic of Korea and Viet Nam, among others, contain rules on trade aligned with international labour and environment standards and laws to prevent a 'race to the bottom'. These EU trade agreements also contain clauses to combat illegal trade in threatened and endangered species of fauna and flora,

Figure 9.12: **Evolution in green and digital patents awarded to inventors from the European Union and selected countries, 2000–2017**



Source: EIB (2021), author's calculations based on PATSTAT data

while encouraging trade that supports measures to tackle climate change.

Ratification of the trade deal agreed between the EU and Mercosur in 2019 has been delayed by concerns over insufficient implementation of the *Paris Agreement* by Brazil, a member of Mercosur (see chapter 7).

As a result of EU member states' rising economic dependency on China, the EU finds itself in a position whereby trade and economic interests are increasingly in conflict with European values such as human rights, democracy and respect for the rule of law. The EU–China investment deal concluded in December 2020 embodies this tension. It remains to be seen whether the agreement will allow the EU to combine economic openness and co-operation with reciprocity, environmental, consumer and labour protection, or whether it has favoured short-term economic interests at the expense of long-term strategic autonomy and democracy. Promoting openness, co-operation and economic growth without undermining European values is possible and necessary but will require long-term strategic thinking and co-ordination among policy areas and with international partners and institutions, along with a clear understanding of the EU's negotiating position in a rapidly changing and increasingly multipolar world.

In 2021, the EU will propose a Carbon Border Adjustment Mechanism to reduce the risk of carbon leakage to the EU and, by the same token, buffer European companies bound by the EU's higher environmental standards, in full compliance with the rules of the World Trade Organization. This will probably entail levelling up the environmental standards of the products and services imported to the EU Single Market, so that carbon-rich imports pay higher customs duties and/or tariffs (EC, 2020b).

CONCLUSION

Sweeping changes on the horizon

Over the past five years, Europe has emerged as the main proponent of international co-operation – not just among European countries but also with the rest of the world – and of open science.[34] The European Commission co-designed and co-implemented an ambitious and holistic open science policy.

Science and technology in Europe, nevertheless, face a number of challenges. The UK's decision to leave the bloc has dealt a blow to European research and related collaboration in several ways. In addition to being a strong proponent of research excellence in the EU, the UK performs strongly in research and is both an important partner for scientific collaboration and a popular destination for European students. The uncertainty over what Brexit means for European research collaboration and the European Research Area, with the exact contours of the UK's participation in Horizon Europe yet to be drawn as we enter 2021, leaves researchers and projects in limbo.

However, given that the EU stands for openness in science and research, it can be expected that Brexit will, ultimately, represent little more than a change in the funding structure of Horizon Europe, with the UK simply joining the list of countries associated with the EU.

Similarly, it can be expected that, although Covid-19 and its aftermath will have far-reaching consequences for research and higher education, it might well further strengthen public commitment to higher education in the EU27 from a funding perspective. In several member states, governments are boosting their investment in universities, partially by increasing funding for Covid-related research and partially by creating more student places. Many EU countries have seen a significant increase in the numbers of university applications in the wake of Covid and, for example, Finland, France, Germany and Sweden are all allocating more government funding to university education.

At the same time, public research universities in the EU may be much less hard-hit by the Covid-19 crisis than Australia, Canada, the UK or USA, which are much more dependent than the EU on the tuition fees of international students from China and India, in particular. On average, European research universities enjoy a relatively high, stable share of funding from public sources.

Early analyses indicate that, in the aftermath of the Covid-19 pandemic, international scientific collaboration is likely to be increasingly concentrated among core partners or, in other words, strong research countries. This could further marginalize less developed regions and countries within the EU (Mallapaty, 2020; Fry *et al*., 2020).

The Covid-19 crisis provides a once in a lifetime chance to drive long overdue change in European academia by renewing education, strengthening co-operation across faculties and disciplines and, at long last, embracing lifelong learning in a more ambitious way. Digitalization can be an effective means of strengthening the quality and reach of education and (re-)defining universities' role in society.

Looking forward, the EU is likely to keep advocating international collaboration in science on the basis of openness, reciprocity, excellence and capacity-building. This position will potentially gain more prominence in light of two parallel trends. The first of these is the USA's retreat from the multilateral system over the past four years under the America First approach (see chapter 5), which has spilled over into science and higher education. The incoming US administration pledged, in January 2021, to return to the status quo ante. The second trend concerns the recent reform of the research evaluation system in China, which advocates researchers publishing more in Chinese and in Chinese journals. This could potentially lead to a lesser Chinese participation in the international science system. Already, the *Joint Research Centre Flagship Report* has pinpointed a decline in Chinese co-patenting with the EU (Alves *et al*., 2019).

The EU: a testbed for addressing global challenges through science?

Over the past decade, the EU has centred its growth and development strategy, *Europe 2020,* around the achievement of a 'smart, sustainable and inclusive economy', the assumption being that each set of policy goals would complement the other.

Compared to the *Europe 2020* strategy, the new *European Green Deal* has the advantage of making sustainability an explicit priority. In so doing, Europe has aligned its own strategy more fully with the United Nations' Sustainable Development Goals. This said, research in the bloc has been focused on issues of sustainability such as affordable and clean energy (SDG7), sustainable cities and communities (SDG11) and climate action (SDG13) for more than a decade (Figure 9.8). These three SDGs represent typical 'common good' issues for the EU, which is why the *European Green Deal* is such a snug fit with Europe's smart specialization strategy.

Education, research and innovation will become even more important in the future for Europe's ability to drive economic transformation while maintaining solidarity and protecting the environment. Strengthening and fully harnessing its knowledge resources will be a prerequisite for driving a sustainable and inclusive economic recovery process but also for maintaining freedom of manoeuvre or, in other words, strategic autonomy. The EU must embrace green innovation without reserve, if it wishes to remain a credible champion for an open rules-based world order in a context of rising geopolitical tensions linked to the current competition for technological supremacy.

The new *European Green Deal* strategy does not erase, however, the inevitable trade-offs between green growth, smart growth and inclusive growth. Within the EU itself, the *European Green Deal* is likely to offer some countries and regions opportunities for development and growth while penalizing others. One might think of coal mining in Upper Silesia in Poland, in this regard. This is why the *European Green Deal* includes significant financial resources targeted at an inclusive green transition with some € 100 billion foreseen for investments over the period 2021–2027 to support workers and citizens of regions most impacted by the transition (a so-called Just Transition Mechanism).

At the same time, there are also major external global trade-offs implicit in the new Green Deal strategy which will need to be addressed. There will be a trade-off between embracing a free-trade zone riding on the unfettered expansion of international trade in goods and services produced through global value chains, on the one hand, and the transition towards a sustainable economic union, on the other. Another trade-off will concern balancing the EU's participation in global agricultural production and specialization with the maintenance of local, sustainable agriculture.

The sustainability challenges looming on the horizon are formidable. To maintain its lead in green innovation, the EU will need to translate its vision into higher levels of investment, since the new US administration has pledged to invest massively, itself, in clean tech.

In 2020, however, the Covid-19 pandemic has had a major negative impact on private firms' investment in Europe. As the European Investment Bank notes, 'in a post-pandemic "new normal", investment in digitalisation, innovation and climate will be more important than ever before. Without such investment, large sections of Europe's economy risk falling behind.'

The challenge for the EU, as for most of the world, will be to redirect investment in the future post-pandemic world to sustainability and climate adaptation and mitigation. Leadership in green innovation will no longer be sufficient. Implementation and practical outcomes at the global level will be what matters. Global collaboration and co-operation will be the essential tools.

In many ways, the EU offers an ideal framework for testing new policies for a green transition at the supranational level. This experiment in multinational governance could then potentially be adapted to suit multinational contexts elsewhere in the world.

KEY TARGETS FOR THE EUROPEAN UNION

- The British government has pledged to raise GERD from 1.7% to 2.4% of GDP by 2027;
- In December 2020, the European Commission adopted the target of a 55% reduction in carbon emissions by 2030 over 1990 levels;
- The European Commission has set the goal of achieving carbon neutrality by 2050;
- The European Commission aims to achieve a zero-carbon steel-making process by 2030;
- There is an ambition to build a European Education Area by 2025.

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ENDNOTES

1 'Few doubt that major epidemics and pandemics will strike again and few would argue that the world is adequately prepared,' wrote Fan *et al.* (2018) prophetically. One attempt to improve preparedness has been the creation of the French agency for research on emerging infectious diseases in January 2021, which will operate within the French Institute for Health and Medical Research (INSERM). It is the first of its kind in the world and will be liaising with institutes in all other EU countries. For details, see Covid-19: from crisis management to sustainable solutions, p. 9).

2 The diversity in confinement policies illustrates the intrinsic limits of 'science for policy' in crisis situations. The scientific rationale is based on the search for a truth which is non-questionable. However, the political rationale is based on values and, hence, pluralistic. In Europe, the political rationale is also culturally pluralistic with very different responses in terms of social behaviour. The dialogue between the two rationales led to very different outcomes in the first outbreak of the pandemic, ranging from highly restrictive to relatively relaxed confinements of the population [see also Soete (2020)]. In the second wave, the fear of an uncontrollable spread of the pandemic, associated with the spread of new, more infectious variants of the virus just before widespread vaccination could take place, became the main driving force behind increasingly strict confinement policies.

3 In full, Yuval Noah Hariri tweeted: 'Humanity's battle with Covid-19 has so far been a scientific triumph coupled with a political fiasco. A year into the pandemic, we still don't have any global leadership or global action plan. Hopefully, in 2021 our politics will finally catch up with our science. Happy New Year.'
See: https://tinyurl.com/Hariri-tweet

4 The UK's own Medicines and Healthcare Products Regulatory Agency approved the BioNTech/Pfizer vaccine three weeks before the European Medicines Agency.

5 Goods containing less than 40% of components made in the UK or EU will pay customs duties or tariffs.

6 Britain hosts one of the Airbus plants. Airbus pays UK suppliers about £ 4 billion per year and employs 15 000 people directly, 4 000 of whom design plane wings and 6 000 of whom manufacture them.

7 Euratom is not an EU body but is, nevertheless, governed by EU bodies such as the European Commission and European Court of Justice.

8 See: https://tinyurl.com/UK-gov-nuclear-research

9 In 2018, the UK secured 11% (€ 1.06 billion) of all Horizon 2020 research grants for that year, down from 16% (€ 1.49 billion) in 2015 (RS, 2020). Overall, the UK received over the whole period of Horizon 2020 12.1% of total funding, including the most grants from the ERC: 1 283; about 20% of these grantees were based at a UK institution. By comparison, the UK's average contribution to the overall EU budget amounted to about 11.4% of the total. See: Schiermeier (2020).

10 See: https://europa.eu/investeu/home_en

11 References to regions in the present chapter denote territories within national borders, as opposed to geographical groupings of countries.

12 See: https://tinyurl.com/Next-generation-EU-explained

13 The scores for the EU's average citation rate were computed using the full counting method. This means that co-authored articles count fully towards the average citation rate for each of the contributing EU countries but get counted once only at the level of the EU. This explains why most EU countries score well above the EU average.

14 See chapter 2 for details on this study.

15 According to scientists, four out of the nine planetary boundaries may already have been transgressed, leading to increasing risks and irreversible environmental change. See: T. Sterner *et al.* (2019) Policy design for the Anthropocene. *Nature Sustainability*, 2: 14–21.

16 This systemic transformative approach extends to trade policy, industrial policy and emissions trading policy, among others.

17 See: https://tinyurl.com/EU-single-use-plastics-2019

18 Among the European Commission's proposals for the Digital Markets Act, the so-called 'gatekeeper platforms' will be prohibited from engaging in practices deemed to be detrimental to 'contestability and fairness' in online markets. Fines for non-compliance with the rules have been pitched at a maximum of 10% of a company's annual global turnover. As part of the Digital Services Act, platforms will face the prospect of billions of euros in fines, unless they abide by new rules across fields that include advertising transparency, illegal content removal and data access. See: Stolton (2021).

19 See: https://qt.eu/

20 See: https://ec.europa.eu/digital-single-market/en/digital-innovation-hubs

21 See: https://dihnet.eu

22 See: https://ec.europa.eu/digital-single-market/en/artificial-intelligence

23 See: https://tinyurl.com/EU-climate-factsheet

24 See: https://tinyurl.com/EU-sustainable-finance

25 This market failure is also addressed by the Pan-European Venture Capital Fund(s)-of-Funds programme (Venture EU), based on funding from the InnovFin equity facility, EFSI equity instrument, COSME equity facility and the EIF, in collaboration with the European Investment Bank.

26 The European Commission has a long tradition of introducing so-called Future and Emerging Technologies flagships. In 2009, it identified the need for Europe to address major challenges through long-term, multidisciplinary research. One of the first was the Graphene Flagship, launched in October 2013 as part of Horizon 2020. The second flagship was the Human Brain Project, designed to revolutionize the future of neuroscience. It was also launched in 2013. In May 2016, the third flagship on Quantum Technologies was proposed. The European Innovation Council initiative should not be confused with these flagship initiatives.

27 The UK's new Advanced Research and Invention Agency will be given great latitude to fund high-risk blue-skies research, in preference to the mission-oriented approach adopted by the European Union.

28 The original concept focused on general purpose technologies but, in practice, many regions have also used a broader definition of innovation extending beyond technologies.

29 Within each technology platform, co-operation is structured in over 17 partnerships focusing on specific technologies or challenges.

30 Edler *et al.* (2020, p. 2) define technological sovereignty as 'the ability of a state or a federation of states to provide the technologies it deems critical for its welfare, competitiveness and ability to act and to be able to develop these or source them from other economic areas without one-sided structural dependency.'

31 See, for example: https://www.economist.com/business/2020/09/19/how-nvidias-purchase-of-arm-could-open-new-markets

32 See: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1867

33 See: https://tinyurl.com/EU-trade-policy-SDGs

34 See: Burgelman, J.-C. (2021) Politics and open science: how the European Open Science Cloud became reality (the untold story). Data Intelligence 3(1). DOI: 10.1162/dint_a_00069

Mobile phones being charged on a smart bench in Belgrade, designed by the Serbian start-up Strawberry Energy. The bench is a standalone system that is fully powered by solar energy. It provides users with free Wifi and battery-charging as well as environmental data, such as on air quality, air temperature and noise levels. These smart benches are present in 23 countries.
© Strawberry Energy

AT A GLANCE

- All five countries are seeking to align their research systems on the European Research Area, in order to prepare their long-anticipated integration in the European Union (EU). They are applying the EU's directives on renewable energy and energy efficiency, for instance, and developing Smart Specialization Strategies for industry aligned with the EU model.

- High youth unemployment remains a driver of the chronic brain drain that could see 25–30% of the region's youth emigrate to the EU in the next couple of years.

- Up to now, economic reform has tended to dominate the policy agenda but, confronted with brain drain and the underutilization of scientific and technical skills in the economy, governments are vowing to invest more in research and innovation.

- One challenge will be to break the mould of the outdated linear innovation model by forging dynamic linkages between the research sector and the economy; to this end, governments are creating innovation funds and their first science and technology parks, among other strategies.

10 · Southeast Europe

Albania, Bosnia and Herzegovina, North Macedonia, Montenegro, Serbia

Djuro Kutlača

INTRODUCTION

Seated in the antechamber

The five countries profiled in the present chapter are all sitting in the antechamber to membership of the European Union (EU). Four have candidate status: North Macedonia since 2005,[1] Montenegro since 2010, Serbia since 2012 and Albania since 2014. Bosnia and Herzegovina presented its application for EU membership in February 2016. The European Commission judges that, 'with sustained effort and engagement, Bosnia and Herzegovina could become a candidate for accession' (EC, 2019a).

All five countries have completed their transition to open market economies (Kutlača, 2015) but remain burdened with high rates of youth unemployment, in particular, as well as corruption and underdeveloped financial systems. GDP per capita remains well below that of Croatia and Slovenia, which integrated the EU in 2013 and 2004, respectively. So far, only Montenegro has attained the region's target of raising GDP per capita to 46% of the EU average (Figure 10.1).

The Covid-19 pandemic has dealt a body blow to the subregion's economies, which were expected to enter into recession in 2020. Serbia has been worst-hit, with more than 621 000 confirmed cases as of April 2021. China and the Russian Federation have both sent doctors and medical supplies to the country. On 6 May 2020, the EU confirmed in the *Zagreb Declaration* the allocation of € 3.3 billion in aid to help Western Balkan countries cover their immediate health needs.

The Covid-19 pandemic has exposed the shortage of medical staff in Southeast Europe but also seen medical professionals living abroad head home to relieve the pressure on their country's hospitals. In Serbia, companies have received support from the Innovation Fund to begin manufacturing ventilators, which are in short supply.

Brain drain a major headache

Brain drain is a chronic problem, with the young, more educated segment of the population proving susceptible to the lure of better living conditions in prosperous EU economies. Since 2005, the cumulative population of the five countries has shrunk by almost 5%, from 16.9 million to 16.1 million. In 2015, a record 60 000 emigrants left Serbia, by far the most populous of the five countries with its 7 million inhabitants, after 57 000 departures the previous year. This compares with a total of 31 000 Serbian emigrants over the entire period from 2005 to 2014, according to the World Bank's International Migration Database (Stevanovic, 2017). The majority of Serbs have moved to Germany and Austria but Sweden and Norway are also popular destinations.

In 2018, the US-based Gallup research centre analysed data from half a million people from 152 countries who had emigrated between 2015 and 2017, for its Potential Net Migration Index. According to the findings of this survey, countries in Southeast Europe top the list for brain drain. One-third (32%) of the educated younger generation hope to leave Albania and Bosnia and Herzegovina in the next couple of years, compared to 30% in North Macedonia and 25% in Serbia (Migali and Scipioni, 2018).

The rankings of the *Global Competitiveness Report 2017–2018* confirm that none of the five countries is in a position to retain or attract talent (Figure 10.1).

Enhanced EU engagement

With the EU being their main export market, the five countries' economic fortunes are closely tied to those of the bloc. All five are still recovering from the Great Recession of 2008–2009 but several key indicators give cause for optimism. Exports of goods and services accounted for half of GDP in 2018, up from one-third in 2013. In parallel, net inflows of foreign direct investment (FDI) have risen in all but Albania and Montenegro and remain high in the latter (Figure 10.1).

The Central European Free Trade Agreement (CEFTA) is a key instrument for integration via regional trade. All five countries have been members of CEFTA since December 2006, as has the United Nations Interim Administration Mission in Kosovo, on behalf of Kosovo*.[2] The latter threw a spanner in the works in November 2018 by levying a 100% import tax on goods from Bosnia and Herzegovina and Serbia, before lifting it in May 2020. Had this trade barrier not been removed, it would have stymied CEFTA's efforts to help Southeast Europe integrate the EU's single market.

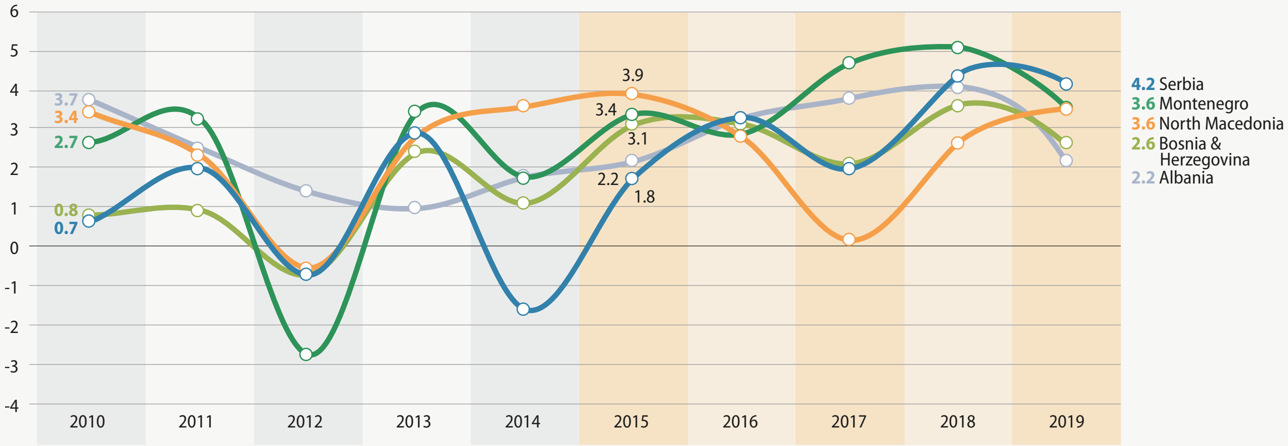
In February 2018, the European Commission adopted a strategy for 'a credible enlargement perspective for, and enhanced EU engagement with, the Western Balkans' (EC, 2018a), thereby confirming the EU's plans to integrate the region into the bloc. The strategy identifies priority actions to support the region's transformation in areas that are of mutual interest to the EU, such as strengthening the rule of law; reinforcing co-operation on security and migration; expanding the EU's Energy Union to Southeast Europe; and lowering roaming charges while rolling out broadband in the region.

In April 2018, the European Council, which supervises the EU enlargement process, decided that Albania had made sufficient progress with regard to the rule of law to warrant scheduling the opening of accession negotiations in June 2019.

Two months later, the Council endorsed the opening of parallel negotiations with North Macedonia, after the country signed the *Prespa Agreement* with Greece on 12 June 2018. On 25 March, 2020 the European Commission decided to open accession negotiations with both Albania and North Macedonia, a decision endorsed by the European Council the following day.

Figure 10.1: **Socio-economic trends in Southeast Europe**

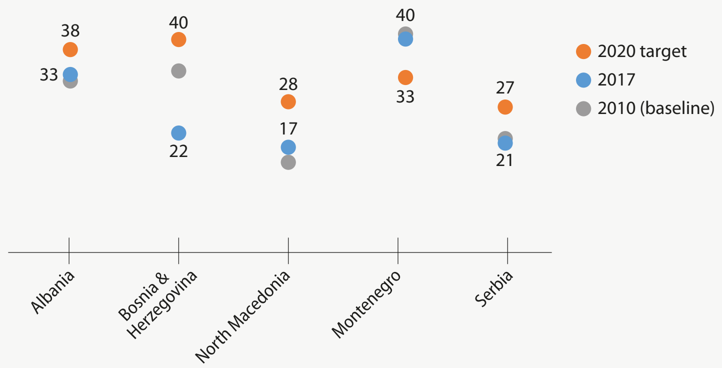
Rate of economic growth in Southeast Europe, 2010–2019 (%)



Key socio-economic indicators for Southeast Europe, 2015 and 2019
Croatia and Slovenia are given for comparison

	Inflation, consumer prices (annual, %)		GDP Per capita, current PPP$		GDP Per capita, current PPP$, share of EU27 average (%)	Unemployed % of labour force (ILO estimate)		Unemployed Share among youth (%)		Exports Goods and services (% of GDP)		Exports High-tech (% of) manufactured exports)		FDI net inflows (% of GDP)	
	2015	2019	2015	2019	2019	2015	2019	2015	2019	2015	2019	2015	2019	2015	2019
Albania	1.9	1.4	11 662	14 495	31.2	17.1	12.3	40.1	28.1	27.3	31.5	1.6	0.1^{-1}	8.7	7.9
Bosnia & Herzegovina	-1.0	0.6	12 014	15 792	34.0	27.7	18.4	62.7	39.7	34.9	40.2	2.9	5.3	2.4	2.4
Montenegro	1.6	2.6-1	16 337	22 989	49.5	17.5	14.9	37.6	30.7	42.1	44.1	13.3	3.2^{-1}	17.3	8.3
North Macedonia	-0.3	0.8	13 831	17 815	38.3	26.1	17.8	47.3	39.1	48.7	61.7	3.3	4.2	3.0	3.8
Serbia	1.4	1.8	14 922	18 989	40.9	17.9	12.7	42.6	30.0	45.3	51.9	–	–	5.9	8.3
Croatia	-0.5	0.8	23 014	29 973	64.5	16.2	6.9	42.4	17.8	46.4	51.1	10.8	8.9^{-1}	0.3	1.9
Slovenia	-0.5	1.6	31 636	40 657	87.5	9.0	4.2	16.3	9.1	77.2	84.4	7.0	6.8-1	4.0	2.6

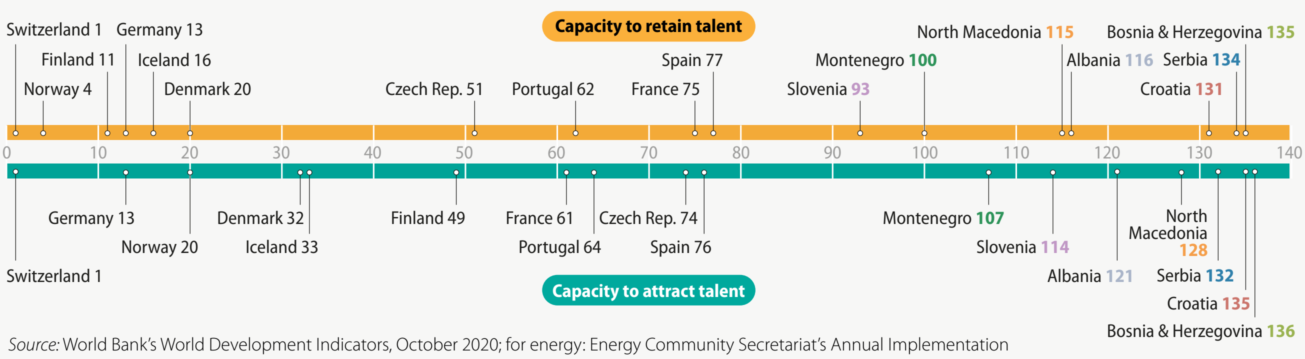
Share of renewable energy in Southeast Europe's gross energy consumption, 2010 and 2017 (%)
Data points refer to the situation in 2017 and the 2020 target



31%
Target to 2020 for Western Balkan 6 for share of renewable energy in gross energy consumption

23%
Progress by Western Balkan 6 as of 2017 towards 2020 target for renewable energy

Capacity of Southeast Europe to retain and attract talent, 2017
Other European countries are given for comparison



Source: World Bank's World Development Indicators, October 2020; for energy: Energy Community Secretariat's Annual Implementation Reports, 2017/2018 and 2016/2017; for capacity to attract and retain talent: WEF (2017), for North Macedonia: WEF (2016)

Partial success in reaching development targets

The *South East Europe (SEE) 2020 Strategy* was adopted by ministers from the region in February 2013. It aims to foster EU integration by stimulating long-term drivers of growth such as innovation, skills and the integration of trade. This strategy focuses on a set of five interlinked development pillars, all of which are critical to the EU accession process: integrated growth (trade), smart growth, sustainable growth, inclusive growth and governance for growth (Hollanders and Kanerva, 2015, pp. 275–277).

According to the latest report of the *SEE 2020 Strategy* Monitoring Committee (SEE 2020, 2019), the region as a whole has surpassed its target for the number of highly qualified persons in the workforce and is on the verge of doing so for the balance of trade and employment rate (Table 10.1). Albania is on track to reach its 2020 targets for renewable energy and Montenegro has surpassed its own target for the same (Figure 10.1).

These targets have been fixed under Southeast Europe's first *Energy Strategy* (2012), designed to foster reform and regional integration in Southeast Europe. The *Energy Strategy* is aligned with the *Energy Community Treaty* (2006), co-signed by the countries profiled in the present chapter.

This treaty established the Energy Community and sought to extend the EU's internal energy market to Southeast Europe and the Black Sea region. Some 94.5% of activities under the treaty – which cover gas, electricity, security of supply, renewable energy, oil, energy efficiency, environment and competition – are financed through the EU budget.

In 2014, the Energy Community launched the Western Balkan 6 Initiative (also known as the Berlin Process) to help the five countries profiled here, plus Kosovo*, strengthen regional co-operation in the areas of energy infrastructure development, energy 'connectivity' and sustainability. This initiative focuses mainly on institutional and regulatory reforms in the energy sector but also aligns value-added tax regimes with EU best practices to support cross-border transactions in electricity.

The Western Balkan 6 are applying the EU's Energy Efficiency and Renewable Energy Directives[3] with a similar level of ambition and commitment as EU member states. They are also aligning their energy and climate policies with the EU's Emissions Monitoring Regulation (#525/2013) and improving related planning, monitoring and reporting systems.

At a summit in Paris in July 2016 to mark the treaty's tenth anniversary, the Western Balkan 6 endorsed a *Sustainability*

Table 10.1: **Progress towards key *South East Europe 2020 Strategy* targets, 2010, 2015 and 2018**

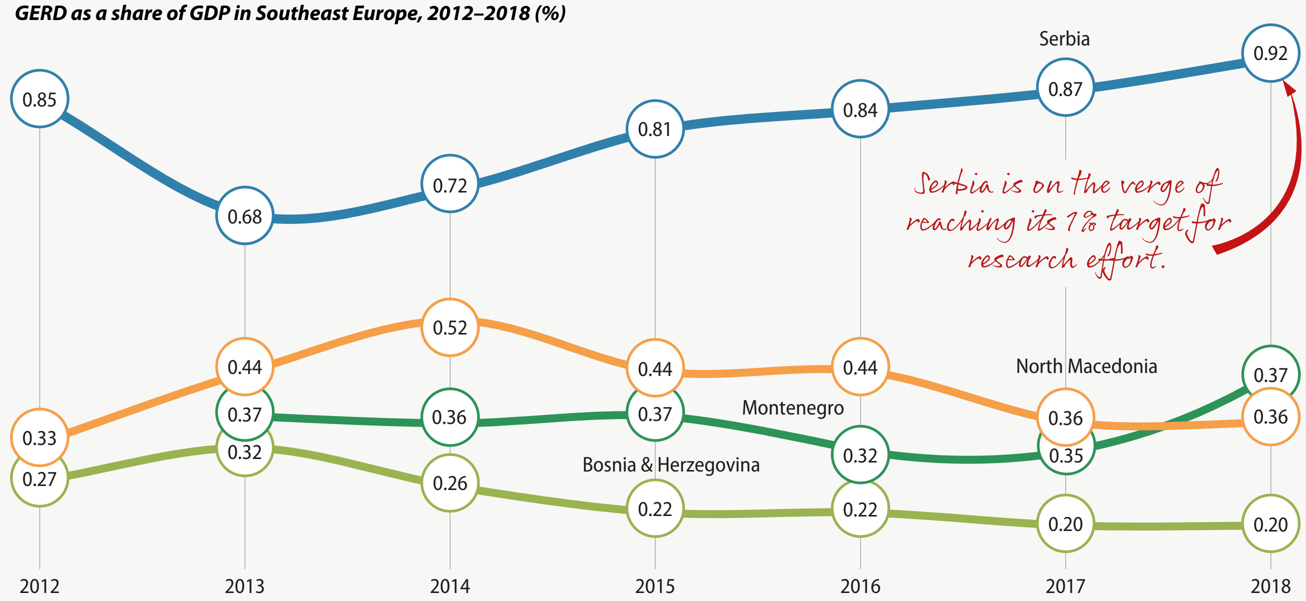
	2010 (baseline)	2015	2018	2020 target	Progress towards target by 2018 (%)
Overall Strategic Goals					
GDP per capita relative to the EU average (in current PPP$, %)	32.8	34.7	35.8	38.0	44
Total trade in goods and services (€ millions)	54 407	72 922	97 857	129 500	58
Trade balance (goods, % of GDP)	-22.9	-19.5	-19.5	-20.8	94
Pillar 1: Integrated Growth					
Intraregional (goods, % of GDP)	9.6	9.1	9.6	14.3	0
Overall FDI inflows (€ millions)	3 611	4 618	6 606	7 300	81
Pillar 2: Smart Growth					
Average annual income per employed person (€)	27 869	31 221	31 030	36 300	26
Number of highly qualified persons in workforce (millions)	1.18	1.56	1.59	1.44	156
Pillar 3: Sustainable Growth					
Net enterprise creation (number of companies)	27 568	83 449	29 335	26 790	109
Share of renewables in gross final energy consumption	23.9	25.0	–	30.7	-7
Pillar 4: Inclusive Growth					
Employment rate, 20–64 years (%)	50.3	52.9	57.1	57.9	89
Pillar 5: Governance for Growth					
Government effectiveness (scale 0–5)	2.20	2.42	–	2.65	54

Note: Data cover Albania, Bosnia & Herzegovina, Montenegro, North Macedonia and Serbia, plus Kosovo*.

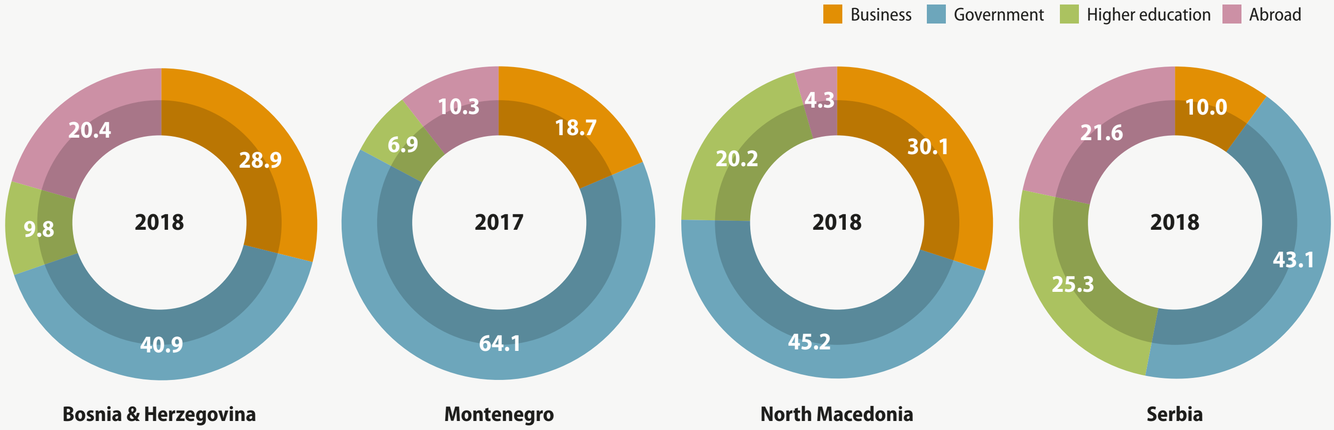
Source: Southeast European statistical offices and administrations; central banks in Southeast Europe; Eurostat; WIIW annual database; calculations by Regional Cooperation Council; for government effectiveness: World Bank's Worldwide Governance Project

Figure 10.2: Trends in research expenditure in Southeast Europe

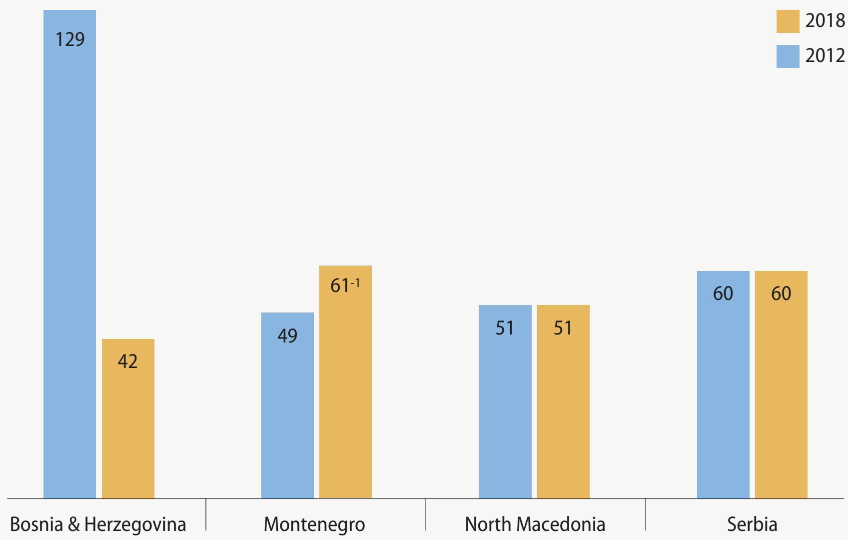
GERD as a share of GDP in Southeast Europe, 2012–2018 (%)



GERD by source of funds in Southeast Europe, 2018 or closest year (%)



GERD per researcher (FTE) in Southeast Europe, 2012 and 2018
In PPP$ thousands, constant 2005 prices



Serbia's GERD distribution, 2018

31%
Basic research

37%
Applied research

32%
Experimental development

Note: Data are unavailable for Albania.

Source: UNESCO Institute for Statistics

Charter to guide the region's transition to low-carbon and climate-resilient energy sectors. The *Charter* prioritizes improving governance for energy efficiency, implementing smart support measures to improve the sustainability of energy systems and fostering climate action as well as transparent sustainable energy markets. The Energy Community Secretariat has been tasked with helping the Western Balkan 6 to co-ordinate the transition process and monitor implementation of specific commitments.

Regional research strategy has not lived up to expectations

There were high hopes for the *Western Balkans Regional Research and Development Strategy for Innovation* at the time of its adoption by ministers in October 2013, with the support of the World Bank, European Commission and Regional Cooperation Council (Zuniga and Correa, 2013).

The strategy's *Action Plan for Regional Cooperation* proposed five regional initiatives to strengthen national innovation systems in Southeast Europe, including a fund for research excellence, a programme for technology transfer to public institutions and a second programme to develop networks of excellence in areas consistent with the region's commitment to 'smart specialization' (Kutlača, 2015, Box 10.1).

Unfortunately, the strategy's implementation has been a casualty of the countries' struggle to adopt the EU's science-oriented innovation model (Kutlača, 2015). Serbia has experienced the greatest difficulty. It has not launched any national calls for research projects since 2010; those Serbian projects selected in 2010 for financing over the period 2011–2015 were prolonged until the end of 2019, to accommodate the country's ongoing reform of public funding mechanisms for research and development (R&D).

This reform package is switching from a quasi-competitive to fully competitive process for project funding through, for instance, a dedicated Science Fund. Pending the outcome of the first public calls for project proposals under the new fund, the Serbian government has decided to maintain the same level of funding for researchers and their host institutions in 2020, and possibly into 2021, to ensure continuity.

Science taking back seat to economic reforms

Although the *Western Balkans Regional Research and Development Strategy for Innovation* was intended to serve as a framework for integrating the region's science systems in the economy, it is economic reform that dominates the policy agenda. Science, technology and innovation (STI) policies have been relegated to second place. This, combined with devastating brain drain, has eroded research capacities and linkages with the productive sector.

The most recent data for Albania on R&D date from 2008, precluding any up-to-date analysis for this country. Three of the four other countries show stagnating investment in R&D. Bosnia and Herzegovina, North Macedonia and Serbia had all fixed a target of devoting 1% of GDP to R&D by 2015–2016 but only Serbia is on the verge of achieving this (Figure 10.2). The amount of funding available to each Serbian researcher diminished slightly after 2012, in constant 2005 PPP$, but had almost fully recovered by 2018. Researchers in Bosnia and Herzegovina have lost the most funding since 2012, a casualty of the country's economic downturn.

The business sector funds about 30% of GERD in Bosnia and Herzegovina, Montenegro and North Macedonia but accounted for as little as 10% of research expenditure in Serbia in 2018, the country most reliant on foreign funding sources (Figure 10.2). Barely one in ten researchers work in industry in Bosnia and Herzegovina, Montenegro and Serbia (Figure 10.3).

Several governments have introduced incentive measures to integrate new graduates in research projects. In Serbia in 2018, 1 157 talented young researchers born after 1988 with a strong record of academic achievement were included in ongoing national research projects. In August 2019, Serbia's Science Fund launched a call for young researchers to submit project proposals within the Programme for Excellent Projects of Young Researchers (PROMIS).[4] The Bosnia and Herzegovina Futures Foundation offers fellowships in March and October each year to undergraduate and graduate students studying any technical field (engineering, manufacturing, computer science, etc.) to enable them to enrol in further study programmes oriented towards industrial needs. The fellowship gives students access to technology, leadership training, mobility and funding opportunities.

Skills underutilized in the domestic economy

There remains a strong interest in engineering, technology and natural sciences, with almost half of researchers working in these fields (Figure 10.3). Unfortunately, the missing link between the research sector and the economy means that these skills remain underutilized in the domestic economy. This is reflected in the low number of patents registered at the world's five largest intellectual property offices (Figure 10.4) as well as in the low share of high-tech exports among manufactured exports (Figure 10.1).

We shall see from the profile of Serbia on page 304 that the country is using science and technology parks to link scientific research with economic goals. The Government of Montenegro, meanwhile, has established the South East European International Institute for Sustainable Technologies to achieve the same goal at the regional level (see p. 304).

The *Global Competitiveness Report* (WEF, 2018) confirms the weak linkages between the research sector and economy. All five countries are classified as being at stage 2 of development (efficiency-driven) and well short of stage 3 (innovation-driven development). In terms of the focus of research, it is interesting to note that, although interest remains highest in health sciences and engineering, researchers from the region are increasingly publishing in the areas of information and communication technologies (ICTs), mathematics and statistics (Figure 10.5).

Smart specialization could accelerate modernization

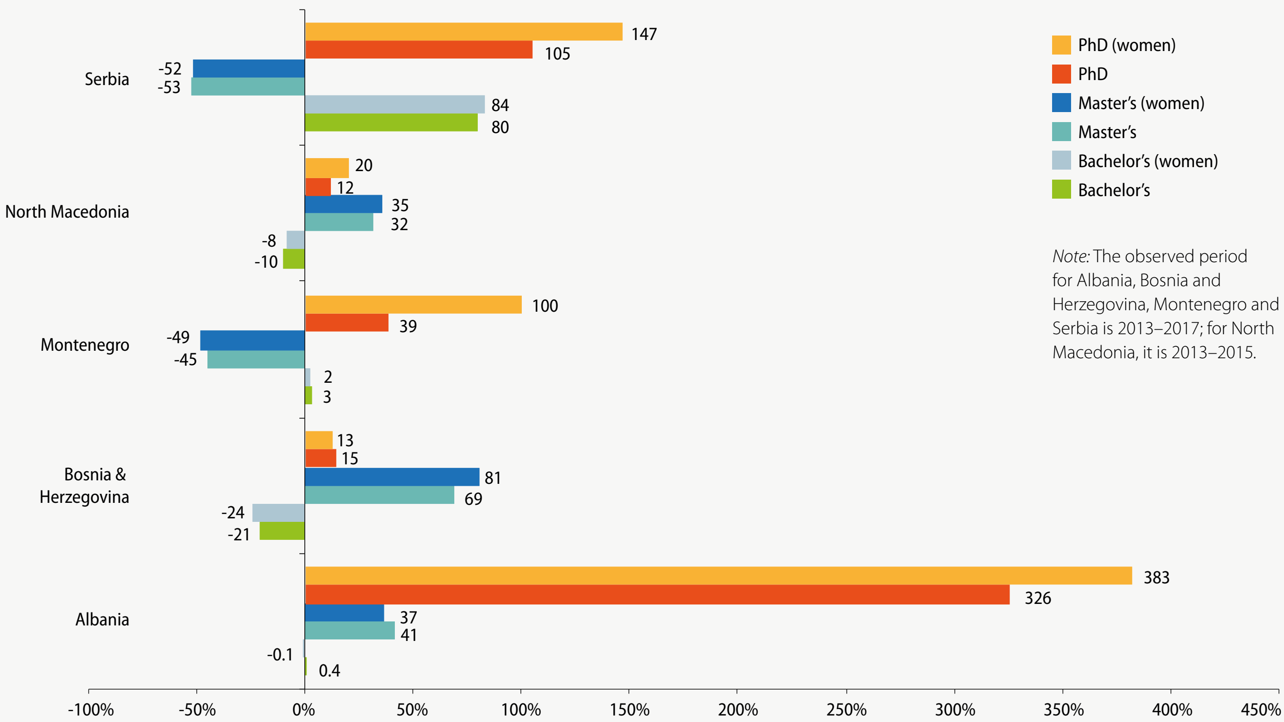
The lack of implementation of the *Western Balkans Regional Research and Development Strategy for Innovation* has not deterred the European Commission from inviting the region's governments to develop their own smart specialization strategy (S3). This strategy could be the missing link that countries need to integrate their research and economic sectors; it would make better use of human resources in science and engineering, while inciting researchers to migrate from the government and higher education sectors to industry.

The concept of 'smart specialization' was developed by an expert group (Foray *et al*., 2009) as a tool to accelerate pan-European development through an 'integrated industrial policy for the globalization era' and an Innovation Union, the latter strategy having been adopted by the EU in 2010 (Hollanders and Kanerva, 2015, Table 9.7). The concept takes a regional, rather than country-level approach to innovation policy, in order to concentrate resources in a handful of priority sectors.

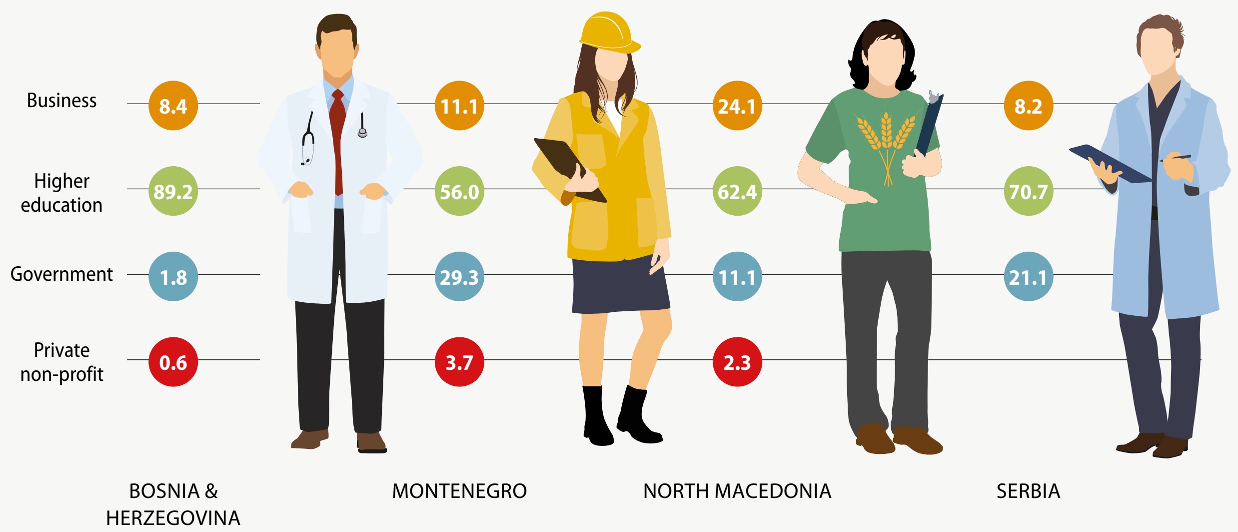
The S3 Platform was established by the European Commission at the Joint Research Centre's Institute for Prospective Technological Studies in Seville, Spain, in order to provide member countries with support, such as guidelines for the development of Research and Innovation Strategies

Figure 10.3: **Trends in human resources in Southeast Europe**

Change in numbers of tertiary graduates from Southeast Europe, 2013–2017 (%)



Researchers by sector of employment, 2018 (%)

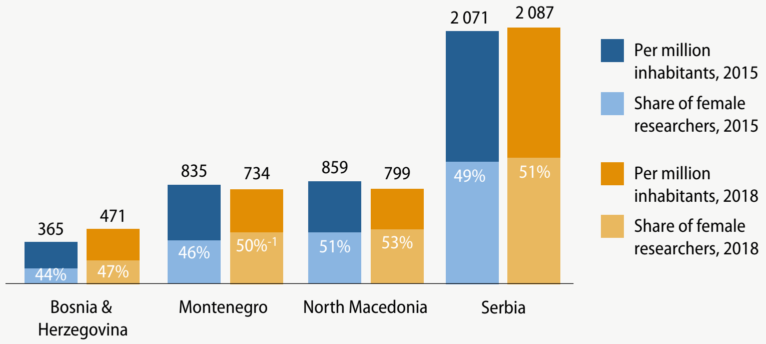


for Smart Specialization (RIS3). The EU's *Cohesion Policy* provides funding to help countries apply these principles to their industrial policy.

The European Commission's guidelines advise governments to select priority sectors only based on the outcome of direct interaction between policy-makers and the private sector, in what has been termed 'the entrepreneurial discovery process' (Gianelle *et al.*, 2019). The selected areas for intervention should correspond to specific societal and environmental challenges or reinforce the health and security of citizens. Governments could, for example, promote the use of ICTs for active ageing, explore solutions to reduce traffic congestion or develop innovative materials for eco-construction (Gianelle *et al.*, 2019). This phase is currently being funded by the EU as the bloc's first 'pilot action'.

The EU's second pilot action will identify and scale up bankable interregional projects that can create European value chains in priority sectors, such as big data, the bio-economy, resource efficiency, connected mobility or

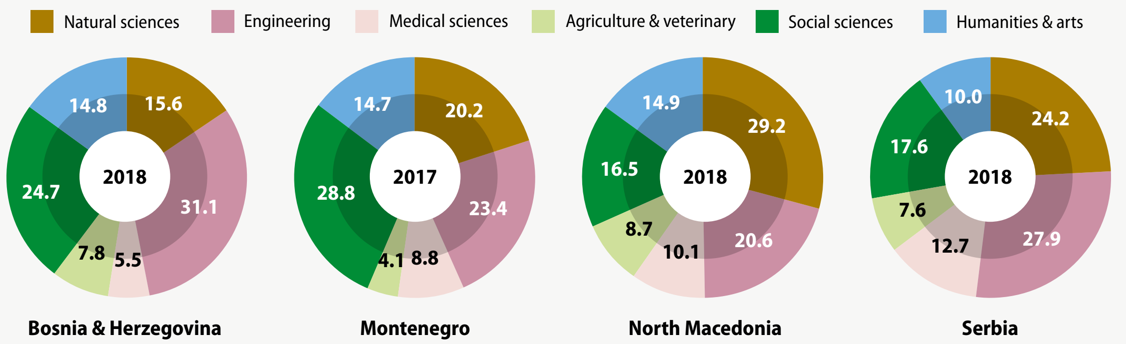
Researchers (FTE) per million inhabitants, 2015 and 2018



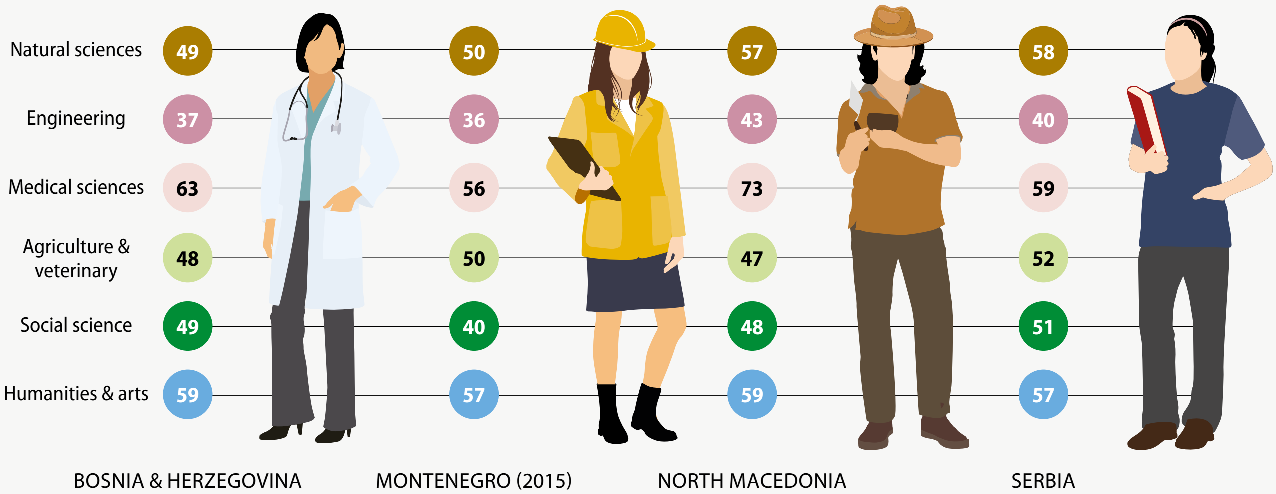
Southeast European researchers enjoy gender parity.

A large proportion of researchers are engineers among both men and women.

Researchers in Southeast Europe (FTE) by field, 2018 or closest year (%)



Share of female researchers in Southeast Europe (HC) by field, 2018 or closest year (%)



-n: data refer to *n* years before reference year

Note: Data on researchers are unavailable for Albania for the period under study.

Source: UNESCO Institute for Statistics

advanced manufacturing. This phase will consist in initiating thematic partnerships that closely involve public authorities, businesses and researchers from different regions.

Towards tailor-made smart specialization strategies

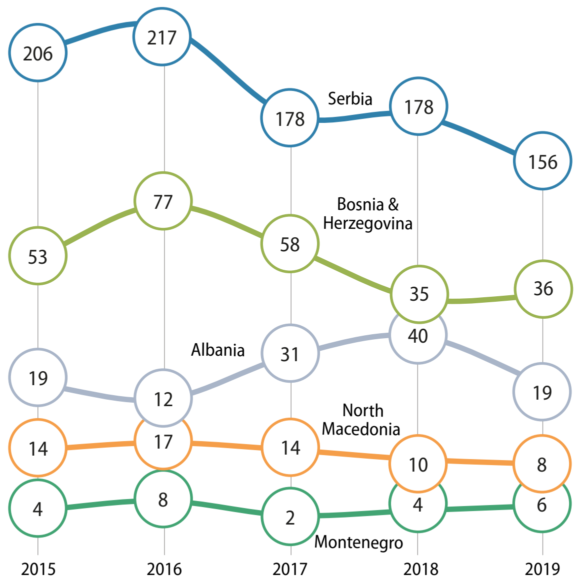
Unlike EU member states, associate or candidate countries for EU membership are not obliged to adopt the smart specialization strategy as a formal policy document for economic development. Nevertheless, the EU regulation establishing the Instrument for Pre-accession Assistance mentions S3 as a thematic priority for assistance to enlargement countries. Thus, although 'not obligatory', having a smart specialization strategy has become a prerequisite for EU accession.

All five countries have, thus, decided to invest in their own smart specialization strategy, with support from the centre in Seville. Serbia was the first to begin its mapping exercise in 2017, followed by Montenegro a year later. In June 2019, Montenegro became the first non-EU country to complete both the mapping phase and entrepreneurial discovery process, at about the time Bosnia and Herzegovina launched the process.

Montenegro's smart specialization strategy for 2019–2024 will serve as the basis for priority investment in research and innovation of about € 174 million. Of this, the government is expected to provide € 116.4 million, the private sector € 21.7 million, the EU € 33.5 million and other international sources about € 2.5 million.

The Montenegrin Ministry of Science co-ordinated the S3 process with the help of the Ministry of Economy and more

Figure 10.4: **Number of IP5 patents granted to inventors from Southeast Europe, 2015–2019**



Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China.

Source: PATSTAT; data treatment by Science-Metrix

than 300 stakeholders from across the academic, economic, public and civil sectors, more than half of whom came from the business sector. This exercise identified the following priority sectors:

- sustainable agriculture and the food value chain;
- sustainable and medical tourism;
- energy and a sustainable environment; and
- ICTs, as a horizontal dimension to provide support in the aforementioned sectors.

In Serbia, the S3 process was initiated by the Ministry of Education, Science and Technological Development. In February 2020, the government adopted its *Research and Innovation Strategy for Smart Specialization: Serbia creates Innovation,* with the following four priority sectors:

- food for the future: high-tech agriculture, value-added produce, sustainable production patterns;
- future machines and manufacturing systems;
- creative industries: production of audio-visual content, video games and interactive content; and
- ICTs.

In September 2017, the Ministry of Education, Sports and Youth began developing Albania's own smart specialization strategy, which should be ready by 2021; it will focus on the region surrounding the capital city of Tirana. The mapping exercise, qualitative analyses and entrepreneurial discovery process should all be completed by the end of 2020, with support from the European Commission's Technical Assistance and Information Exchange instrument (TAIEX). The main priority sectors have been identified as:

- water and energy;
- ICTs; and
- tourism and agritourism.

North Macedonia launched its own S3 process in March 2018 by establishing an interinstitutional working group with members drawn from the government, ministries and the academic community. It is due to begin its own qualitative analysis, having completed the mapping exercise in early 2020.

Efforts to integrate the European Research Area

All five countries have participated in the EU's Horizon 2020 programme and have, thus, competed for related R&D funding. A preliminary analysis suggests that all but Serbia have paid more into Horizon 2020 than they have received in return, owing to the low success rate of their applications for project funding.[5]

Despite a high application rate, Albania has been the least successful, with an overall success rate of 7.8%. This suggests that there may be issues with quality. In the subregion, only Serbia has a positive balance and even its success rate has been lower than for the previous EU framework research programme, which ran until 2013.

Since 2017, Montenegro and Serbia have integrated a number of multilateral frameworks to strengthen their research capabilities. Serbia became the 23rd full member state of the European Organization for Nuclear Research (CERN)[6] in March 2019 and Montenegro signed a Memorandum of Understanding with CERN in July 2017, in order to participate in the Compact Muon Solenoid experiment.

On 5 June 2017, Montenegro became the 29th member of the North Atlantic Treaty Organization (NATO). As such, it is now eligible to join NATO's Science for Peace and Security programme.

Serbia is one of the founding members of the Central European Research Infrastructure Consortium (CERIC), which provides open access to leading facilities in eight countries for research in materials science, biomaterials and nanotechnology. The consortium includes accelerator light sources in Trieste and Krakow, a nuclear reactor in Budapest, an accelerator plant in Zagreb, four specialized laboratories in Graz (Austria), Prague (Czech Republic), Bucharest (Romania) and Ljubljana (Slovenia), as well as a Facility for Modification and Analysis of Materials with Ion Beams (FAMA) in Belgrade (Serbia) that was admitted to CERIC in 2017.

In October 2018, Montenegro became a member of the European Research Infrastructure Consortium's European Social Survey, which measures social attitudes and behaviour patterns. As a result, the country contributed research for the first time in the survey's ninth round.

Steps towards inclusion in the European Innovation Scoreboard

North Macedonia and Serbia have been contributing to the European Innovation Scoreboard since 2010 and 2009, respectively. Following the adoption of the *European Commission Strategy for Southeast Europe* (EC, 2018a), it is planned to include the other countries in the scoreboard as soon as possible.

As a rule, countries can only participate if they have data available for at least 20 indicators. Montenegro already has data for 15 indicators and is expected to participate in the next European Innovation Scoreboard, following a pilot survey by Monstat. Montenegro adopted a programme nurturing innovative start-ups in June 2018, which enjoys the backing of the Horizon 2020 Policy Support Facility.

The 2019 edition of the scoreboard found North Macedonia to be a modest innovator, having steadily improved its innovative performance by 6% relative to the EU average since 2011. It scores particularly well for the number of foreign doctoral students, non-R&D innovation expenditure and medium- and high-tech exports.

Serbia is considered a moderate innovator, with Belgrade and Vojvodina being the most dynamic regions. Serbia's innovative performance has risen by as much as 20% relative to the EU average since 2011. Serbia scores highest for the quality of its innovators, firm investments and the impact of innovation on sales. The Ministry of Education, Science and Technological Development raised the budget of the Serbian Innovation Fund in 2019, in order to align it more closely with the EU's Innovation Union.

The 2019 edition of the scoreboard discussed data availability for four Western Balkan economies. Albania, Bosnia and Herzegovina and Montenegro have all launched their first innovation surveys covering the years 2014–2016 but these only cover ten indicators or fewer. The data are, thus, not sufficiently comprehensive to grant these countries access to the scoreboard. The Albanian government hopes that the establishment of four funds in 2016 will ultimately enable it to participate in the European Innovation Scoreboard. Managed by the Albanian Investment Development Agency, these are the Creative Economy Fund, the Start-up Fund, the Competitiveness Fund and the Innovation Fund. Funding levels are modest, however. Six companies have received a total of € 58 712 through the Competitiveness Fund so far, according to the country report communicated to the European Parliament and European Council in 2018 (EC, 2018b).

COUNTRY PROFILES

ALBANIA

Priority: giving the young marketable skills

Thanks to healthy domestic and foreign demand, the Albanian economy grew by 4.1% in 2018. Macro-economic and fiscal policies in the Economic Reform Programme for 2018–2020 prioritize sustainable growth, a lower public debt and higher employment levels for women, youth and vulnerable people.

As a means of giving more young people marketable skills, the Law on Higher Education (2015) offers scholarships or teaching grants to three categories of student: gifted students; students enrolled in study programmes in areas of national priority, according to the list registered with the S3 platform in Seville;[7] and students from disadvantaged social groups.

Gradual alignment with the European Research Area

The other main policy document currently regulating research and skills development in Albania is the *National Strategy for Science, Technology and Innovation 2017–2022* (2017). It identifies six priorities for aligning the Albanian research system with the European Research Area:

- developing an effective national research system and maximizing research results by reforming the institutional system for research;
- diversifying sources of research funding; integrating the Albanian diaspora; forging closer ties between the research community and business; and monitoring the quality of research;
- fostering optimal transnational co-operation and competition by assessing and improving research infrastructure;
- facilitating mobility and an open labour market for researchers by improving recruitment practices for teachers and researchers; revising the legal framework for scientific mobility and publishing a guide;

- increasing the number of jobs held by female researchers and scholars and the number of research projects led by women by 30% by 2020; and
- ensuring optimal access to, and circulation and transfer of, scientific knowledge by supporting open access science and open data, particularly in light of the National Research and Education Network's association with GÉANT.[8]

The *National Strategy for Science, Technology and Innovation 2017–2022* defines specific objectives for the major public Universities of Tirana and Vlora, including that of internationalizing their research activity, which the universities themselves are keen to do. The *Strategy* also encourages the twin universities to revisit their procedures for assessing academic research activity; this led them to adopt a new methodology in March 2018.

The *Strategy* also intends to raise investment in R&D to 1% of GDP by 2022. This will be an arduous task, since the share of public funds spent on scientific research in 2018 amounted to just 0.06% of GDP (EC, 2019d), less than in 2008 (0.15%).

Albania has no national roadmap for developing research infrastructure, although the National Agency for Scientific Research and Innovation (NASRI) was intending to finish mapping existing infrastructure by December 2020, in co-operation with the Prime Minister's Office and National Agency for an Information Society (AKSHI). The findings of this exercise will feed into the national research database which NASRI is in the process of building.[9]

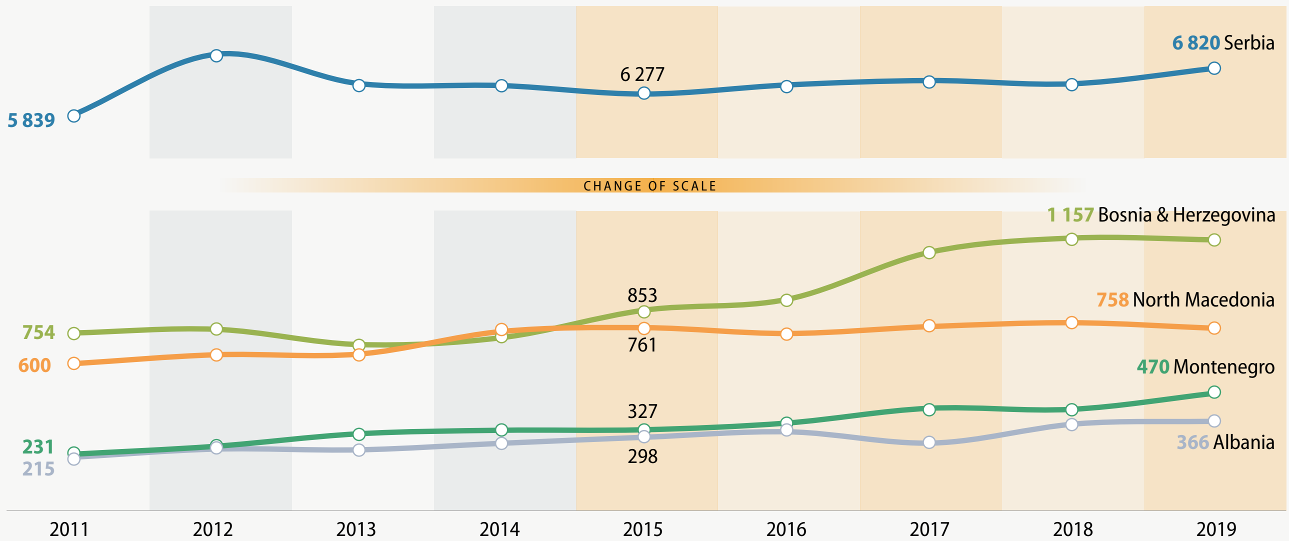
A 'triple helix' approach to improve technological absorption

The other major institution in charge of scientific research is the National Agency for Funding Higher Education. Between 2016 and 2018, spending on education slipped from 4.0% to 2.5% of GDP. The share allocated to higher education likewise receded from 21.2% (2015) to 18.9% (2017) of the total, according to the UNESCO Institute for Statistics.

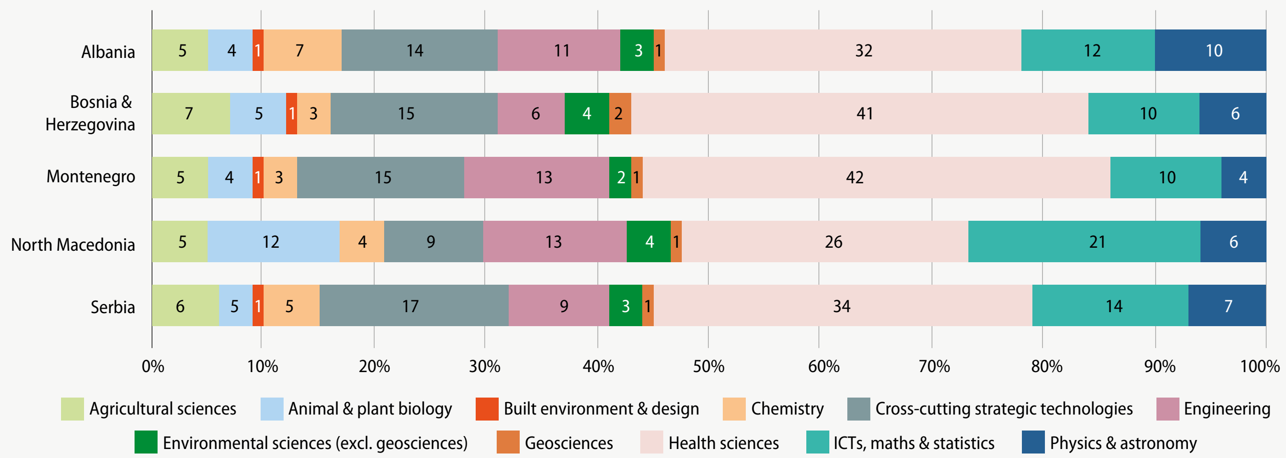
Albania's capacity for technological absorption, research and innovation remains low. This is true even for the agricultural sector, which contributed 18% of GDP in 2018,

Figure 10.5: **Trends in scientific publishing in Southeast Europe**

Volume of scientific publications in Southeast Europe, 2011–2019



Scientific publications in Southeast Europe by broad field of science, 2017–2019 (%)



compared to 6–8% for its neighbours. Although the number of patents (Figure 10.4) and trademark registrations has risen, it has done so from a low starting point: residents applied for just 14 patents and 509 trademarks in 2015.

In January 2017, the government approved the *Action plan 2017–2021: Support for the Development of Innovative Policies based on the Triple Helix approach*. Its aim is to promote better linkages between academia, industry and the government but implementation of the plan stalled in 2018, pending presentation of the draft law on science to parliament the following year; it was still before parliament in 2020.

A law accords science greater prestige

A law redefining the mission of the Academy of Sciences entered into force in October 2019. It affirms the academy's autonomy and its role in providing decision-makers with scientific advice.

The law also emphasizes the need to improve the working conditions of early career researchers and, more generally, to accord Albanian science greater prestige.

Other clauses stress the need to facilitate interdisciplinary dialogue, integrate Albanian research in the international arena and find innovative ways to communicate scientific findings to the public.

BOSNIA AND HERZEGOVINA

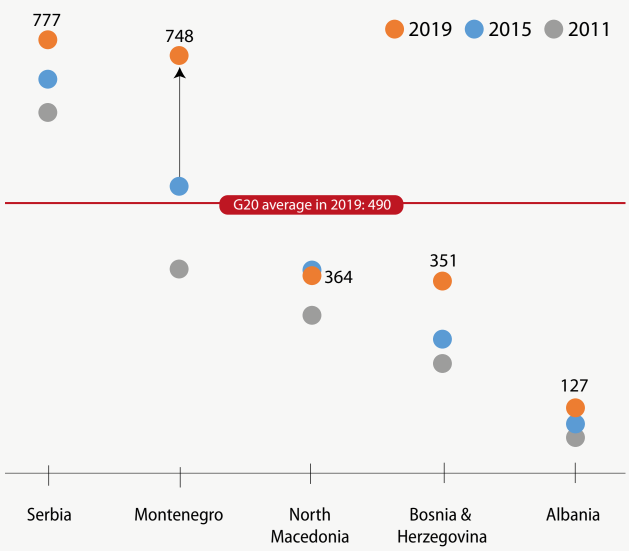
Fragmented political framework slowing progress

Bosnia and Herzegovina has witnessed healthy economic growth of 3% on average since 2015 (Figure 10.1).

The country is composed of three individual entities: the Federation of Bosnia and Herzegovina, the Republic of Srpska and Brčko District. The state-level Ministry of Civil Affairs co-ordinates science policy and international cooperation through its Department of Science and Culture but the country's complex constitutional structure means that responsibility for policy implementation and funding is

Scientific publications per million inhabitants in Southeast Europe, 2011, 2015 and 2019

Data labels are for 2019



How has output on SDG-related topics evolved since 2012?

Scientists in Southeast Europe collectively published more than 300 papers within just seven of the 56 selected SDG-related topics between 2011 and 2019. Growth was fastest for smart-grid technologies, with output doubling from 89 (2012–2015) to 191 (2016–2019) publications across the region.

Three topics had a growth rate of 130% between 2012–2015 and 2016–2019: the sustainable use of terrestrial ecosystems, the status of biodiversity and ecosystem services and regenerative medicine. For another two topics, output grew by 120%: biofuels and biomass and the impact on health of soil, freshwater and air pollution. Output on the latter topic was 1.7 times the global average proportion: 122 (2012–2015) to 150 (2016–2019).

Regional output topped 900 publications for two topics. That on reproductive health and neonatology saw little growth over the period under study: 623 (2012–2015) to 641 (2016–2019). Scientists published 1.2 times the global average proportion on this topic.

Growth was faster (130%) for the sustainable use of terrestrial ecosystems: 410 (2012–2015) to 544 (2016–2019). Output on this topic was on a par with the global average proportion.

For details, see chapter 2

89%
Cumulative share of publications by Serbian and Bosnian scientists in 2019

1.04
Average of relative citations in Southeast Europe, 2014–2016; the G20 average is 1.02

50%
Share of publications with foreign co-authors, 2017–2019 (%); the G20 average is 25%

Top five partners for scientific co-authorship in Southeast Europe, 2017–2019 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Albania	Italy (271)	USA (112)	Germany (105)	Spain (100)	UK (99)
Bosnia & Herzegovina	Serbia (776)	Croatia (591)	Germany (250)	Slovenia (243)	USA (212)
North Macedonia	Serbia (310)	Germany (264)	USA (223)	Italy (215)	Croatia (207)
Montenegro	Serbia (380)	Croatia (186)	Italy (162)	Slovenia (120)	France (119)
Serbia	USA (2 211)	Italy (2 142)	Germany (2 132)	UK (1 903)	Spain (1 669)

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

devolved to each individual entity and to the cantons.

The fragmentation of governance leads to the adoption of policies with competing priorities, thereby limiting their effectiveness at the national level.

For instance, at the national level, the priority of the Economic Reform Programme for 2019–2021 is to align quality infrastructure in the business world with the EU model and reduce the informal economy. However, the Federation has added another priority – that of building more entrepreneurial infrastructure – and the Republic of Srpska has added *three* priorities of its own: health system reform; the creation of a business incentive register; and reducing the share of expenditure for current consumption in the public administration.

Plans to raise research spending

According to the constitutional and legal framework, competences in the area of research rest predominantly with the Republic of Srpska entity, Brčko District and the cantons, whereas the Federation entity exercises a co-ordinating role.

At state level, parliament adopts framework legislation on the fundamentals of scientific research and co-ordinates domestic and international co-operation, in addition to being responsible for foreign policy. There is no specific ministry at state level specializing in scientific research, so co-ordination in this area falls to the Ministry of Civil Affairs. There are, however, ministries in charge of science at the level of the Federation, cantons and the Republic of Srpska.

The revised *Strategy for the Development of Science in Bosnia and Herzegovina 2017–2022* has fixed a target of devoting 0.8% of GDP to R&D by 2022. Its predecessor, covering the period 2010–2015, had fixed a higher ceiling of 1% of GDP for research by 2015. Despite this, the total allocation to R&D was just 0.2% of GDP in 2017, according to the UNESCO Institute for Statistics. It will be important for the government to implement this revised strategy.

Parallel strategies for science

The *Strategy for the Development of Scientific Research in the Federation of Bosnia* defines general, functional and sectoral directions for research for the period 2012–2022. Although it has never been adopted by the cantons, this document serves as a policy basis for R&D in the Federation. Among the sectoral priorities, the following are important: the automobile industry; metalwork, which includes the production and processing of iron, steel and aluminium, as well as mechanical and electrical engineering; food and beverages; wood and furniture processing; and tourism.

Meanwhile, in April 2017, the Republic of Srpska adopted its own *Science and Technology Development Strategy for 2017–2021: Knowledge for Development*. It has six objectives:

- encouraging scientific research quality and excellence;
- stimulating the internationalization of science and innovation;
- fostering interaction between the research and innovation communities and the economy;
- creating conditions for raising the budgetary allocation to science and innovation;
- developing human resources in science and innovation; and
- promoting smart specialization.

It is planned to establish a Science Fund for the Republic of Srpska along the lines of the Serbian model. This Science Fund will receive independent funding to enable it to make public calls for research proposals.

In addition, the Republic of Srpska's Ministry of Scientific and Technological Development, Higher Education and the Information Society has identified a number of priority projects for implementation in 2019, for a total of € 3.4 million. A new line of co-financed scientific projects grouped under the name of Synergy has been designed to stimulate co-operation between the research and economic sectors.

A programme is also being introduced to retrain highly educated people who have joined the ranks of the unemployed.

Another focus is digitalization. The *eSanduce* (e-Mailbox) project is creating a digital platform to enable every citizen and business entity in Republika Srpska to create their own unique 'mailbox' for their communications with the e-government system.

MONTENEGRO

Developing synergies between science and the economy

Fuelled by investment and consumption, the economy grew by 5.1% in 2018. The Economic Reform Programme 2019–2021 focuses on energy and transport markets; sectoral development, primarily in tourism; shrinking the informal economy; R&D and the digital economy; trade-related reforms; and the development of education and skills.

In the field of energy, the focus is on establishing a market for natural gas. Currently, Montenegro does not have access to natural gas or related built infrastructure. It will need to develop interconnections between its own infrastructure and neighbouring power systems, while filling the gaps in its legislative and regulatory frameworks.

As far as the digital economy is concerned, the priority is to improve legislative and regulatory frameworks, to reduce the cost of setting up high-speed electronic communications networks.

The *Higher Education Development Strategy* (2016–2020) aims to improve the quality of higher education and stimulate student creativity. At the national level, a key objective is to harmonize curricula with labour market needs.

The *Strategy* also intends to bolster participation in EU research projects and to internationalize higher education.

Other aims include fostering lifelong learning and establishing a sustainable funding model for higher education.

A programme to raise the status of researchers

The number of researchers remains low (Figure 10.3). In June 2018, the Programme for Strengthening Human Resources and Research Capacities in Research Institutions in

Montenegro 2018–2020 was adopted to improve the status of researchers through training opportunities and greater recognition of their output. The programme also introduced tax incentives to encourage investment in innovative businesses.

An overarching aim is to foster greater integration in the European Research Area. In 2019, the University of Montenegro began preparing a human resources strategy for researchers (HRS4R) with an accompanying action plan, under the EU's EURAXESS initiative.[10]

Plans to increase the research budget

Research expenditure amounted to 0.37% of GDP in 2018, well below the 0.6% target set for 2020. The government's *Strategy for Scientific Research Activities 2017–2021* fixes the target of raising research spending by 50% by 2021 from the 2017 baseline.

Within a year of this document's adoption in 2017, the Ministry of Science's budget had swollen by 60%. This translated into a bumper crop of national programmes endowed with greater funding. Most of these programmes have been co-financed by the business sector. Since 2017, there has been one call for research projects (in 2018) and three calls for innovation projects.

The *Strategy for Scientific Research Activities* has three key goals: developing human resources and research capacities; enhancing international co-operation and networking; and strengthening synergies between the research sector and the economy. The seven priorities are: energy; ICTs; new materials, products and services; medicine and human health; agriculture and food production; sustainable development and tourism; and science, education and identity.

Where science meets business

In 2018, the Ministry of the Economy extended the existing voucher scheme for innovation to all small and medium-sized enterprises (SMEs) through the SME Innovation Improvement Programme 2018–2020.

In parallel, the government is putting in place a framework for strengthening linkages between business and the academic community. The country's first centre of excellence was founded at the University of Montenegro in 2014. BIO-ICT has been working with industrial partners to develop novel bioinformatics technologies to foster food security, environmentally responsible development of the South Adriatic Sea ('blue growth') and a range of consumer goods and services. The centre's slogan encapsulates its approach: 'where science meets business'.

BIO-ICT is partnering with several Montenegrin research institutions and two local SMEs, as well as the St Petersburg Scientific Research Centre for Ecological Safety and the Centre for Teleinfrastruktur at Denmark's Aalborg University.

BIO-ICT has been funded through the seven-year Higher Education and Research for Innovation and Competitiveness project (HERIC) running from 2012 to 2019, which involved the Ministries of Education and Science and benefited from a World Bank loan of € 12 million. Just over one-quarter of this amount (€ 3.42 million) was used to cover BIO-ICT's operational costs up until 2017.

The remainder of the World Bank loan has been invested in setting up the Montenegrin Science and Technology Park in Podgorica, which opened its doors in late 2019. The park is supported by an 'impulse' centre in Nikšić, which operates as

Box 10.1: **Coming soon: an international institute for sustainable technologies in Montenegro**

Countries are joining forces to set up the South East European International Institute for Sustainable Technologies in Montenegro. The objective is to foster regional co-operation in science, technology and industry based on the achievements of CERN and SESAME (see Box 17.3), which have promoted peace through their support for scientific collaboration.

The core of the project is a Facility for Hadron Tumour Therapy and Biomedical Research with Protons and Heavier Ions. Beyond the treatment of patients, it is planned to dedicate 50% of the beam time to research using multi-ion sources (beyond the presently used protons and carbon ions), making the South East European International Institute for Sustainable Technologies a unique project. There is currently no centre offering particle therapy in Southeast Europe, where a growing number of tumours have been registered in recent years.

The facility will offer numerous opportunities for technology transfer within Southeast Europe. In particular, it will benefit local industry, since the procurement of the different components for the machine and beam lines (magnets, vacuum system, girders, beam lines, power supplies, control system, etc.) can be assigned to local industries.

The centre is expected to halt, or even reverse, brain drain. It is credited with having the potential to become a future flagship project within the EU's European Neighbourhood Policy.

The centre was originally proposed by Prof. Herwig Schopper, a former Director-General of CERN. The Government of Montenegro initiated the project, which took on a regional dimension after Albania, Bosnia and Herzegovina, Bulgaria, Montenegro, North Macedonia, Serbia and Slovenia all signed a *Declaration of Intent* on 25 October 2017 at a ministerial meeting at CERN in Geneva, Switzerland. Croatia agreed to join the project *ad referendum* and Greece took on observer status. On 5 July 2019, a *Memorandum of Cooperation* was signed by six prime ministers from the region, during a Summit of the Berlin Process in Poznan, Poland.

Following receipt of the first financial contribution from the European Commission's Directorate-General for Research and Innovation in mid-2019, the project has moved to the design phase, which is being hosted jointly by CERN and a second research centre, the Gesellschaft für Schwerionenforschung in Germany.

Source: https://seeiist.eu

a business incubator. The park is implementing the country's smart specialization strategy by prioritizing investment in fields with the most potential to stimulate growth, namely: energy efficiency and renewable energy; agriculture and food technologies; ICTs; health and medical technologies; wood processing; and interdisciplinary research.

In the same vein, the Centre of Excellence for Research and Innovation was established at the University of Montenegro in May 2018 to foster co-operation between academia and the private sector, within the framework of the *Montenegrin Research Infrastructure Roadmap, 2015–2020*. Steps have since been taken to establish an office for technology transfer at the centre.

On 12 September 2019, the Government of Montenegro adopted *Information on Support for the Establishment of New Centres of Excellence*, which presented the results of a competition run that year. This competition produced two high-quality proposals which the Ministry of Science will present in funding negotiations. These two projects are valued at about € 2.5 million, with co-financing from the budget worth € 1.8 million over three years. The most highly ranked is the Centre of Excellence for Digitization in the Field of Food Safety and Food Authenticity (FoodHub), which has numerous partners at home and abroad. The second centre selected specializes in biomedical research.

The government is also investing in international infrastructure. The South East European International Institute for Sustainable Technologies received official government support in March 2017. It will be mandated to focus on 'science for peace' in Southeast Europe by bringing young specialists together at the institute. At a meeting of the governing bodies on 30 March 2018 in Tirana, members unanimously decided to support the creation of a second international institute on the same premises to develop hadron tumour therapy (Box 10.1).

NORTH MACEDONIA

A new name brings new opportunities

Changing its name to the Republic of North Macedonia in 2018 under the Prespa agreement with Greece has opened up new opportunities for the Former Yugoslav Republic, both in terms of socio-economic development and further integration in the EU and NATO.

Economic growth picked up to 3.6% in 2019, after stagnating in 2017 when political uncertainty eroded investor confidence. The workforce has shrunk by almost 1% in the past five years, however, mainly owing to high emigration.

The government's *Competitiveness Strategy and Action Plan for 2016–2020* (2016) fixed seven strategic objectives: a simpler and more stable business environment; an entrepreneurial and productive SME sector; a dynamic export sector; an attractive environment for domestic investors; a more skilled and entrepreneurial labour force; a reinvigorated industrial policy; and greater funds available for the enterprise sector.

For the Ministry of Education and Science's *Strategic plan for 2019–2021* (2019), the priority for the university sector is to respect the institutions' autonomy and the status of researchers, introduce a more transparent management system, promote co-operation with the private sector and other research institutions and help graduates find their first job through an advisory service.

Old strategies a poor fit for new realities

At the time of their adoption in 2012, the *National Innovation Strategy 2012–2020* and the *National Programme for Scientific R&D Activities 2012–2016* planned to invest in the knowledge society by raising GERD to 1.0% of GDP by 2016 and 1.8% of GDP by 2020, with 50% participation from the private sector. Progress towards these targets has been slow: in 2018, GERD accounted for just 0.36% of GDP (Figure 10.2).

The *National Innovation Strategy's* thematic priorities were largely influenced by the EU's *Europe 2020* (2010) agenda, with its emphasis on the low-carbon economy. There do not seem to be any plans to update this document. Despite the need to adapt policies to new realities, no other relevant policy documents on research, higher education or smart specialization appear to have been developed in recent years.

Nonetheless, there have been some positive developments for industrial R&D. In December 2013, the government established a competitive Fund for Innovation and Technological Development. This fund manages Co-financed Grants for Newly Established Start-ups and Spin-offs, as well as Co-financed Grants and Conditional Loans for the Commercialization of Innovation. The fund seems to be have had an impact, since the share of industrial research funding rose from 17% to 30% between 2015 and 2018 (Figure 10.3).

The Centre for Technology Transfer and Innovation (INNOFEIT), which opened its doors in 2018, provides subcontracting services. INNOFEIT offers innovative companies a plethora of services to increase their value and ensure broader impact, such as match-making highly skilled scientists with entrepreneurs; solving practical problems with regard to product development; conducting collaborative research on novel and innovative ideas; providing access to state-of-the-art FEEIT laboratories (worth € 2 million); and offering a co-working space. So far, INNOFEIT has supported two grant beneficiaries of the aforementioned Fund for Innovation and Technological Development: Torax, a company which is developing a smart photovoltaic storage module; and Inform, which combines portable air pollution monitors with cloud support platforms.

In February 2019, North Macedonia launched a feasibility study for its first science and technology park, at a ceremony attended by Prime Minister Zoran Zaev and the European Commissioner for the Digital Economy and Society, Mariya Gabriel.

SERBIA

A better investment climate

The Serbian economy grew by 4.2% in 2019 (Figure 10.1). The share of informal employment, two-thirds of which used to be in agriculture, has shrunk to about 20% of the total, suggesting that the government's Economic Reform

Programme for 2019–2021 is on track to reduce the size of the informal economy. The country is blighted, though, by acute brain drain, with youth unemployment still at 30% in 2018 (Figure 10.1).

The Economic Reform Programme also prioritizes developing the energy market by building related infrastructure, removing barriers to trade, and improving the competitiveness of industry, in general, and agricultural producers and processors, in particular. The programme also provides a financial package for research and innovation and better e-government services.

The investment climate has improved markedly in recent years, thanks to a range of factors: low interest rates, a surge in government capital spending and a growing stream of FDI encouraged by the EU accession process. Macro-economic reforms have brought greater financial stability and fiscal discipline. Despite this, the income gap with the EU has remained stable over the last decade, at about 40% of the EU average (Table 10.1).

Review recommends more research funding

The Achilles tendon of Serbia's innovation system is the gap between industry and research, a problem it shares with its neighbours. The country's first *Policy Mix Peer Review Report* on research and innovation found scarce interest, or capacity, in the public research sector when it came to working with, and for, industry (CSI, 2017). The review was completed in early 2017, within the framework of the EU's Danube-INCO. NET project. It identified the following key weaknesses in the national innovation system:

- low business research intensity, both in terms of expenditure and researcher numbers;
- insufficient funding for public research institutes;
- a conservative financial market for risk-taking and innovation finance;
- a governance system still based on the linear model of innovation;
- mainly direct support for R&D and supply-driven policy measures; and
- insufficient evidence-based policy-making, with no STI observatory or strategic intelligence function to undertake systematic monitoring, evaluation or foresight exercises or technology assessments.

The peer review team has recommended strengthening demand-side innovation to support uptake of innovation in society, establishing a performance-based quality system in STI and raising research funding.

Serbia has by far the highest research spending among its immediate neighbours: 0.92% of GDP in 2018 but the government's *Strategy for Scientific and Technological Development for 2016–2020* plans to raise funding levels further in both public and private R&D.

A turning point in the research funding system

The years 2018 and 2019 marked a turning point in Serbia's system of research funding, with a switch from quasi-competitive to fully competitive project funding. The first concrete step in this reform was the adoption of the Law on the Science Fund in December 2018. This was followed by the adoption of the umbrella Law on Science and Research in July 2019. A new call for project proposals for competitive project financing is expected by the end of 2019.

The key objective of the government's five-year *Strategy for Scientific and Technological Development: Research for Innovation* to 2020 (2016) has been to strengthen linkages between science, the economy and society to encourage innovation. It intends to raise public investment in R&D and to encourage the business sector to do the same. It also stresses the importance of ensuring a critical mass of research personnel. The number of researchers has declined slightly to 0.8% of total employment in 2017. Serbia has since introduced collaborative grants and innovation vouchers to encourage businesses and academia to work together on innovation.

Serbia's first science and technology parks

The peer review team also recommended developing infrastructure such as science and technology parks (CSI, 2017). Serbia's first such park opened its doors in Belgrade in 2015 (Box 10.2).

Box 10.2: **Software development driving Serbia's first science and technology park**

Serbia's first science and technology park was established in 2015 through a partnership between the Ministry of Education, Science and Technological Development, the City of Belgrade and the University of Belgrade, with support from the Swiss government.

The park specializes in software development. Over the past four years, it has supported the development of more than 100 companies employing more than 800 engineers.

The park provides entrepreneurs, start-ups and technology companies – both small and medium-sized enterprises and the development wings of large companies – with infrastructure tailored to their needs, as well as business support services to foster innovation and commercialization. In 2018 alone, 20 new start-up companies were established within the park and 200 young potential entrepreneurs attended 30 courses on entrepreneurship.

The Science and Technology Park Belgrade covers an area of 16 446 m^2 with five buildings offering modern business spaces, a conference centre and meeting rooms with full audio-visual equipment and translation cabins. There is a 3D innovation lab, as well as recreational facilities, including a gym.

For details: www.ntpark.rs/

Box 10.3: **The BioSense Institute for agriculture of the future**

Founded in 2015, the Research and Development Institute for Information Technologies in Biosystems (BioSense Institute) in Novi Sad cross-fertilizes the two most promising sectors in Serbia: ICTs and agriculture.

Through multidisciplinary research in the fields of micro- and nanoelectronics, signal processing, remote sensing, big data, sensor design, artificial intelligence and biosystems, BioSense contributes to the wider goal of meeting the growing demand for food, while ensuring a sustainable agricultural system. The institute integrates all that ICTs currently have to offer to make agriculture more efficient, developing practical solutions for farmers, companies of all sizes and farms.

The BioSense Institute is participating in more than 30 Horizon 2020 projects. The most important of these, Antares, aims to transform the BioSense Institute into a European centre of excellence for advanced technologies in sustainable agriculture and food security. According to FAO, global food production will need to increase by 50% in the next twenty years, with 80% of the increase coming from intensification.

The Serbian Ministry of Education, Science and Technological Development is providing the Antares project with both institutional and legislative expertise, as well as co-financing to the tune of € 14 million. The participation of the Stichting Dienst Landbouwkundig Onderzoek (DLO), a leading European research institute for applied and market-driven research in agriculture and food security based in the Netherlands at Wageningen University, is helping to transfer expertise and experience to Serbia.

Source: www.cordis.europa.eu/project/rcn/196935/factsheet/en; www.biosens.rs

Serbia opened two more parks in 2020, located in Novi Sad and Nis. For 2019–2020, a budget of € 23.9 million has been set aside for the park in Novi Sad and € 10 million for that in Nis.

Other investments in research infrastructure over the same period are going towards building 210 apartments for young scientists at the University of Kragujevac (€ 5.6 million), running the BioSense Institute in Novi Sad (€ 14 million, Box 10.3) and constructing and equipping the Faculty of Electronic Engineering in Nis (€ 5.2 million).

A booming software industry

Serbia's first science and technology park focuses on software development (Box 10.2). The software industry has become the fastest-growing sector in Serbia, accounting for 6% of domestic GDP by 2017 (Kleibrink *et al*., 2018).

Most companies are changing their business models from outsourcing and simple programming services to the development of their own software products; this market was estimated to be worth € 1.73 billion in 2016. It is strongly export-oriented. Software exports generated about € 1 422 million in 2019 (National Bank of Serbia, 2019). Around 84% of employees in the software industry hold a university degree and more than 80% of them are working on software development.

Several of Serbia's home-grown software development companies have hundreds of employees – even more than 1 000 in some cases.

Companies are proving increasingly successful in penetrating both the domestic and international markets in niche areas such as gaming, entertainment and media, efficient management of large infrastructure networks (big data, distributed data systems), supercomputing (modelling of complex systems, data visualization), smart printing, the development of next-generation encryption technologies, robotics and sector-wide integration built around data acquisition and management – particularly for agricultural, health and environmental applications.

CONCLUSION

Research and innovation must be integrated further

The common target for all five countries remains EU membership. In the interim period, they are likely to focus on aligning their own structures and legal and institutional frameworks with those of the EU, in order to prepare for this transition.

Although there has been tangible progress since 2015, all five countries struggle with outmoded and linear innovation systems that continue to hamper their development. Other major challenges include:

- reversing brain drain, which has exacerbated the problems of an ageing population;
- restructuring research systems which are overreliant on government support to the detriment of co-operation with the business sector;
- reshaping the priorities of universities, which often prefer teaching to research or innovation;
- avoiding saturation in scientific publishing and providing creative minds with the space to focus on the development of technology, patenting and commercial spin-offs and spin-outs;
- reforming the economy and enabling the research system to act as a partner in the quest for efficient and 'smart' solutions to socio-economic challenges; and
- deepening engagement with EU partners to procure valuable Horizon Europe funding from 2021 onwards.

The limited opportunities for co-operation available under the near-forgotten Western Balkans *Regional Research and Development Strategy for Innovation* and the *SEE 2020 Strategy* could be replaced by complementary 'smart specialization' priorities, designed to avoid competition with one another. This could help to accelerate development, as long as countries comply with the methods and procedures followed by the European Commission.

In turn, the EU should engage further in the provision of sustainable financial support and monitoring, in order to foster stable, prosperous economies on its doorstep.

With its software industry showing promise, Serbia could make much better use of its skilled and well-educated population to boost this sector.

For its part, the EU can play a supporting role by funding implementation of the *Smart Specialization Strategies* of both Montenegro and Serbia, the first countries to reach the next stage of the S3 process. If the European Commission does its part, this could motivate the other three Southeast European countries to accelerate the process of preparing their own national innovation systems for the new economy.

KEY TARGETS FOR SOUTHEAST EUROPE

- Albania has fixed the target of devoting 1% of GDP to R&D by 2022.
- Albania plans to increase the number of jobs held by female researchers and scholars and the number of research projects led by women by 30% by 2020.
- Bosnia and Herzegovina aims to raise R&D expenditure to 0.8% of GDP by 2022.
- By 2021, Montenegro plans to raise expenditure on R&D by 50% over the 2017 baseline, when the GERD/GDP ratio was 0.35%.
- By 2020, renewable energy should make up 30.7% of gross energy consumption by the Western Balkan 6.

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ENDNOTES

1 previously known as the former Yugoslav Republic of Macedonia

2 All references to Kosovo in the present chapter and throughout the UNESCO Science Report should be understood in the context of the United Nations Security Council Resolution 1244 (1999).

3 These are the EU's Energy Efficiency Directives referenced 2012/27/EU, 2010/30/EU and 2010/31/EU and the Renewable Energy Directive referenced 2009/28/EC.

4 A review of project proposals submitted to PROMIS was conducted in mid-October 2019. Of the 585 proposals submitted, 454 (77.61%) had been taken forward for further evaluation.

5 Of the 403 Starting Grants awarded to young post-docs by the European Research Council in 2018 for basic research projects, only three came from non-EU countries in Southeast Europe. Two grantees were Serb and one came from North Macedonia. All three were women and based at institutions abroad.

6 CERN is an independent intergovernmental organization subject to its own treaty. As a result, membership is open to non-EU members.

7 The list is as follows: social sciences and Albanology; health; materials; water and energy; agriculture, food and biotechnology; biodiversity and environment; and ICTs.

8 GÉANT is part of Europe's e-infrastructure for education, research and innovation. See: www.geant.org

9 The Albanian National Agency for Scientific Research and Innovation is also responsible for distributing university research funds, identifying research priority areas and evaluating national research programmes.

10 EURAXESS is an information tool for researchers wishing to pursue their careers in the EU or stay connected to the bloc. It is the 30th commitment of the EU's Innovation Union (Hollanders and Kanerva, 2015, Table 9.7).

The Northern Lights subsea platform awaiting transportation to the North Sea off the coast of the Norwegian city of Bergen, where it will be lowered to the sea floor and installed at a depth of 300 m. A well will be drilled from the subsea platform into the rock to a depth of almost 3 000 m to allow carbon dioxide to be injected into this sandstone reservoir.
©Equinor

AT A GLANCE

- Iceland and Norway are striving to raise their research intensity to Switzerand's level.
- Switzerland is stepping up its efforts to retain and diversify its research-intensive industries dominated by pharmaceuticals and chemicals. The government has lowered the tax burden for research-intensive firms and set up the Swiss Innovation Park specializing in areas that include advanced manufacturing, smart buildings and robotics.
- Iceland is exploring how science and technology can be an instrument not only of economic growth but also of 'quality growth'. In parallel, the government is advocating closer policy ties between science and art.
- A key challenge for governments will be to find the right balance between basic and mission-oriented research, on the one hand, and between research universities striving for world-class status and more locally oriented institutions placing greater emphasis on teaching, on the other.
- Iceland, Norway and Switzerland all plan to become carbon-neutral within 30 years. Projects for carbon capture and storage are under way in Iceland and Norway.

11 · European Free Trade Association

Iceland, Liechtenstein, Norway, Switzerland

Hans Peter Hertig

INTRODUCTION

Five good years

For the members of the European Free Trade Association (EFTA), 'five good years' would be an apt summary of developments since the last *UNESCO Science Report* (Hertig, 2015). Up until the Covid-19 pandemic in 2020, all four had enjoyed robust economic growth (Figure 11.1), combined with low unemployment and a stable political climate.

A decade on from the Great Recession, Iceland's economy is back on track. Recovery has been driven by tourism, which has replaced the traditional sectors of fishing and banking as the country's primary industry. With the Covid-19 epidemic having compromised most international travel in 2020, Iceland's budding tourism sector may not emerge unscathed from the crisis.

The economy of Iceland's southern neighbour, Norway, has been buffeted by fluctuating global oil prices for the past five years but continues to report one of highest levels of GDP per capita in the world (Figure 11.1).

Covid-19 has revealed vulnerabilities

The Covid-19 pandemic has revealed structural vulnerabilities. With factories having been 'outsourced' to countries with lower labour costs over the past few decades, all four countries have encountered bottlenecks in obtaining sufficient quantities of protective gear and lung ventilators.

Iceland is an interesting case study. An island nation with a small population (*ca* 360 000 in 2020), it was able to contain the pandemic early on simply by closing its airport. It also tested more than 5% of the population regardless of state of health, one of the highest proportions in the world. Half of those tested were asymptomatic, enabling them to be isolated before they infected others.

On 1 April 2020, the Icelandic government announced the introduction of a contact tracing system to identify those at risk of infection by tracking a person's displacements via their mobile phone. The ultimate goal was to involve at least 60% of the population in the project. Within two days, one in five Icelanders had chosen to download the free app, which is a joint project between the Department of Civil Protection and the Directorate of Health that uses software developed by Aranja, a small company based in Reykjavik.

All EFTA countries have been testing for Covid-19 using throat swabs but it initially took days to obtain the test results. To speed up the process, the Swiss pharmaceutical company Roche developed an automated method that showed results in less than four hours. The US Food and Drug Administration has granted Emergency Use Authorization for the test to be extended to the USA.

Unfortunately, Roche is the exception. The Swiss pharmaceutical industry has tended to neglect the relatively low-profit area of diagnostics up to now. To be ready for the next pandemic, there will need to be a long-term alliance between the local pharmaceutical industry and the public sector.

One promising avenue is serological testing to detect antibodies in the blood of those who have become immune to the pathogen. For example, two Swiss companies, Augurix and GaDia, distributed a co-developed rapid test kit in April 2020 to potential users in Switzerland, pending authorization by the regulatory authorities.

The pandemic will undoubtedly have long-term consequences for the economy and specific policy areas such as health, research and development (R&D) and the environment.

The Covid-19 pandemic has delayed adoption of Horizon Europe, the successor to Horizon 2020 (see chapter 9). The official launch of the EU's new seven-year framework programme for research and innovation in February 2021 paves the way to potentially deeper negotiations with individual EFTA countries over the extent of their own participation in the new programme.

A positive evaluation of grant scheme

Since 2004, the three EFTA members of the European Economic Area, namely, Iceland, Liechtenstein[1] and Norway, have been engaged in a programme aimed at reducing socio-economic disparities among 15 members of the European Union (EU) situated in Central and Southern Europe and the Baltics. It is known as the European Economic Area and Norway Grants programme (Hertig, 2015).

The findings of a recent evaluation of the programme over the 2009–2014 period have been positive (CSES, 2016). Grants for a total of € 1.8 billion were awarded in the areas of social and human development, renewable energy and climate change. The top three beneficiaries for the number of projects were Poland, Romania and Bulgaria, in descending order.

Despite some difficulties in identifying project partners in the donor states, the programme will continue in its current form until 2021. The total contribution for the 2014–2021 period is € 2.8 billion.[2]

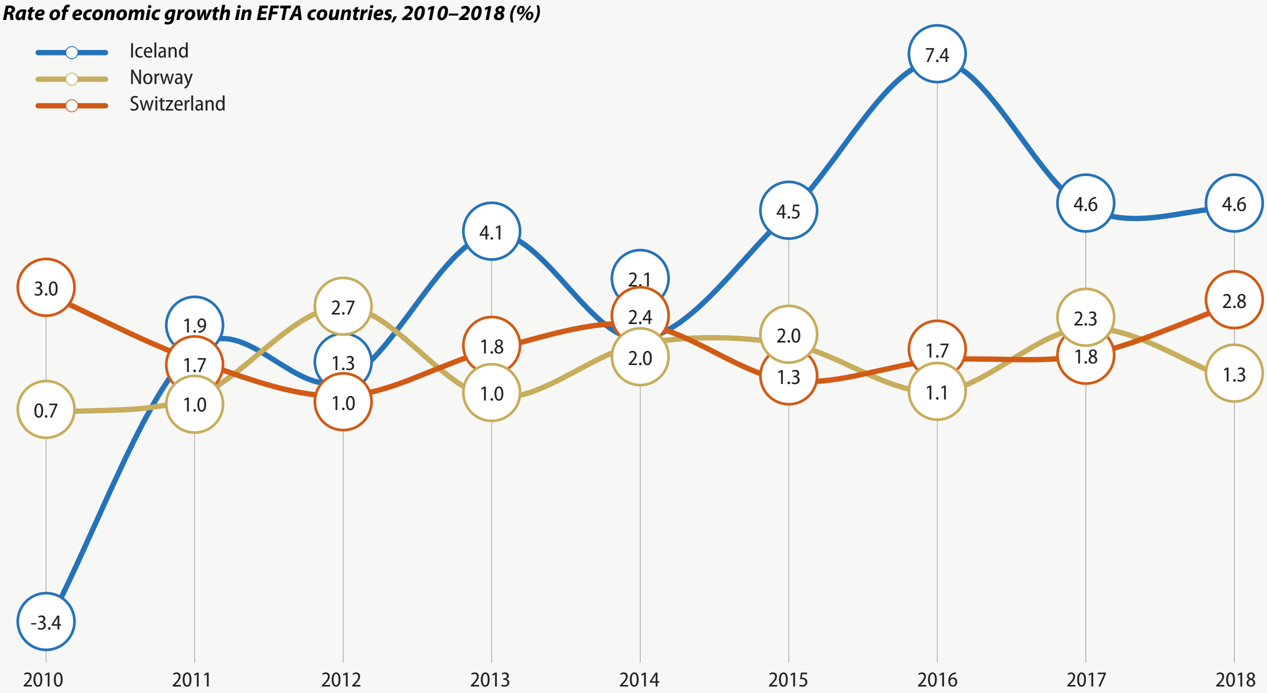
SUSTAINABLE DEVELOPMENT AGENDA

Norway juggling oil exploitation with climate goals

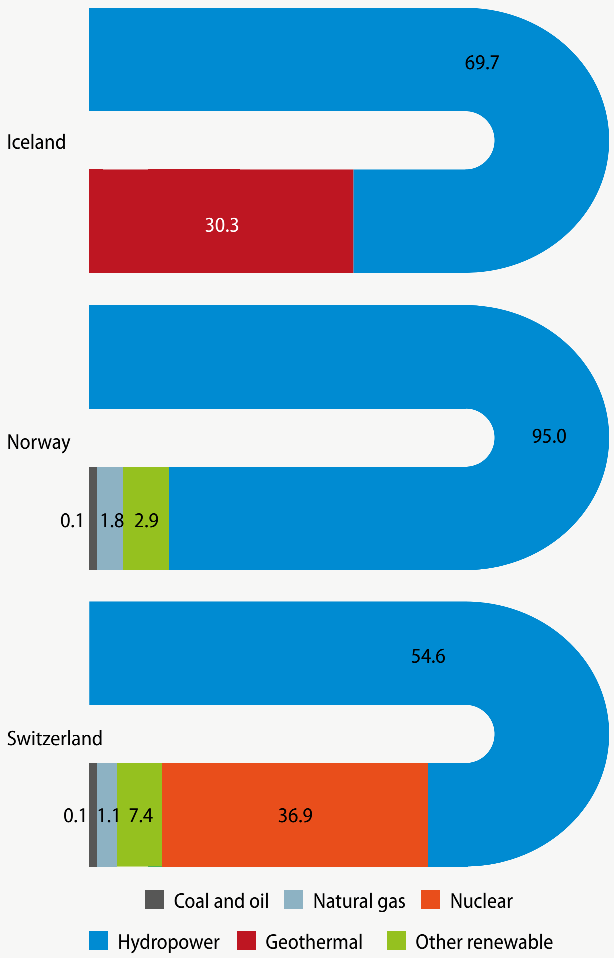
In 2019, the Climate Change Performance Index assessed 56 countries responsible for 90% of global greenhouse gas emissions against their performance in this particular area, as well as with regard to climate policy, renewable energy and energy use (Burck *et al.*, 2019). The two EFTA countries

Figure 11.1: **Socio-economic trends in EFTA countries**

Rate of economic growth in EFTA countries, 2010–2018 (%)



Electricity generation in EFTA countries by source, 2018 (%)



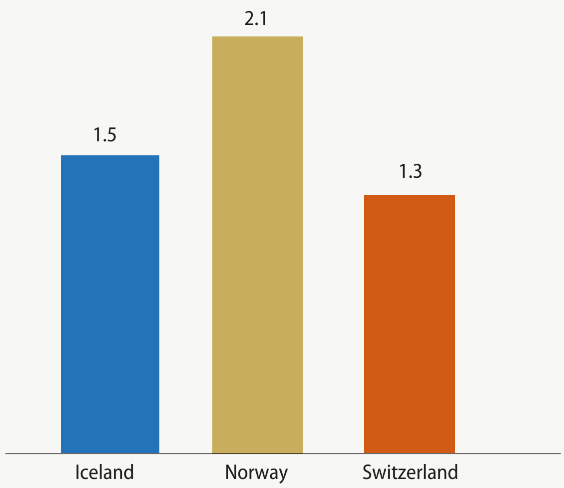
GDP per capita in EFTA countries in 2019
In constant 2017 PPP$

Iceland	Norway	Switzerland
55 874	**63 633**	**68 628**

Central government debt in EFTA countries as a share of GDP (%)

Iceland (2016)	Norway (2019)	Switzerland (2018)
73.5%	**46.7%**	**41.1%**

Public expenditure on higher education as a share of GDP, 2016 (%)



Note: These figures are not drawn to scale.

Source: World Bank's World Development Indicators, June 2020; for electricity generation: International Energy Agency; for cexpenditure on education: UNESCO Institute for Statistics analysed performed well overall, with Switzerland ranking 16th and Norway 12th (Burck *et al.*, 2019).[3]

In the assessment, Norway was rated highly for its international commitment to climate finance reporting and the Green Climate Fund, as well as for its leadership in negotiating climate agreements. At the national level, it was noted that Norway's carbon tax adopted in 2015 was one of the highest in the world (Burck *et al.*, 2019).

Norway received high ratings for all but its energy use, where its lack of either an exit strategy for oil exploration or mandatory energy efficiency measures for industry placed it near the bottom of the table. The authors note that 'Norway is planning for a new peak in domestic production in 2023' (Burck *et al.*, 2019).

The Organisation for Economic Co-operation and Development (OECD, 2019) expects 'a renewed increase in [oil] production in Norwegian fields in the coming years, as the Johan Svedrup and Johan Castberg fields come on stream.' According to Statistics Norway, 6% of total employment was directly or indirectly associated with the oil and natural gas sector in 2017, down from 9% in 2013 before the drop in global oil prices.

A 2019 report found that Norway and nine other leading producers were planning to produce roughly 50% more fossil fuels than would be consistent with a 2°C pathway for the rise in average global temperatures by 2050 (SEI *et al.*, 2019). The government has been offsetting its emissions through allowances purchased from the EU Emissions Trading System but other reports have found that Norway could halve the cost of reaching its 2020 emissions target by slashing investment and production in its oil fields (Fæhn *et al.*, 2017; Hermansen and Lahn, 2019).

Meanwhile, the Norwegian oil giants are striving to compensate for their environmental cost. Equinor, Norway's leading energy company,[4] recently presented a project for an 88 MW offshore wind farm to be completed by 2022. The new wind farm is expected to generate about one-third of the annual energy consumption supplied by Equinor's oil and gas platforms.

Big ambitions for carbon neutrality

In June 2019, Norway's parliament voted to establish a long-term goal that is more ambitious than any pursued by its EFTA partners: carbon neutrality by 2030. This is to be achieved through a wide range of measures that include expanding electrification of road transportation – no other country has more electric cars on the road – and making 'climate, environment and clean energy' one of four long-term research priorities, as we shall see in the profile of Norway.

With its current plans to intensify oil exploitation in the North Sea, the strategy of offsetting 40% of its greenhouse gas emissions through the procurement of carbon credits, as permitted under the *Paris Agreement*, will not suffice for Norway to meet its climate goals. The country will also need to invest massively in compensatory mechanisms such as carbon capture and storage[5] (Hermansen and Lahn, 2019; Box 11.1).

Iceland's sweeping *Climate Action Plan for 2018–2030* could serve as a model for other countries (Govt of Iceland, 2018). The *Plan* tackles an extremely broad range of problems ranging from awareness-building programmes for kindergartens to a huge reforestation project designed to bring back the trees razed by the Vikings at the end of the 9th century. It also sets ambitious goals. Iceland already has a high carbon tax and provides its population with virtually carbon-free electricity and heating from its vast geothermal and hydro-electric resources.

The Government of Iceland plans to take this logic a step farther by raising the existing carbon tax by 10% annually and banning (new) diesel and gasoline cars after 2030. A groundbreaking pilot project, CarbFix, has managed to clean and store carbon dioxide (CO_2) on land (Box 11.2). The overarching goal is for Iceland to become carbon neutral by 2040.

One reason for Iceland's commitment can be found in its glaciers, highly visible victims of global warming that are also a source of national pride and a key tourist attraction. In August 2019, Iceland unveiled the world's first memorial plaque erected to a lost glacier, Okjökull.

Switzerland having many glaciers of its own, one might expect it to have a similarly ambitious policy. In August 2019, the Swiss government revised its already respectable long-term targets for a 50% reduction in CO_2 emissions by 2030 and an 80% reduction by 2050 by promising carbon neutrality by 2050.

Should the Swiss adopt the 2050 target for carbon neutrality in a popular initiative scheduled for late 2020 – direct democracy is a particularity of Swiss political life – parliament will be required to adopt the requisite measures to reach this target, such as by expanding the existing incentive tax on thermal fuels to include motor fuels. A civil rights movement across traditional party lines, supported by prominent activists like Jacques Dubochet, Switzerland's Nobel Prize Laureate in Chemistry of 2017, has thrown its weight behind what it has dubbed 'the Glacier Initiative' (SWI, 2019).

Shortly after the previous edition of the *UNESCO Science Report* (Hertig, 2015) drew attention to plans for a network of energy research centres, the Swiss Competence Center for Energy Research was established in 2015. This network of 30 Swiss scientific institutions, industrial enterprises and federal agencies conducts innovative research in geothermal energy and hydropower. The centre works in co-ordination with the Swiss Federal Office of Energy and is financed by the Commission for Technology and Innovation, as well as by the Swiss National Science Foundation.

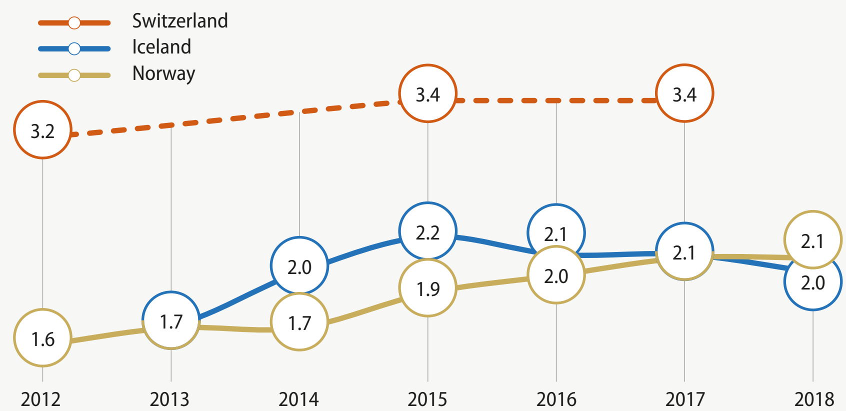
RESEARCH TRENDS

A rise in Norway's research intensity

The Norwegian government funds almost half of gross domestic expenditure on R&D (GERD), compared to just one-quarter funded by the Swiss government (Figure 11.2). The biggest research spender among EFTA countries is not Norway, however, but Switzerland; this is mainly due to the intensive research effort made by the private sector, in general, and by Swiss pharmaceutical and chemical industries, in particular. Switzerland's level of investment in R&D (3.37% of GDP in 2017) is surpassed only by that of Israel (see chapter 16) and the Republic of Korea (see chapter 25).

Figure 11.2: **Trends in research expenditure and personnel in EFTA countries**

GERD as a share of GDP in EFTA countries, 2012–2018 (%)



Share of industrial investment in basic research in Switzerland

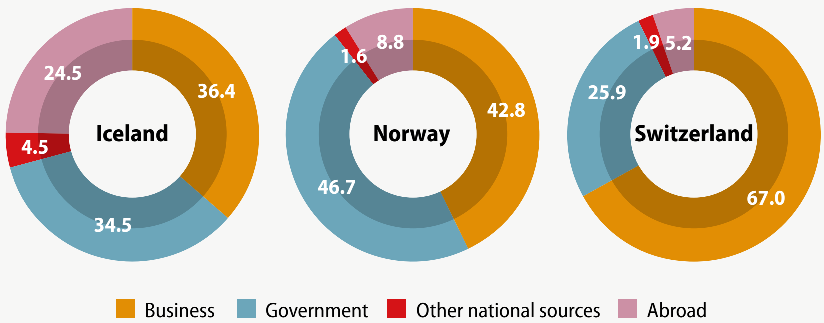
26.7%
in 2017

10.4%
in 2012

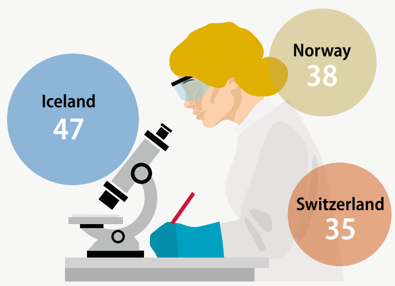
Number of universities in top 200, according to the 2019 QS World University Ranking

2	**7**
Norway	**Switzerland**

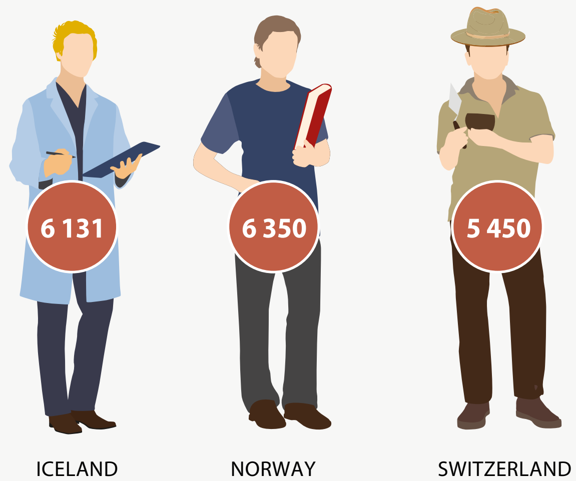
GERD by source of funds in EFTA countries, 2017 (%)



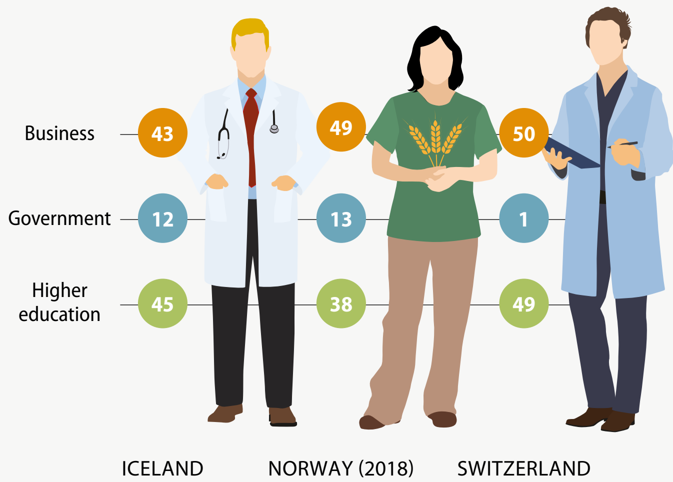
Share of female researchers (HC), 2017 (%)



Researchers (FTE) per million inhabitants, 2017



Researchers by sector of employment (FTE), 2017 (%)



Number of European Research Council grants per million inhabitants, 2014–2019

12	**13**	**42**
Iceland	**Norway**	**Switzerland**

Rank in EU Innovation Union Scoreboard, 2019 (36 countries)

1st	**7th**	**11th**
Switzerland	**Norway**	**Iceland**

Source: UNESCO Institute for Statistics; for Swiss GERD data for 2017: OECD (2020) *Main Science and Technology Indicators*. Organisation for Economic Co-operation and Development: Paris; for basic research in Switzerland: Bundesamt für Statistik (2019) *Forschung und Entwicklung in der Schweiz 2017*, p. 8.

Norway's own research intensity has improved. At 2.11% of GDP (2017), it remains close to the EU average. Successive strategic documents and roadmaps have affirmed science and technology as a national priority.[6]

Switzerland preserves its appeal among foreign talent

Half of Swiss doctoral candidates (51%) were international students in 2012, compared to one-third (34%) in Norway and one-quarter (24%) in Iceland (Avenyo *et al*., 2015). More than half of the faculty members at Swiss universities are non-Swiss (Bundesamt für Statistik, 2019). According to the Global Competitiveness Index, Switzerland leads the world for its ability to attract and retain talent, although Iceland and Norway also perform well (see Figure 10.1).

Switzerland's ability to attract and retain foreign talent was jeopardized in 2014 by the outcome of a popular initiative. By a fragile majority, the Swiss voted to limit the number of work permits for foreigners (Hertig, 2015).

In December 2016, the Swiss parliament adopted a bill that stopped short of introducing quotas for EU citizens or fellow EFTA members, thereby preserving the status quo.

Switzerland leads for research grants

All three nations are strong publishers, both quantitatively and qualitatively (Figure 11.3), with Iceland and Switzerland having the highest publication impact of all OECD countries, a sign of research excellence.

In the case of Norway and Iceland, however, high output has not translated into a high number of grants from Europe's most prestigious funding agency for basic research, the European Research Council (ERC) [Figure 11.2]. Here, Swiss researchers have obtained three times as many grants as Iceland and Norway. In fact, Switzerland leads all the eligible countries within the European Research Area by a large margin for the number of ERC grants, including Israel and the Netherlands.

A closer look at successful participants in ERC calls for project proposals shows the importance of the learning and research environment in which they perform. More than half of Swiss grantees come from the two Swiss Institutes of Technology, namely, the Swiss Federal Institute of Technology Zurich (ETH Zurich) and the École polytechnique fédérale de Lausanne. They lead the group of seven Swiss universities that qualified for the top 200 in the Shanghai Academic Ranking 2019.

Switzerland topped the EU's Innovation Union Scoreboard in 2019, ahead of a Nordic group led by Sweden, Finland

Box 11.1: **Poised to become Europe's first industrial project for carbon capture and storage**

A project under way in Norway since 2014 may become the first industrial-sized project for carbon capture and storage in Europe.

Carbon capture and storage is one of the Norwegian government's climate priorities. The Norwegian state enterprise Gassnova is working closely with industry to demonstrate that carbon capture and storage can be done safely on a large scale. Gassnova co-ordinated the initial exploratory phase with partners Fortum Oslo Varme (waste incineration), HeidelbergCement/Norcem Brevik and Equinor (transport and capture).

The cement industry accounts for 5–7% of global CO_2 emissions. Norcem's location in Brevik may become the world's first cement factory equipped to capture about 400 000 tonnes of CO_2 each year. For its part, Fortum Oslo Varme plans to capture an equivalent amount of CO_2 from their energy recovery plant in Oslo.

Simultaneously, Equinor and partners Total and Shell are exploring how CO_2 emissions by industrial plants in Norway and elsewhere in Europe could be stored deep below the seabed in the North Sea, through the Northern Lights Storage Project. The planned storage site lies to the south of the giant Troll hydrocarbon field and was given the green light by Equinor in early 2020.

On behalf of its partners, Equinor has signed memoranda of understanding with seven European companies* to develop value chains in carbon capture and storage.

More than 20 years of demonstration projects

It was in 1996 that Statoil (now Equinor) commenced CO_2 storage deep under the seabed in the Utsira formation of the North Sea. This project was triggered by one of the world's first carbon taxes, introduced by the Norwegian government for the oil and gas sector in 1991.

Since that first large-scale demonstration project, the Norwegian government, industry and academia have pursued their research with financing from the Norwegian government in the form of research programmes and direct subsidies, with co-financing by industry.

In 2012, the world's largest test centre for CO_2 capture, the Technology Center Mongstad, was inaugurated. A number of international energy companies have since tested their technologies there and matured them for deployment.

Taking carbon storage to the next level

The Full-scale Carbon Capture and Storage project plans to take this technology to the next level by making it more cost-efficient and appealing to the rest of the world. This will be done by sharing experiences and establishing infrastructure for CO_2 transport and storage that offers spare capacity for interested parties.

The project will also serve as a platform for business development of other low-carbon products.

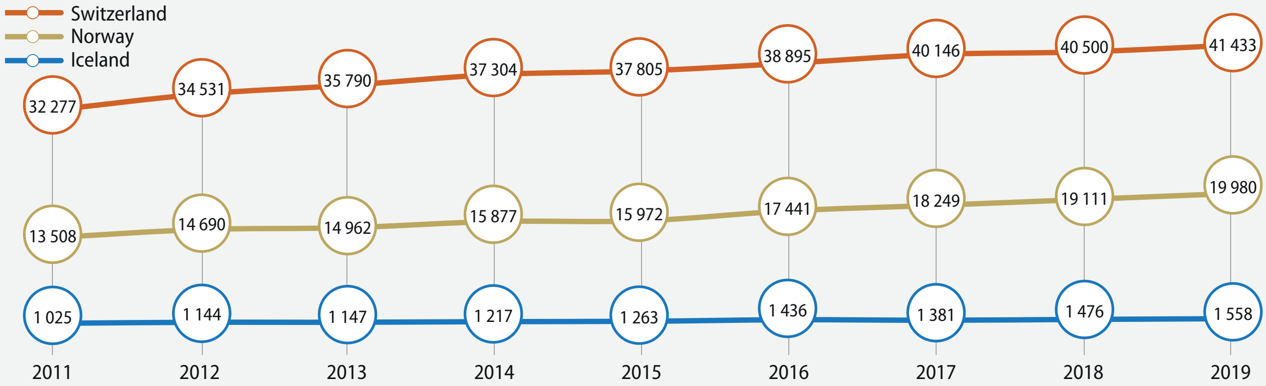
In 2020, Gassnova was awaiting the Norwegian parliament's decision on whether to authorize further investment in the project. Its commercial viability will require government support but further deployment will also depend upon reducing costs and developing a robust business model development.

Source: Vegar Stokset; Gassnova

* These companies are Air Liquide, Arcelor Mittal, Ervia, Fortum Oyj, HeidelbergCement AG, Preem and Stockholm Exergi.

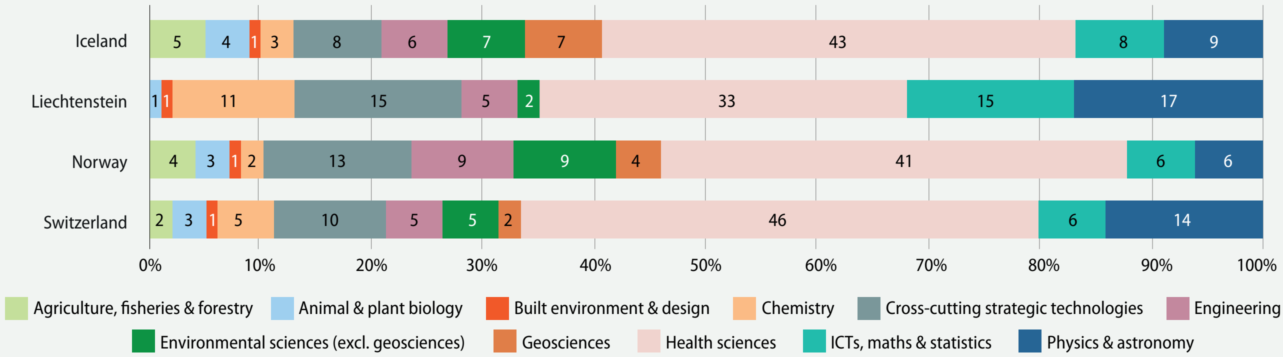
Figure 11.3: **Trends in scientific publishing in EFTA countries**

Volume of scientific publications in EFTA countries, 2011–2019



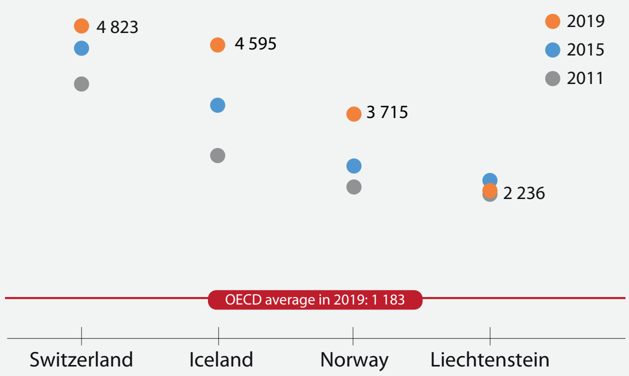
Note: Liechtenstein published between 81 and 102 publications between 2011 and 2019, with a peak in 2014.

Share of scientific publications in EFTA countries by broad field of science, 2017–2019 (%)



Scientific publications per million inhabitants, 2011, 2015 and 2019

Data labels are for 2019



1.57

Average of relative citations for EFTA countries, 2014–2016; the OECD average is 1.11

69%

Average share of papers with foreign co-authors for EFTA countries, 2017–2019; the OECD average is 34%

How has output on SDG-related topics evolved since 2012?

Iceland and Norway are publishing twice as much as would be expected, relative to global averages, on the sustainable management of fisheries and ocean acidification.

Energy is a key topic, with some EFTA countries publishing double the expected proportion of papers on cleaner fossil fuel technology, hydropower, wind turbine technologies, geothermal energy, carbon pricing and carbon capture and storage. Norway's output on the latter is even nine times the global average proportion (Box 11.1). Its output on this topic did drop slightly, though, from 533 (2012–2015) to 470 papers (2016–2019). Iceland is focusing on carbon capture and storage on land (Box 11.2), with researchers publishing six times the expected volume. Not surprisingly, Icelandic researchers publish 59 times the global average intensity on geothermal energy; output has grown from 123 (2012–2015) to 144 papers (2016–2019).

In addition to its traditional focus on tropical communicable diseases, Switzerland's specialization extends to local disaster risk-reduction strategies, radioactive waste management, geothermal energy and hydropower.

For details, see chapter 2

Top five partners for EFTA countries for scientific co-authorship, 2017–2019 (number of papers)

	1st collaborator(s)	2nd collaborator(s)	3rd collaborator(s)	4th collaborator(s)	5th collaborator(s)
Iceland	USA (1 268)	Sweden (1 017)	UK (988)	Germany (814)	Denmark (773)
Liechtenstein	Austria (129)	Germany (123)	Switzerland (83)	USA (63)	Italy (26)
Norway	USA (9 871)	UK (8 884)	Germany (7 000)	Sweden (6 740)	Denmark (4 945)
Switzerland	USA (28 241)	Germany (26 969)	UK (19 863)	France (16 560)	Italy (14 951)

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

Box 11.2: **Injecting gas into rock at Reykjavik**

In June 2016, *Science* published an article in which scientists from Australia, Denmark, France, Iceland, the UK and USA reported on a successful attempt to dispose of CO_2 permanently as environmentally benign carbonate minerals in subsurface basaltic rocks (Matter *et al.*, 2016). Within two years, 95% of the anthropogenic CO_2 injected in a storage formation was mineralized, contradicting the prevailing view that such a process would take up to 1 000 years.

The successful pilot project was run at the CarbFix injection site near Reykjavik. Massive volumes of 'sour gas' emissions* that had been released together with geothermal fluids from the Hellisheidi power plant were captured, mixed with water and pumped back from whence they came.

This technique has since become common practice. The CarbFix method is used to clean and store underground one-third of the annual 40 000 tonnes of CO_2 flowing through gas turbines. Through the same process, two-thirds of the released hydrogen sulphide are also safely deposited in the subsurface.

CarbFix will not solve the world's problem of greenhouse gas emissions, of course. One severe limitation of the method described above is the need for substantial quantities of water and the presence of porous basaltic rock. Both are widely available on the continental margins, such as in Iceland and the Pacific Northwest of the USA, but are rare or absent in other parts of the world.

CarbFix is a step in the right direction, however, and other experiments are already under way, such as to find and use suitable rock strata on the ocean floor (Box 11.1) and capture CO_2 directly from the atmosphere. For the latter, CarbFix is co-operating with the Swiss innovation company Climework, a spin-off of ETH Zürich, in a typical joint venture.

CarbFix itself is the brainchild of four institutions: Reykjavik Energy, the University of Iceland, the National Centre for Scientific Research in Toulouse (France) and Columbia University (USA).

Progress in this field will call for a close partnership between science, technology and industry.

Source: compiled by author

*These are emissions of natural gases that contain high levels of contaminants such as carbon dioxide or hydrogen sulphide.

and Denmark. Iceland and Norway have improved their own rankings. Norway even rose from 16th to 7th place in the Innovation Union Scoreboard. This is a remarkable achievement for an oil-rent economy.

POLICY ISSUES

Commitment to artificial intelligence

The potential of artificial intelligence (AI) has been recognized worldwide. Norway demonstrated its own commitment in 2018 by signing the EU *Declaration of Cooperation on Artificial Intelligence* (see chapter 9) in its capacity as a member of the European Economic Area.

Two years later, in January 2020, the Ministry of Local Government and Modernisation, which has a broad portfolio, published the *National Strategy for Artificial Intelligence* (Govt of Norway, 2020). This policy-oriented document reviews and evaluates the rules that may hinder appropriate and desired use of AI by public entities, the private sector and joint endeavours. R&D is not central to the document, which announces no AI research initiatives. One does learn from it about ongoing efforts in AI, however. Particularly interesting are joint projects between public research laboratories and private companies such as the Norwegian AI Research Consortium and the Norwegian Open Air Lab at the Norwegian University of Science and Technology.

These are recent developments. Norway's *Long-Term Plan for Research and Higher Education 2015–2024* makes no mention of AI.[7] We shall be discussing this document later.

In Switzerland, meanwhile, 50 representatives of the Swiss digitalization scene – entrepreneurs, financiers and politicians – put together a comprehensive blueprint in 2016 to attract the attention of the Swiss government to the potential of AI. Their *Digital Manifesto for Switzerland*[8] argues that politics should play a more active role in this field. The manifesto has served as a veritable wake-up call (Gabus, 2017), although Switzerland had already made great strides in AI, even becoming an international hotspot for AI research (Govt of Switzerland, 2019; SATW, 2019; see also Figure 24.5).

The appropriate vehicle will be the Swiss government's next multi-year development plan for education, research and innovation covering the 2021–2024 period, which shall be discussed later. This plan designates digitalization as one of three transversal themes to be prioritized by funding instruments supported, or co-supported, by the federal government, thereby providing a considerable boost to fields such as blockchain technologies, digital platforms, cloud technologies and AI.

In Iceland, meanwhile, the Institute for Intelligent Machines bridges academia and the private sector. Established in 2009, it issued a policy on ethical issues in 2015, which made it the first research group working on AI to reject the development of technologies intended for military operations (ICRAC, 2015).

Countries embracing open science

The benefits of open science have been spectacularly showcased by the Covid-19 pandemic, which has seen scientists the world over sharing information and data to help their peers. Chinese scientists shared the sequenced genome of the coronavirus online in January 2020, for instance (see chapter 23), enabling German scientists to develop screening tests which they, in turn, shared with the international scientific community.

The concept of open access to scientific data dates back to the 1950s. A milestone was reached in 2013 with the *Berlin Declaration on Open Access to Knowledge in the Sciences and*

Humanities. In 2017, Norway and Switzerland joined other nations in adopting national open access strategies.

Norway made history on 23 April 2019 when, after lengthy negotiations, it established a nationwide licensing agreement with one of the world's major scientific publishers, Elsevier. Under this two-year agreement, articles published by Norwegian academics will be open access in 90% of the publisher's 2 500 journals (Kwon, 2019).

In early 2019, swissuniversities, a consortium of Switzerland's 12 universities, emulated Norway by entering into negotiations with Springer Nature, Elsevier and Wiley (SAAS, 2019). As of mid-2020, the process was still ongoing.

Switzerland has a good track record. An analysis by the European Commission of the Scopus and Unpaywall databases found that 43% of Swiss publications were open access, ranking Switzerland second only to the UK out of a group of 35 countries. Norway fell into 8th place with a 37% share.[9]

Not surprisingly, negotiations are being led on the science side by national research councils and multinational institutions like the European Commission. Under the stewardship of a working group set up by Science Europe and supported by the European Commission and ERC which calls itself cOAlition S, the research funders of 11 countries signed a declaration in September 2018 in favour of unrestricted open access to published research papers.

Norway has signed the declaration but Switzerland has expressed reservations about the radical nature of the plan advocated by cOAlition S; Plan S, as it is known, requires recipients of research funding from cOAlition S members to make the resulting publications available immediately, without any period of embargo, and under open licenses, either on quality open access platforms or journals, or in open repositories (Else, 2018).

In April 2020, Springer Nature announced that many of its non-open access journals, including *Nature,* would join Plan S from 2021 onwards (Van Noorden, 2020).

By April 2020, 17 mainly European funders had signed up to the Plan S initiative, along with the World Health Organization and two of the world's largest private biomedical funders, the Bill and Melinda Gates Foundation and Wellcome (Van Noorden, 2020). For its part, the European Commission is planning to implement an open access policy aligned with Plan S (see chapter 9).

COUNTRY PROFILES

ICELAND

An ambitious reform agenda

In June 2017, Iceland's Science and Technology Policy Council published its *Policy and Action Plan 2017–2019* (Govt of Iceland, 2017). The plan defines ten medium-term reforms and one goal to ensure adequate funding for this ambitious agenda: a 3% GERD/GDP ratio by 2024. These reforms have since been widely discussed by numerous working groups to determine a time-frame and specific measures to foster implementation.

In late 2019, an interim report showed progress in some areas, such as in bringing research priorities closer to the needs of Icelanders, as captured in public consultations. These consultations revealed that Icelanders were most preoccupied by the state of the environment, public health and the impact of new technologies on jobs.

Other challenges, such as those of prioritizing quality-oriented university funding and a more research-friendly tax environment, are still in limbo. There is a question mark hanging over the long-term goal of a 3% GERD/GDP ratio; reaching this highly ambitious target would demand a sizeable and sustainable annual budget allocation.

The *Policy and Action Plan 2017–2019* downplays some of the burning issues confronting Iceland's education and science systems. Icelanders' excellent publication record is less the result of strong domestic institutions – no Icelandic university makes it into the top 200 of major global university rankings – than of Icelanders' capacity to integrate into high-performing research groups abroad. There is nothing wrong with that, of course; on the contrary, high mobility and the willingness to start an academic career in a leading university abroad is an advantage. However, this begs the eternal question for small countries: what does Iceland plan to do to woo its well-trained youth back home?

One answer would be to set up centres of excellence in strategic areas. The *Policy and Action Plan 2017–2019* does not explicitly suggest such an avenue. The government is developing a new funding model which should be in place by 2021. Additional measures will be proposed in the updated policy and action plan, which should be published at around the same time.

Iceland will also need to tackle the issue of its fragmented higher education system; it counts seven universities and 14 research centres for a population of just 360 000. This issue has been raised by the EU's Research and Innovation Observatory (Skogland, 2016) and by Hertig (2015). The latter has suggested that the country should consider concentrating its research effort in one or two flagships.

The *Policy and Action Plan 2017–2019* is very down to Earth. It is noteworthy for addressing its proposals to the citizens of Iceland, as a whole, and for suggesting that the arts be part of the matrix for problem-solving. The introduction reads, 'new challenges also call for new solutions based on increased interdisciplinary collaboration, encouraging greater participation by the humanities, social sciences and arts and on greater involvement of citizens in design, innovation and research.'

An orientation towards 'quality growth'

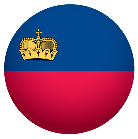
The *Policy and Action Plan* was devised by Iceland's Science and Innovation Policy Council. It evokes the role that key scientific disciplines and technologies will play in mastering the Fourth Industrial Revolution, also known as Industry 4.0.

At the same time, it emphasizes the role of R&D in ensuring 'quality growth,' as opposed to the more hegemonic term of 'economic growth,' by taking into account the potential negative impact of technologies on future users. Although the *Policy and Action Plan* does not refer explicitly to technology assessment, this is the philosophy behind it.

Two of the ten reforms proposed are exemplary in this regard. Firstly, Iceland wishes to ensure that its citizens are well-informed about developments in science and technology, particularly those of relevance to the country's specific geographical and economic situation, where future growth will be subject to natural barriers. In order to improve the population's grasp of science and technology and allow citizens to intervene directly in political decision-making, the *Plan* intends, among other things, to promote the integration of the Icelandic language in computing and technology, including software design.

Secondly, the *Policy and Action Plan* explicitly refers to art and the artistic community as essential sources of innovation. This is an attempt to bring science and art closer together – a rare occurrence in a research strategy – and a homage to Iceland's well-known artistic community. A famous Icelander has already led the way. Jonas Hallgrimsson (1807–1845), Iceland's highly regarded poet, was also a gifted scientist (Lesser, 2018).

LIECHTENSTEIN



Decision pending on participation in Horizon Europe

With a population of 38 000, Liechtenstein is not picked up by the OECD's R&D statistics, making its progress difficult to benchmark.

Some research policy decisions, nevertheless, catch the eye: in 2015, parliament decided against participating in the EU's Horizon 2020 programme, despite the country's privileged status as a member of the European Economic Area.

Whether Liechtenstein will participate in the EU's next cycle of the framework programme beginning in 2021 under the name of Horizon Europe remains an open question at the time of writing in June 2020. The largest party in Liechtenstein's parliament invited the government, in mid-February 2020, to develop a science and research strategy to 2030 which would address the issue of participation in Horizon Europe.

Opting to participate in Horizon Europe would allow the country's major institution of higher learning, the University of Liechtenstein, to link to leading European science networks, enhance its competency in basic research and compete for grants from the European Research Council.

Should Liechtenstein decide not to participate in Horizon Europe, its public-funded research system will remain focused largely on applied R&D. Although the University of Liechtenstein focuses on entrepreneurship, business law and finance, Liechtenstein also funds the University of Applied Science Buchs in neighbouring Switzerland, in tandem with several Swiss cantons.

This dynamic combination would seem to offer the principality a strong profile in applied R&D, since Liechtenstein has the highest density of companies in the world. These companies hold more patents from the top five patent offices than Iceland (Figure 11.4), which has ten times Lichtenstein's population.

NORWAY

Five thematic priorities

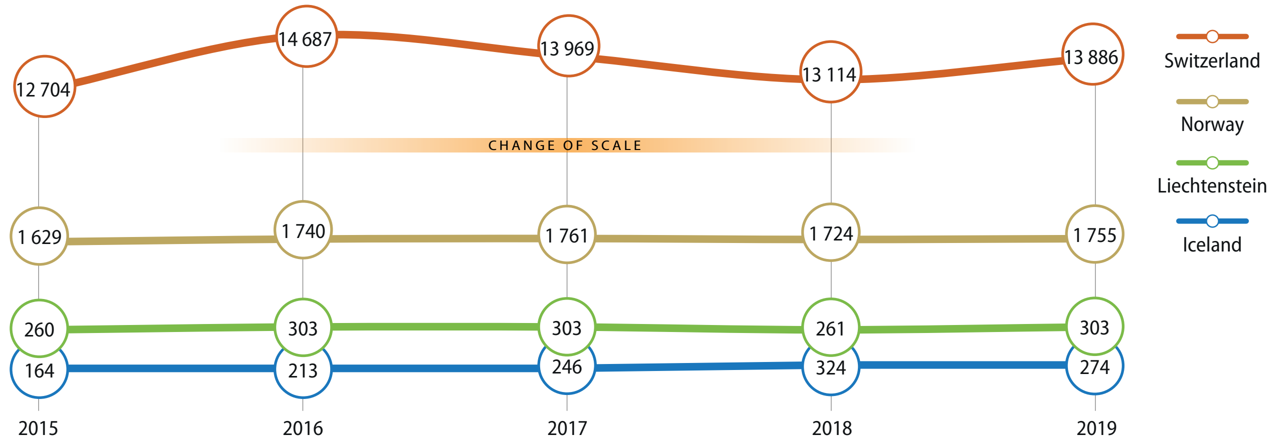
Norway faces the challenge of shifting its specialized, mainly resource-based economy to a more diversified model with a lesser vulnerability to business cycles. To achieve this, it will need to make improvements to its research and innovation system.

The government is well aware of the challenge and has developed a roadmap, the *Long-Term Plan for Research and Higher Education 2015–2024* (Govt of Norway, 2015).

The *Long-Term Plan* defines six priority areas. One of these is structural, that of having academic groups included among the world's best, and five are thematic:

- sea and ocean;
- climate, environment and clean energy;
- public sector renewal, better and more effective welfare, health and care services;

Figure 11.4: **Number of IP5 patents granted to EFTA countries, 2015–2019**



Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China.

Source: PATSTAT; data treatment by Science-Metrix

- enabling technologies; and
- innovative and adaptable industry.

The six interrelate and overlap, of course, but how exactly they mesh is not clear. For instance, 500 new academic positions are foreseen and 400 million Norwegian kroner was invested in modernizing research infrastructure in 2018 but it would seem that this bounty is going primarily to research units in the aforementioned prioritized thematic areas, to the exclusion of industry, even though these areas have a strong industrial component.

Mission-oriented research has become the object of rekindled interest among policy-makers around the globe but it is possible to go too far in this direction, as observed by the *Science and Technology Outlook* in its discussion of the pros and cons of specific types of research funding (Larrue *et al.*, 2018). Moreover, an excessive focus on mission-oriented research could impinge on another priority, basic research, since the path to joining the ranks of the world's leading academic groups will be paved with accomplishments in this area. Avoiding such a trap will demand a considerable increase in overall research expenditure, so as not to penalize basic research.

In this regard, Norway is in a much more favourable position than a couple of years ago; the country has returned to impressive economic growth and public debt is low (Figure 11.1). This healthy conjuncture has not only allowed the country to maintain its traditionally generous spending on the lower levels of its education system but also to extend this outlay to research sectors that had previously suffered from neglect.

On track to achieve its target for research intensity

GERD is still fairly modest but rising (Figure 11.1), thanks to considerably higher investment in R&D by the private sector. Interestingly, large companies with 500 employees or more account for only 32% of private sector expenditure on R&D in Norway, compared to 55% for small and medium-sized enterprises (firms with fewer than 200 employees).

By international standards, industrial expenditure on R&D remains relatively modest; no Norwegian company is ranked among the world's top 50 spenders on R&D.

Nonetheless, if investment pursues current growth rates, the 3% target for research intensity set by the *Long-Term Plan* will be within reach.

The *Long-Term Plan* proposes streamlining and centralizing the university landscape, in order to create a critical mass for specific research priorities. Recent mergers have already reduced the number of universities from 33 to 21, although major universities have not been targeted. Mergers can help, as can the proposed investment in research infrastructure.

However, the *Long-Term Plan* does not earmark more funds for basic research. Rather, these are to be attributed via channels like the non-oriented grants offered by the National Research Council. However, the council's current budget has to cover both project grants and programmes like the Norwegian Centres of Excellence; it is also very low from an international perspective.

Norway still keeps a relatively low profile with regard to calls issued by the European Research Council (ERC) for basic research (Figure 11.2). It obtained a cumulative total of 28 ERC starting grants over the three years to 2019, comparable with the performance of Denmark (32).

Norway has achieved a higher turnover in those parts of Horizon 2020 targeting more applied research. It has become one of the most active countries in Europe in the current framework programme, with the number of grant applications per capita well above average and high success rates.[10]

A 'greener' *Long-term Plan*

The Government of Norway (2019) has published its first evaluation and revision of the *Long-term Plan for Research and Higher Education, 2015–2024*. This mid-term report is 'greener' than the original master plan from 2015, reflecting emerging international trends in relation to sustainable development and climate change.

The revised *Long-term Plan* seeks to promote the integration of *The 2030 Agenda for Sustainable Development* in academic research programmes by encouraging these institutions to develop multidisciplinary internal research communities as well as cross-institutional projects. Sustainability is also a priority of the Norwegian Research Council.

In addition to the aforementioned six priorities of the *Long-Term Plan*, the government has introduced a seventh area: Societal Security and Social Cohesion in a Globalized World.

Generally speaking, the *Long-Term Plan* seems to be on track. Some goals have been achieved sooner than expected and important infrastructure projects have been realized. These include the development of Campus Ås, Norway's largest university building, home to the Norwegian University of Life Sciences; and the construction of a new building for life sciences, pharmacology and chemistry at the University of Oslo. In June 2019, the development of the Ocean Space Centre in Trondheim, foreseen in the *Long-Term Plan*, was spurred on by a report claiming that it could be built within budget at its current site in Tyholt. The centre will educate future specialists in ocean space technology.

Other infrastructural projects are in the pipeline and there is a clear objective to increase public research spending even further.

SWITZERLAND

Decision pending over participation in Horizon Europe

On 20 May 2020, the Federal Council approved the funding necessary for Switzerland's participation in Horizon Europe. As of April 2021, official negotiations have not yet opened with the EU, however.

Swiss scientists are well funded by their home institutions and the Swiss National Science Foundation but it would be a major blow for Switzerland to be excluded from the calls for research proposals launched by Europe's most prestigious funding scheme, the European Research Council (Figure 11.2). This could happen, should no solution be found enabling Switzerland to adhere to a central requirement of framework co-operation agreements with the EU, namely, the free movement of labour.

Should this scenario become a reality, according to initial drafts of the terms of future participation by third countries, Switzerland would belong to a new category of participants in Horizon Europe, in which countries compete in a 'pay as you go' *modus operandi*. In other words, third countries would pay out of their own pocket for the privilege of implementing projects accepted by the EU.

Overreliance on a handful of multinationals

According to a study by Ernst and Young (2018) that analyses 500 companies, Swiss firms invest roughly 7% of their turnover in R&D, the highest ratio in the world.

Two-thirds of Swiss research expenditure comes from the business sector. In 2017, this amounted to US$ 16 billion. Most of it was concentrated in the pharmaceutical sector and, within this sector, in a handful of multinational corporations. Should those multinational corporations decide to take their business elsewhere, Switzerland would lose the heart of its research enterprise.

There are warning signs. Between 2015 and 2017, the extramural portion of business R&D rose by more than 50%, with the lion's share being spent by a handful of multinationals specializing in biotechnology which invested these funds in Switzerland.

This is, of course, part of a global trend towards new forms of production, the lessening dominance of blockbuster patents and the digitalization of industry. These and other factors call for diversified forms of co-operation through internationalized business models. Of note, however, is that intramural business expenditure on R&D did not decline over the same period.

Measures to support start-ups

Switzerland's growing reliance on a handful of multinationals in a narrow field should be of concern. Some recent measures to support start-ups and small and medium-sized enterprises, such as the establishment of the Swiss Innovation Park and a tax reform in favour of research-intensive companies, are a step in the right direction.

The Swiss Innovation Park was formally opened In January 2016. It comprises five legally distinct sites, each with their own priority areas (Figure 11.5). The five sites are co-ordinated by the Switzerland Innovation Foundation and backed by a federal guarantee of CHF 350 million (*ca* US$ 360 million), which is used by the park as collateral for loans.

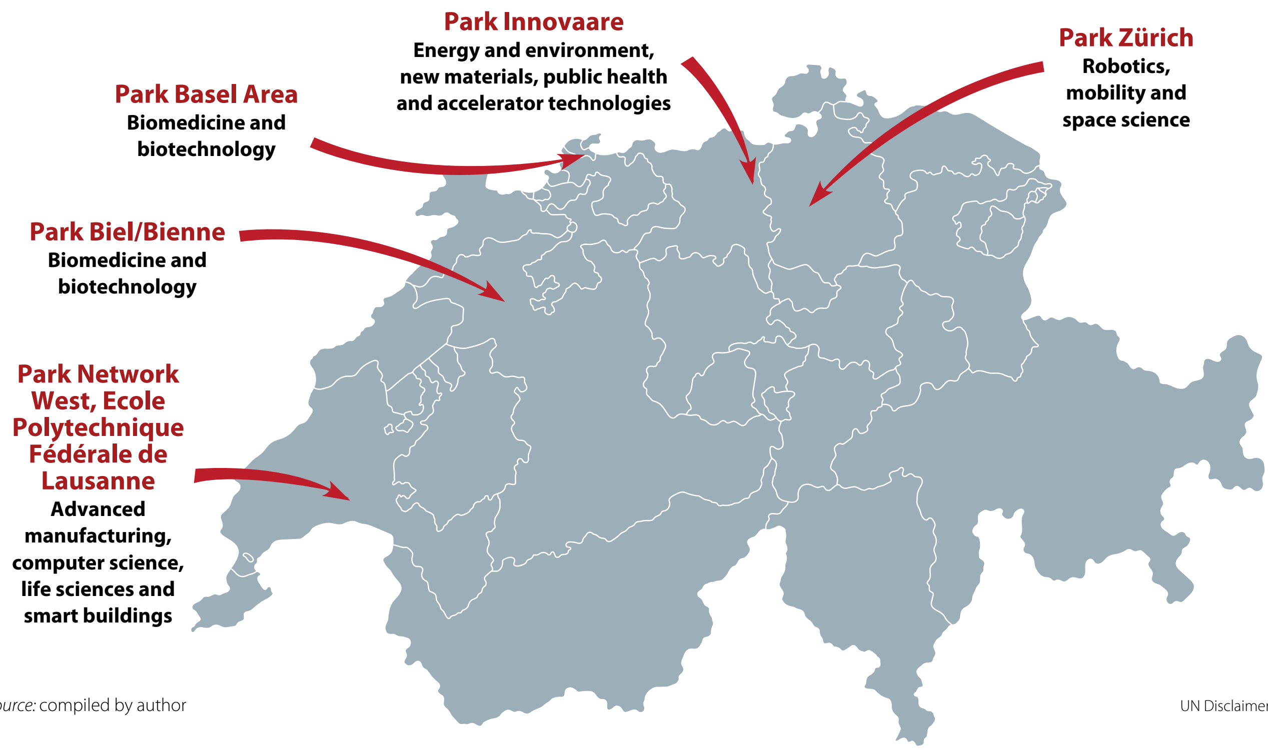
In May 2019, Swiss voters adopted two reforms designed to lower the tax burden for private firms engaging in R&D and innovation; the first introduced a 'patent box' regime, in line with OECD standards, which alleviated the residual income tax burden on patent revenue to as little as 10%; the second permitted inventors to accumulate existing tax deductions on research expenditure with an additional tax reduction of up to 50%.

Basic research: a new division of labour

The exceptionally high ratio of scientific publications involving both public and private enterprises points to another remarkable trend over the past couple of years. It reveals a shift in the traditional division of labour, whereby basic research is conducted by universities while applied R&D remains the preserve of the business sector. In 2017, 27% of business R&D was invested in basic research, double the proportion in 2012.

In light of this development, the public sector will need to reconsider a policy which has been effective for decades: the almost exclusive focus on basic research in the public sector. If public institutions and companies other than SMEs were to co-

Figure 11.5: **Development focus of the Swiss Innovation Park**



Source: compiled by author

UN Disclaimer

finance selected joint projects, this could enhance Switzerland's status as a prime research hub, persuade established Swiss companies to stay home and attract other firms from abroad. That such a policy change would also create new problems in relation to intellectual property and research freedom is equally evident.

This policy change is not reflected in the new multi-annual *Plan for the Promotion of Education, Research and Innovation* over 2021–2024, adopted by the government in February 2020 and sent to parliament for discussion in late 2020 (Govt of Switzerland, 2020). A prosperous past is the enemy of bold reform – and there is always the budgetary question. New instruments and collaboration schemes would come with a price tag and the country would never contemplate introducing these to the detriment of basic research.

Indeed, basic research is treated well in the new *Plan for the Promotion of Education, Research and Innovation*. Discovery research will benefit from annual budgetary growth rates of around 2%, which is slightly higher than in the previous period. New to the plan is the definition of transversal problems that call for an active role from a multitude of players, namely digitalization, sustainable development and equal opportunity. Activities will not be funded under separate budget lines for mission-oriented research. Rather, they will either be part of the research agenda of universities and research centres or they will be taken up by the existing funding instruments of the Swiss National Science Foundation or Innosuisse, Switzerland's innovation agency, which supports the science-based innovation projects of SMEs and start-ups.

CONCLUSION

A need for balance

Scientific knowledge is advancing at breakneck speed, driven by increasingly sophisticated digital technologies. However, the institutions in charge of managing and funding the production of knowledge – universities and research councils – are somewhat conservative bodies that tend to be reluctant to subject themselves to change.

Whereas reporting on scientific progress over a period of five years is a relatively straightforward exercise, the same cannot be said for policy matters. Nonetheless, the available evidence suggests that the EFTA countries are doing well.

In order to ensure that a similar evaluation arrives at the same positive conclusion in five years' time, a few conditions will need to be met: Iceland and Norway will have to succeed in raising their research spending levels and in internationalizing domestic science production. Switzerland, meanwhile, will need to find a satisfying and durable model for its relationship with the EU and step up its efforts to incentivize research-intensive industry to stay.

The main challenge will be to find the right balance: between basic and mission-oriented research, on the one hand, and between research universities striving for world-class status and more locally oriented institutions placing greater emphasis on teaching, on the other.

Iceland is leading the way in showing that science and technology need not be solely an instrument of economic growth but can also be redirected towards mending social cleavages within and between societies to foster 'quality growth.'

KEY TARGETS FOR EFTA COUNTRIES

- Iceland and Norway plan to achieve a 3% GERD/GDP ratio by 2024, which would be approaching Switzerland's research intensity;
- Iceland plans to increase carbon taxes by 10% annually and ban (new) diesel and gasoline cars after 2030;
- Switzerland intends to be carbon neutral by 2050, Iceland by 2040 and Norway by 2030.

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ENDNOTES

1 Liechtenstein is not a member state of UNESCO.
2 For evaluations conducted by the EFTA countries of programmes funded by the European Economic Area and Norway Grants, see: https://eeagrants.org/results/evaluations.
3 Burck *et al.* (2019) do not attribute the first three places in this ranking.
4 The Norwegian government has a 67% stake in Equinor (OECD, 2019).
5 Norway's Energy21 Board prioritized the following research areas in 2018: digitalized and integrated energy systems, climate-friendly energy technologies for maritime transportation; solar power and offshore wind power for an international market, hydropower as the backbone of the Norwegian energy supply and, lastly, climate-friendly and energy-efficient industry, including carbon capture and storage. See: https://www.energi21.no/en/2018-strategy/
6 Norwegian priorities for science and technology were first outlined in the Solberg Government's inaugural address to the Storting on 18 October 2013. They are reflected in various other strategic documents and roadmaps, including the Long-term Plan for Research and Higher Education (2015–2024). For the full inaugural address, see: https://www.regjeringen.no/en/aktuelt/the-solberg-governments-inaugural-addres/id744122/.
7 The *Digital Agenda for Norway* dates from 2015. Norway has also adopted a *Digitalization Strategy for the Higher Education Sector 2017–2021*, which has implications for research and innovation (OECD, 2020).
8 See: https://digitalswitzerland.com/
9 See the European Commission's website with data on trends in open access to publications: https://tinyurl.com/y8uu92dy
10 For Horizon 2020, Norway's success rate (15.3%) has been above the EU average (12.1%).

AT A GLANCE

Employees of software development services provider N-iX work in the company's Lviv office. Eighteen information technology companies operating in Ukraine have made it onto the list of the 100 best tech firms in the world, according to the 2018 listing by the International Association of Outsourcing Professionals. © N-iX

- In recent years, the region's modest economic growth has been driven by factors other than technology and innovation. Countries are still struggling to incentivize experimentation, dynamism and the creation of new knowledge in the economy and wider society.
- Only Belarus and Turkey spent more than 0.5% of GDP on research and development in 2018. Belarus and Ukraine remain the region's most productive countries in terms of technological activity.
- Countries now view the digital economy and energy security as priority sectors for investment.
- All but Belarus are dovetailing with European structures and networks to further their development agenda. However, harmonization with EU programmes remains weak, as does intraregional co-operation via the Organization of the Black Sea Economic Cooperation.
- Several countries are developing closer ties to China via its Belt and Road Initiative.

12 · Countries in the Black Sea Basin

Armenia, Azerbaijan, Belarus, Georgia, Republic of Moldova, Turkey, Ukraine

Deniz Eröcal and Igor Yegorov

INTRODUCTION

Innovation systems not yet driving growth

The countries covered by the present chapter are pursuing outward-looking economic strategies. Their ratio of exports to GDP is on a par with the average for middle-income economies, or higher. In the past four years, however, their economies have been buffeted by protectionist crosswinds emanating from some of the historically most committed advocates of globalization. The global recession triggered by the Covid-19 pandemic in 2020 has injected further uncertainty into the region's economic outlook.

In parallel, the principal geopolitical and territorial frictions that were hampering intraregional co-operation five years ago persist (Eröcal and Yegorov, 2015).

Despite this, most of the 'Black Sea countries', as we shall call them, recorded some economic growth up to 2019 (Figure 12.1), even if declining global prices for raw materials had penalized oil-dependent Azerbaijan directly and Belarus indirectly, owing to the latter's high level of economic integration with the Russian Federation (see chapter 13). In Ukraine, meanwhile, the economy has gradually picked up since 2015, after contracting sharply following the deterioration in political and economic relations with the Russian Federation in 2014.

To generate innovation-driven growth, any economy needs to get broad framework conditions right, such as macroeconomic stability, a competitive business environment and a skilled workforce, in addition to implementing specific science, technology and innovation (STI) policies. So far, the modest economic growth of Black Sea countries has been driven largely by oil (Azerbaijan) and agricultural or low- and medium-tech exports. Countries are still struggling to incentivize experimentation, dynamism and the creation of new knowledge in the economy and wider society.

They can count on a relatively educated workforce but still need to develop a competitive environment for business in both national and international markets and an appropriate policy framework for reaching their Sustainable Development Goals (SDGs).

TRENDS IN SCIENCE GOVERNANCE

A lack of preparedness for Covid-19

The Covid-19 pandemic has revealed the lack of preparedness for an emergency on this scale by most national health care systems. The Black Sea Basin is no exception. With international demand high, most governments have been competing for imports of medical supplies to make up for the shortfall at home.

Turkey has, nevertheless, managed to accelerate the domestic production of masks, medical supplies, drugs and diagnostic tests. The Turkish Scientific and Technological Research Council (TÜBITAK) and Ministry of Health are jointly co-ordinating the nationwide effort by centralizing the information flow on new research and producers of essential supplies.

In Ukraine, the epidemiological service was abolished several years ago; although Ukrainian scientists from the Institute of Molecular Biology were quick to develop tests, at the time of writing in April 2020, the government has, so far, been unable to finance the large-scale production of these.[1]

Officially, the level of infection in the region is much lower than in the USA or Western Europe but it is hard to tell, since the amount of testing being done is much lower than in other European countries. In Ukraine, for instance, testing rates were 20 times lower than in Italy in April 2020.[2]

Governments have adopted different coping strategies. Belarus has barely imposed any travel restrictions at all, whereas Turkey has blocked nearly all international travel and imposed a curfew in its most populous regions.

Some assistance has been promised from abroad. For instance, the European Union (EU) announced a € 140 million package of financial support for its 'eastern partner' countries – Armenia, Azerbaijan, Belarus, Georgia, the Republic of Moldova and Ukraine – in late March 2020.

Sustainable development a daunting agenda?

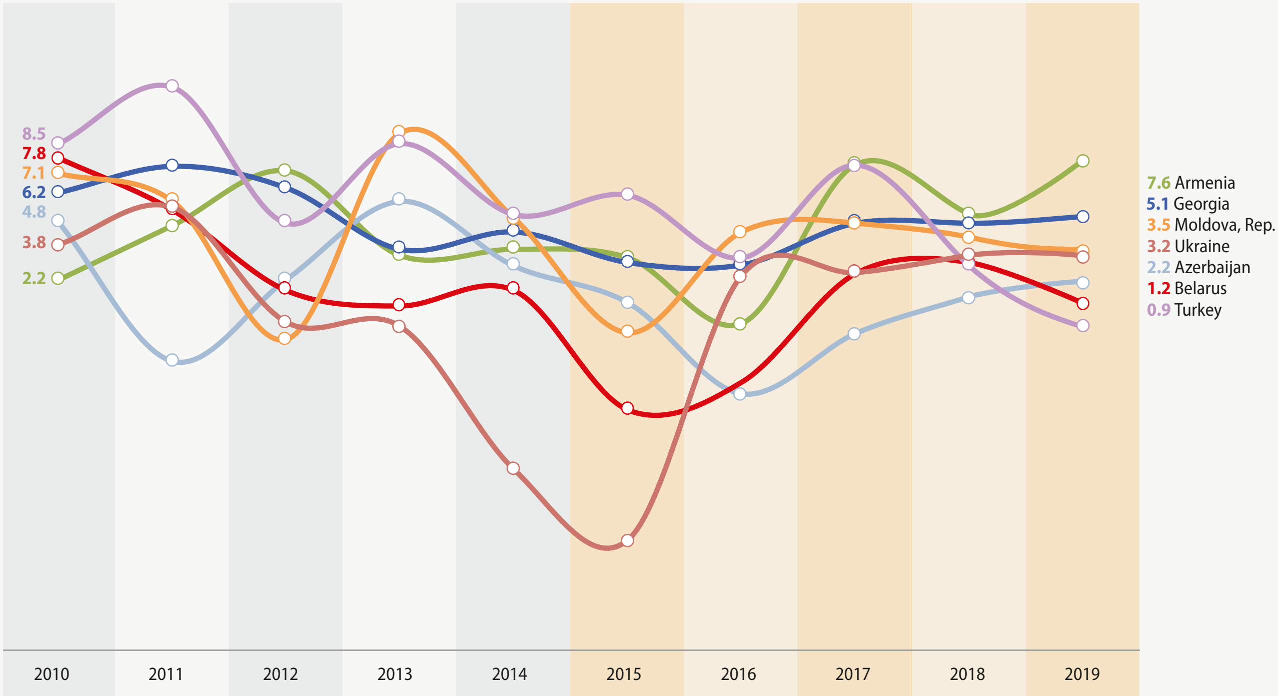
Although the 17 SDGs may seem a daunting agenda, the international monitoring framework put in place by the United Nations could help Black Sea countries ensure that their policies target their most pressing development challenges. This monitoring framework is composed of a range of regular reports, including the present volume, as well as the United Nations' High-Level Political Forum on Sustainable Development, which meets in July each year to monitor the status of implementation. So far, six Black Sea countries have produced one or more *Voluntary National Reviews* for this forum: Armenia (2018), Azerbaijan (2017 and 2019), Belarus (2017), Georgia (2016), Turkey (2016 and 2019) and Ukraine (2020).

Armenia's establishment of a National Sustainable Development Goals Innovation Lab in November 2017, creating 'a space for experimentation, collaboration, analytics and solutions' to meet sustainability challenges, recognizes that innovation drives sustainable development.

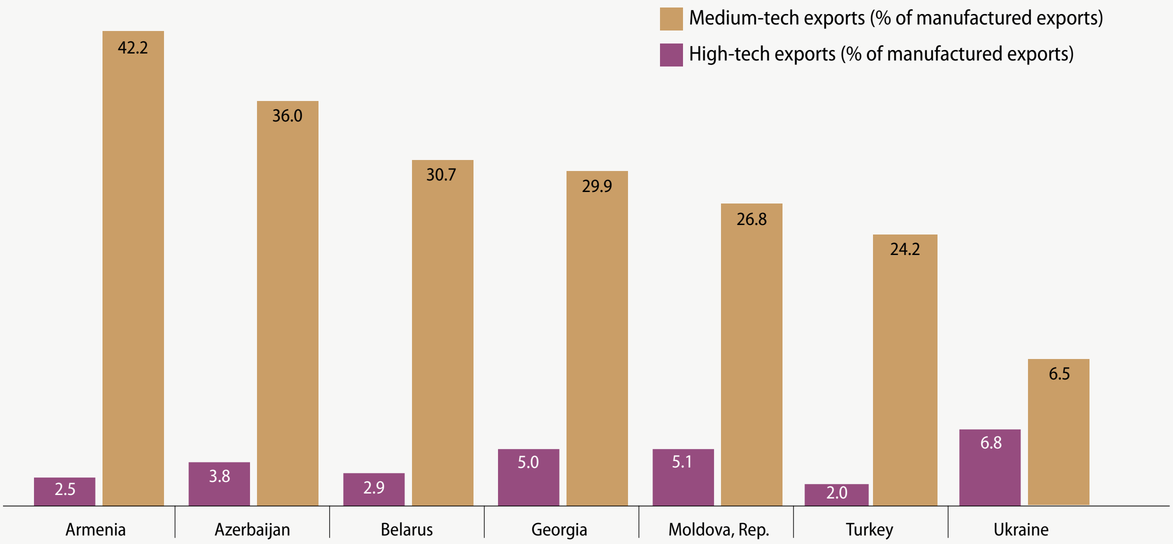
Turkey, meanwhile, is contributing to SDG17 on partnerships by hosting the new Technology Bank for Least Developed Countries in Gebze, inaugurated in June 2018. This United Nations body is currently undertaking assessments for several countries of their technology needs and science systems, in co-operation with UNESCO (Rep. Turkey, 2019a).

Figure 12.1: **Socio-economic trends in the Black Sea Basin**

Rate of economic growth in the Black Sea Basin, 2010–2019 (%)



High- and medium-tech exports from the Black Sea Basin as a share of manufactured exports, 2017 (%)



Level of economic openness in the Black Sea Basin, 2013–2015 and 2016–2018

	FDI inflows (US$ millions)		R&D funded from abroad (US$ millions)		Merchandise exports (US$ millions)		Manufactured exports (US$ millions)	
	2013–2015	2016–2018	2013–2015	2016–2018	2013–2015	2016–2018	2013–2015	2016–2018
Armenia	309	281	5.0	4.3	1 495	2 150	326	499
Azerbaijan	3 699	2 923	1.0	0.2	25 518	16 695	620	581
Belarus	1 920	1 333	264.5	357.5	33 330	28 831	15 750	15 610
Georgia	1 502	1 528	3.4	10.6	2 659	2 734	1 206	1 016
Moldova, Rep.	267	163	19.8	6.6	2 245	2 392	782	863
Turkey	15 391	12 840	615.2	970.8	151 084	155 830	118 563	120 039
Ukraine	2 802	2 915	1 281.3	955.6	52 221	42 324	28 875	20 200

Source: UNESCO Institute for Statistics; World Bank's World Development Indicators, April 2020

Outward-looking strategies caught in protectionist cross winds

For the small Black Sea countries, opening up to international competition remains the most realistic means of enhancing their competitiveness and re-examining the oligarchic economic structures that stifle innovation.

However, in the past few years, protectionism has become more acceptable in both rhetoric and practice across the globe. A recent report found that 'the majority of business leaders believe a political protectionist stance on innovation would be beneficial to business at a national level' (GE, 2018, p. 31).

Trade flows have ebbed in some Black Sea countries and stagnated in others, as trade tensions have shaken the global economy. Neither of the region's key trading partners, the European Union (see chapter 9) and Russian Federation (see chapter 13), has been spared by the resultant global economic slowdown since 2017.

The Black Sea region's outward-looking development strategies have been caught in these protectionist cross winds. Inflows of foreign direct investment (FDI) have fallen in all seven countries (Figure 12.1), even if this trend is partly the consequence of the completion of ambitious infrastructure development projects in some countries. Examples are the expansion of the South Caucasus Pipeline (2015–2018) and the Baku–Tbilisi–Kars Railway crossing Azerbaijan and Georgia, completed in 2017. In Turkey, where most inflowing FDI takes the form of equity investment in existing foreign affiliates, it is the falling exchange rate that caused inflows of FDI to dip in 2017 and plummet in 2018.

The most abundant inflows of FDI to Turkey in recent years have come from within the region. Azerbaijan has invested heavily in Turkish infrastructure projects, including a major new oil refinery. In the first quarter of 2019, the country accounted for 30% of FDI inflows to Turkey (The Economist, 2018).

Research and development (R&D) funded from abroad remains relatively high in Ukraine and has risen in Belarus and Turkey in recent years (Figure 12.2). Future prospects for foreign funding will depend on greater integration in global manufacturing networks.

Closer research ties to the EU and CERN

Of the seven, it is Turkey that has the longest-standing collaboration with the EU's framework programmes for research and innovation. However, the last five years have seen a cooling of relations with the EU, its main scientific partner.

Armenia, Georgia and Ukraine, on the other hand, have recorded modest but tangible advances in their own scientific co-operation with the EU since becoming formally associated with its Horizon 2020 programme in 2015–2016 (Figure 12.2).

Ukrainian and Georgian researchers submitted their first project proposals in 2015 and 2017, respectively, to the European Research Council (ERC), which allocates competitive grants for basic research under Horizon 2020.

However, only Turkish scientists have been awarded ERC grants so far. They have received Advanced and Proof of Concept Grants for wearable augmented reality three-dimensional displays, for instance.

The participation of countries associated with Horizon 2020 has, nevertheless, been growing and their success rates in grant applications are comparable with the EU average of 12.6% for 2014–2016 (Figure 12.2) [EC, 2017c, p. 18].

Turkey and Ukraine have been affiliated with the European Organization for Nuclear Research (CERN) since the 1960s. Since becoming associate members in 2015 and 2016, respectively, both have increased their participation in CERN experiments. Although both countries still derive a fairly low industrial return on their participation, the rate is growing.[3]

Turkey's participation in industrial procurement increased from two successful bids out of 21 in 2016 to seven out of 52 in 2018. Sectors concerned included electrical engineering and magnets, transportation, vehicles and mechanical engineering and raw materials. Ukraine, meanwhile, has been awarded industrial contracts relating to: gases, chemicals, radiation and waste equipment; information technology; and particle detectors.

Ukraine has a long history of CERN involvement through its membership of the Joint Institute for Nuclear Research (JINR), an intergovernmental institute based in Dubna in the Russian Federation. Through JINR, the Russian Federation also sends scientists to work at CERN.

Ukraine operates a Tier-2 computing centre in the Worldwide Large Hadron Collider (LHC) Computing Grid that federates globally distributed resources to process and analyse the massive amounts of data generated by the LHC experiments.

Belarus, the most industrialized of the seven countries, continues to engage in practical scientific co-operation with both the Russian Federation and the EU but refrains from closer institutional integration with the latter. In 2016, CERN sent Belarus a proposal for an updated International Cooperation Agreement to replace the one dating from 1994 (CERN, 2020).

In 2015, CERN's Director of Research signed a Letter of Intent with Georgia for the establishment of an institute in Tbilisi that will host a megaproject on particle therapy. The project is being led by CERN, the Georgian government and Italy's National Centre of Oncological Hadron Therapy and its National Institute of Nuclear Physics (CERN, 2020).

Azerbaijan submitted an application for associate membership in 2015, which was withdrawn in 2016 following a restructuring of the Ministry of Communications and High Technologies (CERN, 2020).

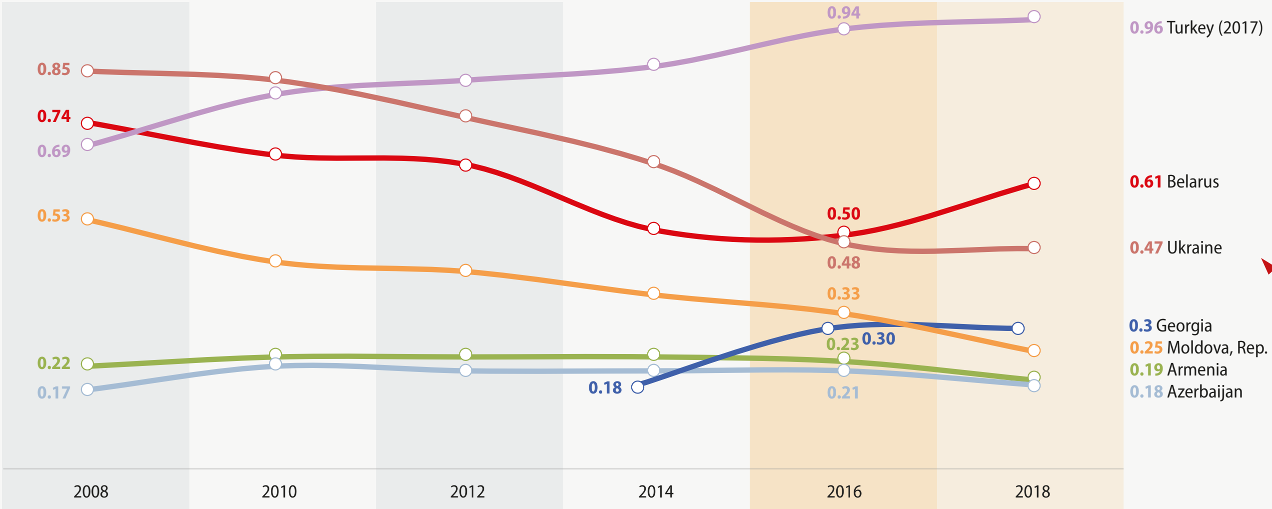
The Republic of Moldova has expressed interest in exploring collaboration between its own institutes and CERN, which would be a first for the country.

A timid *Action Plan* for the region

All but Belarus are members of the Organization of the Black Sea Economic Cooperation (BSEC). The BSEC's *Plan of Action on Cooperation in Science and Technology* (2018–2020) is the fourth such plan since 2005 and by far the slimmest volume, at just four pages long. Under the heading of Joint Projects

Figure 12.2: **Trends in research expenditure in the Black Sea Basin**

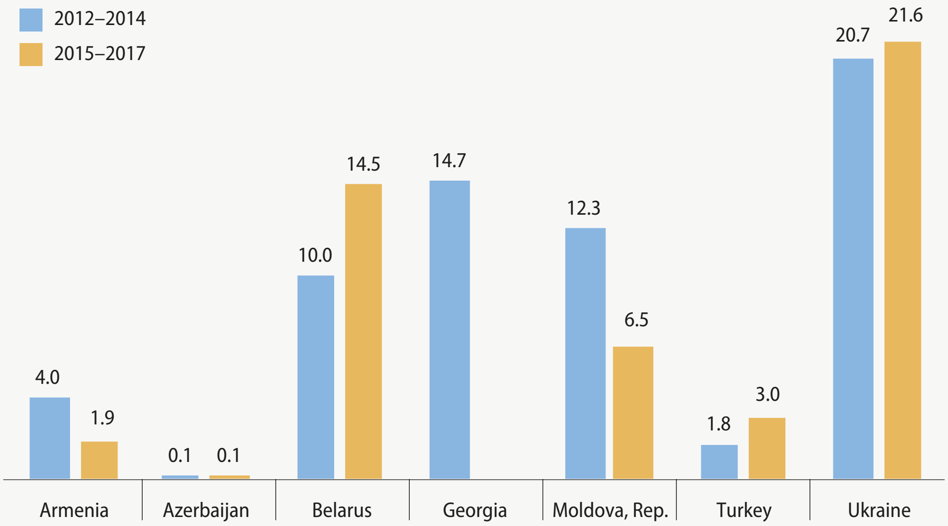
GERD/GDP ratio in countries of the Black Sea Basin, 2008–2018 (%)



Note: GERD data are partial for Armenia and there are no data for Georgia for 2006–2012. The 2013 data for Georgia cover only the higher education sector and those for 2014–2017 exclude the business and private non-profit sectors. The data for Ukraine for 2014–2017 exclude some regions.

Source: UNESCO Institute for Statistics

Foreign-funded R&D as a share of GERD in the Black Sea Basin, 2012–2014 and 2015–2017 (%)



The economic crisis of 2014–2016 sent Ukraine's research intensity to an all-time low in 2018. The share of innovative enterprises in industry has fallen by more than one-fifth.

Participation in Horizon 2020 by countries from the Black Sea Basin, 2014–2016

	Horizon 2020				
				European Research Council	
	Start of participation	Number of participations	Success rate (%)	Number of proposals evaluated	Grants awarded
Armenia	2016	91	13.2	0	0
Georgia	2016	153	11.1	18	0
Moldova, Rep.	2014	248	12.5	0	0
Turkey	2014	3 854	11.0	152	7
Ukraine	2015	939	8.1	3	0

Note: This table includes the period during which countries participated as a 'third country' prior to acquiring EU associate status. Neither Azerbaijan nor Belarus participate in Horizon 2020.

Source: *Horizon 2020 in Full Swing – Three Years On – Key Facts and Figures 2014–2016*; presentation by the European Commission's Directorate-General for Research and Innovation, December 2017; ERC Funded Projects online; UNESCO Institute for Statistics and Activities, it outlines some modest initiatives related to information-gathering, cross-border co-operation and digitalization. For instance, the document advocates digitizing an existing database on member states' national and regional research infrastructure (BSEC, 2018).

The *Plan of Action* appeals to member states to 'encourage development of joint international educational programmes in the field of artificial intelligence, blockchain, the Internet of Things and the digital and green economy'. It also advocates promoting scientific research in ocean science, 'especially in the context of implementation of SDG14' on conserving and sustainably using the oceans, seas and marine resources (BSEC, 2018).

BSEC activities are ostensibly designed to complement the EU's 'neighbourhood' co-operation programmes in and around the Black Sea Basin but they are actually limited in scope. For instance, the principal focus of EU programmes in the 'neighbourhood' under Horizon 2020 has been on energy security but the word 'energy' is not mentioned in the BSEC *Plan of Action* for 2018–2020.

One EU priority is the Southern Gas Corridor. Implemented under the Commission Initiative on Central and South-Eastern European Energy Connectivity (CESEC), this project is extending existing pipelines, in order to transport natural gas from Azerbaijan through Georgia and Turkey to Greece, Albania and Italy, and, thereby, diversify the EU's sources of energy. CESEC has a broad mandate spanning electricity, renewables and energy efficiency (Bozatli, 2019).

Closer ties to China

In order to reduce its reliance on a depressed Russian economy (see chapter 13), Belarus has deepened its economic ties with China. Since 2017, China has invested in the development of the Great Stone Industrial Park near Minsk. China's Belt and Road Initiative (BRI) attracted presidential-level participation from both Azerbaijan and Belarus at the BRI Leaders' Forum in April 2019.

Although there has been some debate over the impact of BRI loans on debt sustainability, an analysis by the Center for Global Development estimated that the BRI lending pipelines for Armenia, Belarus and Ukraine posed little risk (Hurley *et. al*, 2018).

China does not consider any of the seven Black Sea countries as being among its 'fast growth research partners' (UGlobe, 2018), even though one Ukrainian and 12 Turkish institutions are part of the BRI's University Alliance of the Silk Road initiative.

First steps towards tech-intensive economies

Between 2013 and 2017, gross domestic expenditure on R&D (GERD) declined by 33% in real terms for the six post-Soviet states taken as a whole but rose by 45% in Turkey.

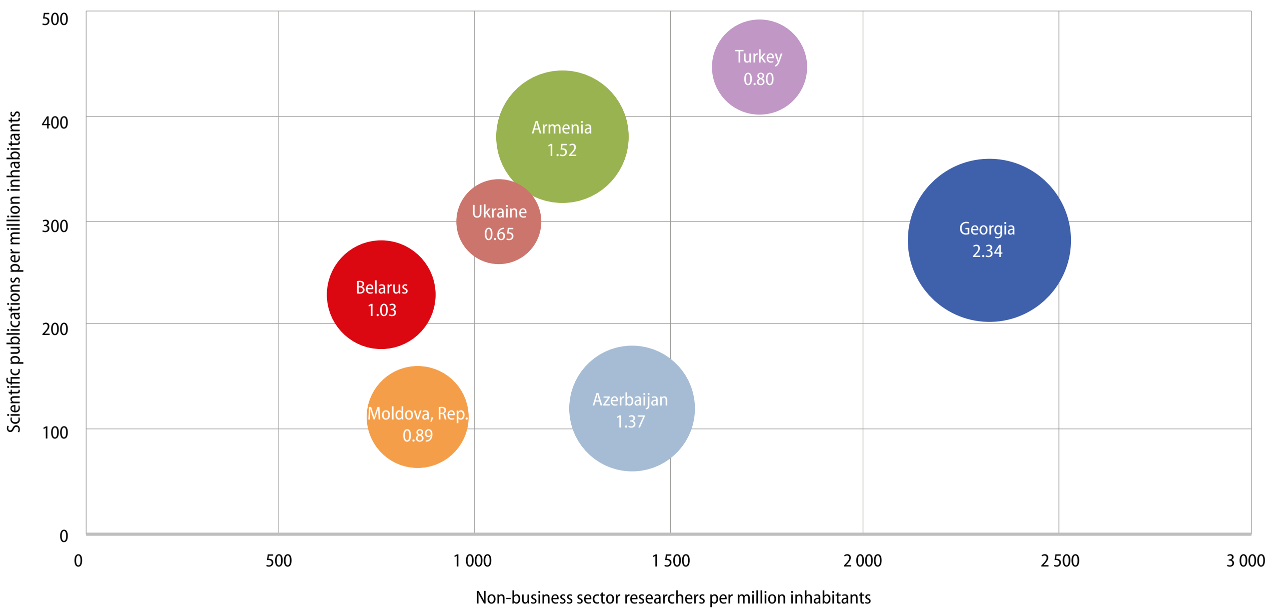
Currently, only Belarus and Turkey have a research intensity above 0.5% (Figure 12.2). Although Turkey has fallen short of its ambitious target of raising GERD to 3% of GDP by 2023, its own research intensity (0.96% of GDP in 2017) is gradually approaching the average for upper middle-income countries: 1.57% of GDP in 2017.

Geopolitical developments in Ukraine have taken a heavy toll on its own research spending. In an inflationary context that saw consumer prices climb by 117% between 2013 and 2017 and military expenditure as a share of GDP rise by 50%, according to the Stockholm Peace Research Policy Institute, research expenditure grew by just 20% in local currency over the same period.

Chapter 12

Figure 12.3: **Density of public-sector researchers, publications and citations in the Black Sea Basin, 2017–2018**

The size of the bubble is proportionate to the average relative citation rate over 2013–2015



Source: UNESCO Institute for Statistics; for publications, Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

The availability of R&D data has improved in Georgia but neither it, nor Armenia, survey business R&D.

In terms of technological activity, Belarus and Ukraine remain the most productive countries. Turkey has also seen a rise in high-tech exports but this performance is being dwarfed by even more impressive growth in exports of low and medium technology (Figure 12.1).

Turkey has a considerable lead over its neighbours when it comes to patent applications (Figure 12.4). This may indicate a quest for technology-based competitiveness in global markets, although the majority of these patents are for military-use technologies.

Turkey's patenting *intensity* remains lower, however, than that of Armenia, Belarus, Moldova or Ukraine (Figure 12.4).

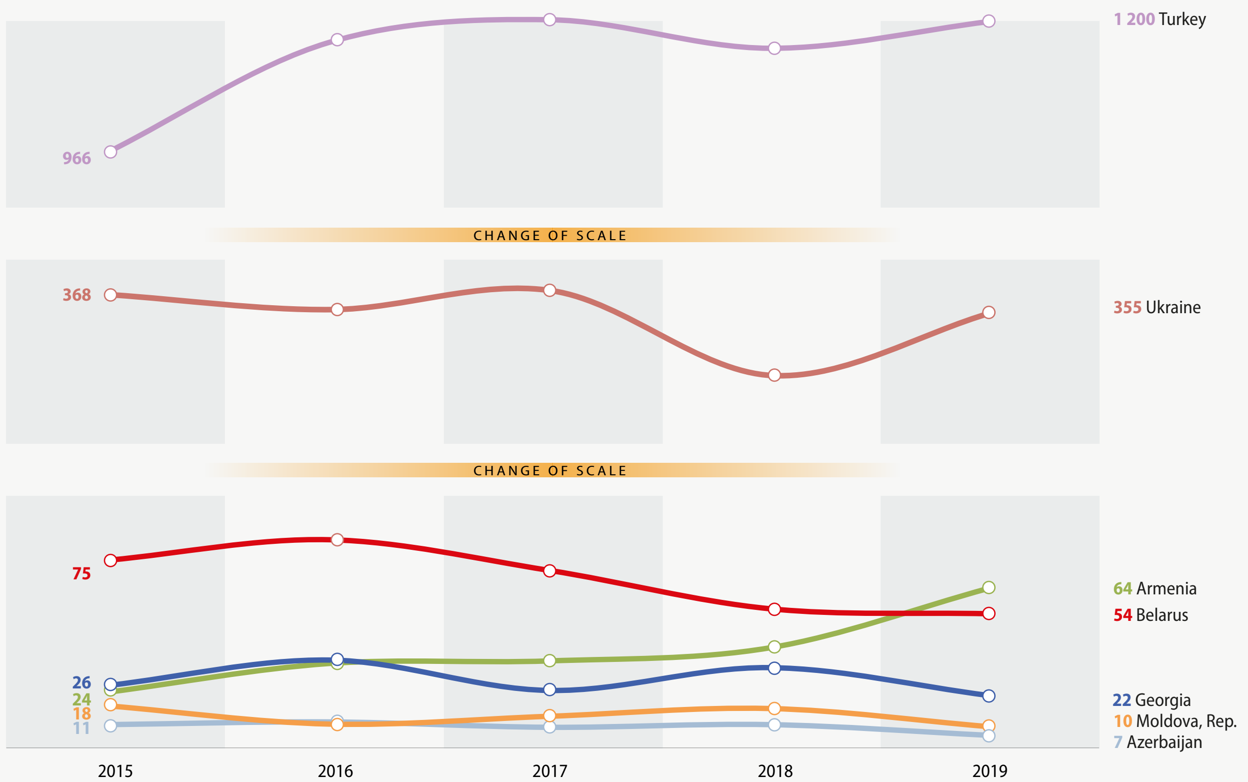
Of note is that non-residents account for few of Belarus' new patent applications, most probably reflecting the country's small market size and lack of association with major trading blocs (Figure 12.4).

Digital economy seen as enabling growth

All Black Sea countries see the digital economy as a growth engine. Ukraine adopted a *Concept for the Development of a Digital Economy and Society* for 2018–2020 and an accompanying *Action Plan* in January 2018. The *Concept*

Figure 12.4: **Trends in patenting in the Black Sea Basin**

Number of IP5 patents granted to inventors from the Black Sea Basin, 2015–2019



Patent applications and patents in force in the Black Sea Basin, 2018

	Number of patents in force		Number of patents in force per million inhabitants		Patent applications per 100 billion GDP (constant 2011 PPP$)
	Resident	Non-resident	Resident	Non-resident	Resident
Armenia	195	14	66.1	4.7	380
Azerbaijan	199	37	20.0	3.7	116
Belarus	1 674	576	176.5	60.7	340
Georgia	215	957	57.6	256.5	272
Moldova, Rep.	266	67	75.0	18.9	400
Turkey	7 957	60 929	96.7	740.2	371
Ukraine	10 099	13 606	226.3	304.9	607

Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China.

Source: PATSTAT, data treatment by Science-Metrix; World Intellectual Property Organization defines the main priorities as being: digital infrastructure, development of digital competences, implementation of the 'digital workplace' concept, digitalization of the economy (including Industry 4.0), public security, education, health care, tourism, e-democracy, ecology and environment, cashless payments, e-governance and harmonization with the EU and international research initiatives. Information technology (IT) already accounts for more than 40% of Ukrainian exports in the services sector.

Belarus is also developing its IT sector. The Belarus High Technologies Park near Minsk, which specializes in IT, has been given a new lease of life by the Presidential Decree on the Development of a Digital Economy of 28 March 2018, which waived almost all taxes for companies registered in the park for the next 30 years.

Between November 2017 and mid-2019, the number of resident companies soared from 192 to 505; companies export their IT products and services directly to more than 70 countries.

In 2018, more than one-fifth (21.2%) of Belarusian service exports related to IT. The park has also managed to attract companies and employees from abroad: 2 000–3 000 Ukrainian software specialists are working remotely on a permanent basis for companies in the Belarus High Technologies Park, which are deemed to offer better working conditions than Ukrainian employers.

In 2014, the Armenian government adopted its e-Governance Strategic Programme. In August 2017, the government established the Digital Armenia Foundation to co-ordinate the digital economy. Until it was closed down in 2018, the foundation was responsible for designing and administering a statistical monitoring system for the digital economy; its functions have since been transferred to the Ministry of Transport, Communication and Information Technologies, which is expected to design strategies for comprehensive data collection to support the digital economy.

The readiness of Armenian industry to liberalize mobile and Internet communication has led to low tariffs and widespread Internet-based interaction. Although a number of sophisticated platforms linking citizens, businesses and government services have been created,[4] the lack of sophisticated information infrastructure is holding back the digital economy.

Another difficulty is the relatively small size of Armenia's internal market for software products and services. Having greater access to foreign markets would enable the country to make the most of its highly skilled workforce.

The same can be said for the Republic of Moldova. In 2017, the Ministry of the Economy and Infrastructure published a report monitoring implementation of the *Action Plan for Digital Moldova 2020*. The report noted that, over the period 2013–2017, investment in the information and communication technology (ICT) sector had increased to more than 2 billion Moldovan Leu (*ca* US$ 100 million) annually. By 2017, the country's ICT sector had a market value of more than 9 billion Moldovan Leu (*ca* US$ 500 million) annually, with the most 'vigorous' increases taking place in the markets for mobile telephones and Internet-access services.

Signs of turbulence in the higher education sector

Belarus and Ukraine have tertiary enrolment rates typical of many advanced economies and Georgia has been able to reverse the downward trend observed a decade ago.

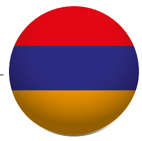
In Turkey, meanwhile, a phenomenally strong rise in tertiary enrolment (Figure 12.5) has increased the supply of graduates with a wide range of skills but their sheer number has overwhelmed the labour market in recent years: university graduates made up nearly half of the 18% growth in the number of unemployed between 2014 and 2016 (World Bank, 2019a).

The volume of scientific publications has climbed in all countries since 2011 (Figure 12.7), partly due to the inclusion of more of the region's journals in international indices. In the past couple of years, though, Turkish scientific output has seen a downturn, following the loss of tenure by many academics in the aftermath of the attempted military coup of July 2016 (Erdoğmuş, 2019, p. 119). Turkey had significantly expanded its researcher population over the past decade (Figure 12.5).

Since 2016, Azerbaijan's own academic environment has suffered collateral damage from the turbulence in Turkey, its top partner for scientific co-authorship. For example, the private Qafqaz University – funded by Turkish sources and thought to be one of Azerbaijan's finest – had to be closed down in 2017, together with its technology park.

COUNTRY PROFILES

ARMENIA



A quest for greater energy security

Armenia has been a member of the Eurasian Economic Union (EAEU) since its inception in 2015 and, in parallel, remains closely associated with the EU's Horizon 2020 programme, having signed a Comprehensive and Enhanced Partnership Agreement in 2017.

Armenian scientists have received € 2.5 million in research grants from Horizon 2020, corresponding to a success rate of 13.5% that is close to the average for association countries. The research community managed this feat, in spite of the 14% drop (to 4 822) in personnel numbers between 2014 and 2017 (SCA, 2018).

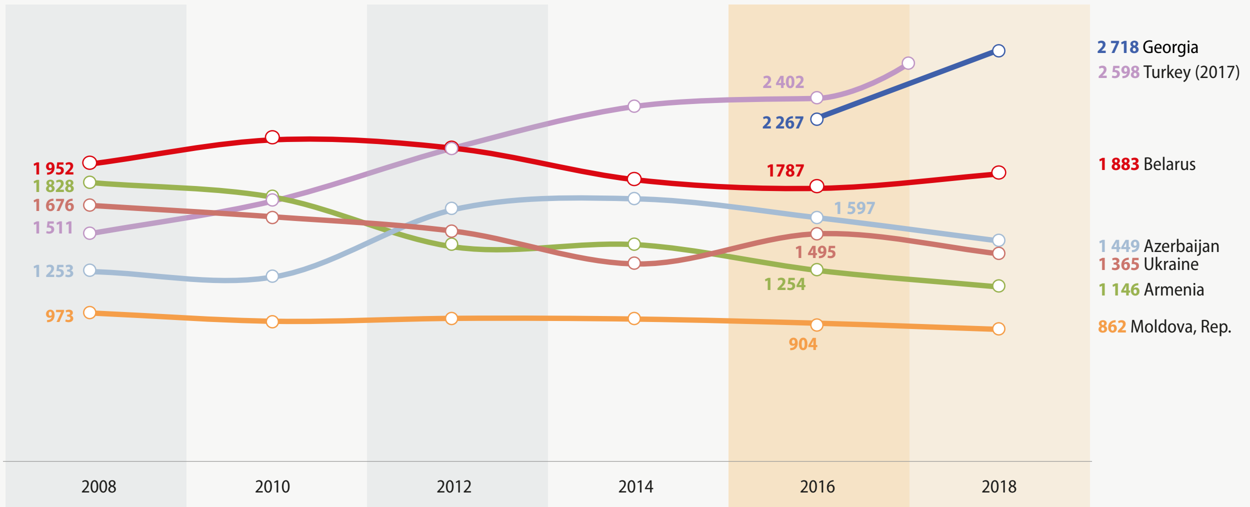
Armenia plans to join the EAEU's new Common Electricity Market, due to be launched on 1 January 2025. In a press release, the Eurasian Economic Commission stated that the new common market would foster energy security, promote transparent prices for electricity and allow businesses to choose from among different energy suppliers (EEC, 2019).

Armenia has also been an Observer to the *Energy Community Treaty* since 2011 (see chapter 10). Armenia has no fossil fuel reserves, so imports much of its fuel. Its sole nuclear power plant is now 40 years old. There are plans to extend the plant's lifetime by ten years, at an estimated cost of US$ 300 million (ECS, 2017).

The *Armenia Development Strategy* for 2014–2025 considers renewable energy a priority. Armenia is a water-rich country with two large dams, Vorotan Cascade and Sevan-Hrazdan

Figure 12.5: **Trends in human resources in the Black Sea Basin**

Researchers (HC) per million inhabitants, 2008–2018



Note: Partial data are available for Armenia and Georgia (business sector not surveyed); for Georgia, data for 2013 (683) and 2014 (1 816) have been excluded as they represent sharp breaks.

Trends in secondary and higher education in the Black Sea Basin, 2018 or closest year

	PISA 2018		Share of population 25 years and older holding a:				Gross tertiary enrolment ratio (%)		Doctoral graduates	
			bachelor's degree (%)	5-year change (%)	doctorate (%)	5-year change (%)			Total	Female (%)
	Science Score	Change in score since 2015	2017		2017		2018	5-year change	2017	2017
Armenia	–		24.4	-0.04^-1	0.31	0.01	54.6	8.8	348	43.4
Azerbaijan	398†		15.7^-1	0.06	–	–	27.7	6.3	622	52.7
Belarus	471		–		–	–	87.4	-6.1	881	49.4
Georgia	383	(+28)	34.0	3.85	0.51	0.28	60.3	22.4	469	55.4
Moldova, Rep.	428	(0)	20.1^+1	1.08	0.15^+1	0.09	39.8	-1.5	445	56.9
Turkey	468	(+43)	16.4	3.50	0.42	0.08	109.5	27.8	4 516^-3	47.7^-3
Ukraine	469		–	–	–	–	82.7^-4	–	7 417	56.2

† Baku only

-n/+n: data refer to n years before or after reference year

Note: PISA stands for OECD Programme for International Student Assessment; the OECD average score in 2018 was 489.

Georgian researchers (HC), the strongest rise in the region over this period

10 879
in 2018

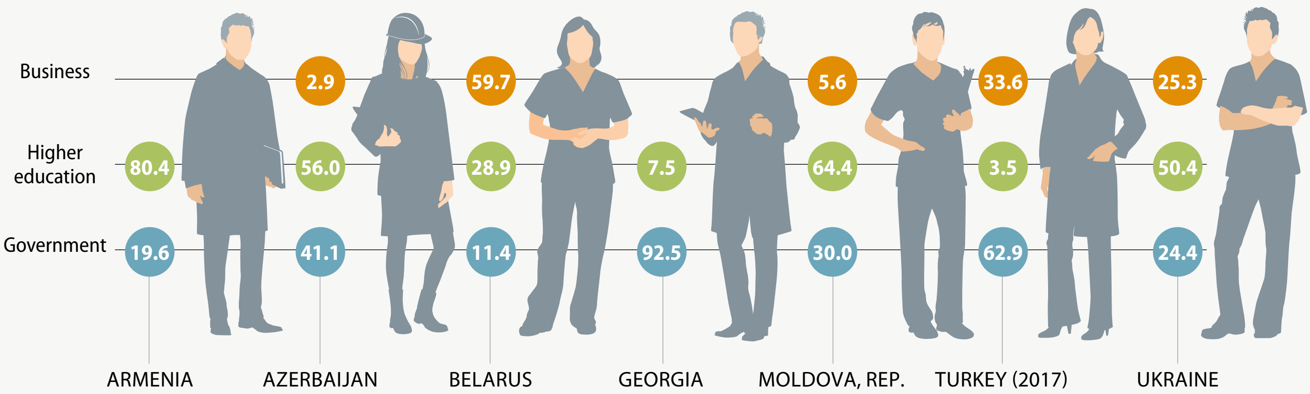
2 762
in 2014

Researchers (HC) in Azerbaijan, the only drop in the region

16 137
in 2015

14 412
in 2018

Researchers employed in the Black Sea Basin by sector, 2018 (%)



Source: OECD (2016) *PISA 2018 Results in Focus;* Ministry Of National Education (2018) *National Education Statistics Formal Education 2007-2018*, Turkish Statistical Institute; for researchers: UNESCO Institute for Statistics

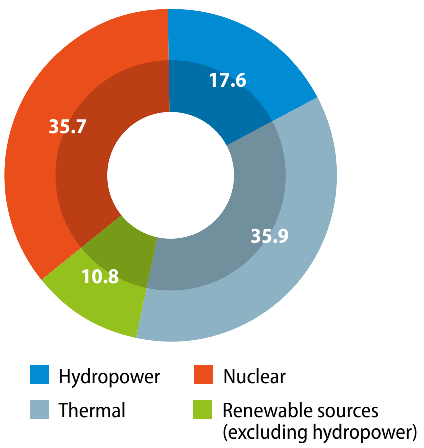
Cascade.[5] The government envisages raising the share of hydropower from 18% to 26% of the energy mix by 2025 (ECS, 2017; Figure 12.6). Recent legislative changes provide financial incentives for the development of renewable energy; the *Law on Energy* (2001, last amended in 2018) guarantees the purchase of all electricity generated by renewable energy sources for 15 years for small hydropower plants and 20 years for solar, wind, biomass and geothermal (Rep. Armenia, 2018).

The establishment of a revolving fund for energy efficiency retrofits to public buildings based on energy performance, contracted through the Renewable Resources and Energy Efficiency Fund (2006), has helped to achieve 50% energy savings in more than 160 public buildings and nine urban lighting systems (Rep. Armenia, 2018). Armenia is planning to roll out this financial tool to banks and to upscale public-sector investment in energy efficiency, in line with the second *National Plan for Energy Efficiency and Renewable Energy* (2017), which used a template recommended by the Energy Community Secretariat. The aim is to reduce energy consumption by 37% (ECS, 2017).

In 2017, the government set up the National Sustainable Developments Goals Innovation Lab, in partnership with the United Nations, to draw upon methodologies and expertise available around the world to accelerate its own reform agenda. The lab operates from the Centre for Strategic Initiatives, a public–private partnership which facilitates dialogue between policy-makers, private and public stakeholders and international partners.

In December 2014, the government approved new broad development priorities for 2015–2019, most of which mirror earlier research priorities. Of note is the replacement of the reference to 'renewable and new sources of energy' (Eröcal and Yegorov, 2015) by 'secure and efficient energy'. The other new priorities are: Armenian studies; life sciences; key enabling technologies and ICTs; space, Earth sciences, sustainable use of natural resources; and basic research for key problems tied to scientific and socio-economic development.

Figure 12.6: **Distribution of electricity generation capacity in Armenia, 2015 (%)**



Source: ECS (2017)

Reaching out to business

Armenia's research intensity accounted for just 0.19% of GDP in 2018 (Figure 12.2). This ratio has remained stable for the past few years, even though, in absolute terms, research expenditure was 20% higher (AMD 14.3 billion, or *ca* US$ 29.9 million) in 2018 than in 2014.

The following national funding mechanisms, implemented by the State Committee of Science, aim to stabilize and diversify research funding (Arzumanyan, 2019):

- core funding: the main source of financing for state research organizations, accounting for about 70% of the total science budget;
- thematic (project-based) funding: distributed on a competitive basis; and
- goal-oriented (targeted) project funding.

Established in 2010, the Targeted Projects Programme innovated in 2018 by issuing a call restricted to research projects that involve both research institutes and industrial partners, whereby the latter are obliged to contribute at least 15% of project funding.

Further to the Law on the National Academy of Sciences (2011), which authorized this body to develop business activities (Eröcal and Yegorov, 2015), the National Academy of Sciences set up an Applied Projects Department in 2017 to help its 35 affiliated research institutes and centres promote technology transfer and the commercialization of research outcomes. A package of around 40 innovative research projects has been collected from the Academy's research institutes for presentation to government agencies and possible investors for further commercialization, out of which around 10 projects relate to environmental research and climate change.

This is significant, since the National Academy of Sciences is currently the country's main performer of research. The Academy's International Scientific and Educational Centre conducts a range of graduate and postdoctoral practical training courses in tandem with the Academy's own affiliated institutes and centres.

Established in 2016, the Foundation of Armenian Science and Technology is a private initiative. The foundation runs programmes supporting young talent, entrepreneurs and technological start-ups primarily specializing in data and computer science, biotechnology and advanced materials.

Since 2013, the government has supported several so-called 'system-forming' projects. One such project is the Centre for the Advancement of Natural Discoveries using Light Emission (CANDLE) in Yerevan. CANDLE is a third-generation synchrotron light source for basic and applied research which also provides services to industry (UNECE, 2014).

Another newcomer to Yerevan is the European Centre of Nuclear Medicine, which opened its doors in November 2019. It has been fitted with state-of-the-art equipment to provide radioactive iodine therapy for thyroid cancer, which is prevalent in Armenia and the wider region. This is the first such facility in Armenia (Badalian, 2019).

A grading system to stimulate research excellence

In November 2019, the State Committee of Science announced the introduction of a new grading system for the evaluation of research institutes, as well as a broader set of performance indicators.

Henceforth, research institutes will be divided into four categories. Those that fall into the fourth group will be immediately closed or merged with other institutes. The third group will be given a few years to improve its performance. Research institutes in the top two categories, meanwhile, will receive not only core funding but also bonuses for scientific output.

Research institutes will continue to be judged on the basis of their scientific publications, participation in conferences, patents and awards but the committee will also pay attention to factors such as the number of degree-holders among researchers, the number of young scientists (up to 35 years) and the number of applied projects.

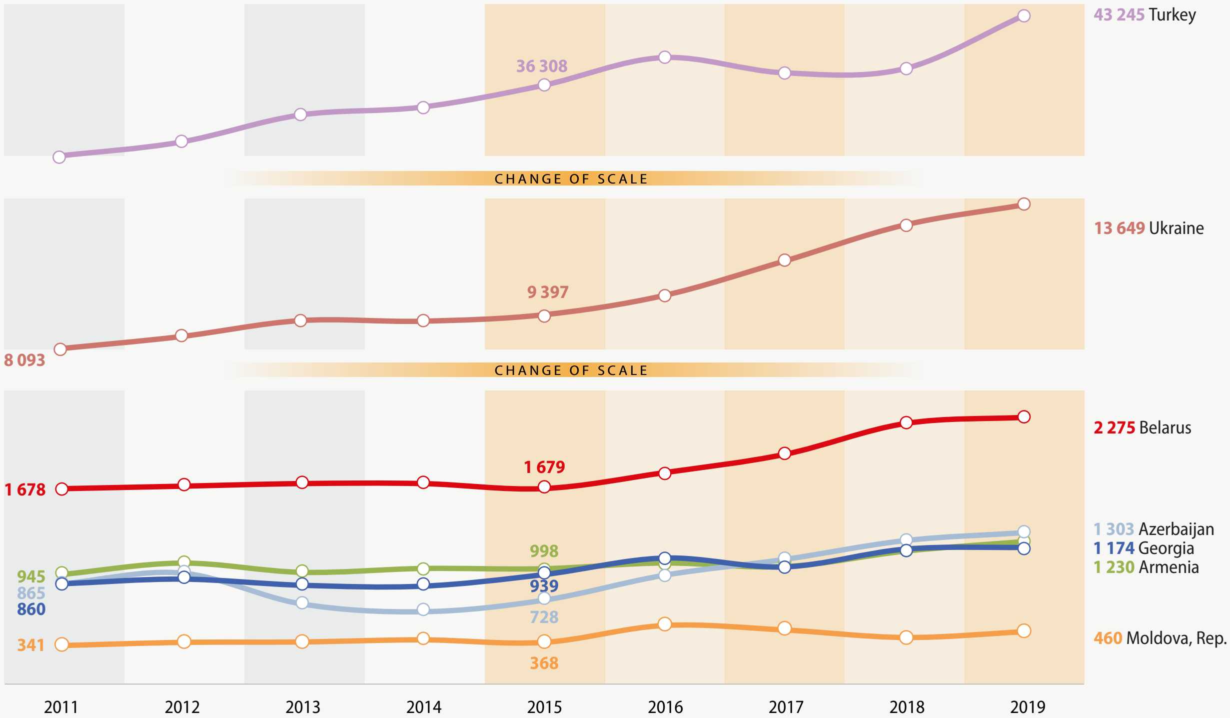
AZERBAIJAN

An acute form of Dutch disease

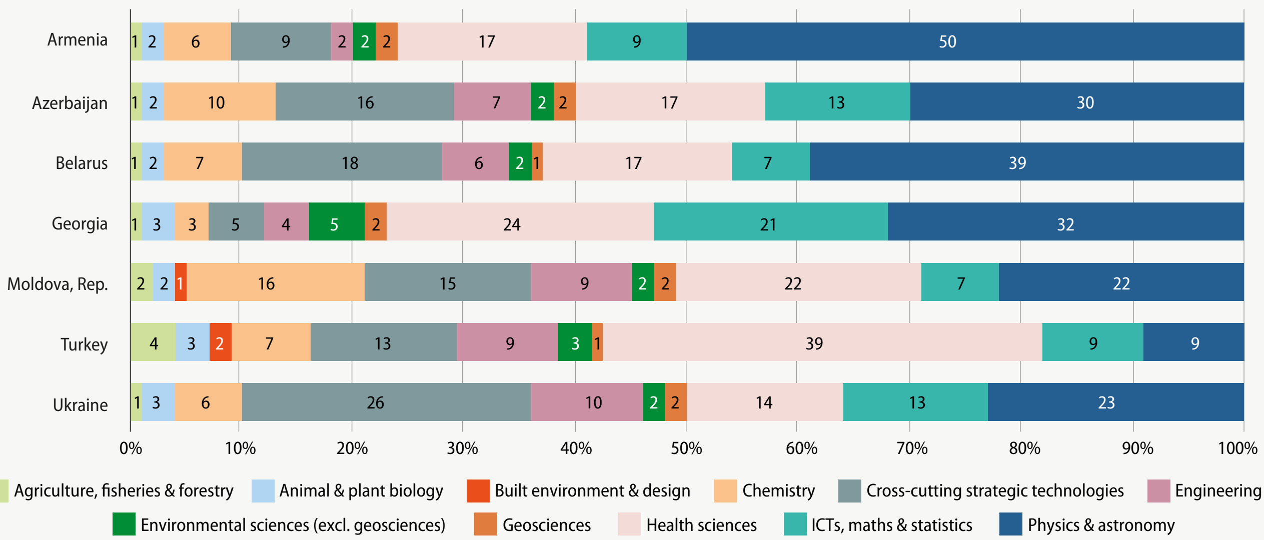
Azerbaijan has made a concerted effort in recent years to diversify and link its non-oil economy to the rest of the

Figure 12.7: **Trends in scientific publishing in the Black Sea Basin**

Volume of scientific publications from countries in the Black Sea Basin, 2011–2019



Scientific publications in the Black Sea Basin by field of science, 2017–2019 (%)



world, focusing in particular on infrastructure, as evidenced by its completion of the Baku–Tbilisi–Kars Railway and its 2019 participation in discussions on the Belt and Road Initiative at the presidential level.

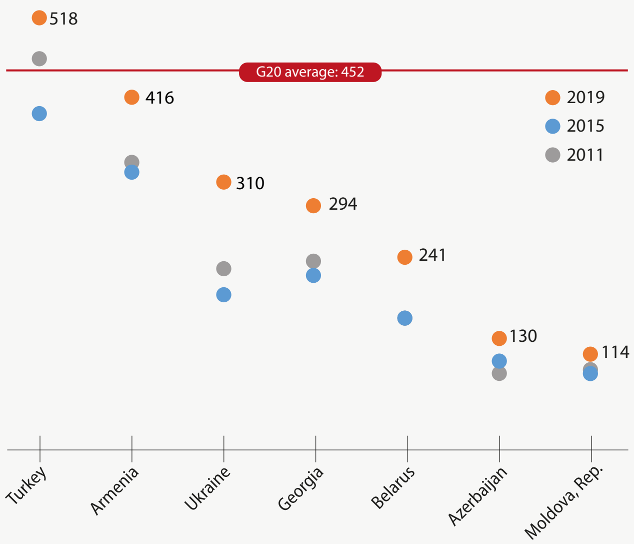
However, it has not yet surmounted its principal economic challenge of ending heavy dependence on energy extraction and exports: as of 2017, the oil sector still accounted for 43% of GDP and 91% of exports (EIU, 2019; OEC, 2019).

The government's objective of steering Azerbaijan towards a technology- and innovation-driven economy has not been realized, either (Rep. Azerbaijan, 2009). Measured research expenditure continues to stagnate at around 0.2% of GDP (Figure 12.2); the absolute number of researchers is down 11% from 2015 levels, according to the UNESCO Institute for Statistics; and per capita high-tech exports – stagnating at US$ 1 – have the lowest value among the Black Sea countries (Figure 12.1).

Azerbaijan is suffering from an acute form of 'Dutch disease'. The fall in oil prices since 2014 has caught the country off guard. Despite a flurry of policy activity, the non-oil sector in Azerbaijan has not seen a resurgence. Moreover, a brief rebound in oil revenue over 2015–2017 has not affected the national poverty rate (World Bank, 2018a, p. 44).

Scientific publications per million inhabitants, 2011, 2015 and 2019

Data labels are for 2019



69–70%

Share of foreign co-authors in Belarus, Georgia and the Republic of Moldova in 2019, the highest proportion in the region

How has output on SDG-related topics evolved since 2012?

Output on SDG-related topics is modest in relation to total output but there has been noticeable growth in hydrogen energy (Armenia, Azerbaijan, Ukraine, Turkey), hydropower (Georgia, Turkey), the status of biodiversity and ecosystem services (Belarus, Georgia, Ukraine) and medicines and vaccines for tuberculosis (Armenia, Azerbaijan, Moldova). The Republic of Moldova's output on the latter topic was even four times the global average proportion, with 25 (2012–2015) and 43 (2016–2019) publications.

Georgian output on national integrated water management surged from 1 (2012–2015) to 38 (2016–2019) publications. Belarus doubled its output on photovoltaics to 68. Azerbaijani scientists published their first 11 articles on human resistance to antibiotics between 2016 and 2019. Ukrainian output on radioactive waste management was 2.3 times the global average and grew by 130%: 65 (2012–2015) to 86 (2016–2019) publications.

For topics with over 100 publications, Ukraine registered the fastest growth in sustainable transportation (460%), wastewater treatment, recycling and use (360%), smart-grid technologies (340%) and the sustainable use of ecosystems (280%) but output was still less than half the global average.

Turkey's output on geothermal energy was 2.5 times the global average (130% growth rate): 184 (2012–2015) to 246 (2016–2019) publications. Eco-industrial waste management was the fastest-growing (180%) topic and on a par with the global average: 172 (2012–2015) to 301 (2016–2019) publications.

For details, see chapter 2

Only Azerbaijan counts another 'Black Sea' country among its closest partners.

25%

Share of foreign co-authors in Turkey in 2019, the lowest proportion in the region

1.92

Average of relative citations for Azerbaijan, 2014–2016, the highest ratio in the region; the G20 average is 1.02

Top five partners for scientific co-authorship in the Black Sea Basin, 2017–2019 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Armenia	Russian Fed. (1 338)	USA (1 188)	Germany (1 076)	France (1 037)	Italy (1 008)
Azerbaijan	Turkey (895)	Russian Fed. (831)	USA (518)	Germany (505)	China (455)
Belarus	Russian Fed. (2 687)	Germany (1 121)	Poland (1 105)	USA (998)	France (961)
Georgia	USA (1 175)	Germany (1 026)	UK (928)	Russian Fed. (913)	Italy (891)
Moldova, Rep.	Germany (266)	Romania (264)	Russian Fed. (223)	USA (146)	France (115)
Turkey	USA (9 132)	UK (4 453)	Germany (4 279)	Italy (3 785)	France (3 121)
Ukraine	Poland (3 961)	Russian Fed. (3 583)	Germany (2 794)	USA (2 532)	France (1 881)

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

A renewed drive to embrace tech-based growth

However, there are distinct signs of a renewed policy drive to embrace tech-based growth. In 2016, the year in which Azerbaijan's investment rating was downgraded by S&P and Moody's, two presidential decrees established *Strategic Roadmaps for the National Economy and Main Economic Sectors* with detailed sectoral policy and institutional targets to foster innovation in the non-oil economy.

This was followed by the founding of the Agency for Small and Medium-sized Enterprises in December 2017, tasked with business incubation and support for innovation. The government's emphasis on business creation and competitiveness is reflected in Azerbaijan's improved rankings in the World Bank's ease of doing business index since 2015.

In January 2019, the government passed a Law on Education entitling universities to receive research funding from the private sector; it also introduced a package of corporate tax breaks enabling companies to deduct up to 10% in return for funding 'the development of science, education, health and culture'.

The renewed focus on technology is also reflected in the establishment of an Innovation Agency in November 2018 through the merger of the State Fund for Development of Information Technologies and the High-Tech Park Limited Liability Company (both established in 2012) under the Ministry of Transport, Communications and High Technologies. The agency is expected to provide direct support in the form of venture capital to innovative businesses, including start-ups. New bodies include an e-Government Development Centre (since December 2018) and a Department of Innovative Development and e-Government Issues within the Presidential Administration (2019).

Grassroots initiatives for tech start-ups

There are numerous grassroots initiatives promoting tech-based start-ups and the institutions that can support them, such as technology parks.

Yeni Fikir (New Idea) is a start-up competition backed by the Baku Engineering University and sponsored by British Petroleum; since 2016, it has secured support for 100 projects and provided 35 of these with incubation services.

Initiatives supported by the Korea International Development Agency, such as the Smart Bridge or the Promotion of Digital Government, are striving to enhance technology transfer, university–business collaboration and the capacity to survey e-governance needs; Smart Bridge provided 60 academics and business representatives with two weeks of training in August 2019, for instance.

The principal issue with initiatives such as these, in addition to the limited impact conferred by their modest scope, is that their focus on promoting technology *uptake* grabs attention, even as activity generating science and innovation directly remains limited.

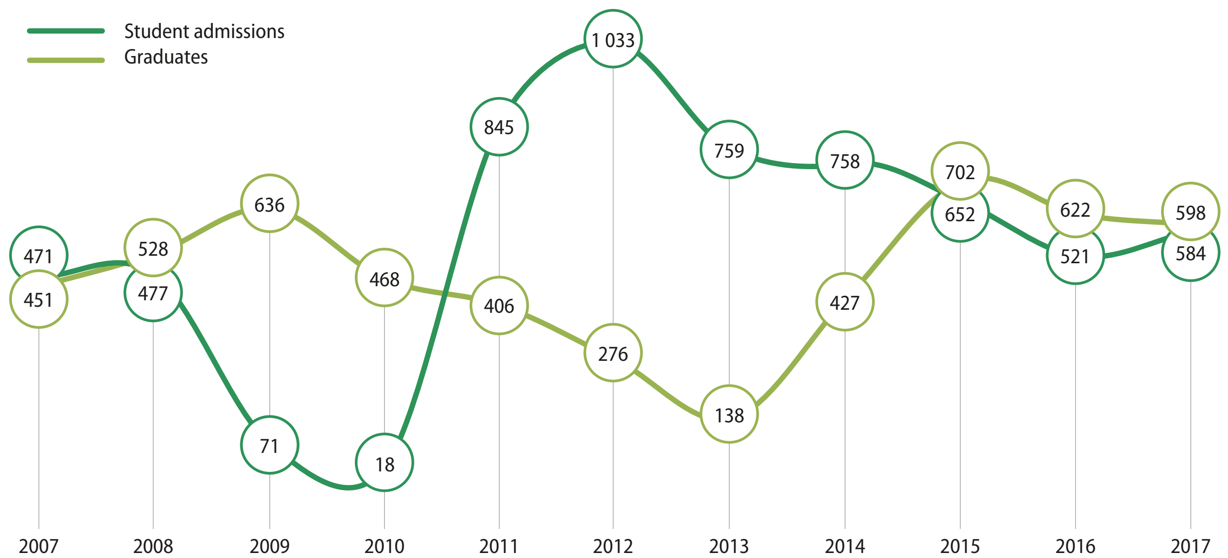
Universities focused on teaching

As underlined in the previous edition of the *UNESCO Science Report* (Erӧcal and Yegorov, 2015), the key problem for basic science resides in the inability of Azeri universities to expand PhD enrolment and scientific output to any significant extent (Figures 12.7 and 12.8).

The World Bank (2018a) notes that Azeri universities still focus on teaching, with research management being left to the National Academy of Sciences, a legacy from the Soviet era.

Universities, thus, derive little sustained income from intellectual property and technology transfer. Indeed, the former Director of Qafqaz University Technology Park,

Figure 12.8: **Doctoral admissions and degrees at Azerbaijani universities, 2007–2017**



Note: Data cover both PhDs and Doctor of Science degrees.

Source: State Statistical Committee of Azerbaijan (online)

Dr Isa Qasimov, told the present authors, in a phone interview in August 2019, that 'university technology transfer offices perform little in the way of actual commercialization of research' and that, 'at the institutional level, universities lack a clearly defined commercialization process.'

Academic reward systems are often blamed for not incentivizing universities to make links with the business world but the World Bank (2018a) notes that several Azeri universities have introduced successful incentive mechanisms for commercially viable research; this is largely thanks to an astute use of internal funds and the willpower of individual rectors, including those of three public institutions, the Azerbaijan State University of Economics, ADA University[6] and Baku State University. The task for these universities will now be to link these individual efforts to the wider quest for policy- and institution-building.

BELARUS

Fluctuating research intensity and ageing personnel

Belarus has been a member of the Eurasian Economic Union since its inception in 2015.

It is one of the region's most technologically productive countries, even if it did slip from 53rd to 79th place in the Global Innovation Index between 2015 and 2019. This slide suggests that Belarus would benefit from building closer ties with neighbouring EU countries, in order to support economic modernization and broaden its market for endogenous innovation.

GERD amounted to 0.6% of GDP in 2018, falling short of government targets (Figure 12.2) [Shumilin and Gusakov, 2018]. In its *Action Plan to Achieve a Safe Level of National Security for 2016–2020* (2016), the government lowered its sights for domestic research spending from 1.2% of GDP in the *National Strategy of Sustainable Socio-Economic Development to 2030* to 1% of GDP by 2030.

A green economy prioritized by the development strategy

Since the *National Strategy for Sustainable Socio-Economic Development to 2030* was adopted in February 2015, seven months prior to the Sustainable Development Goals, its priorities are not directly aligned with *The 2030 Agenda*.

The *National Strategy* does, however, promise a structural and institutional transformation incorporating the principles of the 'green' economy and according priority to the development of high-tech industries and services to improve competitiveness and quality of life.

The *National Strategy* outlines plans for industrial innovation clusters and for a shift towards sustainable production and consumption patterns through the effective management of renewable and non-renewable resources and behavioural change.

It also prioritizes regulating the market and supporting local initiatives and an 'effective structure of ownership' to make the public administration system more effective. By 2030, 2–3% of GDP is to be spent on the environment (Meerovskaya, 2016).

In 2017, the government established the Institute of the National Coordinator to pilot the implementation of the SDGs, appointing Vice-Prime Minister Marianna Shchetkina to lead the institute. Members of the Council for Sustainable Development have also been designated from different ministries and state agencies.

The National Statistical Committee has prepared a set of 255 indicators to assess progress towards each of the country's SDG targets. In 2018, Belarus ranked 23rd out of 156 countries in the United Nations' *Sustainable Development Report*.

In 2017, the government adopted a National Programme for the Development of Innovation for 2016–2020 to improve Belarus' innovative performance across 16 main indicators.[7] One measure sets out to reduce the economy's energy intensity by 0.8% over 2018–2019. By the end of the current five-year programme on innovation in 2020, it is expected that most of these measures will have been implemented.

A plan to foster innovation

Since 2015, the government has been reforming the national innovation system. By 2018, the authorities had issued more than 90 legal acts directly or indirectly relating to R&D. Several were issued by the president, such as those relating to the salaries of employees of state research organizations, support for the digital economy, protection of intellectual property rights and improvements to the special legal regime of the new Chinese–Belarusian Great Stone Industrial Park.

In one presidential decree, the government declared 2017 the Year of Science. The main event of the year was the Second Congress of Scientists of Belarus on 12–13 December, attended by the president. The Congress concluded with the adoption of a long-term programme to accompany the *Science and Technology Strategy, 2018–2040* developed by the National Academy of Sciences.[8]

The purpose of the *Science and Technology Strategy* is to identify a set of priorities and related policy tools. The strategy is based on *Intellectual Belarus*, the country's economic blueprint, and comprises the following aspects:

- full-scale digitalization of the economy;
- development of a neo-industrial complex (*New Industry 2040*); and
- establishment of a 'highly intelligent society' (*Society of Intelligence 2040*).

Consolidating existing funds for more effective innovation

The State Programme for Innovative Development over 2016–2020 aims to kick-start new industries that are critical to Belarus' development, including high-tech industries and the services and export sectors. By 2018, 86 projects had been financed and 19 of these had already arrived at their term.

In 2016, no fewer than 25 innovation funds were being co-ordinated by various public administrations and other state institutions. The government decided to combine these disparate funds into a single Republican Central

Innovation Fund. The consolidated fund actually functions as a state agency, receiving finance from the state budget and operating in conjunction with seven local funds. Some 10% of income tax contributions goes towards the fund. In addition, the fund has a mechanism for redistributing unused funds.

Local funds are financed by contributions from corporate taxes, paid to local budgets in seven provincial centres (oblasts) and the City of Minsk. Projects are selected for funding on a competitive basis, with € 30–40 million per year being sourced for innovative projects.[9]

A need to rejuvenate the research pool

About one-third of researchers with doctorates are approaching retirement age. This raises concerns about the availability of qualified researchers in the near future. To tackle this challenge, the government has fixed the target of raising the number of researchers from 16 900 to 20 100 between 2015 and 2020. If past practice is anything to go by, the government will probably reach this target by augmenting the number of vacancies at selected research institutes and recruiting through a competitive process.

Policy-makers will also need to focus on rejuvenating personnel at research institutes and improving the quality of postgraduate studies. In 2017, there was an increase in research personnel for the first time in eight years, after a loss of more than 20% over the same period (SCB, 2019).

GEORGIA

Building on its strengths, albeit slowly

Georgia stands out from other post-Soviet states in several ways. For one thing, agriculture still employed four out of ten citizens in 2018, according to the World Bank, even though this traditional sector remains unproductive, generating just 7% of GDP.

Georgia also has a stronger record for market-oriented reforms than its neighbours. It ranks 7th in the World Bank's Ease of Doing Business 2020 Study and 16th in The Heritage Foundation's 2018 Index of Economic Freedom, making it the region's most liberal economy (World Bank, 2018b).

Georgia's Free Trade Agreement with China came into effect in January 2018.[10] Georgia also benefits from a preferential trade regime with the EU, thanks to its association agreement, known as the *Deep and Comprehensive Free Trade Area Agreement* (2016).

Most urgent policy issues being addressed

Recent years have seen modest, yet tangible efforts to address some of the urgent policy issues highlighted five years ago (Eröcal and Yegorov, 2015), most notably in the areas of data availability, policy direction and coherence, as well as linkages with European scientific networks. Annual GERD data for Georgia are now available (Figure 12.2), for instance, although the business and non-profit sectors have not yet been surveyed.

Georgia's research and innovation governance framework is largely decentralized and non-interventionist. The Research and Innovation Council (RIC) was created in 2015 to enhance interministerial co-ordination. It is chaired by the prime minister.

Having no budget of its own, RIC relies for operational support on Georgia's Innovation and Technology Agency (GITA), which dates from 2014 and counted 35 employees as of 2017. The Law on Innovation (2016) called upon the government to formulate a state policy on innovation and established RIC as the central co-ordinating body for its implementation.

More than 80 research priorities

These initiatives follow the government's broader *Socio-economic Development Strategy of Georgia – Georgia 2020*. This document instructs GITA to develop instruments to fund R&D in the business sector and provides a medium-term framework to guide STI policy, in a language inspired by international best practice; it advocates 'fostering science–industry collaboration', for instance, and 'promoting evaluation'.

The absence of a clear priority-setting mechanism for public support of STI in Georgia has been highlighted (State Audit Office, 2014). The European Commission highlights the 'extreme fragmentation' of the research and innovation system, which is steered by 'over 80 research priorities (or *de facto* no prioritization at all)' [EC, 2018, Table 3].

Reliance on European research partners

Coming on the heels of the association agreement signed with the EU in 2014, Georgia's accession to the Horizon 2020 programme as an associate member in 2016 is a feather in the cap of the country's science diplomacy.

Other measures, such as the visa waiver for short-term visits to the Schengen area, can only further facilitate international scientific contacts. This waiver will not, however, grant access to the UK, which was not part of Schengen and has now left the EU. The UK had been the top destination for grants from the European Research Council.

Georgia's modest research enterprise remains reliant on foreign funding sources. Some 834 research projects active in Georgia are funded partially or entirely by the International Science and Technology Centre hosted by Kazakhstan, or its sister organization, the Science and Technology Centre in Ukraine; by the North Atlantic Treaty Organization (NATO); the Civilian Research and Development Foundation, which has offices in the USA, Ukraine and Jordan; the International Association for the Promotion of Cooperation with Scientists from the Independent States of the Former Soviet Union; and the EU's Seventh Framework Programme for Research and Innovation (2007–2013), cumulatively representing US$ 73.5 million (IncrEAST, 2016).

Closer international ties have not fostered competitiveness

However, the institutional rapprochement with Europe contrasts with the stagnant volume and declining overall share, between 2008 and 2018, of Georgia's merchandise exports to the EU. A similar trend is observed when it comes to exports to the USA, which is also actively cultivating linkages with the country.[11]

Broadly speaking, foreign ties through science appear to be poorly connected to Georgia's economic competitiveness and trading relationships with the rest of the world. Almost all foreign R&D stems from foreign governmental sources, which are not necessarily focused on enhancing the competitiveness of Georgian economic entities (IncrEAST, 2016, p. 14).

This said, the *Deep and Comprehensive Free Trade Agreement* includes financial and technical assistance mechanisms to give Georgian small and medium-sized enterprises (SMEs) better access to EU markets.

This assistance has enabled the creation of the Georgian ICT Cluster, a platform for dialogue between government policy-makers and the nascent ICT industry.[12] Support has also taken the form of the Adaptation Programme – Support for SME Competitiveness in Georgia (2015–2019), implemented through the European Bank for Reconstruction and Development, and the Better Business Sophistication in Georgia project (2019–2023) targeting exporting SMEs, implemented by the German development agency GTZ.[13]

A growing government research effort

Georgia's research and innovation infrastructure and spending have grown since 2013, albeit modestly. USAID (2017) estimates that Georgia's technology sector accounted for around 6% of GDP in 2015, of which 'ICTs constitute 90%'.

Biotechnologies have also been identified as a dynamic area in Georgia. Pharmaceuticals produced in the country were valued at US$ 80 million in 2015, about half of which were exported (USAID, 2017).

Despite the presence of innovation-driven activity, actual reported GERD remained stagnant at around 0.3% of GDP between 2015 and 2017 (Figure 12.2).

The Shota Rustaveli National Science Foundation remains the main government funding agency for R&D. Over the period from 2006 to 2017, the foundation's support amounted to around US$ 62 million (USAID, 2017, p. 57), within striking distance of the US$ 74 million received from foreign sources over the same period.

Government expenditure on civilian R&D grew by 110% in local currency between 2013 and 2016, even as military research expenditure fell by 15% to settle at 32% of overall government research funding. Government expenditure on R&D essentially consists of direct support; tax incentives are not used in Georgia, in line with EU recommendations for 'transition economies' migrating from centrally planned to market economies (EC, 2018, p.94).

When the Georgian Statistics Agency Geostat surveyed business R&D for the first time in 2016, it estimated it to be worth GEL 396 million (*ca* US$ 134 million) – 87% of which was spent on the acquisition of machinery and software – but withheld release of the publication owing to concerns over the quality of the survey (USAID, 2017, pp. 57–59). The agency's voluntary admission of this shortcoming may be an indication of its transparency.

Reinforcing the STI base requires education reform

Of Georgia's 10 879 researchers in 2018, 93% worked in higher education, a sector suffering from low pay and limited appeal. The average age of academic staff is 56, with 30% being older than 65 years (EC, 2017a).

The European Commission notes that little R&D is being performed at private universities, even though these account for 55 out of 75 Georgian universities (EC, 2017a, p. 28).

If Georgia is to embark on a development path driven by science and innovation, which its lack of natural resources and low recent productivity would tend to encourage, it will need to institute a major overhaul of its higher education system and improve the inward mobility of researchers. International comparisons in the OECD's *Pisa 2015 Results in Focus* and the Global Innovation Index (2019) reveal quality issues at both secondary and tertiary levels of education (Figure 12.5).

The government's recent strategic documents recognize the need to connect the university system with development needs: unemployment is highest among university graduates and youth unemployment is highest among graduates of technical secondary schools (Rep. Georgia, 2014, Figure 8). The government recommends improving universities' attractiveness through large-scale initiatives. These include the Study in Georgia programme, designed to attract foreign university students, and the University City of Kutaisi, which the government plans to turn into the largest campus in the Caucasus (Rep. Georgia, 2016, p. 34).

REPUBLIC OF MOLDOVA

Scientific reform part of European integration

For the Republic of Moldova, reforming its science system is part of a broader policy of integrating more closely with Europe.

The Republic of Moldova participates actively in Horizon 2020, having submitted no fewer than 422 applications by 2019 with a respectable success rate of 13.6%. It has some research potential in agriculture, chemistry and IT but also faces hurdles when it comes to exploiting this potential. An evaluation of its research sector by the Horizon 2020 Policy Support Facility identified the following weaknesses (EC, 2016):

- insufficient research funding, with inadequate attention being paid to this sector in state and sectoral development programmes;
- inefficient research and innovation, with fragmentary implementation of research results;
- a dearth of researchers and a low proportion of young people among research personnel;
- outdated research equipment and a lack of access to international research infrastructure;
- a mismatch between the priorities of public-sector research and the needs of domestic firms;
- low levels of business R&D; and
- relatively weak participation in international projects.

The Academy of Sciences of Moldova has developed a *Strategy for the Development of Science* to 2020. This document outlines five key objectives, most of which deal with the issues identified by the European Commission (Perchinshi and Turcan, 2015):

- development of human, institutional and infrastructural capacities;
- identification of new research priorities;
- promotion of dialogue between science and society, dissemination of knowledge and commercialization of research results;
- internationalization of research and closer integration with the EU research area; and
- introduction of a research management model based on the principles of efficiency and competitiveness.

The *Strategy for the Development of Science* to 2020 makes provision for raising the GERD/GDP ratio to 1.5% of GDP by 2020. One of the strategies for boosting this ratio is to develop closer university–industry ties by multiplying the number of scientific co-publications between the business sector and academia and developing a joint information system for evaluating research projects.

In order to rejuvenate the research pool, the strategy recommends attracting more foreign researchers and encouraging people to complete tertiary education. The strategy has fixed a number of targets to 2020, including raising the percentage share of (Perchinshi and Turcan, 2015):

- 30–34 year-olds completing tertiary education to 32% (20% in 2016);
- 20–24 year-olds completing tertiary education to 78% (60% in 2016);
- employees in skills training programmes to 15%;
- graduate students in engineering to the average level of EU countries in 2020; and
- young researchers to at least 40% of the research pool.

The country's advocacy of closer university–industry ties is laudable but, since universities remain mainly learning institutions, they themselves would benefit from closer integration with the Academy of Sciences, which has some key research institutes.

Changes in R&D management

Since the Law on the Introduction of Changes to the Existing Laws of the Republic of Moldova (#190) of 21 September 2017, a number of reforms to science governance have been implemented.

For instance, the National Research and Development Council has been established as an advisory body to the prime minister on related government policy. The council ensures communication and co-operation between the main organizations involved in the development and implementation of policies in this area.

In addition, science funding has been broken down into core research funding for organizations and their subsidiaries, used to cover running expenses such as staff salaries, competitive funding and joint research funding for public–private partnerships.

The National Agency for Research and Development has been established to co-ordinate the competitive process of selecting, evaluating and funding scientific research programmes and development projects. The agency operates in partnership with ministries, the Academy of Sciences and the Rectors Council.

The Academy of Sciences has been empowered to ensure that academic departments and institutes organize internal and public examination of research projects and their results.

Certification and regulatory frameworks have also been introduced to encourage vocations in science among the young, together with means to evaluate their effectiveness.

In September 2019, the Republic of Moldova finalized preparations for its National Programme for Research and Innovation for 2019–2022, prepared with the help of Romanian and Austrian experts. This programme has been proposed within the framework of the European Commission's Technical Assistance and Information Exchange Instrument (TAIEX), which helps public administrations to enforce EU legislation and share the EU's best practices.

TURKEY

In a middle-of-the-road-innovator trap?

Turkey is the only country analysed in the present chapter that has seen both substantial economic growth and a modest rise in research intensity since 2015 (Figures 12.1 and 12.2).

This said, research spending does not correlate directly with indicators on innovation output such as growth in economy-wide productivity or in the export of high-tech products. The economy's growing competitiveness is still being driven primarily by medium and low technology (Figure 12.1).

In 2015, we observed that businesses in Turkey 'have not grasped the government's helping hand' in support of technological development and innovation (Eröcal and Yegorov, 2015). This remains the case. Recent firm-level evidence shows that Turkey's technology-intensive firms carry out little R&D relative to their size.[14]

This picture contrasts sharply with the state's strong emphasis on supporting innovation. For instance, tax breaks for technology-intensive firms grew three-fold in local currency between 2015 and 2018, according to the Turkish Statistical Institute. Public discussion on innovation among Turkey's business elite and media has also been broadly positive (GE, 2018).

New developments, old problems

In 2017, business-funded R&D exceeded that funded by the government and higher education sectors combined, for the first time, although most business-funded investment goes towards military and dual-use technologies. For instance, the leading Turkish firm for the number of patents is the principal military industry conglomerate Aselsan; it owns 54% of all resident patents, compared to just 17% for the leading patent-owner in Israel, Teva Pharmaceuticals (TEPAV, 2017). The Turkish Exporters Assembly has reported that defence and aerospace was the leading sector in terms of export growth in the first five months of 2019, according to a press release by the Anatolia Agency on 5 June 2019.

A growing share of business-funded R&D is being driven by tax incentives, the sectoral composition of which is determined by the government. A 2018 business opinion survey found that, in Turkey, 'multinationals are driving innovation, while large enterprises [have] also gain[ed] momentum since 2014' (GE, 2018).

However, this trend mainly concerns innovation in manufacturing, which is open to competition largely thanks to the Customs Union with the EU in effect since 1996. Research funding from abroad has, indeed, progressed to about 3.5% of total research spending in 2017, up from 2% in 2015. Most well-known global corporations have been present in Turkey for decades. As of 2017, the top 250 enterprises in Turkey in terms of research expenditure included Ford (3rd), Mercedes (9th) and Siemens (17th) [Turkishtime, 2018].

The prevailing sentiment in academic circles, however, is that there is a mismatch between the level of public support for innovation and the amount of innovation in the economy. This sentiment is shared by Prof. Hasan Mandal, the head of TÜBITAK, who notes the insufficiency and lack of focus of public support given to development 'from prototypes to production'. He admits that there has been an 'insufficient connection of R&D efforts to the needs of final consumers and needs analyses' (Mandal, 2018).

More importantly, firms in the services and construction sectors, which accounted for 63.5% of GDP in 2018, remain largely shielded from competition. Even those that treat innovation as an afterthought remain profitable. They can afford to ignore the government's support programmes for R&D and manufacturing-focused innovation.[15]

The low returns that researchers can expect for their efforts are impeding the development of the national innovation system. Although patent applications by Turkish inventors have been growing, as have granted patents, available evidence suggests that inventive activity in Turkey is largely disconnected from global collaboration networks. For example, TÜBITAK's own analysis confirms that foreign actors approach Turkish institutions within the framework of Horizon 2020 projects without any discernible logic or pattern when it comes to seeking partnerships (Yildirim, 2018). Patent data on information technologies corroborate the analysis that

Table 12.1: **Turkey's achievements and targets for the economy, research and broadband, 2012–2023**

Variable (unit)	**Base value**	***Tenth Development Plan* (2014–2018) target**		**Value in 2018 or closest year**	***Eleventh Development Plan* (2019–2023) target**
	2012	**2018**	**2023**	**2018**	**2023**
General targets					
GDP per capita (current PPP$)	20 640			28 205	37 423
Employment rate (% of population of working age)				47.4	50.8
Merchandise exports (US$ billions)	152	277	500	168	227
Share of Turkish products in global trade (%)	1.0	1.5		1.0	
Share of high-tech products in exports (%)				3.2	5.8
Share of high- and medium-tech products in exports (%)				36.4	44.2
Targets for R&D					
GERD/GDP ratio (%)	0.86	1.80	3.00	0.96^{-1}	1.8
Share of GERD performed by business (%)	43.2	60.0	66.7	56.9^{-1}	67.0
GERD performed by business as a share of GDP (%)	0.37	1.08	2.00	0.55^{-1}	
Expenditure by SMEs as a share of total GERD (%)				19.6^{-1}	25.0
Researchers (FTE)	82 122	176 000	300 000	$111\,893^{-1}$	
Researches in business sector (FTE)	35 034		180 000	$62\,305^{-1}$	
Share of researchers (FTE) employed in private sector (%)				55.7^{-1}	67.0*
Researchers with a PhD per million inhabitants				323^{-1}	863
Triadic patent applications (number)	35^{-2}	167		39^{-4}	
Turkey's global rank in new patent applications				13	10
Broadband targets					
Mobile broadband penetration rate (% of population)				74.5	100.0
Fibre broadband penetration rate (% of population)				3.4	11.5

* Defined as the private sector's share

Note: Triadic patents are those submitted simultaneously to the European, Japanese and US patent offices for the same invention.

Source: Eröcal and Yegorov (2015); Rep. Turkey (2019b); WTO (2019) *World Trade Statistical Review*; UNESCO Institute for Statistics

Turkey's involvement in international collaborative networks is limited.

Scientific productivity has also been a casualty of the loss of tenure by many academic research staff and the sharp fall in applications for university research projects in 2016, in the aftermath of the attempted coup of July 2016 (Erdoğmuş, 2019, p. 119). For the first time since 2002, output declined by 5.2% between 2016 and 2018. Publications continue to exhibit low international co-authorship and citation rates (Figures 12.3 and 12.7).

Meanwhile, tertiary enrolment has grown rapidly. To accommodate this new influx, no fewer than 30 universities were founded between 2016 and 2019, 20 of which are public institutions. By 2018, the gross enrolment ratio was 109.5% (Figure 12.2), and the number of doctoral students had risen by 22% to 95 100 since 2015 (Erdoğmuş, 2019, p.126).

However, the unemployment rate among university graduates increased from 10.3% in 2008 to 12.7% in 2017. Just 2% of university entrants study natural sciences or mathematics, statistics and computer science in Turkey, compared to an average of 6% and 5%, respectively, in other OECD countries (Erdoğmuş, 2019, p. 101).

The pursuit of science and innovation in Turkey continues to be a largely government-driven endeavour. The heavy focus on defence-related capabilities is not likely to generate a significant spillover to the rest of the economy. The principal recommendation in the previous *UNESCO Science Report* (Eröcal and Yegorov, 2015) remains valid and pressing. It called for Turkey to 'interconnect better the different players in the Turkish innovation system to make the whole more coherent: scientists, universities, public laboratories, large or small enterprises, non-governmental organizations and so on.'

Diversifying the energy mix for greater security

Turkey's *Eleventh Development Plan* (Table 12.1) identifies energy storage as being among critical technologies requiring careful government study; it includes numerous targets

Box 12.1: **How Turkey became a role model for geothermal energy within a decade**

Between 2009 and 2019, the number of geothermal power plants in Turkey shot up from 3 to 49. This corresponds to a geothermal capacity of 1.5 GWe, placing Turkey fourth in the world for this indicator after the USA, Indonesia and the Philippines, according to the Turkish Energy Market Regulatory Authority.

In the past decade, Turkey has drilled more than 1 000 geothermal wells in Western Anatolia (Kaya, 2017). Thanks to this extensive experience, geologists have managed to drill wells as deep as 4 500 m in the Büyük Menderes Graben, an active rift basin in western Turkey with great geothermal potential that is about 140 km long and up to 14 km wide.

Geothermal exploration has accelerated since the adoption of the Law on Geothermal Resources and Natural Mineral Waters in 2007. This law gave potential private partners the necessary confidence to invest, eliminating some of their concerns with regard to legislative, technical and administrative hurdles. For instance, the law reduced the number of licenses to two.

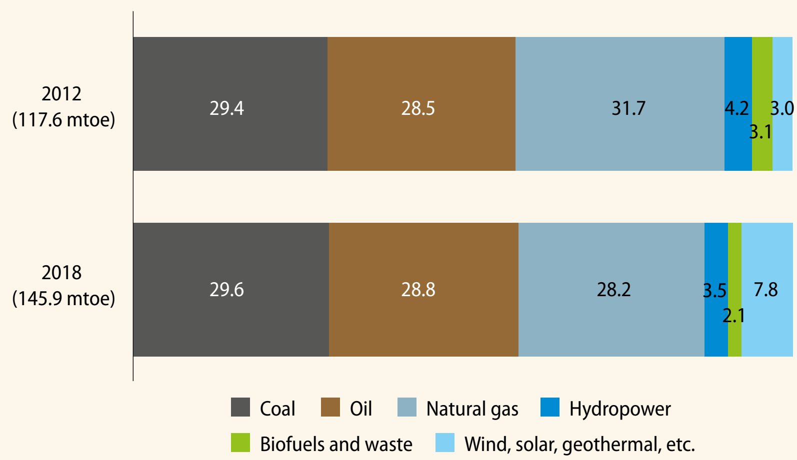
In parallel, the Renewable Energy Support Scheme of 2010 introduced a new feed-in tariff (US$ 0.105 per kWh) guaranteeing companies a purchase price for the energy they generated at a fixed rate for ten years. Investors are currently waiting for news of the new feed-in tariff from 2021 onwards before renewing their commitment to geothermal power production in Turkey.

The European Bank for Reconstruction and Development has also supported the development of geothermal energy financially to accompany the decarbonization of Turkey's economy.

Turkish geothermal power companies have participated in the EU's Horizon 2020 programme through consortia. This has enabled them to interact with technology providers and operating companies in Europe, in particular. Two of these big-budget, multidisciplinary projects are Geosmart and GeoPro. The Turkish hydro-electric power company, Zorlu Energy, has received around € 3.5 million from Horizon 2020 through its participation in six research projects.

Source: compiled by Füsun Servin Tut Haklidir, Department of Energy Systems, Istanbul Bilgi University

Figure 12.9: **Breakdown of Turkey's primary energy supply by source, 2012 and 2018 (%)**



Source: International Energy Agency (https://www.iea.org/countries/turkey)

Box 12.2: **Kanal Istanbul: a testing ground for anticipatory policy-making**

In February 2020, the Turkish Ministry of Transport and Infrastructure approved the zoning plan for construction of a shipping canal, in order to bypass Istanbul's busy Bosporus Strait. A tender for the project is to be launched by the end of 2020.

For Turkey's central government, the 45 km-long canal is necessary to relieve the growing (+29% since 2006) maritime traffic in the Bosporus: 613 million tonnes of shipping in 2018, one-quarter of which concerned oil delivered primarily by Russian tankers. This congestion has led to waiting times of up to 30 hours for the larger ships.

For its detractors, the project is of dubious financial and technical feasibility, with a potentially severe environmental impact on the fragile ecosystems of the Marmara Sea and the inshore lagoons and lakes which provide the metropolis of 16 million inhabitants with its freshwater supply (see, for example, Dogan and Stupar, 2017; Kundak and Baypinar, 2011).

The project will be a testing ground for anticipatory policy-making. For instance, should the world move decisively away from fossil fuels in the coming decades, the problem of traffic congestion in the Bosporus Strait will dissipate, removing one of the justifications for the canal.

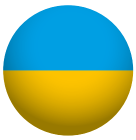
Source: compiled by the authors

for greater energy efficiency but refrains from establishing specific goals (Rep. Turkey, 2019b).

The government has been diversifying the country's energy mix in an effort to reduce Turkey's high dependency on imports of fossil fuels from Eurasia and the Middle East, where political tensions are affecting the supply chain. The contribution of hydropower has plateaued in the face of natural barriers, prompting the government to turn to wind, solar and geothermal sources. Between 2012 and 2018, their share in Turkey's primary energy supply rose from 3% to 8% (Figure 12.9). Geothermal energy has become a major contributor to Turkey's energy mix (Box 12.1).

A massive infrastructure project may get under way soon. In February 2020, the Turkish Ministry of Transport and Infrastructure approved the zoning plan for construction of a shipping canal designed to bypass Istanbul's busy Bosporus Strait (Box 12.2).

UKRAINE



A smaller share of innovative firms

Ukraine is going through a trying period. The frozen conflict in the east of the country and annexation of Crimea in 2014 have cost the country about 15% of its research potential (UKRStat, 2019).

The economic crisis of 2014–2016, during which GDP dropped by 13% (in current international PPP$), according to the World Bank, sent the country's research intensity to an all-time low in 2018 (Figure 12.2). In the past four years, the share of innovative enterprises in industry has fallen by more than one-fifth (UKRStat, 2019).

Although the frozen conflict has exacerbated the situation, systemic problems related to research and innovation have developed over many years in Ukraine to the point where quick, inexpensive solutions will no longer suffice.

For instance, over the 2014–2018 period, science was one of 66 priorities outlined in the National Programme for Development. All of these priorities were formulated in isolation, without a proper analysis of potential in other areas.

In 2018, the Ministry of Education and Science initiated preparatory work for a new foresight-oriented project to formulate priorities in S&T policy but adequate financial and organizational resources had not been provided by early 2020 to take the project forward.

Impetus for change

Ukraine's desire for a rapprochement with the EU has provided impetus for change. Although hopes were high that the association agreement with the EU signed in June 2014 would open the country to a vast new market,[16] substantial growth and diversification in exports have not materialized. Agricultural products, ferrous metals and basic chemicals, which provide little added value, remain the country's key exports.

Moreover, rapprochement with the EU may have weakened Ukraine's ties to Russian and post-Soviet markets, to which it has traditionally exported manufactured goods.

As of March 2020, 239 Ukrainian establishments had participated in the Horizon 2020 programme. The country's success rate for grant applications (9.2%) is lower than the average for Associated Countries, which stands at 13.9%.

In 2016, the European Commission launched a Peer Review of the Ukrainian Research and Innovation System to provide Ukrainian authorities with external advice and operational recommendations on potential reforms.

The review highlighted the need to optimize available policy instruments, internationalize research and integrate Ukraine into the European Research Area. According to the Deputy Minister of Education and Science, these recommendations are being implemented (Ministry of Science and Education, 2017).

As a result, Ukraine is participating in the European Innovation Scoreboard, where it figured at the bottom of the Innovation Index in 2019. With the exception of indicators related to education, it performs well below the EU average.

Following a complete revamp in 2016–2019, two approaches are now being used in the public sector to evaluate research bodies. The first approach uses qualitative assessments and analysis against selected quantitative indicators: number of research papers, patents, participation in international conferences, etc. In 2017, the National Academy of Sciences started using this approach based on the experience of the German Leibnitz Association.

The second type of evaluation uses transparent procedures to assess research projects and programmes implemented by research institutes. The government has begun involving foreign experts in evaluation processes.

A sweeping reform of the legal framework

Since 2015, the government has reformed the management of the national innovation system. The State Agency for Science, Innovation and Information has been abolished, with the transfer of all functions related to policy formulation to the Ministry of Education and Science, although a number of other ministries and agencies also allocate state money to specific activities.

Ukraine's legal framework was substantially modified in late 2015 with the adoption of new laws reinforcing institutional support for the national innovation system. The Law on Scientific and Technical Activities (2015) places the National Council for Science and Technology Development under the control of the Cabinet of Ministers. The council is tasked with ensuring the effective co-operation of representatives from the scientific community, state agencies and the business sector in the preparation and implementation of related state policy.

In addition, the National Fund for Research (2015) has replaced the State Fund for Basic Research, which was subordinate to the Ministry of Education and Science. The new fund's key function is to provide competitive grants for basic and applied research. The fund is also mandated to support experimental development and innovation in priority areas.

The new legal framework is expected to play an important role in transforming Ukraine's public academies of science, especially the National Academy of Sciences. It has paved the way to involving ordinary scientists in the election of academies' governing bodies; it has also placed constraints on academies' membership and top positions.

Additionally, public research institutions now have the legal right to co-found commercial companies and to take part in the formation of their share capital.

A number of other key legislative acts relating to science, innovation and science parks were under revision in 2020. However, the effective implementation of legislative acts remains the Achilles' heel of Ukraine's science and innovation policy.

A special high-tech office

One outcome of reform will be the creation of a special High-Tech Office within the government to stimulate high-tech industries, especially in the expanding ICT sector. In 2020, business associations, along with government experts, were preparing the legal groundwork for the establishment of this office. The growth of Ukraine's ICT sector is reflected in the depth of its exports of related services, which now account for more than 40% of total exports. Ukraine's success in this area is tied to its relatively large pool of specialists.

Ukraine has been implementing key elements of its e-governance strategy since 2015. One outcome is ProZorro, an electronic system for public procurement, established in 2016–2018. Early signs indicate that ProZorro has helped to reduce corruption in the attribution of government contracts.

Environmental sustainability still elusive

Ukraine's 2020 *Voluntary National Review* on its progress towards the SDGs offers a candid analysis of the state of the environment. Although greenhouse gas emissions and environmental pollution have diminished, it states that this was 'largely due to the economic recession' (Ministry for Development of Economy, Trade and Agriculture, 2020).

The size of Ukraine's forested areas and nature reserves and national parks has grown, with 4% of land area and 3% of marine area protected, according to the World Database on Protected Areas. However, the *Voluntary National Review* notes the poor quality of surface water – 70% of which is not potable – and the 'little or no progress [made] in the energy sector, especially in terms of energy efficiency and renewable energy'.

One interesting development has been the installation of a solar power plant in 2018 in Chernobyl, the site of the world's worst nuclear disaster (see Box 24.1).

In July 2019, the Ukrainian parliament voted to limit the scope of green tariffs (preferential electricity rates) offered by local utilities to households operating small private power stations. The green tariffs had attracted foreign investment but pushed up the price of electricity for consumers.

In July 2020, parliament adopted a law reducing tariffs by 7.5% for wind farms and by 15% for solar parks, in an attempt to balance the interests of 'green' and traditional energy producers.

In 2019, just 2% of energy production in Ukraine came from renewable sources, according to the *Voluntary National Review*. This figure excludes hydropower, which accounted for a further 5% of energy generation.

CONCLUSION

Limited rewards for innovation

The Black Sea countries face a range of structural challenges. The historically strong tertiary education and science systems of the six post-Soviet countries are waning, hampered by restrictive political and economic structures that limit the rewards for innovation. This is the case even in Georgia, which has taken the boldest steps to improve its business environment.

Turkey, on the other hand, benefits from a pluralist business environment[17] able to reward innovation but its tertiary education and science systems are beset with quality issues.

There is the additional resource curse. When global markets for raw commodities boom, they provide dazzling returns to Azerbaijan and, to a lesser degree, to Ukraine, where the two main pipelines for Russian gas traverse the country's territory on their way to export markets. This natural advantage has, so far, disincentivized a genuine focus on technology- and innovation-driven experimentation. In Belarus, meanwhile, development is constrained by the traditional orientation towards the Russian market, which still endures today.

In each of the seven countries, there remains a need to *combine* the different ingredients of their respective innovation systems so that they reinforce and complement one another as an integrated whole. This is especially so, in view of the flurry of new science laws and policies surveyed in the present chapter, which have not yet delivered the desired outcome for most Black Sea countries.

A narrow international focus

The prevailing focus on dovetailing with European structures and networks provides a useful framework for reform but it comes at the expense of keeping abreast of developments in comparable economies worldwide. Even within the region, the Black Sea countries do not appear to perceive each other as close scientific and economic partners, or even as competitors. The Belt and Road initiative, which is connecting the region with China's more pragmatic and business-oriented economic culture, may prove to be an eye-opener for Black Sea countries, despite concerns about the initiative's effectiveness and geopolitical implications.

Cross-border co-operation and science diplomacy have been largely confined to engagement with the EU and EAEU. The main regional co-operation body, the Organization of the Black Sea Economic Cooperation, seems to have no greater ambition than to maintain elbow contact between its members. The current *Action Plan for Science and Technology* is paper-thin.

Ultimately, it is the responsibility of each individual Black Sea country to establish meaningful and achievable targets for STI-driven development, to improve their ability to measure progress towards those goals and to deepen co-operation with one another.

Creativity thrives on intellectual independence

The Black Sea countries must embrace the fact that fostering STI-driven development through government policy also requires them to promote political and economic freedoms and experimentation in business, research and in society at large.

The *UNESCO Recommendation on Science and Scientific Researchers,* adopted unanimously by UNESCO member states in November 2017 and, thus, also by Black Sea countries, establishes scientific freedom of expression as a basic right and calls for a process to measure and monitor scientific freedom (see essay on p. 24).

The *Recommendation* could serve as a guide for the countries to review their practices, beginning with the current dependency of their national academies of science (and universities, in some cases) on executive political power. We have seen in the preceding pages that Ukraine has taken some steps recently to strengthen the intellectual independence of its own national academy.

In sum, the seven countries analysed in the preceding pages still face the fundamental challenge of combining STI policies with economic and societal framework conditions that make the pursuit of technology and innovation profitable for non-state actors. There are some success stories, as we have seen, which are all the more commendable for having emerged in a deteriorating climate for international co-operation and investment.

KEY TARGETS FOR COUNTRIES IN THE BLACK SEA BASIN

- Belarus' new target for its GERD/GDP ratio of 1% is to be reached by 2030.
- The Republic of Moldova aims to raise the share of 'young people' in its researcher population to 40% by 2020.
- Turkey is to rise to 10^{th} place in global rankings for the number of new patent applications by 2023, up from 13^{th} in 2018.
- The share of expenditure by SMEs in Turkey's overall GERD is to reach 25% by 2023, up from 19.6% in 2017.
- Ukraine aims to raise the share of competitive research funding to 20% of the state budget for research by 2022.

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1 See: https://ru.krymr.com/a/news-koronavirus-v-ukraine/30495366.html

2 See: https://42.tut.by/676885 and https://www.2000.ua/v-nomere/svoboda-slova/mnenie_svoboda-slova/isaak-trahtenberg-chtoby-reformirovat-zdravoohranenie-nado-vosstanovit-to-chto-razrushili.htm

3 A CERN Council decision of June 2018 defined the industrial return coefficient as the ratio between a member state's percentage share of the value of all supply contracts and the proportion of the CERN budget contributed by the said member state over the same period. A return coefficient equal to or greater than 1.00 indicates that a member state is 'well balanced'. Ukraine's rate was 0.81 for the period 2019–2020, compared to 0.70 for Turkey. This places them in 12th and 17th place respectively, out of CERN's 30 member states and associate member states. Both countries showed improvement since the previous year, when Ukraine achieved a coefficient of 0.25 and Turkey 0.51. Turkey's coefficient could reach 0.87 in 2020–2021.

4 These include www.e-gov.am, a hub for services and information relating to tax filing, procurement notices and legislation, and www.e-register.am, a platform for business registration.

5 In 2018, Armenia published its first Satellite Water Account System, which provides comprehensive data on the extent and use of existing water resources (Rep. Armenia, 2018).

6 ADA University resulted from the merger, in January 2014, of the Azerbaijan Diplomatic Academy and the Information Technologies University.

7 This programme was adopted by presidential decree on 31 January 2017. See (in Russian): www.mshp.gov.by/programms/fdbac4b499a1dde8.html

8 The National Academy of Sciences is still Belarus' largest scientific organization. In 2017–2018, it employed 32% of researchers and 57% of researchers with scientific degrees.

9 See: https://gosstandart.gov.by/the-republican-centralized-innovation-fund/

10 China exported US$ 757 million worth of mainly manufactured goods to Georgia in 2017, compared to US$ 209 million in Georgian exports to China, most of which (72%) consisted in copper ore, according to the Massachusetts Institute of Technology's Observatory of Economic Complexity.

11 See: UN Comtrade Database, https://comtrade.un.org/

12 See: https://ictcluster.ge/en/.

13 See: http://eu4business.eu/programmes.

14 See the EU Industrial R&D Investment Scoreboards for 2013–2018.

15 Interview with Mr Ussal Sahbaz, CEO of the Centre for Economics and Foreign Policy Studies (EDAM), Istanbul; see: https://edam.org.tr/

16 The Association Agreement paved the way to more active scientific co-operation with EU countries through the Horizon 2020 programme. The trade-related prong of this agreement, the Deep and Comprehensive Free Trade Area, has been provisionally applied since January 2016.

17 The system of oligarchic ownership of a country's productive economic assets does not exist in Turkey, which has a competitive business environment.

AT A GLANCE

Quantum optics and nanophotonics study light at the nanoscale. Potential applications include components for quantum computers, which consume much less power than traditional computers and supercomputers. Pictured here is the Ultrafast Laser Spectroscopy Lab at the Quantum Optics and Nanophotonics Joint Department of the Higher School of Economics (HSE) in Moscow and the Russian Academy of Sciences' Institute of Spectroscopy in Troitsk. © HSE/Mikhail Dmitriev

- The centrepiece of the government's new economic model are 13 ambitious projects that align with The 2030 Agenda for Sustainable Development. Over a six-year period to 2024, the government is investing more than than US$ 1 trillion in science, the digital economy, ecology, health, education, housing and other areas.
- Readiness for the Fourth Industrial Revolution is a cross-cutting priority of the 13 projects and the national strategy for artificial intelligence.
- The government is espousing a goal-oriented management system to strengthen national competitiveness, independence and security. There are plans to develop world-class infrastructure in selected regions for 'a new geography of science'.
- One challenge will be to raise expenditure on research and education, especially since improving the quality of public universities is a priority.
- Since 2015, solar, gas and wind consumption have progressed each year but the use of renewable energy is being hampered by the centralized management of the Russian energy sector, higher consumer prices for renewable energy and the rigours of the country's cold climate.

13 · Russian Federation

Leonid Gokhberg and Tatiana Kuznetsova

INTRODUCTION

A country at a crossroads

In 2020, the Russian economy has emerged from a turbulent period which saw a combination of plummeting global oil prices and international sanctions plunge the country into recession. By 2016, the economy had rebounded (Figure 13.1). By 2018, the trade surplus amounted to almost US$ 200 billion and both inflation and unemployment rates were under 5%.

This recovery can be explained by several factors. On the one hand, robust global market prices for raw materials until the end of 2019 enabled the government to accumulate monetary reserves from the higher export revenue. In parallel, the import substitution policy adopted in 2014 has cushioned the effect of sanctions on domestic markets for agrifood products, chemicals, civil engineering and information and communication technologies (ICTs), among others.

At the International Arctic Forum in April 2019, President Putin acknowledged that sanctions had hindered the country's development but 'not critically and, to a certain extent, they push us to actively develop our own technologies' (PoR, 2019). Two months later, at the World Economic Forum, he observed that 'global trade has ceased to be the engine of the world economy; trade wars are under way and protectionism is growing. Attempts to monopolize the new technological wave limit access to its fruits and bring the global inequality problem to a completely new, different level' (RIA, 2019).

In 2020, the Russian Federation finds itself at a crossroads. It may have emerged from recession but, prior to the Covid-19 pandemic, the economy was still growing at a slower rate than the world average (2.3% in 2018) and less than half as fast as the emerging economies of India and China (see chapters 22 and 23) [IMF, 2019].

The same structural imbalances persist. The Russian economy remains heavily reliant upon oil, gas, metals, chemicals and agricultural products. In 2019, revenue from the extraction and export of hydrocarbons accounted for 39.4% of federal revenue. In this sector, output, profit margins and investment are all on the rise, including investment by foreign partners (Minfin, 2020).

The growth of most low- and high-tech sectors is limited by the insufficient scale of domestic markets and poor global competitiveness of many manufactured products. This is the case for machinery and equipment, construction materials, aircraft and shipbuilding, for instance.

Development remains hindered by the pedestrian diversification of the national economy, coupled with a mismatch between demand for, and supply of, scientific knowledge and technology, as well as tepid interest among businesses in investing in science, technology and innovation (STI) [Gershman *et al.*, 2018; Gokhberg and Kuznetsova, 2015; Gokhberg *et al.*, 2018; HSE, 2018].

Public funding mobilized for Covid-19 research

In 2020, the Covid-19 pandemic has become a challenge for the Russian Federation, as for the rest of the world. The government has been quick to allocate additional funding to develop rapid testing kits, vaccines, lung ventilators and the like. In parallel, procedures for state registration of vaccines and medical equipment have been expedited.

Leading Russian research institutes and pharmaceutical companies are rushing to develop a vaccine and other antiviral drugs, including with the help of genome sequencing tools. Among these institutes are the State Research Centre of Virology and Biotechnology 'Vector', National Research Centre for Epidemiology and Microbiology, Faculty of Biology at the Moscow State University and Research Institute of Influenza.

Following pre-clinical trials, promising prototypes are being tested on human volunteers then submitted for regulatory approval (RBC, 2020a).[1]

The Skolkovo Foundation is actively supporting Covid-19 start-ups developing new technologies to battle the virus. Examples are indoor air decontamination and sanitation systems, antiviral drugs, biobanks and clinical decision support systems supported by artificial intelligence (AI) to speed up interpretation of X-ray images of patients with suspected pneumonia (SIC, 2020).

A group of developers and manufacturers of medical equipment have formed a consortium with private companies from a range of sectors, such as defence contractors, to take advantage of their expertise and cutting-edge technologies and equipment. Thanks to this consortium, the production rate of components for lung ventilators is projected to increase by 25–30 times, covering not only domestic needs but also satisfying some demand overseas (RIA, 2020).

TOWARDS A NEW ECONOMIC MODEL

Thirteen national projects to boost the economy

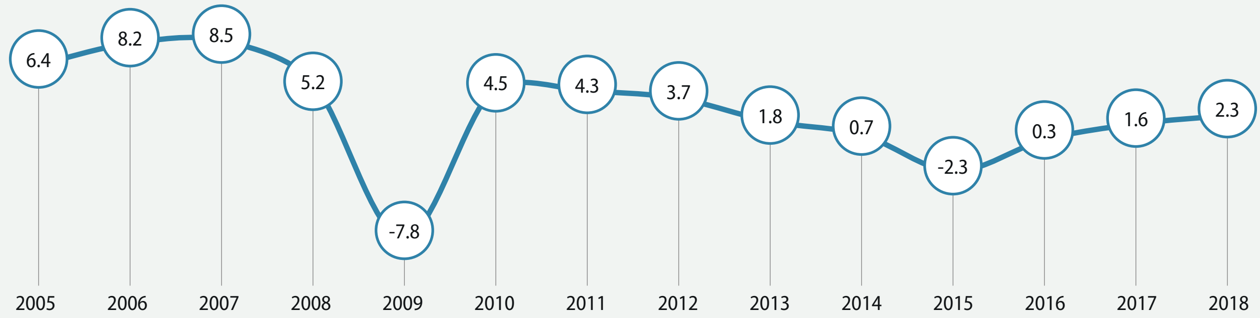
The government is seeking to introduce a new economic model that will allow the country to reap the rewards of the Fourth Industrial Revolution (Industry 4.0) and compete globally, through the development of human capital and greater investment in infrastructure and innovation.

This ambition is enshrined in the Presidential Decree on National Goals and Strategic Objectives for the Development of the Russian Federation to 2024 (Decree 2018). A total of RUB 25.7 trillion (*ca* PPP$ 1.04 trillion) is being invested over this six-year period in infrastructure, housing, education, health care, science, the digital economy, ecology and other areas.

The originality of Decree 2018 lies in the introduction of 13 ambitious large-scale, mission-oriented national projects, all of which are aligned with *The 2030 Agenda for Sustainable*

Figure 13.1: **Socio-economic trends in the Russian Federation**

Rate of economic growth in the Russian Federation, 2005–2018 (%)

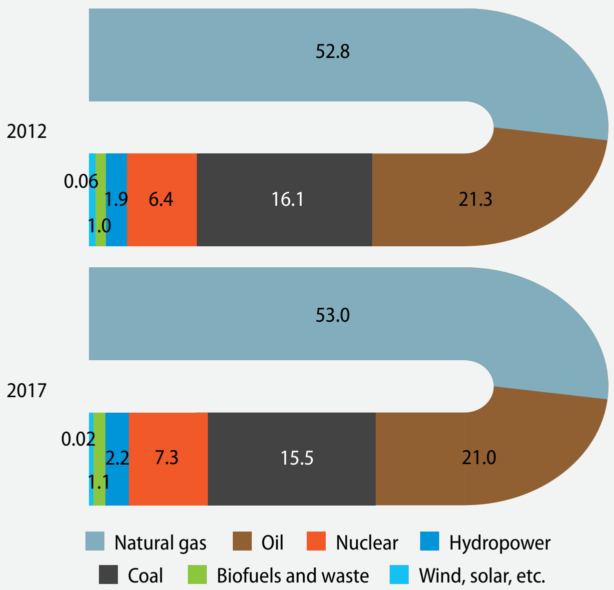


Change in the Russian Federation's economic performance, 2014–2018
Percentage change over previous year or five-year period

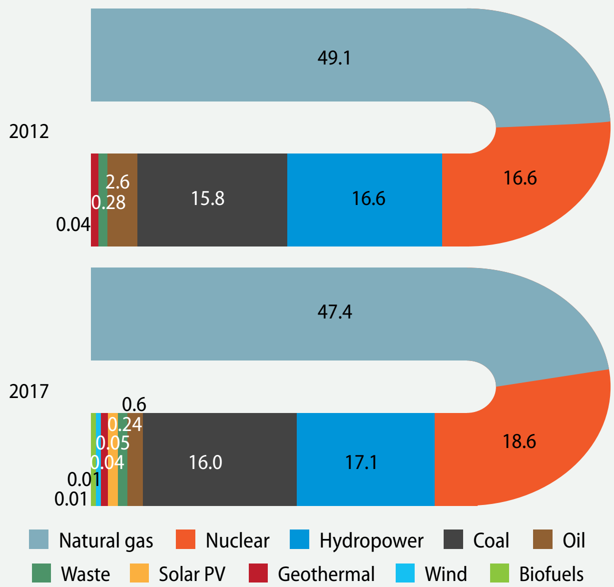
Indicator (%)	2011–2015	2014	2015	2016	2017	2018
Inflation (annual)	14.0	11.4	12.9	5.4	2.5	4.3
Industrial production (growth)	1.4	2.5	-0.8	2.2	2.1	2.9
Capital investment (growth)	4.5	-1.5	-10.1	-0.2	4.8	4.3
Foreign trade turnover (growth)	-3.5	-6.9	-32.9	-11.0	25.0	17.1
Labour productivity (growth)	–	0.7	-1.1	0.2	1.9	2.3
Real disposable personal income (growth)	1.1	-1.2	-2.4	-4.5	-0.5	0.1
Real wages of employees (growth)	1.2	1.2	-9.0	0.8	2.9	6.8
Surplus deficit of consolidated budget (share of GDP)	–	-1.1	-3.4	-3.7	-1.5	2.9

Population of Russian Federation

Total primary energy supply in the Russian Federation by source, 2012 and 2017 (%)

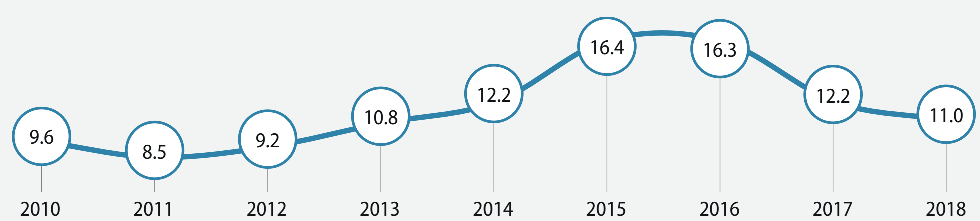


Electricity generation in the Russian Federation by source, 2012 and 2017 (%)



Note: These figures are not drawn to scale.

Russian high-tech exports as a share of manufactured exports, 2010–2018 (%)



From 2008 to 2018, wind power capacity increased 6-fold and solar energy 8-fold.

Source: For population: Rosstat (2018) Russia in figures. Russian Federal State Statistics Service: https://tinyurl.com/ya25q8fu; for economic performance: Minfin (2020); for economic growth and exports: World Bank's World Development Indicators (June 2020); for energy: International Energy Agency (May 2020)

Development (Figure 13.2). Emphasis is being laid, for instance, on generalizing responsible consumption and production patterns, counteracting the negative impact of climate change and environmental pollution, preserving ecosystems and fostering environmentally safe mining, agriculture and organic farming.

A focus on high tech for the digital economy

One of these 13 projects focuses on the digital economy. It has identified specific areas for priority development, including quantum technologies, neural technologies and artificial intelligence, wireless technologies, blockchain, robotic and sensory components, advanced manufacturing technologies and virtual and augmented reality.

Strictly speaking, the National Project for the Digital Economy is not new, since it was launched in 2017. The government has since approved specific incentives for leading high-tech companies to stimulate investment in the development of digital products, services and platforms. These incentives include lower rates for obligatory social security payments, tax exemptions for research expenditure on digital technologies and an exemption from value-added tax for software and database development.

One objective is to promote effective co-operation between businesses, academia, the state and the general public. A network of leading research centres engaged in the development and commercialization of digital solutions is emerging.

The project is improving the regulatory environment for digitalization. The Ministry of Economic Development and the Skolkovo Foundation have drafted a Law on Experimental Legal Regimes in the Field of Digital Innovation to make regulatory requirements hindering digital innovation more flexible in areas such as telemedicine, transportation, education and finance. This is part of the 'regulatory sandbox' being proposed by the government (see section on **An industry-specific toolkit to cultivate innovation**). In 2018, the Central Bank of the Russian Federation adopted a special regime making it possible to pilot innovative technologies and services in financial markets (fintech) for allied businesses and public agencies (CBR, 2018; Minec, 2019a).

The project is also developing information infrastructure, digital technologies and cybersecurity, introducing e-government and training personnel for the digital economy.

A national strategy for AI

In 2017, President Putin stated that 'artificial intelligence is the future, not only for Russia, but for all humankind. It comes with colossal opportunities but also threats that are difficult to predict […]. Whoever becomes the leader in this sphere will become the ruler of the world' (EWDN, 2017).

Released in October 2019, the Decree on the Development of Artificial Intelligence approved the *National Artificial Intelligence Development Strategy for 2020–2030*. This strategy will complement the National Project for the Digital Economy and target the creation of new high-performance jobs, competitive remuneration and favourable working conditions for AI professionals; it will also support research and development (R&D) and improve the availability and quality of data, hardware and software.

In addition, the strategy prioritizes developing educational programmes and skills, while building public awareness of the potential of AI.

Energy the key to environmental safety

How the energy sector evolves in the coming years will be central to solving the country's environmental problems. Major companies such as Gazprom, Rosneft and Lukoil have signed up to the government's National Project for Ecology (Figure 13.2) by raising their investment in green technology, in order to reduce their greenhouse gas emissions and increase utilization of gas extracted as a by-product of oil extraction, what is known as associated oil gas. For example, the Rosneft strategy contains provisions for investing RUB 300 billion for this purpose over the next five years. When making investment decisions, domestic investors are increasingly attentive to the need for corporate environmental and social responsibility (RBC, 2020b).

Over one-third of electricity is generated by hydropower and nuclear power plants. Consumption of coal and petroleum products dropped from 33% to 29% of the fuel and energy balance between 2015 and 2018.

Since 2015, gas consumption has increased each year by 3.5% on average and that of solar and wind energy by as much as 13%. The long-term benefits make renewable energy a viable proposition from a socio-economic standpoint. By 2024, it is projected to build 1 908 MW of solar power plants, 3 377 MW of wind power plants and 168 MW of small hydropower plants.

By 2036, renewable energy is to account for 4% of the total national energy balance (Minenergo, 2019; Minec, 2019a). Currently, the use of renewable energy is being hampered by the centralized management of the Russian energy sector, higher consumer prices for renewable energy and the rigours of the country's cold climate, which limits solar radiation and damages wind turbines.

The Russian Federation's *Energy Strategy to 2035* was approved by the government in June 2020. Its stated key goals are to sustain Russia's position in energy markets worldwide, diversify energy exports towards Asian markets, ensure the availability of affordable energy for domestic consumers, reduce energy intensity and emissions and further develop renewable energy systems.

The provisions for renewable energy in this strategy come on the heels of Decree #449 (2013), which established a legal framework for building renewable energy capacity. Within this framework, developers of energy projects with an output of 5MW or more can bid for capacity supply contracts with the country's Trading System Administrator.

In addition, the Law on Energy Microgeneration (2019) enables individuals and small businesses to produce energy for their own utilities and sell the surplus to receive state support, with emphasis on renewable sources. Moreover, up until 2029, revenue from sales of renewable energy will not be liable for taxation (RG, 2020).

Figure 13.2: **Funding and focus of Russian national projects, 2019–2024**

Selected targets and measures of particular relevance to science (expenditure in roubles)

HEALTH CARE

1.73 trillion (*ca* PPP$ 70 billion)

Key targets to 2024:
- lower mortality rate in working-age population from 437 to 350 per 100 000 inhabitants;
- generalize annual preventive physical examinations; and
- make primary medical care readily available.

Measures:
- develop domestic medical research centres and their networks;
- introduce innovative technologies: early diagnosis system, remote patient monitoring, etc.;
- establish lifelong medical training system, including e-learning;
- create disease prevention programmes for heart disease and cancer; and
- extend platform-based e-services.

EDUCATION

785 billion (*ca* PPP$ 31.7 billion)

Key targets to 2024:
- enter global top 10 for quality of education; and
- cultivate socially responsible individuals.

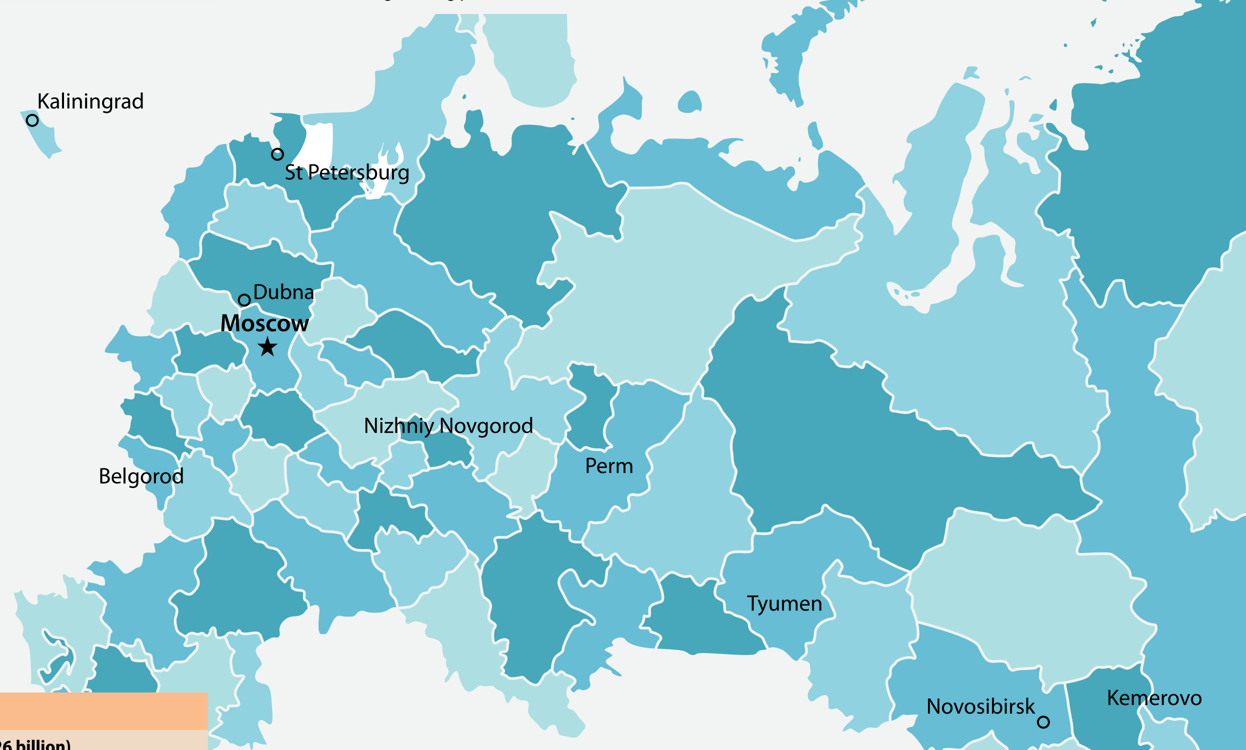
Measures:
- introduce new teaching methods and edutech in vocational training, etc.;
- develop e-learning;
- develop a system to detect, support and cultivate talent in children and young adults;
- upscale international competitiveness enhancement programme for universities;
- give priority support to exports of education services;
- make higher education more attractive; double number of foreign university students; and
- create lifelong learning platform.

DEMOGRAPHY

3.11 trillion (*ca* PPP$ 126 billion)

Key targets to 2024:
- increase healthy life expectancy to 67 years; and
- raise birth rate to 1.7 children per woman, up from 1.63 in 2019.

Measures:
- improve quality of life for the elderly, development of geriatric centres, social services and vocational training;
- provide employment assistance and state aid for women with children: 100% affordability of preschool education by 2021, free courses for women on maternity leave, financial support for families; and
- establish individual health plans for 5.5 million citizens.



SCIENCE

636 billion (*ca* PPP$ 26 billion)

Key targets to 2024:
- join the top five countries for research performance;
- make Russia attractive to leading and young domestic and foreign scientists; and
- accelerate rise in research intensity.

Measures:
- create world-class research centres, including in mathematics and genomics;
- create at least 15 world-class research and education centres in partnership with firms;
- staff under 39 years of age to manage 30% of all new labs and 50% of priority research projects;
- create advanced research infrastructure, including 'megascience' facilities;
- upgrade at least 50% of research instruments at leading R&D organizations; and
- set up training and career development system for R&D personnel, create conducive conditions for young researchers.

CULTURE

114 billion (*ca* PPP$ 4.6 billion)

Key targets to 2024:
- raise number of visits to cultural destinations by 15%; and
- bring about a five-fold increase in access to digital cultural resources.

Measures:
- build 39 cultural centres in cities with a population under 300 000;
- renovate museums, theatres, public libraries;
- establish more art schools for children; and
- train personnel for cultural institutions.

ENVIRONMENT

4.04 trillion (*ca* PPP$ 163 billion)

Key targets to 2024:
- improve industrial and household waste management;
- raise the quality of drinking water;
- restore ecological potential of reservoirs;
- strengthen efforts to conserve biodiversity; and
- lower air pollution by 22%.

Measures:
- create safe waste management infrastructure;
- liquidate 75 hazardous waste facilities;
- increase production of environmental infrastructure using best available technologies;
- conserve the unique aquatic ecosystems of the Volga River, Lake Baikal and Lake Teletskoye;
- establish 24 conservation areas with a combined surface area of 5 million ha; and
- increase forest restoration area to 1.5 million ha.

SAFE AND QUALITY ROADS

4.78 trillion (*ca* PPP$ 193 billion)

Key targets to 2024:
- build better roads, including those of regional importance; and
- lower road traffic mortality rate by 3.5 times.

Measures:
- invest in infrastructure and smart traffic control systems; and
- register best available technologies and building materials for use in roadwork contracts.

HOUSING AND THE URBAN ENVIRONMENT

1.07 trillion (*ca* PPP$ 43 billion)

Key targets to 2024:
- ensure affordable housing for middle-income families;
- build more houses; and
- secure 30% growth in Urban Environment Quality Index, halve number of cities with lowest score.

Measures:
- introduce advanced technologies in engineering and construction;
- instigate smart city projects; and
- improve 31 000 public spaces by 2024.

SMEs AND SUPPORT FOR ENTREPRENEURIAL INITIATIVE

482 billion (*ca* PPP$ 19.5 billion)

Key targets to 2024:
- ensure that 25 million either become entrepreneurs or are employed by SMEs;
- raise share of SMEs to 32.5% of GDP, up from 22.9% in 2019; and
- raise share of SMEs in volume of non-commodity exports to 10%.

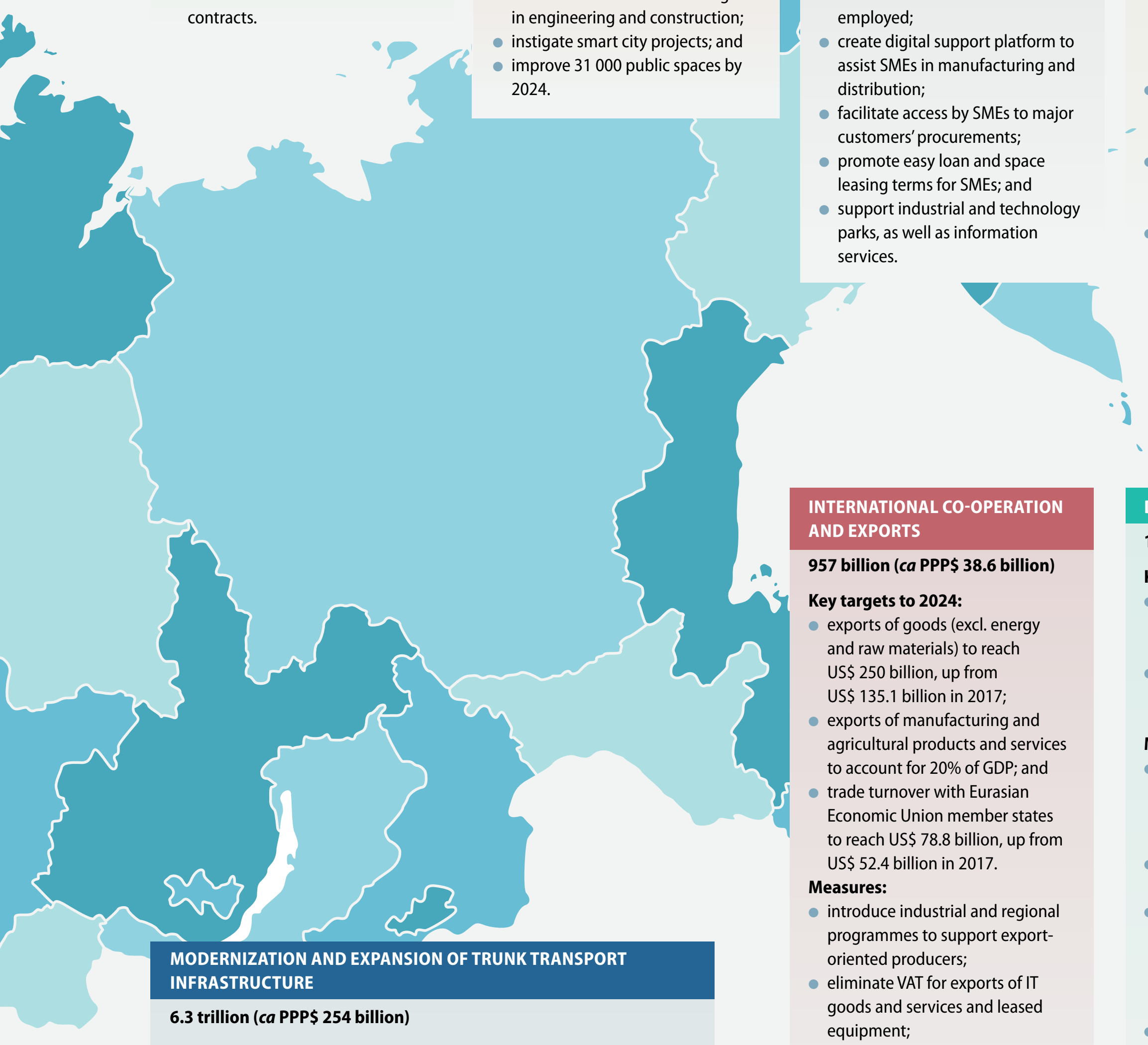
Measures:
- introduce tax benefits for the self-employed;
- create digital support platform to assist SMEs in manufacturing and distribution;
- facilitate access by SMEs to major customers' procurements;
- promote easy loan and space leasing terms for SMEs; and
- support industrial and technology parks, as well as information services.

WORKFORCE PRODUCTIVITY AND EMPLOYMENT SUPPORT

52 billion (*ca* PPP$ 2.1 billion)

Key target to 2024:
- improve labour productivity by at least 5% annually in medium-sized and large firms.

Measures:
- introduce tax incentives for firms that innovate to increase labour productivity and modernize equipment;
- launch pilot projects to improve performance in 10 000 enterprises, via staff training and international internships, etc.;
- extend Industrial Development Fund's loan-based funding programmes;
- introduce interest payments on loans: subsidies for SMEs that raise productivity; and
- create 65 centres of competence in labour productivity.



MODERNIZATION AND EXPANSION OF TRUNK TRANSPORT INFRASTRUCTURE

6.3 trillion (*ca* PPP$ 254 billion)

Key targets to 2024:
- boost connectivity by modernizing all key transportation infrastructure; and
- raise Transport Infrastructure Quality Index to 115.5% of 2017 value.

Measures:

Develop:
- international transport routes 'West–East' and 'North–South';
- volume of cargo transportation in the waters of Northeast Passage;
- transport communication lines connecting economic growth centres;
- regional airport infrastructure and passenger traffic on aviation routes bypassing Moscow;
- high-speed railway lines; and
- a reliable and affordable electricity supply.

INTERNATIONAL CO-OPERATION AND EXPORTS

957 billion (*ca* PPP$ 38.6 billion)

Key targets to 2024:
- exports of goods (excl. energy and raw materials) to reach US$ 250 billion, up from US$ 135.1 billion in 2017;
- exports of manufacturing and agricultural products and services to account for 20% of GDP; and
- trade turnover with Eurasian Economic Union member states to reach US$ 78.8 billion, up from US$ 52.4 billion in 2017.

Measures:
- introduce industrial and regional programmes to support export-oriented producers;
- eliminate VAT for exports of IT goods and services and leased equipment;
- simplify administrative procedures in trade, including export licensing and exchange controls;
- introduce unified multimodal international cargo transport documents; and
- pursue a policy of visa liberalization for foreign nationals travelling to Russia for tourism, medical treatment, education, business, cultural purposes, sports.

DIGITAL ECONOMY

1.63 trillion (*ca* PPP$ 66 billion)

Key targets to 2024:
- raise gross domestic expenditure on the digital economy to 5.1% of GDP, up from 1.7% in 2017; and
- provide broadband Internet access to all households, up from 72.6% in 2017.

Measures:
- develop infrastructure security and stability for high-speed transmission, processing and storage of large data volumes;
- bring 5G to all cities with over 1 million inhabitants;
- raise share of Russian-made software to 90% at public agencies and 70% at state-owned firms, up from 60% and 45% in 2019;
- provide grants to innovative digital technology projects and secondary schools leading in teaching mathematics and informatics;
- establish five world-class research and education centres for mathematics and digital technology; and
- promote e-government services for citizens and businesses.

Note: VAT stands for value-added tax.

Source (in Russian): https://futurerussia.gov.ru

UN Disclaimer

Towards a 'new geography' of Russian science

The National Project for Science focuses primarily on advancing research in priority areas, along with the development and practical application of state-of-the-art technologies. It prioritizes science–industry co-operation and the construction of megascience facilities and other advanced research infrastructure. Modern equipment and research materials will be made more readily available to leading R&D-performing organizations.

The project also intends to contribute to the emergence of a 'new geography' of Russian science. The objective is to set up world-class research and education centres (RECs) in selected regions, in order to develop new competitive technologies and products and train professionals in line with their smart specialization profiles, while promoting interregional co-operation (Figure 13.2).

RECs will be organized into consortia grouping leading research institutes and universities, in collaboration with interested businesses. Regional authorities are expected to take part in priority-setting and to provide financial support and facilities.

Resources will go not only towards setting up the RECs but also to implementing innovative programmes targeting regional development, such as through regional and interregional research and venture capital funds, including those established by large companies.

Partnerships will be forged between regions and other territories with a high potential for research, innovation and production in areas such as problem-oriented research, technology transfer, high-tech products, infrastructure development and the creation of networks grouping modern university campuses with dormitories and other housing for students, researchers and teachers.

The key principle is to 'strengthen the strong'. Of the 15 planned RECs, five had been selected on a competitive basis by 2019 in the following areas:

- digital transformation of the oil and gas industry, 'cold world' resources, people in the Arctic and biosafety (Tyumen Region);
- exploration, production, transportation and processing of solid minerals; mining engineering; recovery and transformation of industrial areas (into technoparks, recreational areas, etc.); and medicine (Kemerovo Region);
- mechanical engineering, chemical industry, robotics, intelligent monitoring and environmental safety in mining (Perm Region);
- supercomputer modelling, geophysics, genetics and personalized medicine (Nizhny Novgorod Region); and
- biotechnology, genetic engineering, digital transformation and resource-saving in the agricultural sector (Belgorod Region).

Along with the 'geographical' dimension, the National Project for Science is supporting a network of world-class specialized research centres through projects involving consortia of leading research institutes and universities.

Seven such projects got under way in 2019. Four of these specialize in mathematics and three in the following areas of genomics: biosafety, genetic technologies for agriculture and industrial microbiology.

Across the higher education sector, the quality of training will be improved to ensure a greater 'research' component in postgraduate studies and encourage students to defend a dissertation. Promising scientific journals will be entitled to financial support and academics who patent abroad to tax benefits.

A NEW POLICY MODEL FOR SCIENCE AND TECHNOLOGY

Seven mission-oriented priorities

The *troika* made up of the National Projects for Science and for Digital Economy and the *National Artificial Intelligence Development Strategy for 2020–2030* translate key provisions of the *Strategy for the Development of Science and Technology* (2016) and Decree 2018 into ambitious, yet practical goals with specific objectives.

The *Strategy for the Development of Science and Technology* to 2035 (2016) has been touted as a new national policy model. It fixes seven mission-oriented priorities, namely: digital manufacturing; clean energy; personalized medicine; sustainable agriculture; national security; infrastructure for transportation and telecommunications; and readiness for the future.

The strategy also prioritizes five key policy initiatives to stimulate a vocation for science and engineering, create favourable conditions for R&D, establish effective science–industry co-operation, improve science governance and promote international scientific co-operation.

An industry-specific toolkit to cultivate innovation

The Presidential Decree on National Goals and Strategic Objectives for the Development of the Russian Federation to 2024 fixes the target of augmenting the share of companies engaged in technological innovation to 50% by 2024, compared to 20% in 2018.

To this end, it is planned to introduce more industry-specific tools to involve a wide range of firms, including small and medium-sized enterprises (SMEs), in innovation in major sectors, such as manufacturing and agriculture, services and creative industries.

The aim is to provide incentives for private and state-owned businesses to invest in innovative projects. This toolkit of incentive measures includes research subsidies, tax incentives, preferential loans, consultancy and training services, the scaling up of seed funding for tech start-ups and the removal of administrative barriers, in order to improve the framework conditions for entrepreneurship and innovation. Other tools will include the introduction of special legal regimes, known as regulatory sandboxes, for different kinds of innovation and innovative companies.

Steps will be taken to promote an innovation culture in government structures, particularly through specialized training, earmarked selection procedures and subsequent career promotion.

Business circles and the general public will also be encouraged to adopt an innovation culture. For instance, companies and individuals will be offered courses in entrepreneurship and information technology (IT). Schoolchildren will be exposed to vocational programmes in science, technology, engineering and mathematics (STEM).

Imagining industrial needs in 2035

The National Technology Initiative, first announced by the president in an address to the Federal Assembly in 2014, is a future-oriented exercise that sets out to help the Russian Federation become a global leader in emerging high-tech markets by 2035 (Gokhberg and Kuznetsova, 2015). This policy initiative provides models of what global frameworks for industry could look like in 2035 and where the Russian Federation would fit into this picture; it also implements projects supporting the development of cutting-edge technologies that are expected to be vital in future markets.

Under this umbrella initiative, several sector-specific roadmaps have been developed in areas considered to be of great promise for the Russian Federation, complete with their anticipated budget allocation. These areas encompass advanced manufacturing technology (TechNet), distributed energy systems (EnergyNet), distributed drones (AeroNet), marine (MariNet) and road (AutoNet) transport systems, food products (FoodNet), personalized health care (HealthNet), human–machine communication and neurotechnology (NeuroNet) and, lastly, ICTs and cybersecurity (SafeNet).

The TechNet roadmap prioritizes Industry 4.0 opportunities and sets the target of having the Russian Federation account for at least 1.5% of the global market for engineering and industrial design services by 2035. This roadmap contains specific projects for such fields as digital design and modelling, new materials, additive technologies, the Industrial Internet and robotics.

The National Technology Initiative has supported more than 500 major technology projects, such as robots for underwater dwellings, autonomous dump trucks for mines, local smart-grid energy supply systems and digital design software for industrial applications. Fourteen existing research institutes and universities have been turned into centres which promote innovative cross-cutting solutions, provide companies with technical assistance and run education and training programmes (NTI, 2019).

The *Russian National Science and Technology Foresight 2030* study, approved by the government in 2014, has also contributed to setting national priorities for science and technology.

This study has been followed by a series of industry-specific roadmaps and foresight studies for science and technology, such as for health care, energy, aircraft manufacturing and agriculture. These roadmaps are being widely used by public authorities, research institutes, universities and businesses as the basis for government or corporate programmes. A network of Foresight Centres in Science and Technology run by leading universities and research institutes has supported this effort since 2014 (Gokhberg, 2016; Gokhberg and Kuznetsova, 2015).

Innovation hubs and technoparks building momentum

The Russian Federation now hosts more than 130 technoparks and innovation hubs, including the flagship Skolkovo Innovation Centre (Gokhberg and Kuznetsova, 2015). There are 2 374 companies registered in Skolkovo alone, up from 1 000 in 2015, along with 138 large domestic and global industrial partners: Microsoft, IBM, Intel, Boeing, Alstom, General Electric, Samsung, Siemens, etc. To ensure that technology is commercialized, Skolkovo provides resident companies with tax and customs incentives, mini-grants for start-ups, grants for research and intellectual property protection, legal advice, etc. (SIC, 2019).

More than 3 000 km away in southwestern Siberia, Academpark, a technopark founded in Novosibirsk in 2007, is home to hundreds of innovative firms. Academpark has become a hub for IT, instrument-making, nanotechnology and biomedicine. A plan is being drawn up to further increase its capabilities in closer collaboration with local research institutes and universities, dubbed Academgorodok 2.0.

In June 2015, a new 'high tech' city was born in the Republic of Tatarstan. Built in just three years, Innopolis already hosts 290 companies in a city of about 3 500 inhabitants. In addition to the usual business infrastructure, it hosts a private IT university and social infrastructure such as schools and hospitals. It aims to attract young and highly qualified professionals from all over the Russian Federation and abroad through minimal corporate taxes and tax-exempt wages.

Despite their benefits, these success stories do not provide the critical mass which would compensate for the rent-seeking behaviour of many Russian industrial companies which, not being integrated in global value and knowledge chains, pay little heed to innovation.

IMPACT OF KEY REGULATORY MOVES

As we saw in the previous edition of the *UNESCO Science Report* (Gokhberg and Kuznetsova, 2015), the overall framework for related policy-making over the period 2012–2017 was set out in the Presidential Decree on Measures to Implement National Education and Science Policy (Decree 2012). This document established qualitative objectives and quantitative indicators for overcoming stagnation and improving the global competitiveness of the national innovation system.

Both covering the period from 2013 to 2020, the State Programme for the Development of Science and Technology and the Basic Research Programme for State Academies of Sciences have proven instrumental in re-orienting research institutes and universities towards scientific excellence and co-operation with industry. These programmes have provided funding for basic and applied research projects, as well as grants for early career researchers and international collaboration.

A megagrant programme launched in 2010 has, likewise, provided additional support for domestic research supervised by leading Russian and foreign scientists. A total of seven tenders have since been launched. In the 2019 round, 36 new projects were selected for funding. Over the 2014–2018 period, the financial resources of public science foundations grew by 90%, examples being the Russian Foundation for Basic Research and the Foundation for Assistance to Small Innovative Enterprises.

Reform of institutions that guide the research sector

The Russian Academy of Sciences has obtained a new status as *the* major national expert institution responsible for scientific supervision and evaluation of publicly funded research.

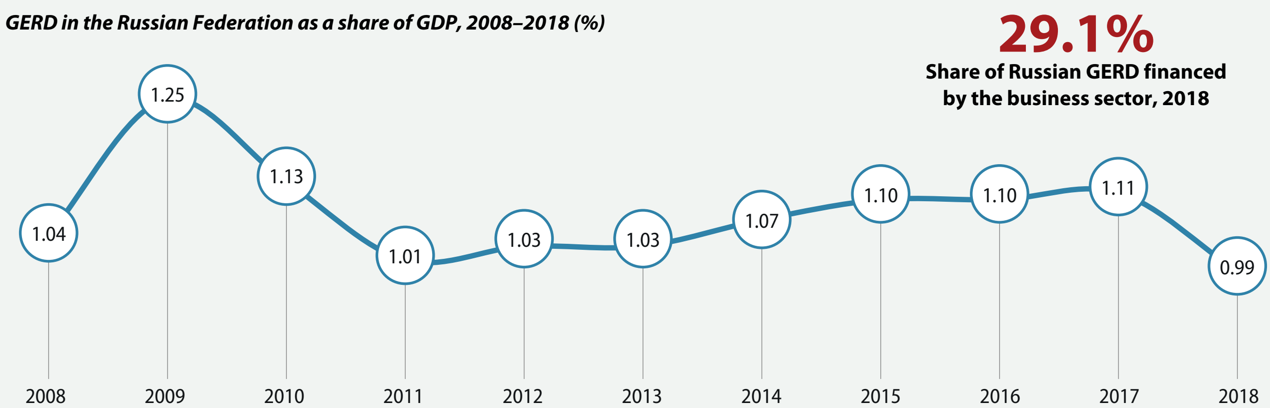
As we saw in the previous edition of the *UNESCO Science Report* (Gokhberg and Kuznetsova, 2015, Box 13.2), a far-reaching reform in 2013 established a system with two nodes of power divided between the Russian Academy of Sciences, on the one hand, and the Federal Agency for Scientific Organizations, on the other. The academy initially retained responsibility for co-ordinating basic research across its institutes (known as academic institutes) and, more recently, for evaluating research results across the entire public research sector.

However, the reform transferred responsibility for managing the academy's finances, property and infrastructure to the Federal Agency for Scientific Organizations. It was entrusted with the mission of constructing a network of allied research institutes, registering their capital assets and launching a new financing mechanism which conditioned project funding for research institutes on the outcome of an evaluation of their productivity. Of the 454 research institutes that used to be co-ordinated by the Academy of Sciences, 142 are considered to be leaders in their field, 205 as developing satisfactorily and 107 as no longer undertaking any research activities whatsoever (RG, 2018).

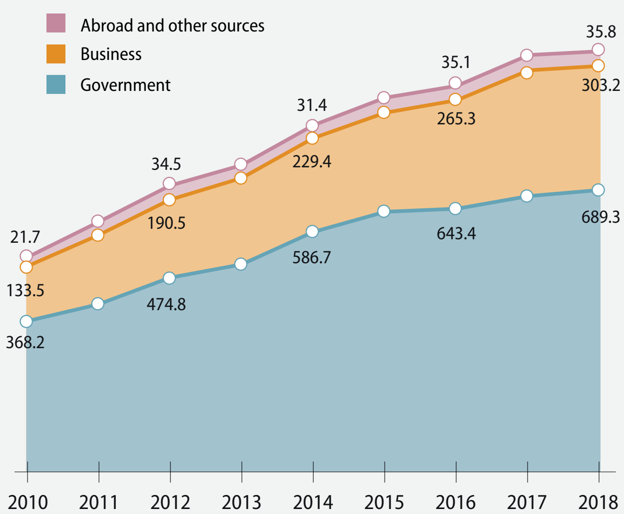
Having completed its mission, the agency was closed in 2018 and its functions transferred to the Ministry of Science and Higher Education (Minobrnauki), which as a result became the authority governing the country's largest network of public research institutes and universities. Minobrnauki is the product of the split of the former Ministry of Education and Science into two separate ministries in 2018 for a better

Figure 13.3: **Trends in research expenditure in the Russian Federation**

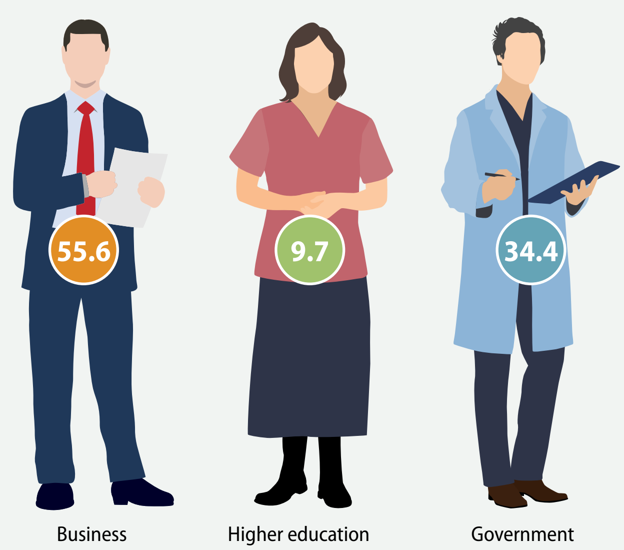
GERD in the Russian Federation as a share of GDP, 2008–2018 (%)



GERD in the Russian Federation by source of funds, 2010–2018
In billions of roubles



GERD by sector of performance in the Russian Federation, 2018 (%)



Source: UNESCO Institute for Statistics; for GERD by sector: HSE (2019a, 2020a) alignment of priorities. The new Ministry of Education is responsible for pre-university education.

Mergers to improve research efficiency

Some 60% of the 3 950 R&D-performing organizations[2] in the Russian Federation are still owned by the federal government (HSE, 2019a and 2020a). Moreover, nearly 40% are research institutes that are administratively detached from both the higher education and industrial sectors. This situation limits the ability of institutes for applied research to attract industrial contracts. It also does little to encourage regional authorities to integrate state-owned bodies into their own regional innovation systems.

The reform of the former academic institutes is being pursued with a view to merging the smaller ones with top-level bodies to create specialized federal and regional research centres. This should improve research productivity by pooling researchers with complementary profiles while making more efficient use of public funding.

One strategic policy aim has been to encourage universities to conduct R&D, such as through relevant state programmes and, more recently, through the National Project for Science (Figure 13.2). Between 2000 and 2015, the number of universities engaged in R&D grew by 160% before falling by almost 12% between 2015 and 2018 following several mergers of state universities. Despite this, the share of universities in the pool of research organizations increased from 19% to 23% over the 2014–2018 period.

RESEARCH TRENDS

Research effort stable but modest

Between 2014 and 2018, gross domestic expenditure on R&D (GERD) grew by 20% in current prices (Figure 13.3), although, in constant prices, it actually dropped by 6%. This places the Russian Federation 9th worldwide for this indicator in absolute terms. In terms of research effort, however, the country is boxing beneath its weight: it devoted just 0.99% of GDP to R&D in 2018, slightly below its effort a decade earlier (HSE, 2019a, 2019b and 2020a) [Figure 13.3].

R&D is still predominantly government funded (Figure 13.3). Several factors explain the modest contribution made directly by foreign sources. One explanation lies in the predominant orientation of foreign direct investment (FDI) towards industry. In addition, Russian scientists are not eligible to apply for funding from major international programmes such as the European Union's (EU) Horizon 2020 (HSE, 2019a, 2019b and 2020a).

Although universities have become more deeply engaged in R&D, these gains are mostly accounted for by a relatively narrow pool of leading universities. The higher education sector has performed a stable 9–10% of GERD for several years. Universities employed 20% of the country's researchers in 2018 (in full-time equivalents), nearly the same share as three years earlier (HSE, 2019a, 2019b and 2020a).

Budget divided among state programmes

In 2019, civil research accounted for RUB 422.1 billion (*ca* PPP$ 28 billion), or 2.8% of the federal budget. About nine-tenths of this amount goes to state programmes, mainly divided between the State Programmes for the Development of Science and Technology; Space Activities; Health Care Development; and the Development of the Aviation Industry (HSE, 2019a, 2019b and 2020a).

The first of these programmes is co-ordinated by Minobrnauki and covers basic research funding, institutional subsidies for public research institutes and universities, collaborative science-industry activities, megascience projects and international scientific co-operation.

The space programme is co-ordinated by the Roscosmos State Corporation for Space Activities, formerly the Russian Space Agency, and includes provisions for R&D relating to space industries and exploration.

The programme on health care, co-ordinated by the Ministry of Health, prioritizes personalized medicine, telemedicine, genomics and biopharmaceuticals.

The programme dedicated to aviation, co-ordinated by the Ministry of Industry and Trade, is looking at prospective aeroplane concepts and engines, new materials and avionics. One recent 'first' in the aircraft manufacturing industry has been the use of three-dimensional printing to create large parts of aircraft engines. This unique approach has made domestic aircraft engines more competitive (MISIS, 2019).

A drop in industrial R&D

The business sector performs the bulk of GERD but its share has declined slightly since 2013 (Figure 13.3). Between 2017 and 2018, business spending on R&D even dropped by 10.6% at constant prices (Figure 13.3). The lack of interest in research demonstrated by firms stems from ineffectual incentives (Gokhberg and Kuznetsova, 2015; Gershman *et al.*, 2018).

To compensate for companies' insufficient participation in funding R&D, the government supports business R&D using a variety of tools ranging from direct R&D subsidies to tax rebates on research expenditure (Gokhberg and Kuznetsova, 2015).

A rise in remuneration to boost numbers

Numbers of researchers, technicians and support staff have been dwindling for years. Since 2010, the researcher population has shrunk by a further 5.7% (HSE, 2019a, 2019b and 2020a).

In 2012, the government set a number of targets to staunch the flow and, thereby, redress the inverted age pyramid (Gokhberg and Kuznetsova, 2015). Chief among them was the decision to increase the remuneration of researchers by 2018. This target has been reached. Following hefty cash injections from the federal budget, the average salary for researchers in most regions had reached, or exceeded, 200% of the average regional wage by 2018 (HSE, 2019a, 2019b and 2020a).[3]

The average age for researchers was 47 years in 2018 (Figure 13.4). Almost one in four had reached retirement age and one in ten was over 70 years old. The good news is that researchers under the age of 39 years are making up a bigger share of the researcher population, thanks to the aforementioned wage growth policies and various grant programmes targeting this age group.

Government efforts to boost researchers' salaries do seem to have succeeded in improving the appeal of a scientific career, judging from a recent survey of public attitudes to science (Box 13.1). However, less than 1% of university graduates are choosing to work for research organizations, suggesting that job conditions in other sectors remain more alluring (HSE, 2019a, 2019b and 2020a).

Women account for 39% of Russian researchers and 57% of the university teaching population, a legacy of policies enacted in the Soviet era that actively promoted gender equality. However, only about one-third of female researchers hold a doctorate and just 2% of full members of the Academy of Sciences are women. Across the board, women still hold fewer prestigious, high-paying jobs than men (HSE, 2019a, 2019b, 2020a).

The distribution of researchers by field of science has remained stable for decades, reflecting the country's predominant specialization in engineering (62% in 2018), mathematics and physical sciences (22%) [HSE, 2019a, 2019b and 2020a].

Russian science more visible

Russian science is becoming increasingly visible in the global research landscape. Between 2015 and 2019, overall scientific output and publication intensity both increased by about 50% (Figure 13.5).

The share of publications by Russian authors indexed in the Scopus database accounted for 3.5% of the world total in 2019.[4] The Russian Federation is counted among world leaders in fields such as physics, engineering, mathematics and chemistry but there are signs of a gap in biology, medicine, agricultural science and psychology (HSE, 2020a). Publications on AI and robotics grew at one of the fastest rates in the world between 2011 and 2019: 3.6% annually (see Figure 13.5), reflecting the priority accorded to this field.

Almost all basic research programmes funded by government agencies and public science foundations now include indicators of publication activity in their expected results. Measurable output is also a priority for the workplans of public research institutes and universities.

Since 2017, the government has offered financial support to help national journals enter the Web of Science and Scopus databases. The Russian Science Citation Index (RSCI) on the Web of Science platform was launched in 2015 at the initiative of the Russian Academy of Sciences, Moscow State University, the Higher School of Economics and the e-Library. Nearly 800 Russian scientific journals are included in the RSCI.

The Russian research community is strongly integrated in international collaboration networks. One-quarter of Russian publications are co-authored by foreign scholars (Figure 13.5).

Russian inventors targeting domestic market

Russian research centres, universities and companies are poorly integrated in global technology chains and hold a weak standing in international markets for intellectual property. In 2018, 17.7% of applications were filed by national inventors at foreign patent offices.

Applicants tend to focus primarily on the domestic market. Since 2015, they have increasingly filed applications for inventions in food chemistry, computer technology, semiconductors, microstructure technology and nanotechnology, reflecting the changing priorities of Russian inventors.

Between 2015 and 2018, the total number of patent applications filed at the Russian Federal Service for Intellectual Property (Rospatent) fell considerably, mostly due to fewer patent applications by domestic inventors (Figure 13.6). The share of foreign applications remained relatively stable at 34–36%.

In response to the downturn, the government has taken steps to stimulate patenting activity. It has reduced the patent duties for applicants and offered tax cuts to alleviate the cost of patenting, loans and credit guaranteed by intellectual property rights. Subsidies are available to those filing patent applications abroad. These efforts need to be scaled up.

The Russian Federation's share of global patents was only about 1% in 2018, compared to 44% for China and 16% for the USA, according to the database of the World Intellectual

Box 13.1: **Russian public has a higher opinion of research profession**

Public opinion surveys conducted by the Higher School of Economics over the past five years reveal that Russians have an increasingly positive view of the impact of science and technology on their daily lives.

This was the case for 88% of citizens in 2018, for instance, up from 83% in 2016. Moreover, seven-tenths (70%) of respondents were of the view that future scientific and technological progress would be more beneficial than harmful for society.

Although most Russians (62%) would welcome their child's decision to become a researcher, this is a lower proportion than in the USA or Israel (80%) where science has an extremely positive public image.

The majority of Russian university students (61%) intend to pursue a career in business; only one-tenth are contemplating a career in science. The main reasons cited are material considerations.

Importantly, it seems that public views about the desirability of scientific careers are shifting. Only 28% believed that researchers earned less than other professions in 2019, down from 42% in 2014.

This is a remarkable shift in public perception in just five years. It suggests that government efforts to boost researchers' salaries and, thereby, improve the appeal of a scientific career, have achieved the desired result.

There is still work to do, however, when it comes to changing popular stereotypes: more than half (54%) of those surveyed in 2018 considered research to be a boring occupation.

Source: HSE (2017, 2018 and 2019a)

Property Organization (WIPO). This value has remained stable, in spite of government incentives, suggesting once again that systemic issues have not been addressed.

Technology trade growing slowly

Exports and imports of tech-related goods and services are growing but progress has been slow and uneven, reflecting the country's relatively poor global competitiveness in certain technological sectors, such as pharmaceuticals, electronics and computer hardware.

In 2018, engineering services dominated technology exports and imports, accounting for about half of all technology trade. Engineering services often accompany large-scale investment projects, such as foreign automobile manufacturing in the Russian Federation or the construction of nuclear power stations abroad by Rosatom. Earnings from protected industrial property accounted for just 2.4% of total revenue stemming from Russian technology exports.

Since 2015, there has been little change in turnover from foreign trade in technology, although revenue did decrease slightly over the 2017–2018 period. There is a persistent deficit in the balance of payments for trade in technology (US$ 1.7 billion in 2018).

The Russian Federation ranked 27th among members of the Organisation for Economic Co-operation and Development (OECD) for the volume of technology exports in 2017 and 22nd for imports of the same. Despite sanctions, little has changed in the structure of import and export markets since 2015: about 60% of Russian exports of technology and 80% of such imports involve contracts with OECD countries, mainly the USA and Germany. By comparison, about 7% of technology exports and 1% of imports of the same involve members of the Eurasian Economic Union (EAEU), a static ratio since 2015.

One in five firms engaging in tech innovation

One in five (19.8%) Russian firms engage in technological innovation, including in the industrial sector (Rosstat, 2020). Manufacturers are the group which applies this type of innovation most actively but, even here, this concerns only 28% of manufacturers. In high-tech sectors, the level of technological innovation ranges from 48% in pharmaceuticals to 60% in computers and electronics, on a par with EU countries. However, high-tech sectors only make up about 4% of Russian industrial output.

Russian companies, particularly in low-tech industries, predominantly adhere to business strategies that focus little on research and innovation. Innovative development is being hampered by the low level of competition in the economy, companies' limited funds, the high short-term costs required to innovate and the risks associated with investing in innovation.

Business expenditure on technological innovation, in constant prices, has stagnated since 2015. It tends to remain heavily concentrated (75%) within the same narrow group of large companies, those with between 1 000 and 4 999 employees; 43% of these enterprises are active in innovation and produce 82% of the total value of innovative products.

TRENDS IN HIGHER EDUCATION

Fewer Russians value higher education

The Russian Federation is among global leaders for the rate of completion of higher education programmes: almost 57% of those aged 15 years or above hold a university degree,[5] with the gender balance slightly favouring women (Figure 13.4). Among graduates, 11% obtained specialist diplomas (typically a five-year programme) in 2018, which correspond primarily to university engineering programmes targeting industry.

Across all demographics, the share of the population with a bachelor's degree or higher is on a par with other developed countries but this proportion is expected to decline in the coming years, since the older generation is more likely to hold a degree than younger Russians. A growing proportion of Russians have come to the conclusion that the importance of higher education is 'exaggerated.' More than half of the population (56%) held this view in 2018, up from 45% in 2008 (VCIOM, 2018). The proportion of sceptics even rises to 72% for 18–24-year olds.

Several factors may be responsible for this cultural shift. For one thing, higher education has become more elitist. Even though the paid segment of higher education dropped from 59% to 54% in 2015–2018, tuition fees rose by 45% over the same period and cities hosting leading universities tend to have a high cost of living.

The wages of university graduates are 60% above the national average but graduates have found that a well-paid job can be difficult to come by, even with a degree. This is because, on the whole, the Russian higher education system is not yet turning out graduates with the requisite competencies and skills for the shifting needs of the economy and society at large (Kuzminov *et al*., 2019).

Since improving the quality of Russian universities is a government priority, public policies will need to invest more in the higher education sector. Public expenditure is, currently, lower than in other developed countries (Figure 13.4).

Tangible results for the 5/100 Programme

The government's 5/100 Programme has produced some tangible results. It was adopted in 2013 to raise the global competitiveness of Russian universities to the point where at least five figured in the top 100 (hence the programme's name) and the remainder in the top 200 of global university rankings (Gokhberg and Kuznetsova, 2015). By 2020, the programme had selected 21 universities, on a competitive basis, grouping over 360 000 students. More than half are prestigious national research universities.

In 2019, 12 Russian universities ranked in the top 300 by Quacquarelli Symonds, the Academic Ranking of World Universities and the Times Higher Education Supplement were 5/100 participants. Eight of these also entered the global top 100 in rankings by specialization, namely the Higher School of Economics in Moscow, the Moscow Physics and Technology Institute and the Moscow Institute of Steel and Alloys, the Novosibirsk University, the University of Information Technologies, Mechanics and Optics in St Petersburg, Tomsk Polytechnic University, Kazan Federal University and the Moscow Engineering Physics Institute.

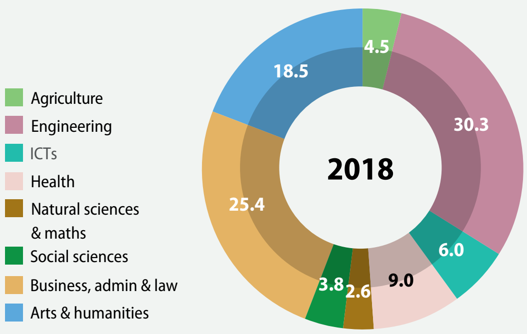
The 5/100 universities have managed to step up their contribution to research and innovation. By 2018, they accounted for half of the top 10% most highly cited Russian academic publications, compared to 24% in 2013.

They have managed to attract leading Russian and foreign academics, as well as talented young people, and expand the range of educational programmes that they offer in partnership with renowned international universities and research centres.

Since 2014, the 5/100 universities have organized themselves into the Association of Global Universities, to improve co-ordination and enable them to shape public policies for education, science and technology.

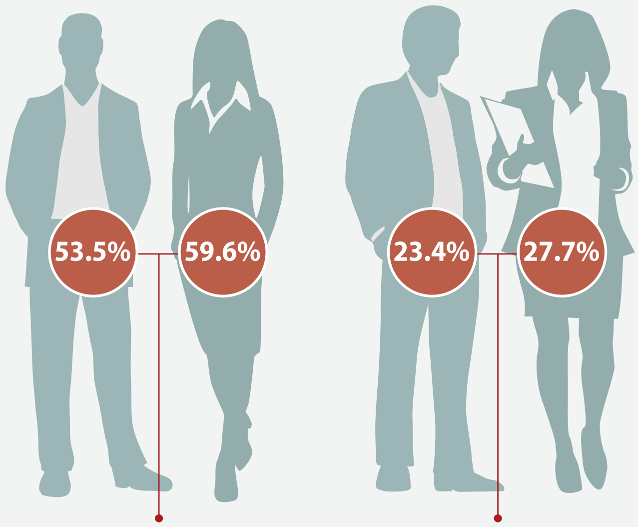
Figure 13.4: **Trends in human resources in the Russian Federation**

Distribution of tertiary students in the Russian Federation by programme, 2018



42.9%

Gross enrolment ratio for tertiary students in the 15–25 year age bracket in 2018



Russians over the age of 15 years who hold a tertiary degree, 2018

Russians over the age of 15 years who hold a specialist diploma, 2018

Number of students and graduates attending Russian institutions of higher education, 2015–2018

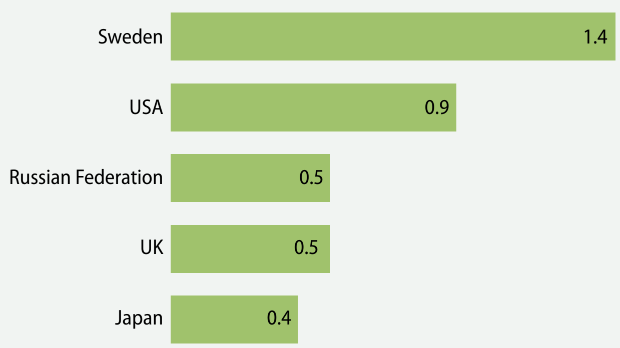
	Bachelor's/master's or equivalent		**PhD or equivalent**			
	Number of students (millions)	Graduates (millions)	Enrolled (thousands)	Graduates (thousands)	Number of defended dissertations (thousands)	Students having defended their dissertations on time (%)
2015	4.8	1.3	109.9	25.8	4.7	18.0
2016	4.4	1.2	98.4	26.0	3.7	14.4
2017	4.2	1.0	93.5	18.1	2.3	12.8
2018	4.2	0.9	90.8	17.7	2.2	12.4

Note: Tertiary studies from the bachelor's to the master's or equivalent level correspond to levels 5–7 of the International Standard Classification of Education (ISCED). The numbers of students for PhD and Candidate of Science degrees are combined here, corresponding to ISCED level 8.

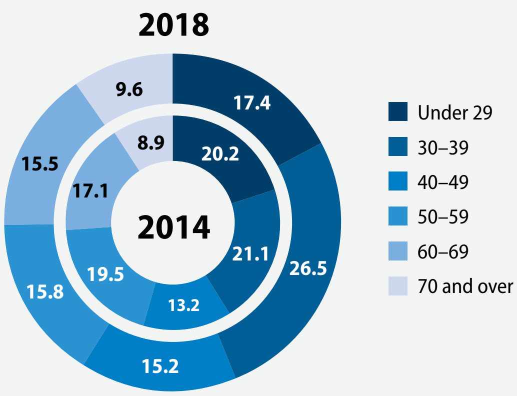
The average age of Russian researchers was 47 years in 2018.

Public expenditure on higher education in the Russian Federation as a share of GDP, 2018 (%)

Other countries are given for comparison



Breakdown of Russian researchers by age, 2014 and 2018 (%)



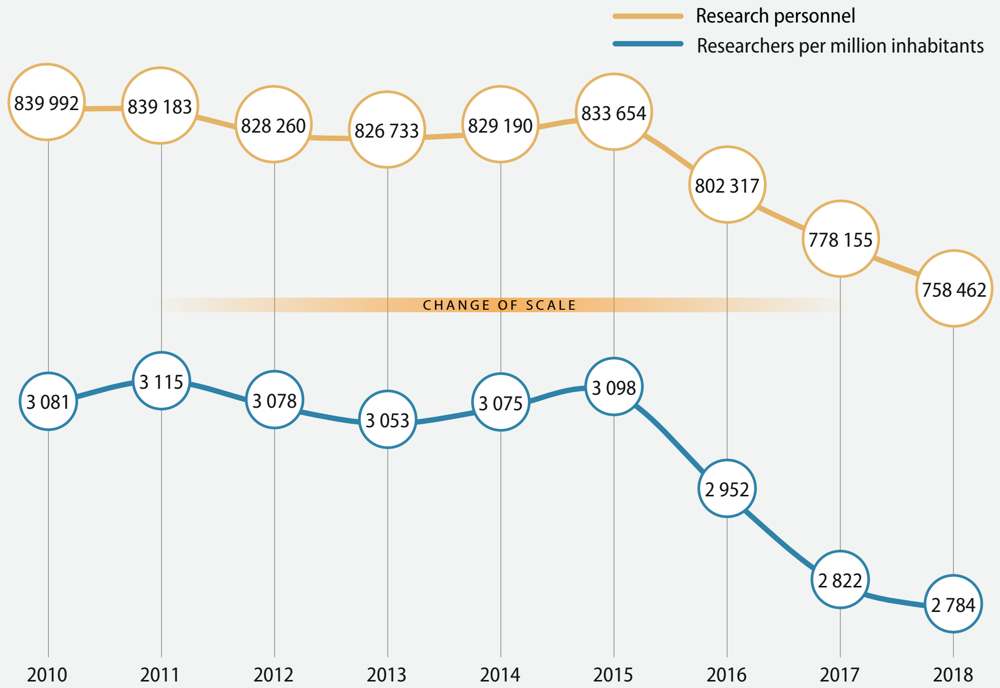
Postgraduate programmes deteriorating

If leading universities are in a class of their own, the performance of postgraduate programmes has been deteriorating. The inefficiency of such programmes risks mortgaging the future of Russian research by impeding the renewal and rotation of the national research pool.

The legislative adoption of the educational programmes format for postgraduate studies in 2012–2014 has broadened the divide between learning and research, essentially making it optional for PhD students to defend a thesis.

Many experts are leaning towards the idea of strengthening the role of the postgraduate system as a way of training

Research workforce in the Russian Federation (FTE), 2010–2018



Note: Research personnel encompass researchers, technicians and support staff.

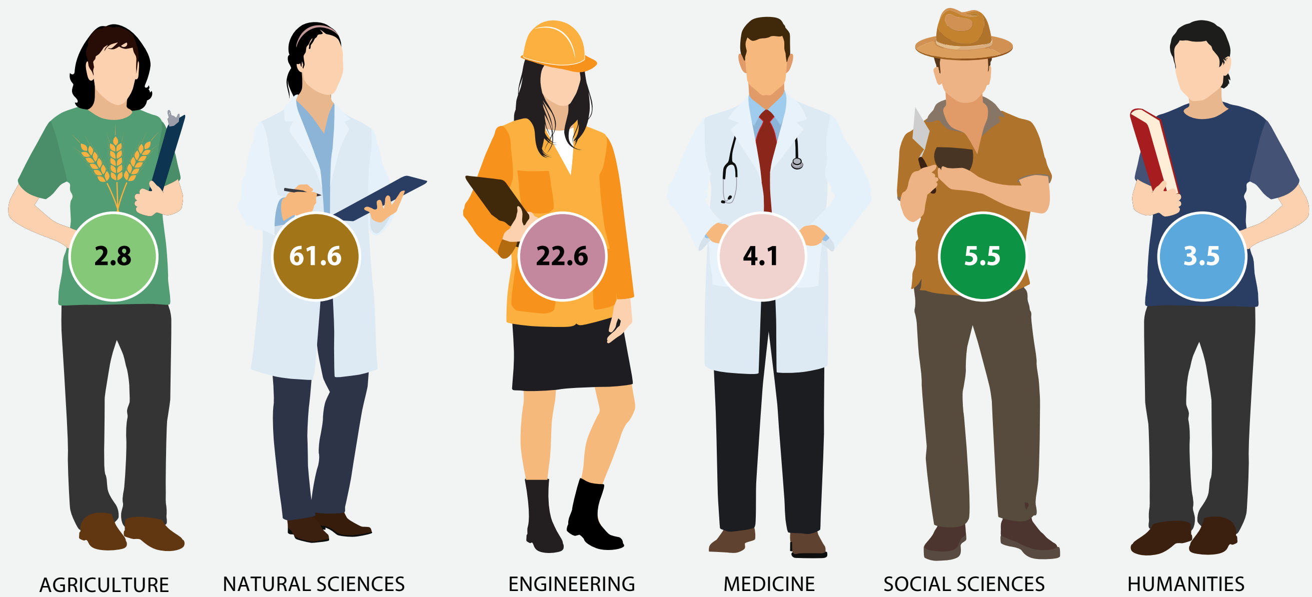
347 854
Number of researchers in 2018 (head counts), equivalent to 405 772 in FTE

39%
Share of women among Russian researchers

57%
Share of women among Russian university teaching personnel

The Russian research workforce, including technicians and support staff, is the fourth-biggest in the world after those of the USA, China and Japan.

Russian researchers by field (head counts), 2018 (%)



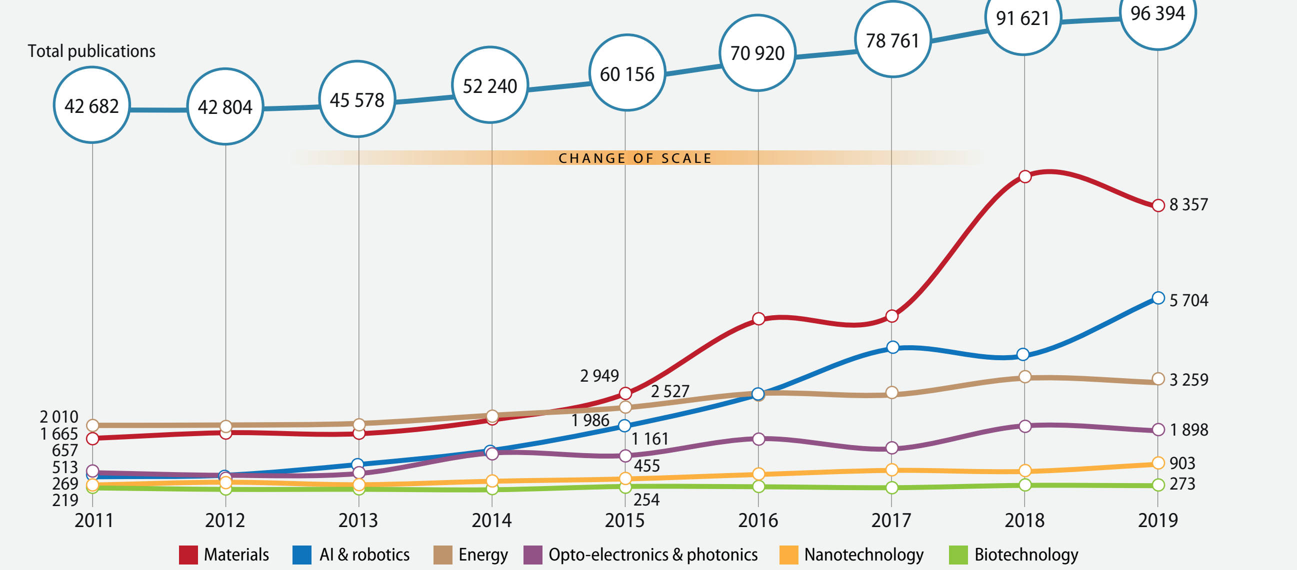
Source: HSE (2019a,c; 2020a,b); UNESCO Institute for Statistics

Chapter 13

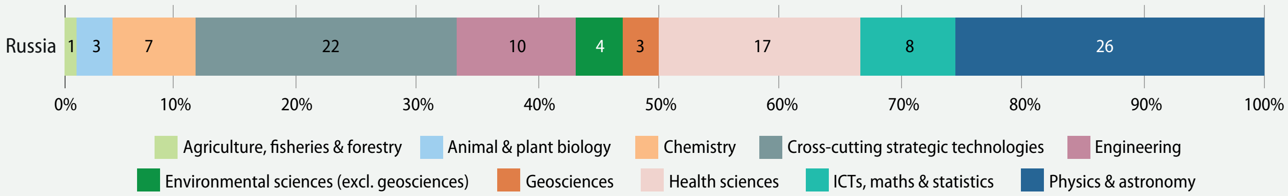
Figure 13.5: **Trends in scientific publishing in the Russian Federation**

Volume of scientific publications in the Russian Federation, 2011–2019

Total publications and output on cross-cutting strategic technologies



Scientific publications in in the Russian Federation by broad field of science, 2017–2019 (%)



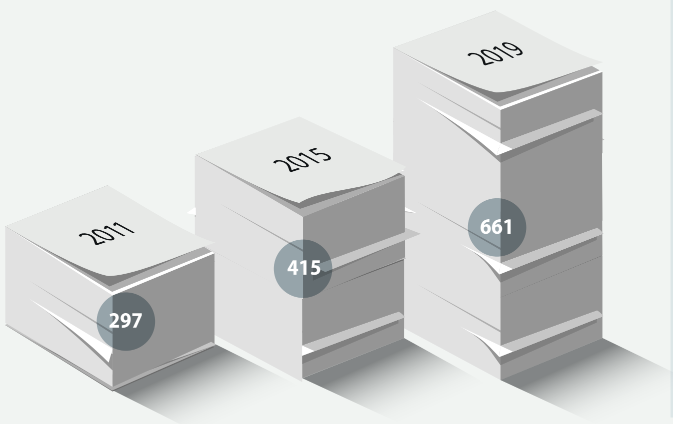
0.71

Average of relative citations, 2014–2016; the G20 average is 1.02

24%

Share of Russian publications with foreign co-authors, 2017–2019; the G20 average is 25%

Scientific publications per million inhabitants in the Russian Federation, 2011, 2015 and 2019



How has output on SDG-related topics evolved since 2012?

Russian scientists are publishing more on nuclear fusion and radioactive waste management than would be expected, relative to global averages.

On the topic of nuclear fusion, their intensity is double the global average. Output rose from 869 (2012–2015) to 1 042 publications (2016–2019) and on radioactive waste management from 387 (2012–2015) to 607 (2016–2019) publications.

The Russian Federation has 36 operational nuclear reactors. It has been working with the European Union to improve nuclear waste treatment (Box 13.2). It also has a stake in the International Thermonuclear Experimental Reactor in France, which will be developing nuclear fusion technology.

Among selected topics with at least 100 publications during the period under study, sustainable transportation showed the fastest growth, with a seven-fold increase from 83 (2012–2015) to 607 (2016–2019), even though this topic is underrepresented in the Russian Federation, relative to global averages (SI = 0.32).

The next-fastest growth occurred in other underrepresented topics (SI = 0.2–0.6): eco-construction materials; precision agriculture; wind turbine technologies; wastewater treatment, recycling and re-use; agro-ecology; and eco-industrial waste treatment.

Note: SI = specialization index. For details, see chapter 2

Russian Federation's top five partners for scientific co-authorship, 2017–2019 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Russian Federation	USA (14 476)	Germany (14 026)	France (8 621)	UK (7 874)	China (7 297)

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

researchers specifically. An important step in this direction was a government decision in 2015 to allow 25 leading universities and four research institutes to award their own advanced degrees with stronger emphasis on meeting international academic standards.

SCIENCE DIPLOMACY

A desire to deepen scientific co-operation

The Russian Federation is embracing science diplomacy as a means of supporting the research community's efforts to find common technological solutions to global challenges and, secondly, improving the country's international image. Russian interest in subregional associations and bilateral partners is growing.

One manifestation of this desire to deepen bilateral and multilateral scientific co-operation is the country's participation in the construction and operation of facilities for megascience projects. For example, the Russian Federation owns 27% of the European X-Ray Free-Electron Laser Facility (XFEL) project in Germany. The construction and launch of this international centre for basic research was the starting point for the approval of the bilateral *Roadmap for Russian-German Cooperation in STI* in December 2018. The document is broken down into four sections: Large Research Infrastructure; Priorities; Young Talent; and Innovation, Science and Society. The *Roadmap* was officially approved in 2019 (Minobrnauki, 2019a).

Another example is the joint hosting of the annual meeting of the Global Research Council in Moscow in May 2018 by the Russian Foundation for Basic Research and the National Research Foundation of Korea, on the dual topics of science diplomacy and revisiting peer review practices (GRC, 2018).

A third example is the growing role of science diplomacy in the Arctic (Box 13.2).

A fourth example is the partnership with UNESCO to create the Mendeleev International Prize for the Basic Sciences, which will be awarded for the first time in 2021. The US$ 500 000 prize recognizes outstanding achievement in biology, physics, chemistry and mathematics, including in emerging fields such as computational science and climate modelling. It is named after Dmitri Mendeleev, considered the father of the periodic table of chemical elements. The annual prize builds on the United Nations' International Year of the Periodic Table of Chemical Elements in 2019, which was sponsored by the Russian Federation.

The country's objectives are defined in its long-term *Science and Technology Development Strategy* (2016) and *Concept of International Science and Technology Cooperation* (2019). These documents reflect the national interest, international approaches to meeting global challenges and the sustainable development agenda.

The government's efforts focus on:

- defining the goals of, and formats for, co-operating with other nations, taking into account their level of technological development and innovative potential;
- establishing strategic partnerships in priority areas and stepping up science diplomacy;
- developing global research infrastructure, with a focus on localizing facilities and implementing major international research projects in the Russian Federation;
- increasing Russian participation in international peer review and forecasting systems;
- supporting Russian research bodies and manufacturing companies wishing to enter global knowledge and technology markets; and
- promoting Russian proactive participation in the development of technological standards and formats for research and education to enhance its role in creating new markets.

Growing scientific co-operation with China

At the bilateral level, some of the most multifaceted co-operation is being developed with China. The Association for Scientific and Technical Cooperation between the Russian Federation and China has been operational since 2018. It supports joint projects by academic institutions at the regional level.

The *Russian-Chinese Roadmap for Scientific and Technical Cooperation* for the medium and long term was being finalized in 2020. It covers a broad range of areas, including digital technologies, intelligent transportation systems, new materials, large data processing systems, personalized medicine, new sources of energy, energy-saving and environmentally friendly technologies and genomics for plant and animal production.

In addition, an agreement has been reached to implement four subprojects with China at the new Nuclotron-based Ion Collider Facility; this facility is being built at the Joint Institute for Nuclear Research in Dubna in the Russian Federation and should be completed in 2022 (Minobrnauki, 2019c).

Bilateral business contacts are also being activated. For example, in 2018–2019, the Chinese firm Huawei signed contracts with Russia's VimpelCom and with a number of other Russian companies and universities for the development of artificial intelligence, the Internet of Things and piloting and integration of 4.5G/ 5G technological solutions. Huawei will be adding research centres in at least three more regions to its existing ones in Moscow and St Petersburg.

Space main channel for co-operation with USA

The Russian Federation is pursuing scientific co-operation with the USA mainly through the National Aeronautics and Space Administration (NASA), in relation to the International Space Station, and with the US National Academy of Sciences.

A new agreement between the Russian Academy of Sciences and the US National Academy of Sciences was signed in 2019. Co-operation spans exploration of the Moon and Venus and other space-related research, population ageing, new diagnostic methods and the treatment of neurodegenerative diseases.

A broad agenda for BRICS

Priority areas for co-operation were identified with fellow BRICS (Brazil, India, China and South Africa) in 2015. They include: space systems and astronomical observations;

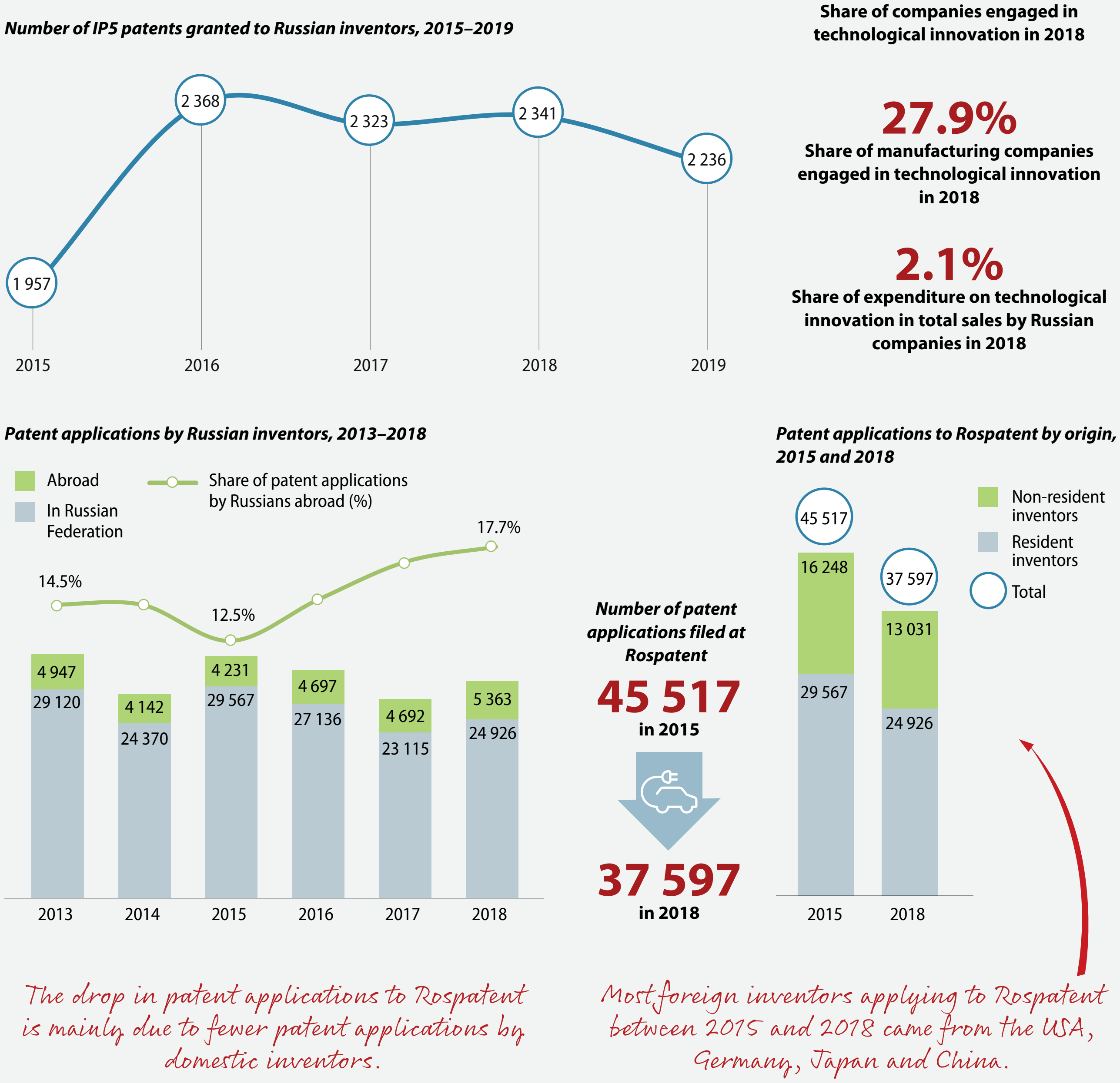
ICTs, advanced manufacturing technologies and robotics; renewable energy sources; climate change, environmental protection and disaster management; and water resources.

This co-operation was formalized through the *Memorandum on STI Co-operation* (2015) and the *BRICS Economic Partnership Strategy* (2015). Workplans for 2015–2018 and 2019–2022 have also been approved.

The five partners also decided in 2016 to develop the BRICS Networking Platform and Framework Programme for Multilateral STI Projects. The five countries use this platform to launch co-ordinated project tenders. Between 2016 and 2019, 93 projects were supported in materials science (29 projects), biotechnology and biomedicine, including health care and neural science (13), new and renewable energy sources (11), IT and high-performance computing (8), water resources (8), photonics (6), the prevention and management of natural disasters (5), astronomy (5), geospatial information systems (4), the global ocean (3) and aeronautics (1).

The BRICS Global Research Advanced Infrastructure Network (GRAIN) is also under construction. This platform will support the participation of scientists from BRICS countries in megascience projects, as well as data sharing. One idea is to use research

Figure 13.6: **Trends in innovation in the Russian Federation**



Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China.

Source: HSE (2019b and 2020a), based on Russian Federal Service for Intellectual Property (Rospatent) and World Intellectual Property Organization (WIPO) data; Rosstat (2020); for IP5 patents: PATSTAT, data treatment by Science-Metrix vessels from the BRICS member states for joint expeditions to the Arctic and Antarctic Oceans (Minobrnauki, 2019b).

Meanwhile, the New Development Bank has accumulated about US$ 100 billion since it was established by the BRICS in 2015. It is investing in infrastructure development projects in renewable energy, protection of nature, water purification and cultural heritage.

EAEU: a territory of innovation?

In 2018, the Russian Federation took advantage of its rotating presidency of the Eurasian Economic Union (EAEU) to propose a number of areas in which to 'readjust' the Union, including the formation of a common digital space (see also chapter 14) and energy market for member states; and co-operation in the fields of green technology, renewable energy sources, bioengineering, nanotechnology, ecology, medicine and space.

EAEU members are keen on the idea of creating a 'territory of innovation' which would take advantage of their different strengths to promote technological breakthroughs. Global networking is considered a priority with the following major organizations, among others: Shanghai Cooperation Organisation, Association of Southeast Asian Nations (ASEAN), EU, Mercosur, World Trade Organization and the OECD (EAEU, 2018). An action plan for this purpose will be discussed in the near future.

A strong focus on tech markets elsewhere in Asia

The *ASEAN–Russia Plan of Action on STI* to 2025 was adopted in 2016. In 2019, joint projects with ASEAN were implemented on biological (parasitic) safety and new technologies for industrial water treatment.[6] The partners are also fostering academic mobility and student exchanges in the field of engineering (Minobrnauki, 2020).

The Russian Federation is participating in the Asia–Pacific Economic Community's (APEC) Policy Partnership on Science, Technology and Innovation (2016–2025), which supports innovation-based economic growth. In 2019, recommendations were approved for a dialogue on how to use nanotechnology to increase energy efficiency.

The interactive APEC Platform for the Economies' Clusters is now operational and is being co-ordinated on the Russian side by the Higher School of Economics' Russian Cluster Observatory.[7] The aim is to harmonize policies shaping future technology markets and promote co-operation with a view to commercializing and disseminating radically new technologies. This co-operation is taking the form of information-sharing on issues such as the regulation of new technology markets and intellectual property protection in the APEC economies through the future APEC Technology Communication Network and Cloud Platform (APEC, 2015 and 2018; Minec, 2019c).

Box 13.2: **The Arctic: a new frontier for science diplomacy**

With warmer temperatures making the Northern Sea Route navigable for longer over the summer months, the Arctic has become a key strategic focus for the Russian Federation, China, EU and USA.

President Putin stated in April 2019 that one-tenth of the country's economic investment went to the Arctic region and that its role in the national economy would increase (PoR, 2019). The region is rich in mineral resources, including untapped oil and gas.

It is hard to underestimate the role of science diplomacy in the Arctic, where scientists are actively stepping up co-operation to reduce international tensions. According to the EU's ambassador-at-large for the Arctic, states are engaged in 'co-operation, not competition'. The EU and Russian Federation have worked together on issues that include water waste management and treatment of nuclear waste (Astrasheuskaya and Foy, 2019).

On 11 May 2017, the eight Arctic States, namely Canada, Demark, Finland, Iceland, Norway, the Russian Federation, Sweden and USA (with China as an observer) signed the Agreement on Enhancing International Arctic Scientific Cooperation. The agreement was negotiated under the auspices of the Arctic Council, co-led by the Russian Federation and the USA (Berkamn *et al.*, 2017). This is the third legally binding international instrument to be signed by the Arctic States, following those on search-and-rescue and marine oil pollution preparedness and response.

This agreement targets better use of existing infrastructure in the Arctic region; enabling mobility of researchers, equipment and personnel; promoting data sharing; and encouraging those who possess local and traditional knowledge to participate in scientific activities conducted across the Arctic territories.

At the Fifth International Arctic Forum on The Arctic: Territory of Dialogue, in St Petersburg in 2019, no fewer than 45 agreements were signed, including one on scientific co-operation and the development of high-tech sectors.

For example, the Russian Federation and China agreed to establish a research centre to study the Arctic and preserve its biodiversity. A second agreement between the Russian Federation and Finland approved plans to study the region jointly from both a scientific and cultural perspective.

The Russian Federation will hold its second chairmanship of the Arctic Council over 2021–2023. This intergovernmental forum fosters co-operation, co-ordination and interaction among Arctic states, indigenous communities and inhabitants, with a focus on sustainable development and environmental protection. Eleven legally recognized indigenous groups live close to, or above, the Arctic Circle (Arctic Council, 2020).

Ripples from scientific co-operation in this area have the potential to flow into wider government policy-making.

Source: compiled by authors

CONCLUSION

Time for a rapid-reaction policy evaluation system

Quality research and technological innovation are key to strengthening the competitiveness, independence and security of any nation. Countries are increasingly focusing on assessing external and internal challenges and risks, developing goal-setting and communication mechanisms, improving their resource potential and co-ordinating regulatory measures. The Russian Federation is no exception.

The government is keenly aware of the need to develop an effective management system capable of finding practical solutions to prevailing challenges. For the Ministry of Finance, 'successful national projects are not so much a question of resources as having a goal-oriented management system. An innovative approach to management will ensure that the entire system is structured from the federal to municipal levels, that all relevant authorities are involved and that progress is monitored' (Minfin, 2019).

It is time to re-evaluate existing STI policy tools, in order to upscale those that have produced results and adjust those that have not. To this end, and following the example of other countries, the Russian Federation would do well to introduce a national system for evaluating the relevance, effectiveness and demand for policies currently being implemented, in order to improve the co-ordination of regulatory mechanisms. This policy evaluation system should include feedback mechanisms which provide opportunities to make timely adjustments to regulatory measures for efficiency gains.

In order to take its rightful place among global leaders in science and technology, the Russian Federation will need to act quickly and develop at a faster rate than its primary competitors.

KEY TARGETS FOR THE RUSSIAN FEDERATION

See Figure 13.2 for national targets to 2024.

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ENDNOTES

1 By late July 2020, there were 800 000 confirmed Russian cases of Covid-19, according to the Johns Hopkins Coronavirus Resource Center in the USA.

2 There are two ways of classifying R&D-performing organizations. The first is by ownership: in the Russian Federation, 60% are owned by the federal government and the rest by regional authorities or public and private companies. The second is by type: 40% are research institutes and the remainder design bureaux, universities, industrial enterprises and so on.

3 In regions with a high concentration of research capacity and high average incomes, research careers are slightly less competitive in terms of the local labour market than in other regions. For example, in Moscow, the remuneration ratio was 192% and, in St Petersburg, 195% of the average income in 2018.

4 For the three types of publications indexed in the Scopus database, namely articles, reviews and conference papers.

5 For adults over the age of 24 years, these values are even higher: for university degrees in general, this figure is 65%, which breaks down into 60% for men and 70% for women. For university diplomas, this figure is 30%: 26% for men and 34% for women (HSE, 2020b).

6 In February 2019, the Russian Federation and ASEAN decided to substantiate their collaboration at the Third ASEAN–Russia Summit, by maximizing the utilization of the ASEAN–Russia Dialogue Partnership Financial Fund (2007) for joint projects. See: https://asean.org/asean-russia-commit-deepen-cooperation

7 For details, see: https://cluster.hse.ru/mirror/pubs/share/337949718

AT A GLANCE

In July 2019, a solar panel provides a nomadic community in the Gobi Desert with electricity. By 2030, Mongolia aims to raise the share of renewables in its electricity supply to 30%. Countries in Central Asia are focusing on 'greening' transportation, energy, agriculture and waste management, among other sectors. © Mikhail Kokhanchikov

- Rapid economic growth over the past 20 years has raised domestic demand for electricity, pushing up carbon emissions and eating into export revenue.
- Countries are working with international partners to transition to a green economy and, thereby, mitigate their water and energy problems; one challenge will be to balance competing demands for innovation from the mining sector, which forms the bedrock of their economies.
- All countries are keen to embrace a digital economy and develop e-governance, in order to improve public service delivery and create a better business climate, but they face a skills gap.
- Confronted with an ageing researcher population after years of negligible research budgets, governments are seeking to improve the status of researchers through measures such as pay rises, competitive research grants and greater interaction with institutional partners abroad.
- Governments are setting up communication channels with the private sector like technoparks to nurture an innovation culture and, thereby, relieve the heavy burden on the state budget while modernizing their economies.

14 · Central Asia

Kazakhstan, Kyrgyzstan, Mongolia, Tajikistan, Turkmenistan, Uzbekistan

Yerbol Suleimenov

INTRODUCTION

Structural reforms still work in progress

Situated at the crossroads of Asia and Europe, Central Asia is of growing strategic importance.[1] Rich in minerals and hydrocarbons, it serves as a major transit zone, supplying the global economy with vital raw materials: oil, gas, coal, metals and agricultural products. Hydrocarbons and metals account for as much as 30% of Kazakhstan's GDP, 70% of its exports and up to half of government revenue (OECD, 2018a).

During the commodities boom, Kazakhstan, Mongolia and Turkmenistan saw some of the highest economic growth rates in the world. These boom periods being cyclical, the slump in global oil prices after mid-2014 affected growth in these countries (Figure 14.1).

Although growth rates across the region averaged 4.4% in 2018, price volatility for commodities has been a source of instability in a region where the economy remains largely driven by wholly or partly state-owned entities. Small and medium-sized enterprises (SMEs) tend to operate on the fringes of the informal economy (OECD, 2018a).

Conscious of this vulnerability, Central Asian governments have been pursuing efforts to eliminate structural imbalances and transition to a more multilayered market economy. There are plans to privatize state property and numerous enterprises further.

In order to create a more investment-friendly climate for business, Kyrgyzstan and Uzbekistan have taken energetic steps since 2017 to combat corruption in public administration.[2]

Exports of goods and services as a share of GDP have risen in all but Kyrgyzstan and Turkmenistan since 2015 (Figure 4.1) but the economic base remains relatively narrow. Mineral fertilizers form the bedrock of the chemical industry in all but Kyrgyzstan,[3] reflecting the considerable role played by agriculture in the economy (Figure 14.1).

Agricultural processing and manufacturing tend to take place elsewhere, however, resulting in little value addition (Hofman, 2018). Despite agriculture contributing almost one-third of Uzbek GDP (Figure 14.1), value-added agriculture totalled less in 2018 (US$ 14.3 billion) than in 2014 (US$ 25.2 billion). The modernization of agriculture is a key focus of Uzbekistan's development strategy to 2021 (Rep. Uzbekistan, 2017).

Another priority is consumer goods. Kazakhstan, Mongolia and Uzbekistan are all developing machine-building capacities, with an emphasis on the production of cars, trucks and buses (KEU, 2019; Rep. Uzbekistan, 2018; ADB, 2014).

A desire to attract foreign business investment

High levels of government debt pose a challenge to Mongolia, Kyrgyzstan and Tajikistan (Figure 14.1). Research has shown that a rising central government debt-to-GDP ratio beyond 50–60% heightens the risk of debt distress (Chudik *et al.*, 2015).

Loans represent the bulk of foreign investment in current international infrastructure projects in Central Asia, including a number of major highways, railways, pipelines and hydropower plants. This is reflected in the investment portfolios of the World Bank and European Bank for Reconstruction and Development (EBRD), as well as China's Belt and Road Initiative, which is building a pipeline from China to Mongolia, Kyrgyzstan and Tajikistan (Hurley *et al.*, 2018).

In its *Mongolia Sustainable Development Vision 2030* (2016), Mongolia fixes a target of reducing foreign debt to 50% of GDP by 2025 and to 40% of GDP by 2030.

The region has not escaped the global downturn in foreign direct investment (FDI). The sharp drop in inflows to Kyrgyzstan (Figure 14.1) may also be linked to the fact that the government's *Medium-term Foreign Debt Management Strategy* (2018–2020) offers no financial guarantees for foreign companies interested in investing in the country.

Mongolia, by contrast, has amended legislation to improve its own business environment. Since 2013, foreign state corporations need not obtain prior state authorization to acquire more than 33% of the shares in a Mongolian enterprise in a strategic sector, or more than 50% in other industries.

The combination of a better business climate and higher metal prices channelled FDI worth US$ 1.5 billion into Mongolia in the first 11 months of 2018, a 26% increase over the same period in 2017. According to the Ministry of Finance, most FDI has gone into the second phase of a project developing the underground Oyu-Tolgoi copper and gold mine in the Gobi Desert, which was expected to account for one-third of state revenue in 2019.

Closer ties to the outside world

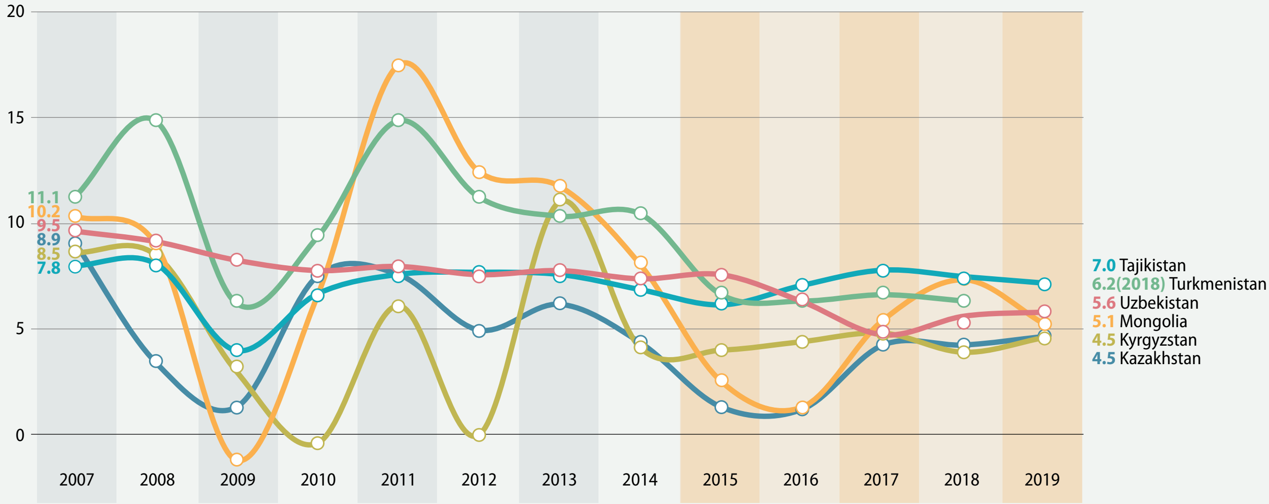
Kazakhstan became a member of the World Trade Organization (WTO) on 30 November 2015, following the accession of Kyrgyzstan and Tajikistan in 1998 and 2013, respectively. This is an important step towards Kazakhstan's integration in international institutions, as it ensures market access for a wide range of goods and services and provides a framework for negotiating trade agreements (OECD, 2018a).

Kazakhstan's integration into the WTO came just months after it had formed the Eurasian Economic Union with Belarus and the Russian Federation. Today, this customs union groups five members, including Armenia and Kyrgyzstan (see also Chapters 12 and 13).

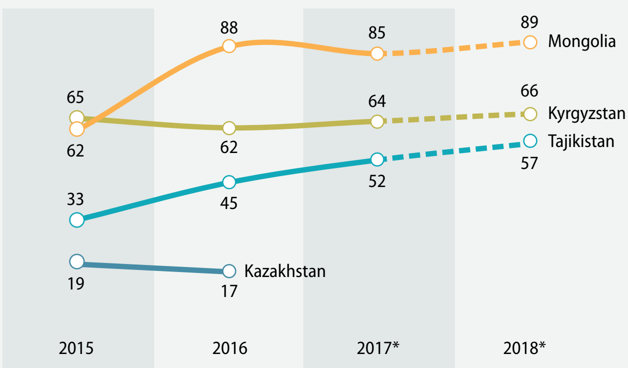
In parallel, Kazakhstan signed an Enhanced Partnership and Cooperation Agreement with the European Union (EU) in 2015. Over the period 2014–2020, the EU allocated € 1.1 billion to development co-operation with Central Asia (EEAS, 2019).

Figure 14.1: **Socio-economic trends in Central Asia**

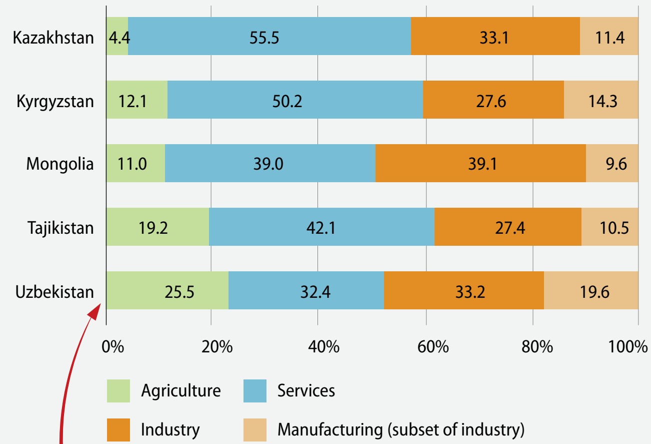
Economic growth in Central Asia, 2007–2019, annual and forecast (%)



Central government debt-to-GDP ratio in Central Asia, actual and forecast, 2015–2018 (%)

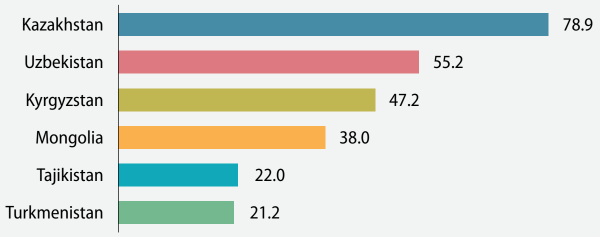


GDP per economic sector in Central Asia, 2019 (%)



Note: Agriculture includes agriculture, fisheries and forestry; industry includes the construction industry; manufacturing is a subset of industry.
Source: World Bank's World Development Indicators, March 2020

Internet access per 100 inhabitants in Central Asia, 2018



The modernization of agriculture is a key focus of Uzbekistan's development strategy to 2021.

FDI inflows have surged since Mongolia removed barriers to foreign share acquisition.

	GDP per capita (current PPP$)		FDI inflows as a share of GDP (%)		Exports of goods and services as a share of GDP (%)		High-tech goods as a share of manufactured exports (%)	
	2015	2019	2015	2019	2015	2019	2015	2019
Kazakhstan	25 123	27 444	3.6	2.0	28.5	36.5	41.4	28.2
Kyrgyzstan	3 458	5 471	17.1	1.7^{-1}	35.2	37.4	12.2	8.1^{-1}
Mongolia	12 188	12 820	0.8	17.6	45.6	61.3	4.2	5.0^{-1}
Tajikistan	2 820	3 520	5.8	2.6	10.5	15.7^{-2}	–	–
Turkmenistan	16 012	15 196^{-1}	8.5	4.9^{-1}	35.7	22.7^{-1}	–	–
Uzbekistan	6 088	7 289	0.1	3.9	28.5	31.2	–	0.5^{-1}

*forecast
-n: data refer to *n* years before reference year
Source: World Bank's World Development Indicators, July 2020; for the central government debt-to-GDP ratio for Kyrgyzstan, Mongolia and Tajikistan: IMF surveillance reports, cited in Hurley *et al.* (2018)

In April 2019, Mongolia received laboratory equipment from the EU after joining the bloc's project in 2016 on Strengthening the National Legal Framework and Provision of Specialized Training on Biosafety and Biosecurity in Central Asian Countries. Mongolia has acceded to three multilateral treaties since 2014, all of which relate to bioresources.[4]

In January 2015, the Kazakh government signed a memorandum of understanding with the Organisation for Economic Co-operation and Development (OECD) for a country programme to support national reforms across a number of policy areas, notably addressing Kazakhstan's ambitions for green growth and its target of becoming one of the 30 most advanced economies by 2050,[5] as encapsulated in its *Kazakhstan 2050 Strategy* (2012) [Mukhitdinova, 2015, Table 14.3].

Countries energy-rich and water-poor, or vice versa

Twenty years of rapid economic growth have raised demand for electricity in Central Asia, pushing up carbon emissions and eating into export revenue: 86% of Uzbek natural gas is now used for domestic consumption, for instance (Buyuk Kelajak, 2019). Almost three-quarters (72%) of Kazakhstan's electricity was generated by ageing coal-powered plants in 2016; heat and power generation account for 80% of Kazakhstan's carbon emissions, which have grown by approximately 40% since 2006 (EBRD, 2017).

Countries are split into two groups: whereas Kyrgyzstan and Tajikistan are 'energy-poor but water-rich' upstream states – accounting for 75% of the region's water resources – with little arable land and almost no hydrocarbon reserves, the downstream states of Kazakhstan, Turkmenistan and Uzbekistan are 'energy-rich but water-poor' with abundant hydrocarbon reserves (EPRS, 2015).

In a region confronted with glacier melt and unreliable rainfall, transboundary rivers are the main source of freshwater. In 2014, Tajikistan resuscitated plans to build the Rogun Dam on the transboundary Vakhsh River, following endorsement of the project by the World Bank. This decision initially heightened tensions with Uzbekistan, which is dependent on irrigation for agriculture.

However, since succeeding Islam Karimov as President of Uzbekistan on his death in 2016, President Shavkat Mirziyoyev has signalled his interest in the Rogun Dam project and in improving trade relations with Tajikistan (Hammond, 2018).

Countries transitioning to a green economy

The prospect of transitioning to a green economy offers the region an opportunity to mitigate its water and energy problems, while respecting international commitments.

Countries are focusing on 'greening' transportation, energy, agriculture, waste management, biodiversity conservation, public procurement and payments for ecosystem services, as well as development finance, while also fostering education for sustainable development (Rep. Kyrgyzstan, 2018).

In May 2013, Kazakhstan became the first member of the Commonwealth of Independent States to adopt a *Concept for the Transition to a Green Economy*, by Presidential Decree (#577). To help reach its targets (Table 14.1), the government has adopted regulations on renewable energy that include the introduction of feed-in tariffs and an auction scheme for projects that are still work in progress.

In May 2018, the Kazakh Ministry of Energy announced the first auctions to select the best renewable energy projects. The winners were awarded a 15-year guaranteed contract for the purchase of electricity from a single customer, the Renewable Energy Finance Centre (Shamsharkhan, 2018). By 2017, the country had managed to reduce its energy intensity by 18.6% over 2008 levels, placing it within striking distance of its 25% reduction target for 2020 (Table 14.1).

Like Kazakhstan, Mongolia adopted its *Concept of Sustainable Development* in 2013. A *Green Development Policy* followed in 2014 then the *Mongolia Sustainable Development Vision 2030* in 2016. These documents fix a number of 'green' targets to be met by 2030 (Table 14.1). Mongolia plans to have an operational nuclear power plant by 2030 but this seems unlikely, given that it only signed a memorandum of co-operation with the Russian State Atomic Energy Corporation (Rosatom) in 2018.

Uzbekistan has also made transitioning to a green economy a national priority. In May 2015, the government established a Republican Commission on Energy Efficiency and the Development of Renewable Energy Sources. It also created a department for improving energy efficiency within the Ministry of the Economy to work with the commission.

In October 2018, Uzbekistan adopted a resolution on Measures to Implement the National Sustainable Development Goals and Targets until 2030 (#841). This was followed by the establishment of a Co-ordination Council and roadmap for implementing and monitoring the Sustainable Development Goals (SDGs). In March 2019, the State Statistics Committee created a web portal to report on progress (Elci, 2019).

Immediately following the signing and ratification of the *Paris Agreement* in June 2019, Uzbekistan approved its *Strategy for the Transition to a Green Economy*. This involves raising the share of alternative energy generation to 19.7% by 2025 and building 25 solar power plants by 2030 (Table 14.1).

Uzbekistan is planning to build 42 new hydropower plants and to modernize a further 32 between 2017 and 2021 to expand its hydropower capacity 1.7-fold by 2025. Under the Law on the Use of Renewable Energy Sources (2019), manufacturers of this type of installation are exempted from paying property and land taxes on their plants (installations of 0.1 MW or more) for ten years and from all taxes for a period of five years from the date of their state registration. Importers enjoy tax rebates and pay lower customs duties. In addition, consumers whose residential buildings are disconnected from conventional energy networks pay no property tax at all for three years.

Turkmenistan has fixed itself the modest target of achieving zero growth in greenhouse gas emissions by 2030 (Table 14.1). It opened the Scientific and Methodological Centre for the Sustainable Development Goals in September 2017, at the Institute of International Relations within the Ministry of Foreign Affairs.

In 2018, Turkmenistan joined the International Renewable Energy Agency. The following year, the government ceased funding research and development (R&D) through the Academy of Sciences, including the academy's renowned Institute of Solar Energy, to compensate for a dip in GDP from lower receipts in the energy sector.

Kyrgyzstan, the last Central Asian nation to ratify the *Paris Agreement* (2015) on climate action in 2019, adopted its own *Concept of the Green Economy* in June 2018.

A quest for green finance

Central Asian countries are co-operating with major international partners to attract the foreign investment they need to reach their sustainable development goals.

Kazakhstan's feed-in tariffs and auction scheme have been developed under the Kazakhstan Renewables Framework, a project co-financed since 2017 by the EBRD and Green Climate Fund, which is facilitating the competitive entry of low-carbon investors into a market dominated by conventional fossil-fuel power producers.
This project is supporting the construction of an estimated 330 MW of mainly solar and wind power plants, equivalent to approximately 18% of the government's renewable targets for 2020 (Table 14.1), together with some modest biogas and mini-hydropower projects (EBRD, 2017).

In 2016, Kazakhstan launched its first solar power plant with a capacity of 50 MW, followed by two more in 2018 and 2019. These were built with the help of international investors, including through the Kazakhstan Renewables Framework. In September 2019, the EBRD extended the lifespan of this framework with a pledge for a further € 300 million in investment.

Kazakhstan has implemented 33 other projects since 2015 in conjunction with the United Nations Development Programme (UNDP) and its Global Environment Facility. Kazakhstan now operates 74 alternative energy facilities with a total capacity of 679 MW, which are mapped on the online *Atlas of Solar Resources of Kazakhstan*, developed in collaboration with UNDP. The total available capacity of power plants in the country was 18 894.9 MW in 2019 (KEGOC, 2019).

Kazakhstan and Mongolia are both paying particular attention to green financing. In Mongolia, the banking sector is implementing an environmental financing policy based on a memorandum signed by all of the country's commercial banks in 2015. Kazakhstan created the Astana International

Table 14.1: **Central Asian green economy targets for 2020 and 2030**

	Sector	Indicator	Target for 2020	Target for 2030
Kazakhstan	Greenhouse gas emissions	Reduction against 1990 baseline	–	15%
	Electricity supply	Share of alternative sources of energy	3% renewables	10% wind and solar; 20% other alternatives
	Energy efficiency	Reduction in energy intensity against 2008 baseline (units of energy per unit of GDP)	25%	30%
Kyrgyzstan	Greenhouse gas emissions	Reduction against business-as-usual scenario	50%	11.5–13.8%; with international support: 29.0– 30.9%
	Electricity supply	Share of alternative sources	At least 10% by 2023 from renewable energy sources	26%
Mongolia	Greenhouse gas emissions	Reduction against 2015 baseline	2%	14%
	Electricity supply	Share of alternative sources of energy	20% from renewables; construction of nuclear power plant	30% from renewables; nuclear power plant operational
	Energy demand	Satisfy national energy demand from domestic supply	85%	100%
Tajikistan	Greenhouse gas emissions	Percentage of 1990 baseline	–	Unconditional target: 80–90%; conditional target: 65–75%
	Electricity supply	Development of hydropower	26.2 billion kWh	40.7–45 billion kWh
Turkmenistan	Greenhouse gas emissions	Reduction against 2000 base year	–	Zero growth in emissions
Uzbekistan	Greenhouse gas emissions	Reduction in CO_2, CH_4 and N_2O per unit of GDP against 2010 base year		10%
	Electricity supply	Share of alternative sources of energy	–	19.7% by 2025 (25 solar power plants will provide 5 GW of solar power; 42 new hydropower plants will be established and 32 upgraded by 2021)

Source: for Kazakhstan: EBRD (2017); *Mongolia Sustainable Development Vision 2030* (2016); *National Development Strategy of the Kyrgyz Republic for 2018–2040 (2018)*; for Kyrgyzstan, Mongolia, Tajikistan and Turkmenistan: Intended Nationally Determined Contribution towards achievement of global goal of United Nations Framework Convention on Climate Change, in accordance with decision 1/CP. 20 UNFCCC (2015);[24] country studies from 2019 for Kyrgyzstan, Tajikistan and Uzbekistan: *Sustainable Infrastructure Development for a Low-Carbon Transition in Central Asia and the Caucasus: Mapping of Potentially High-impact Infrastructure Projects and Needs Assessment, Strategic Infrastructure Planning for Sustainable Development*; Rep. Uzbekistan (2019) *Strategy for Transition to a Green Economy*

Financial Centre in December 2015 to develop green financing and an International Centre for Green Technologies and Investment Projects in 2018.

In April 2019, the Kazakh Ministries of the National Economy and Energy convened with the National Bank of Kazakhstan at the International Finance Centre in Astana to develop a common taxonomy for green projects with a group of international experts. The experts were led by the Chair of the China Green Finance Committee, who is advising both China and Mongolia on how to develop a taxonomy for green projects (IFC, 2019a).

The Uzbek government plans to attract about US$ 1 billion in private investment to finance the development of green energy sources. The country's first-ever solar auction led to Masdar Clean Energy from the United Arab Emirates being awarded the tender for construction of the first 100 MW solar power plant in the Navoi region in October 2019 (IFC, 2019b). Days later, the government signed an agreement with the International Finance Corporation, a member of the World Bank Group, to develop up to 900 MW of solar power through public–private partnerships (IFC, 2019c).

Also in October 2019, Royal Dutch Shell's subsidiary, Shell Catalysts and Technologies, signed a process licensing agreement with the Uzbek Surhan Gas Chemical Operating Company for construction of a natural gas processing plant south of Surkhandarya Province by 2025.

With the support of the Asian Development Bank, Uzbekistan has produced a roadmap for the development of solar energy over 2014–2031 and, with the World Bank, an *Atlas of Wind in the Republic* (2014). A 750 kW wind power plant was launched in the Bostanlyk district of Tashkent in 2017, at a total cost to the state of US$ 1.84 million.

In 2019, the EU announced that it was extending its SWITCH-Asia programme to Central Asia.[6] Since 2007, the programme has implemented more than 100 projects to support sustainable consumption and production. In Mongolia, which participated in the original phase, six projects have focused on eco-product development and labelling, eco-construction materials and their recycling, and reducing air pollution. For example, in 2016, Mongolia launched the production of heat-insulating materials from lamb's wool.[7]

Like the EU, China is a vital partner for Central Asian countries' sustainable development plans. Through the Belt and Road Initiative, Uzbekistan is planning to launch, in 2020, the first plant in Central Asia for the production of mineral wool thermal insulation material, which could reduce natural gas consumption by about 1 billion m^3.

Kazakhstan leading the field for the digital economy

All countries are eager to embrace the digital economy but not all are at the same stage of development.

Kazakhstan already has good Internet penetration (Figure 14.1). One of the five thrusts of Digital Kazakhstan is to digitalize industry (Box 14.1). The focus in 2021–2022 will be on introducing legislative changes to increase occupational safety tied to digital technologies and create the requisite conditions to develop the Internet of Things. Training will be a key requirement: just 3% of university students were enrolled in programmes on information and communication technologies (ICTs) in 2018 (Figure 14.3).

Kyrgyzstan announced its own *Taza Koom* (Smart Nation) Digital Transformation programme in 2017, as part of its *National Sustainable Development Strategy* to 2040. *Taza Koom* is presented as a tool for eradicating corruption in the government sector by minimizing the human factor through automation of administrative processes and procedures and the provision of digital public services. The programme is also fostering public participation in municipal decision-making.

Digital Kyrgyzstan 2019–2023 followed in 2018, with a focus on developing digital skills to transform priority economic sectors.[8]

The Eurasian Economic Union (EAEU) launched its own *Digital Agenda* in 2018, following a joint study by experts from the Eurasian Economic Commission and World Bank in 2016 analysing the experience of other economic blocs (EEC and World Bank, 2017).

The aim is to create a single digital economy by 2025 by developing broadband Internet access in EAEU member countries and creating opportunities for the emergence of innovative industries, new types of services, new jobs and more efficient interaction among countries through online tools for citizens and businesses. It will, thus, be important to develop synergies between the domestic Kazakh and Kyrgyz programmes and the EAEU's *Digital Agenda*.

Since adopting a *Concept for Development of a Digital Economy over 2019–2025* (2018), Turkmenistan has opened centres of excellence at the Institute of Telecommunications and Informatics in Industry 4.0 technologies like artificial intelligence (AI).

Tajikistan and Uzbekistan, meanwhile, are still at the stage of developing a regulatory framework to attract investment in core infrastructure for ICTs.

As for Mongolia, it has been using wireless technologies to provide its small, dispersed population with Internet access. Since the launch of the programme in 2017 through the country's mobile operator, more than 200 000 residents – *circa* 6% of the population – have gained access to the network.

The *Mongolia Sustainable Development Vision 2030* (2016) sets a target of providing 70% of the population with a high-speed Internet connection by 2020, while applying the same tariffs across the entire territory and increasing bandwith.

Persistently low research spending

Despite the stated desire of Central Asian governments to boost their research effort, gross domestic expenditure on R&D (GERD) amounted to less than 0.15% of GDP in all countries in 2018 (Figure 14.2).

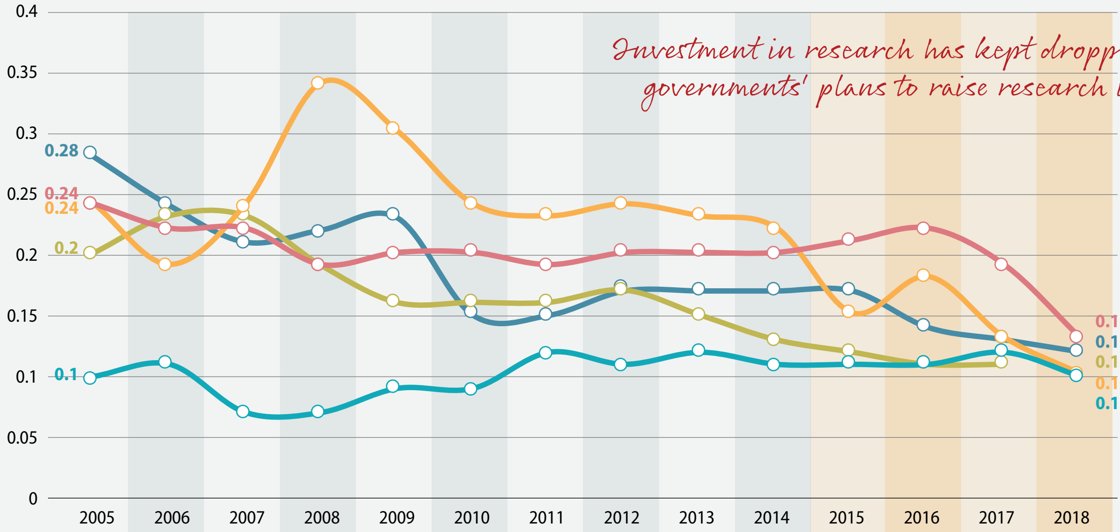
Kazakhstan and Mongolia have witnessed the biggest drop in the past decade. This is despite the fact that the *Kazakhstan 2030 Strategy* (1997) fixed the target of devoting 1% of GDP to R&D by 2015 and a top priority of Mongolia's *Master Plan for Science and Technology* (2007–2020) has been to increase the share of non-government resources in research funding. Between 2015 and 2017, the share of business research funding even dropped in Mongolia to just 4.6% of the total.

The *Mongolia Sustainable Development Vision 2030* (2016) sets the targets of devoting 0.6% of GDP to R&D by 2020 and 1.2% of GDP by 2030.

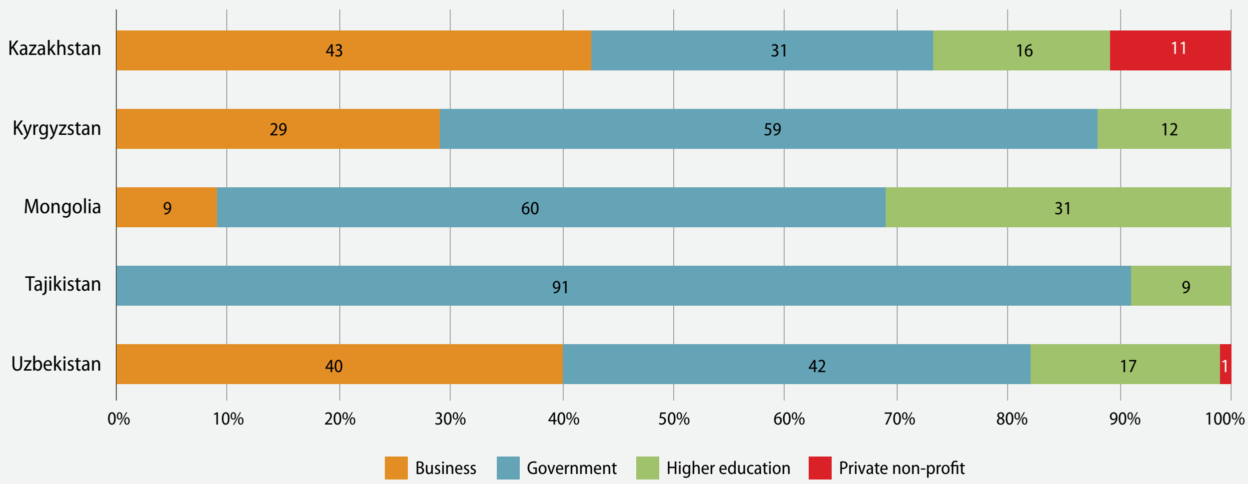
Figure 14.2: **Trends in expenditure on research and education in Central Asia**

GERD as a share of GDP in Central Asia, 2005–2018 (%)

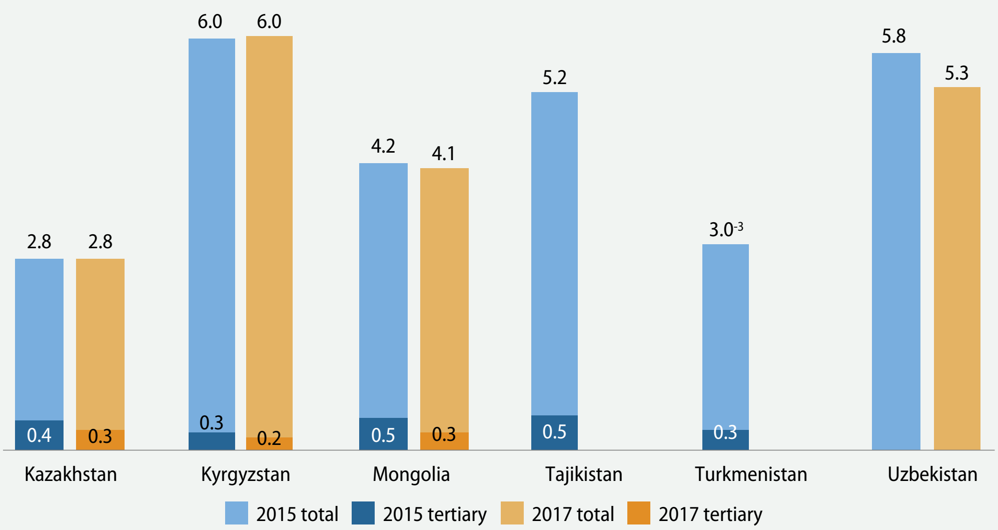
Investment in research has kept dropping, despite governments' plans to raise research intensity.



GERD by sector of performance in Central Asia, 2018 (%)



Public expenditure on education as a share of GDP, 2015 and 2017 (%)



The Uzbek corporate sector is booming: the number of newly registered joint ventures tripled between 2018 and 2019.

Source: UNESCO Institute for Statistics

Persistently low investment in R&D has implications for countries' plans to use science, technology and innovation (STI) to modernize their economies. Researcher density is down in all countries, as is technician density in all but Mongolia.

The great majority of researchers in the region still work in the government and academic sectors, although the business enterprise sector now accounts for four-tenths of research spending in Kazakhstan and Uzbekistan (Figure 14.2).

The *STI Agenda 2026* adopted by the Organisation of Islamic Cooperation (OIC) at its Astana summit in September 2017 invites member states to 'consider doubling annual expenditure by 2025 on scientific infrastructure and R&D in those countries which spend less than 0.3% of GDP'. It calls upon governments to invest in every sphere of science (education, basic science, big science, etc.) and to establish science and technology funds to nurture joint bilateral and multilateral projects.

Status of researchers compromising future

Central Asia's science and higher education systems have undergone widespread reform in recent years, with the adoption of the three-tiered bachelor's–master's–PhD degree system and the certification of scientific personnel (Mukhitdinova, 2015).

Scientists and teachers, nevertheless, remain poorly paid, a consequence of the low status accorded to their professions and negligible research funding. These factors have spawned a vocational crisis, with young science and engineering graduates either opting for other professions or seeking better career prospects abroad. This has upturned the age pyramid, imperilling countries' future research capacities (Mukhitdinova, 2015).

As we shall see from the country profiles that follow, countries are taking steps to remedy this situation. One encouraging sign is the rise in PhD enrolment across Central Asia between 2015 and 2018 (Figure 14.3).

Box 14.1: **Digital Kazakhstan: digitalizing the economy by 2022**

A new development path

Digital Kazakhstan seeks, in the medium-term, to accelerate economic growth and improve quality of life through the use of digital technologies and, in the long term, to transition to a 'fundamentally new development path' grounded in the digital economy.

Digital Kazakhstan builds on Information Kazakhstan 2020 (2013), which targeted infrastructure. It is co-ordinated by the Ministry of Information and Communications, with a five-year budget to 2022 of *ca* US$ 362 million. Implementation has been entrusted to central and local executive bodies, as well as semi-private bodies.

The programme has a wide scope, spanning the energy, transportation and financial sectors, infrastructure, mining and agriculture sectors, cybersecurity, the education system, municipal services and political institutions. It is using the Internet of Things, artificial intelligence and 3D printing to integrate smart systems, automation, big data analysis and principles of openness and connectivity into these sectors.

Key economic sectors targeted

In the agriculture sector, Digital Kazakhstan is focusing on a precision agriculture pilot project.

In the energy sector, smart technologies will provide systematic responses to demand.

In transportation, the programme expects to augment freight traffic by combining video surveillance, traffic control and information about users into a unified smart transportation system.

In the financial sector, it is supporting e-commerce by establishing service support centres and mainstreaming electronic payment systems. New technologies are being introduced, such as distributed ledgers (blockchain) and open application programming interfaces.

The Astana Technology Park

To support innovation in information technology (IT), the programme launched the Astana Hub International Technology Park in November 2018. It operates as a Special Economic Zone, offering generous tax incentives. By the end of 2019, 130 IT companies and 690 start-ups at the hub were participating in incubation and acceleration programmes. Government research grants are awarded to collaborative partnerships between start-ups and universities.

E-education and e-government

In education, there are plans to phase in introductory programming courses at primary level, add courses on new digital technologies to teacher training programmes and create a national open education platform with courses in engineering and other technical disciplines.

Digitalization will also extend to the governmental sphere: 'open budgets' will allow for public input on spending plans; 'open legal acts' will allow the public to engage in discussion on legislative drafts; and 'open data' will see data released into the public domain for commercial use.

Infrastructure will serve as the backbone of the programme, thanks to modern satellite communications, the extension of fibre-optic communication lines to rural areas and the development of 4G mobile infrastructure for urban centres. A 'digital identification mechanism' is planned for financial, state and other bodies.

Ambitious targets

By 2022, it is expected that 82% of the population will be using the Internet and 83% will be digitally literate. Digitalization is also expected to create 300 000 jobs and add about US$ 4.3 billion to the economy by 2022.

Source: Digital Kazakhstan: www.digitalkz.kz/en/about-the-program

Kazakhstan extending its lead for research output

Kazakhstan accounts for two-thirds (65%) of the region's scientific output (Figure 14.4). Productivity has grown rapidly since Kazakh scientists first began subscribing to Thomson Reuter's Web of Science in 2011 (Mukhitdinova, 2015), a practice emulated by Kyrgyzstan and Uzbekistan in 2016.

Only Turkmenistan, where there is no requirement for scientists to publish in international journals, has seen a downturn in productivity (Figure 14.4).

Kazakhstan may also owe its regional leadership in scientific publishing to its exacting standards for assessing research performance and awarding scientific degrees.

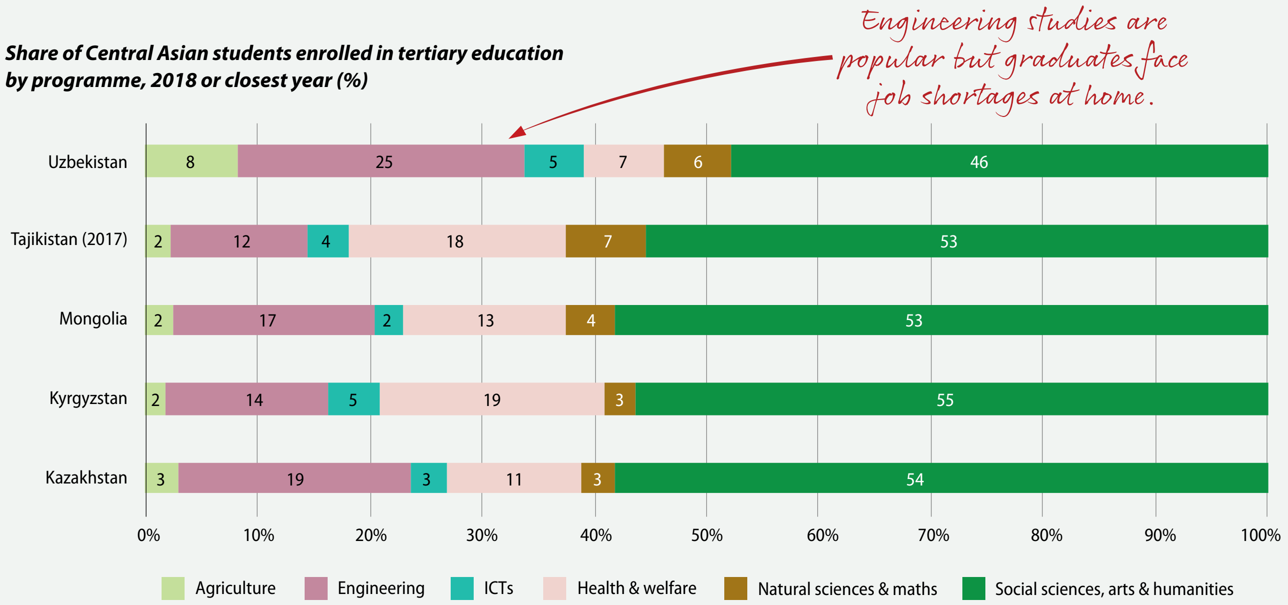
Patenting activity, meanwhile, remains low in Kazakhstan, Uzbekistan and Kyrgyzstan and non-existent elsewhere, a reflection of the difficult business climate (Figure 14.4).

Close collaboration among Central Asian scientists will be necessary to solve many of the region's problems, yet this remains the exception, rather than the rule. Only Kyrgyz and Turkmen scientists count Kazakhs among their top five partners (Figure 14.4). The often-low level of funding available for research impedes some joint projects among Central Asian scientists.

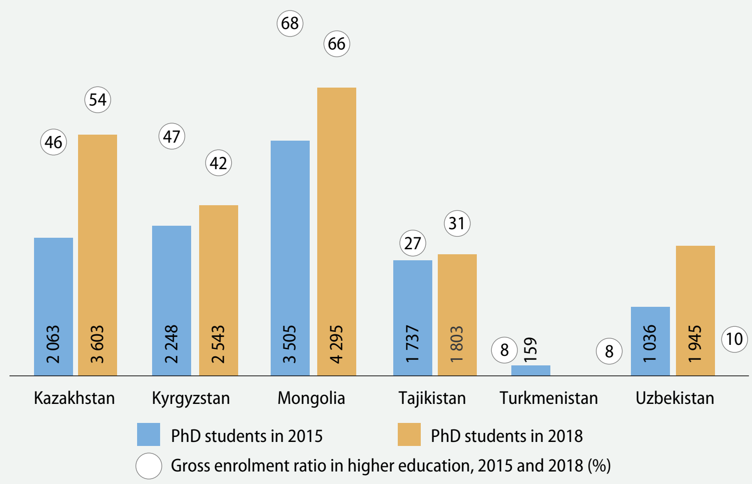
Central Asian scientists tend to collaborate mostly with their Russian peers (Figure 14.4).[9] With English now being the universal language of science, Central Asians will be at a disadvantage if they do not master it. However, proficiency in English remains rare in the region, according to the 2018 Education First English Proficiency Index.

Figure 14.3: **Trends in human resources in Central Asia**

Share of Central Asian students enrolled in tertiary education by programme, 2018 or closest year (%)



Enrolment in PhD programmes and gross enrolment ratio at tertiary level, 2015 and 2018



Proportion of female PhDs in engineering in Kazakhstan and Mongolia in 2018, the highest in the region

COUNTRY PROFILES

KAZAKHSTAN

The region's powerhouse

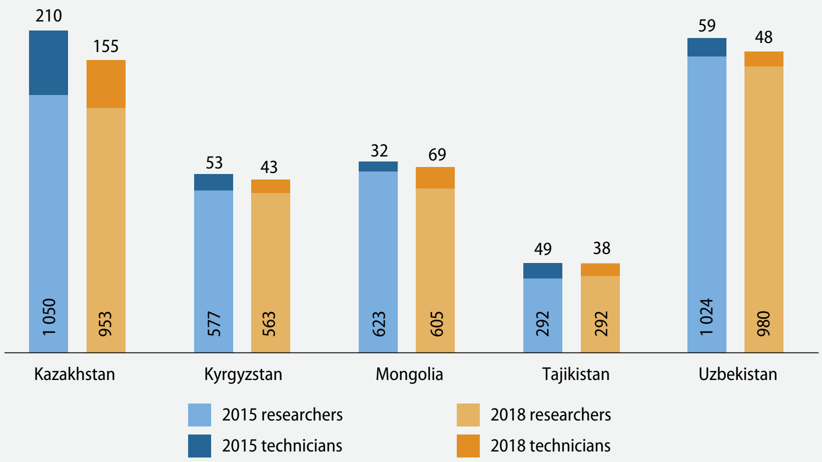
More than half of GDP in Central Asia is generated by Kazakhstan, making it the region's economic powerhouse. Kazakhstan is home to 8% of the world's iron ore reserves, 25% of global uranium reserves and, around the Caspian Sea basin, *circa* 3% of oil reserves and 1% of natural gas. It is also one of the region's primary wheat producers.

The government is striving to make the manufacturing sector more competitive by stimulating growth in the non-oil sector, restricting use of the National Fund and streamlining budget expenditure.[10] The planned comprehensive privatization of state enterprises under the *Privatization Plan for 2016–2020* should help to reduce the burden on state budgetary expenditure. By 2028, government debt is expected to decline from 25.0% (2018) to 18.7% of GDP.

The government also plans to develop a more sustainable approach to agriculture through the State Programme for the Development of the Agro-Industrial Complex over 2017–2021. Two targets identified by the *Kazakhstan 2050 Strategy* (2012) are to cultivate 15% of acreage with water-saving technologies and develop drought-resistant crops by 2030 (Mukhitdinova, 2015).

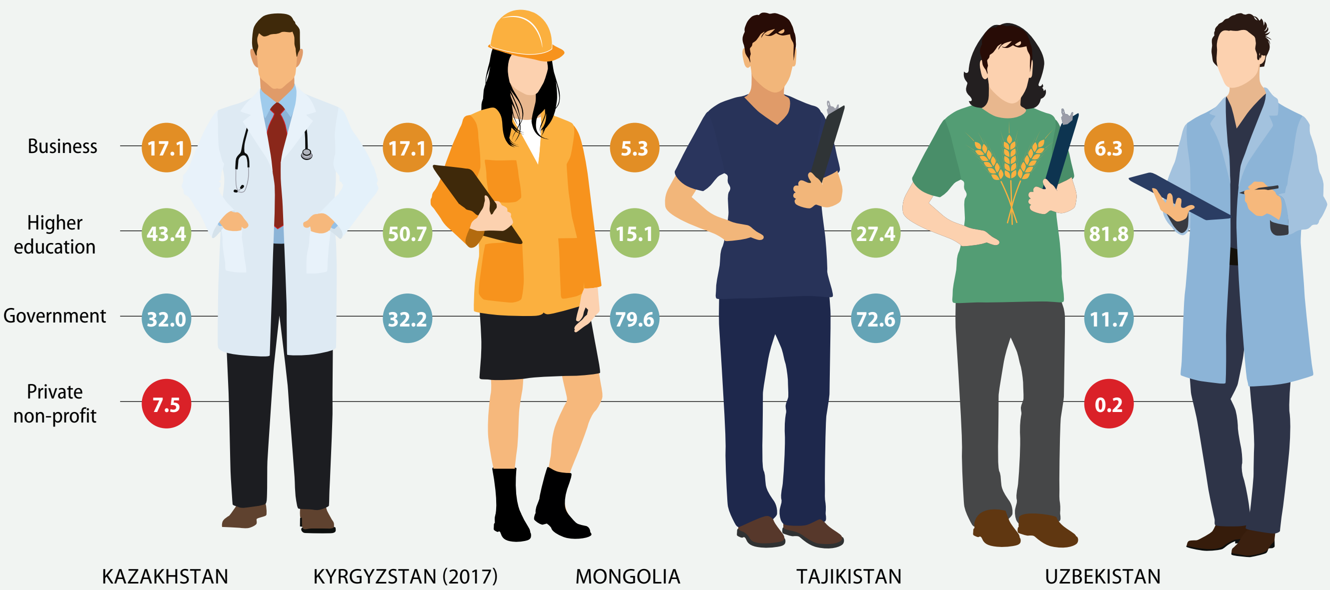
The government is also investing in the industries of tomorrow through its Digital Kazakhstan programme (Box 14.1).

Researchers and technicians (HC) per million inhabitants in Central Asia, 2015 and 2018



Governments are striving to improve the status of researchers to counter the disaffection for a research career.

Researchers by sector of employment in Central Asia (HC), 2018 or closest year (%)



Note: Data are unavailable for Turkmenistan.

Source: UNESCO Institute for Statistics.

Chapter 14

Greater investment in non-oil sector

Industrial production grew by 7.3% in 2017 but this owed more to the dynamism (+9.3%) of the extractive industries (oil, natural gas, metal ore, coal and lignite) than the performance of the real economy (+5.6%) [MNE, 2018].

The main drivers of economic growth in 2018 were, nevertheless, concentrated in the non-resource segment of the economy: communication services and trade (+5.9% each), industry (+5.2%), transportation (+4.9%) and agriculture (+4.0%) [MNE, 2018]. These sectors benefited from a surge in investment through projects implemented under the State Programme for Infrastructure Development (Nurly Zhol) and the State Programme for Industrial and Innovative Development,[11] both of which cover the period 2015–2019.

The manufacturing sector accounted for 11.4% of GDP in 2018 (Figure 14.1), meaning that Kazakhstan has missed its 12.5% target for 2014. By contrast, labour productivity improved 1.5-fold between 2008 and 2014. Overall, 77% of the targets of the State Programme for Accelerated Industrial and Innovative Development (2010–2014) have been reached (KIDI, 2015).

Missed targets owe much to escalating geopolitical tensions and a vertiginous drop in global prices for oil and metals in 2014. The Caspian Energy Hub (Mukhitdinova, 2015) has been one casualty of these geopolitical tensions; plans to develop a research and training complex in Aktau have been abandoned over territorial disputes in a basin that is responsible for about one-fifth of the world's natural gas exports.

Box 14.2: **The Kazakh tech incubators embracing the Fourth Industrial Revolution**

In 2015, the government established the Autonomous Cluster Fund. This fund manages the Alatau Park of Innovative Technologies and the Tech Garden Innovative Cluster, both of which are incubating promising start-ups. In all, the Autonomous Cluster Fund groups 233 organizations, including 23 universities, 24 research institutes, a development institute, 48 firms and a joint investment fund.

Alatau Park of Innovative Technologies

Situated 30 km east of Almaty, the park was set up in 2005 by the Institute of Nuclear Physics, which dates from the Soviet era. It is using venture capital to increase the share of Kazakh content in high technologies in the following areas:

- smart industry and new materials;
- smart environment;
- new sources of energy and clean technologies;
- financial technologies (fintech);
- e-commerce; and
- new media.

The park has manufacturing complexes and houses research facilities for institutions such as the Kazakh-British Technical University and International University of Information Technologies.

It operates as a Special Economic Zone. Local and foreign investors are entitled to preferential tax rates and are exempt from property, land, corporate income and social taxes.

Venture capital is made available by the Global Venture Alliance, which is based in San Francisco, USA.

The international accelerator programme, Start-up Kazakhstan, is open to participants from the Commonwealth of Independent States and Europe. The Damu Entrepreneurship Development Fund of the National Agency for Technological Development and the national Science Fund (2006) also provide financial support for new projects. In addition, the government has approved competitive innovation grants.

Tech Garden

The Tech Garden Innovative Cluster also operates as a Special Economic Zone, with the same fiscal advantages. It serves as a test site for the digitalization of industry, through pilot projects, model factories and laboratories.

It runs an international accelerator programme for start-ups in central Almaty called icoStartup.kz, supported by the Ministry for Investment and Development, with three main tracks:

- **Industry 4.0**: industrial Internet of Things, robotics and autonomous systems, energy efficiency and conservation, additive manufacturing (3D printing) and smart logistics;
- **Smart cities**: building information modelling, next generation network and data transfer, smart transportation and infrastructure and social technologies; and
- **Fintech**: blockchain, e-commerce and digital technologies.

Start-ups at icoStartup.kz have access to research labs shared by multinational corporations such as IBM (USA) and the British technology companies IntelliSense and Metalysis. In partnership with IntelliSense, a laboratory for Industry 4.0 helps to prepare Kazakh companies for digitization of up to 75% of working processes in the mining sector. With Metalysis, Tech Garden is setting up an R&D centre to explore avenues for producing 3D powders and alloys from Kazakhstan's raw materials, as well as pilot projects for the production of metal powder. Since there is not yet any clear leader in this field, this area could become an export niche for Kazakhstan in a few years.

One aim is to provide start-ups with access to markets in the Eurasian Economic Union and elsewhere. Tech Garden offices have opened in Silicon Valley (USA) and the Russian Federation's technoparks in Skolkovo and Novosibirsk. Innovative start-ups get an opportunity to participate in mentoring programmes in Almaty and Silicon Valley.

The Tech Garden invests up to US$ 100 000 in each start-up. It is planned to finance nearly 500 innovative start-ups and incubate at least 50 high-tech and export-oriented companies by 2020. Funding is provided through a joint venture with the Global Venture Alliance (GVA Alatau Fund).

Source: Shayakhmetova (2017); Interfax (2017); https://techgarden.kz/ru/startupkz_en

An exodus of skills

From 2014 to 2018, Kazakhstan's research budget slid from 0.17% to 0.12% of GDP (Figure 14.2). This low level of funding is hampering the government's plans to make research and innovation a pillar of growth. It translates into low wages and means that research institutes and universities are deprived of the modern equipment they need to do cutting-edge research. It sends the message that science is not a national priority and, thus, not worthy of prestige. Legislative restrictions also prevent scientific organizations from using the funds they are allocated by the state to create innovative enterprises.

In turn, the lack of investment in science is discouraging young people from choosing a career in research. The country's researcher density shrank from 790 to 667 full-time equivalent (FTE) researchers per million inhabitants between 2014 and 2018, despite a surge in enrolment at PhD level (Figure 14.3).

More generally, Kazakhstan is facing a net outflow of skilled labour. In parallel, state costs are rising as the administration strives to replace departed specialists, invest in vocational training and retrain unskilled immigrants.

A need to modernize science management

It has become urgent to modernize the management of science, which no longer corresponds to economic realities. The rapprochement between education and science, on the one hand, and science and industry, on the other, is still in its infancy. The scientific community communicates little with the manufacturing sector, thereby remaining detached from the real needs of the economy. The resulting lack of economic competitiveness has led to the demise of entire industrial sectors.

Most of the priority areas for 2017–2019 approved by the Higher Scientific and Technical Commission for investment are broad, making it difficult to prioritize the limited research funding available.[12] The list includes energy and engineering, the rational use of natural resources, including water, geology, new materials and technologies, safe products and structures, as well as information, telecommunications and space technologies.

In addition to raising research spending, the government can bolster scientific capacity by revising its migration policy to attract more foreign scientists and by introducing postdoctoral programmes at all universities to help young researchers embark on a scientific career.

Targeted regulatory mechanisms would help to rationalize limited resources. To determine the optimal number of highly qualified personnel, for instance, a multilevel system should be put in place to monitor and forecast needs. Incentive measures should be introduced to ensure that the number of PhD-holders keeps rising. A system should also be established to analyse and forecast market needs for specialists in various fields.

Research university has added strings to its bow

In his annual message to the population on 31 January 2017, former President Nazarbayev underscored the important role universities could play in making the country more competitive through innovation, stating that 'we must develop our scientific and innovative potential based on universities, Nazarbayev University and the Alatau Park for Innovative Technologies' (Box 14.2).

Nazarbayev University is the country's first international research university. It could serve as a model for a network of like institutions. In line with the *Kazakhstan 2050 Strategy* (2012), Nazarbayev University has consolidated its mandate since 2015:

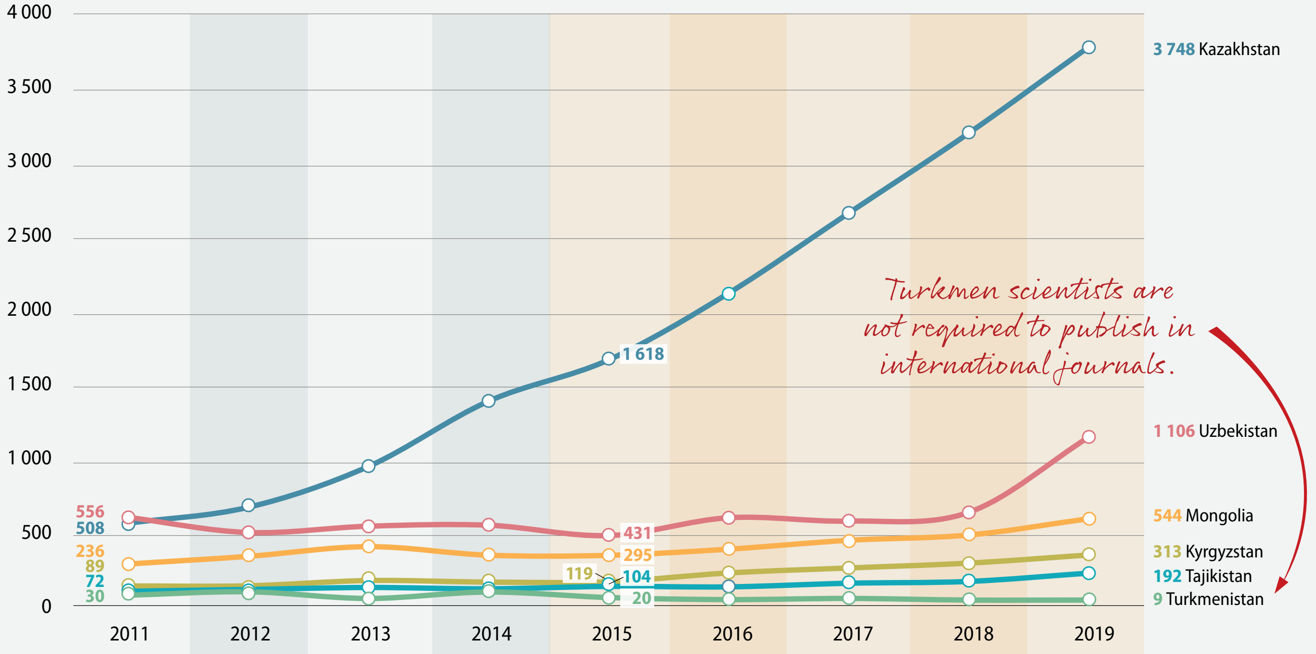
- The Medical School launched in 2015 hosts clinics and four universities attached to the University Medical Centre, as well as a Life Sciences Centre and School of Medicine. The University Medical Centre groups four hospitals.
- The School of Mining and Geosciences opened in 2017. It offers two master's programmes and three undergraduate programmes and should ultimately form a Geological Cluster of Schools with a Centre for Geological Research.
- A Centre for Energy and New Materials opened in 2015 as part of the National Astana Laboratory. The centre houses laboratories working on, *inter alia*, green energy and the environment, advanced materials and systems for energy storage and advanced solar energy materials and systems.
- In May 2019, the university presented its new ion accelerator, the Innovative Nazarbayev University's Research Accelerator (INURA). Designed for use in both theoretical and applied research and financed by the Kazakh Ministry of Education and Science, it is the fruit of a five-year inter-university effort by researchers from Nazarbayev University, the US Lawrence Berkeley National Laboratory and the Russian National Research Tomsk Polytechnic University.
- Since 2016, the university has launched several specialized services for external organizations, including: biotechnology laboratory services for start-ups in the field of biomedicine and laboratory services for companies specializing in the chemical and food industries.
- In October 2016, the university launched the ABC Quick Start programme to support start-ups. In collaboration with Shell Kazakhstan and other donors, this programme provides start-ups with capital, access to technology, business advice and specialized professional support.
- On the university's Astana Business Campus, the new innovation cluster comprises a technology transfer office, business incubator and experimental workshop.

SMEs face an uphill struggle

Only 5% of Kazakh SMEs are exporters, compared to 19% across all upper middle-income countries (OECD, 2018a). SME innovation rates remain low, despite a steady increase in the past decade. SMEs face competition from the informal sector, which accounts for almost one-fifth of total employment. They also lack access to finance. According to the OECD (2018a), only '19% of SMEs held a bank loan or a credit line in 2014, down from around one-third in 2008–2009, a drop that in part reflects the troubles the financial sector has experienced in recent years'.

Figure 14.4: **Trends in scientific publishing and patenting in Central Asia**

Volume of scientific publications from Central Asia, 2011–2019



69%

Kazakhstan's share of Central Asian scientific publications in 2018

60%

Regional average for the share of foreign authors, 2016–2018

How has output on SDG-related topics evolved since 2012?

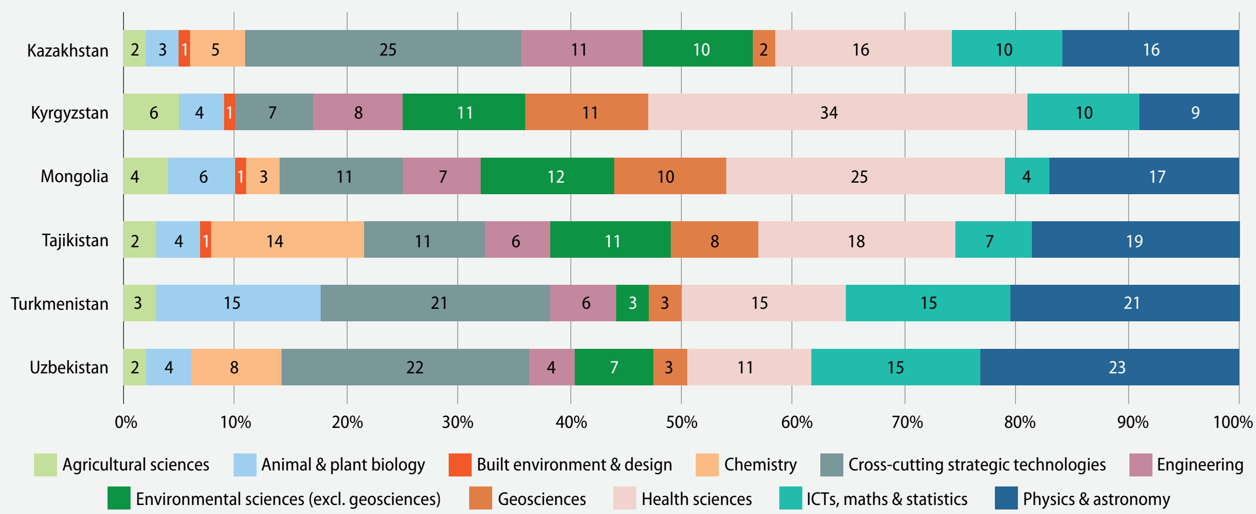
Central Asian countries are publishing twice as much as would be expected on freshwater-related topics, relative to global averages. Regional output on transboundary water resource management is even 38 times the global average proportion (42 publications over 2012–2019), driven by specialization within Kazakhstan and Uzbekistan. Of note is that Tajikistan's output on hydropower (22 publications over 2012–2019) is 17 times the global average proportion; this may relate to the government's 2014 decision to pursue construction of the Rogun Dam.

Although regional output on sustainable transportation and smart-grid technologies remains low, it has surged from 4 and 8 (2012–2015) to 39 and 65 (2016–2019) publications, respectively. Other topics have grown at least four-fold, albeit from a low starting point: wastewater treatment, recycling and re-use (from 9 to 50), the impact on health of soil, freshwater and air pollution (20 to 86), biofuels and biomass (11 to 46), greater battery efficiency (28 to 113) and climate-ready crops (3 to 24).

Mongolia's specialization in the conservation and sustainable use of ecosystems and the status of terrestrial biodiversity may relate to its accession to three multilateral treaties on bioresources since 2014.

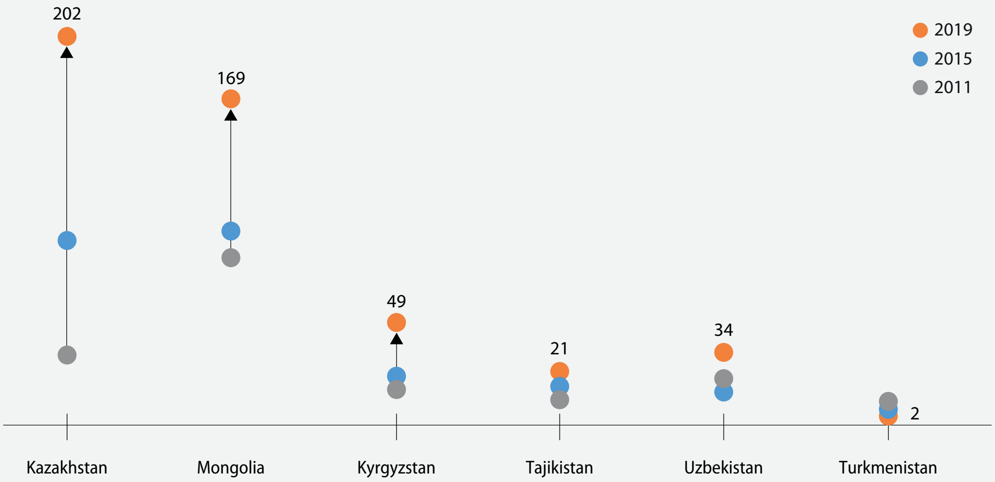
For details, see chapter 2

Scientific publications in Central Asia by broad field of science, 2017–2019 (%)



Scientific publications in Central Asia per million inhabitants, 2011, 2015 and 2019

Data labels are for 2019



490

G20 average for scientific publications per million inhabitants in 2019

The Russian Federation, USA and Germany remain the region's top partners.

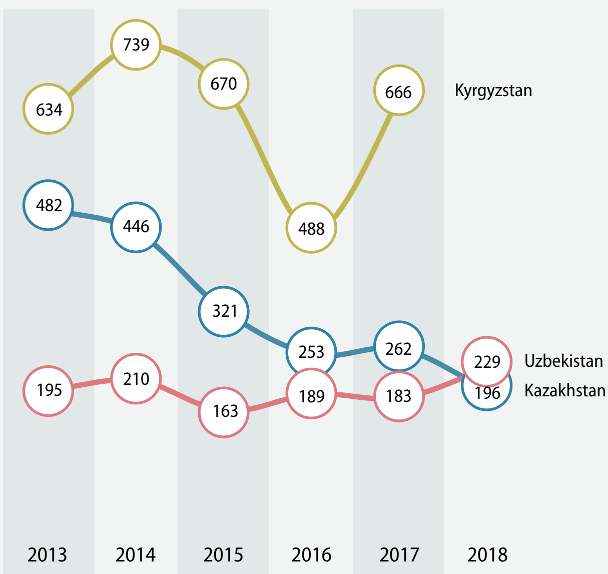
Top five foreign partners for Central Asian researchers, 2017–2019 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator(s)	4th collaborator	5th collaborator(s)
Kazakhstan	Russian Fed. (2 151)	USA (758)	Ukraine (602)	Poland (583)	China (404)
Kyrgyzstan	Russian Fed. (213)	Germany (139)	Turkey (131)	Kazakhstan (123)	China (106)
Mongolia	Russian Fed. (355)	USA (346)	Japan (292)	China (285)	Korea, Rep. of (253)
Tajikistan	Russian Fed. (141)	USA (58)	Germany/Pakistan (52)		China (42)
Turkmenistan	Turkey (12)	USA (8)	Germany/Kazakhstan/ Russian Fed. (4)		
Uzbekistan	Russian Fed. (326)	China (203)	Germany (154)	USA (137)	Italy/Spain (89)

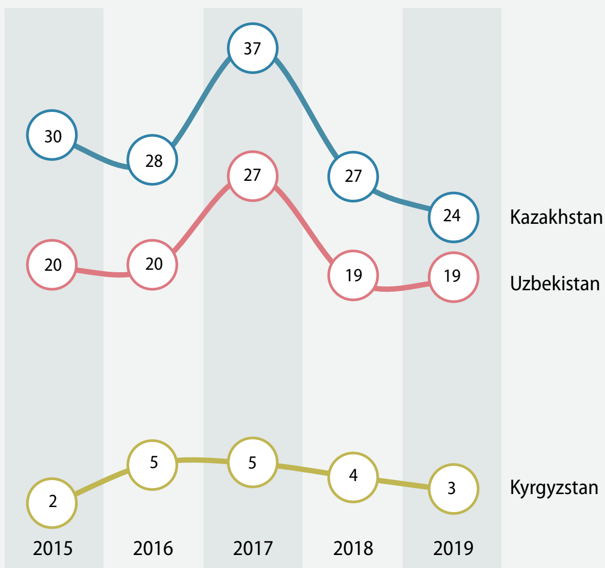
Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

The challenging business climate in Central Asia limits patenting.

Resident patent applications per 100 billion GDP (2011 constant US$) from Central Asia, 2013–2018



Number of IP5 patents granted to Central Asian inventors, 2015–2019



Note: Mongolia and Turkmenistan received no IP5 patents over 2015–2018. IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China. For resident patent applications, Tajikistan does not feature, as it has data only for 2013 (15 applications) and 2015 (9 applications).

Sources: World Intellectual Property Organization; PATSTAT, data treatment by Science-Metrix

Despite these hurdles, three out of four Kazakhs see entrepreneurship as a desirable career choice, according to the 2016 survey by the *Global Entrepreneurship Monitor* (OECD, 2018a).

A charm offensive for foreign start-ups

President Nazarbayev, who stepped down in March 2019 after almost 30 years in power, introduced a *Plan of the Nation* in May 2015 which translates the *Kazakhstan 2050 Strategy* into 100 concrete steps. These steps are grouped under five institutional reforms: formation of a professional state apparatus; the rule of law; industrialization and economic growth; identity and unity; and the formation of accountable government.

One translation of the *Plan of the Nation* is the Astana Hub International Technology Park, which opened in November 2018 under the Digital Kazakhstan programme (Box 14.1). The park's accelerator programme stems from Step 63 of the *Plan of the Nation*.

The Astana Hub is one of the country's three main technology parks, along with the Alatau Park for Innovative Technology (2005) and the Tech Garden, established in 2015 (Box 14.2). Each is nurturing domestic start-ups in cutting-edge technologies. In a first for Kazakhstan, foreign start-ups are also being encouraged to register in Kazakhstan and hire local labour, to accelerate the development of a start-up culture.

In 2016, the national Science Fund (2006) became an operator for the award of grant funding to commercialize research results. By 2019, this measure had led to the creation of 11 start-ups.

Weaving innovation into multiple legislative tracks

No single legislative act defines relations among the players in Kazakhstan's complex innovation ecosystem. The Law on Science (2011) was followed a year later by a separate legislative tool governing innovation in the business sector, the Law on State Support for Industry and Innovation (2012). This twin track has led to parallel state policies being formulated in the field of innovation.

The Law on Commercialization of the Results of Scientific and/or Technical Activities (2015) was amended in 2018 to expand coverage to innovation. The amended law regulates both public and private actors, including tech-based start-ups, service companies and technology parks. The Science Fund is, thus, able to support successful projects; since 2014, it has funded 151 projects through four calls. Of these, 42 projects have generated revenue of about US$ 6 million from commercialization (Science Fund, 2019).

Another positive step has been the amendment of the *Entrepreneurial Code* (2016) in August 2019 to create a better climate for entrepreneurs by limiting their direct contact with government bureaucracy to 'one window'. The code has also minimized the number of documents entrepreneurs need to submit and introduced a pre-trial mechanism to settle disputes which has already reduced the number of court appeals filed by entrepreneurs.

Last but not least, Kazakhstan aligned its definition of a utility patent with that of the majority of countries in April 2015, through the Law on Amendments and Additions to Certain Legislative Acts on the Legal Regulation of the Field of Intellectual Property. Essentially, this law replaces the Kazakh model of patent registration and verification with the simpler system used by other countries.

KYRGYZSTAN

Open for business but a narrow focus

Kyrgyzstan is credited with having the most open economy of the former Soviet countries in Central Asia (Yamano *et al.*, 2019; UNECE, 2019). It has substantial economic potential as a regional transport and logistics hub (UNCTAD, 2016a).

Kyrgyzstan remains dependent, however, on mining and remittances. There is a large informal economy and economic gains have had little impact on rural areas, which are falling behind in terms of infrastructure, public services and access to education (UNECE, 2019).

Analysts agree on the need to diversify the economy. Approximately half of exports are unprocessed commodities, offering limited opportunities for employment. The Kumtor mine accounts for more than 10% of GDP, whereas the mining sector as a whole is responsible for less than 1% of employment (MAPS Mission Team, 2019). The planned closure of the Kumtor mine in 2023–2026 is expected to amputate a large slice of government revenue.

Kyrgyzstan possesses abundant water resources for hydropower generation. The *National Strategy for Sustainable Development 2013–2017* had set targets for shifting towards green technologies and renewable energy sources but the skills gap is creating bottlenecks in these areas (ILO, 2018).

The skills gap also affects the agriculture, mining, metal-working and garment industries. In the agriculture sector, for instance, there are gaps in technical knowledge of innovative technologies for selecting, cultivating, harvesting and storing crops. A 2018 review identifies a 'quantitative and structural mismatch' between regional economic needs and the profiles of graduates. In 2016–2017, there was an estimated need for over 70 000 specialists (ILO, 2018).

There is growing interest among Kyrgyz youth in computer programming. This has led to a boom in tech-oriented start-ups and software companies. Over the period 2014–2017, the number of resident companies in the High-Tech Park climbed from three to 27 and annual revenue from US$ 1 million to US$ 3.5 million (MAPS Mission Team, 2019).

Some barriers to investment lifted

Kyrgyzstan has taken steps to improve its competitiveness and investment climate. Since 2013, the country has improved access to finance in agriculture, provided some provisions for workplace training and promoted investment through an active dedicated agency and a strategy to attract FDI (OECD, 2016).

However, these reforms have not attracted enough non-mining FDI. Net inflows of FDI even plummeted between 2015 and 2018, perhaps due to an undiversified investment portfolio and the lack of financial guarantees for potential investors (Figure 14.1).

Considerable obstacles to investment remain, including insufficient protection for intellectual property rights, an inadequate judicial system, poor infrastructure and small domestic markets (Komendantova *et al.*, 2018).

In 2018, the International Institute for Applied Systems Analysis conducted a series of interviews with Kyrgyz stakeholders to assess the main barriers to investing in industrial projects in the country (Komendantova *et al.*, 2018).

Political barriers (instability and dependence on political decisions made by neighbouring countries) were considered to be the most obstructive, followed by customs and administrative barriers (bureaucratic procedures and state interference) and sectoral barriers (fragmented production chains) [Komendantova *et al.*, 2018].

Although a variety of initiatives support entrepreneurship, these tend to focus on firm creation and survival, rather than on 'promoting new activities or modernisation'. There are no mechanisms for venture capital or business angel investment (UNECE, 2019).

Two key sources of investment are the World Bank and the Russian–Kyrgyz Development Fund (Komendantova *et al.*, 2018). The latter fund was created in 2014 to support Kyrgyzstan's integration into the Eurasian Economic Union. In 2014–2016, the Russian Federation invested US$ 500 million in the fund, which offers loans directly to businesses, as well as through financial and credit institutions. According to Komendantova *et al*. (2018), 33 projects had been directly funded by 2017 for a total of US$ 145 million in areas such as agriculture, textiles, construction, mining, communication and software development.

The government hopes to stimulate enterprise and international investment through free economic zones (FEZ). As of 2019, the country's largest FEZ in Bishkek counted 324 resident enterprises with 3 700 employees (UNECE, 2019).

Underinvestment in research

There is little investment in R&D. The private sector's modest contribution even dropped between 2015 and 2017 (Figure 14.2). From 2014 to 2018, the volume of science funding shrank by 21%, according to the National Statistical Committee, following cutbacks to basic research (-30%). The latter, nevertheless, still accounted for 15% of GERD in 2018, compared to 60% for applied research and 25% for experimental development.

In 2015, Kyrgyzstan approved its *Concept for Reform of the Organization of the Scientific System*. This document proposed creating a regulatory framework to guide the training and certification of research personnel for easier integration into global scientific networks. The *Law on Science and the Basics of State Scientific and Technical Policy* followed in 2017 to provide this regulatory framework. The *Concept for Reform* also proposed a tripartite system of research funding: core funding for research infrastructure, administration and personnel; programme-targeted funding, granted on a competitive basis to support research in accordance with government priorities; and research grants.

Much of the government research budget still goes towards fixed costs such as salaries or, in other words, core funding. The Academy of Sciences[13] consequently suffers from low levels of project funding (UNECE, 2019). In 2019, it counted 1 810 employees and 53 ongoing research projects funded through the state budget (*ca* US$ 1.7 million) and international science foundations (*ca* US$ 1.04 million).

The Academy of Sciences sets its own research priorities. For 2013–2017, these were (UNECE, 2019):

- water and energy, including renewables;
- information technology, mathematical modelling and management;
- materials (nanotechnology, biotechnology);
- geosciences and natural resources;
- mechanical and instrument engineering;
- reproduction of biological resources and biosecurity;
- ecology, human ecology and climate change; and
- the individual and society: challenges of globalization.

A need for an innovation culture

The government's ambition of using business innovation to drive industrial modernization is evident in its *Concept for Scientific and Innovative Development* to 2022 (UNECE, 2019).

However, the governance system is fragmented. The high-level Council on Innovation, established in 2012, has 'not fully assumed a much-needed leadership and co-ordination role' (UNECE, 2019). A number of public councils advise on public policy but these suffer from a lack of funds and decision-making power.

Kyrgyzpatent, the state intellectual property office, is increasingly driving public support for innovation. It co-ordinates the State Programme for Development of Intellectual Property 2017–2021, which seeks to reinforce the legislative base for intellectual property rights in accordance with international norms, as well as the *Concept for Scientific and Innovative Development*. It is also responsible for a fund offering public innovation grants (UNECE, 2019).

However, business executives perceive academia as being disconnected from their problems and state researchers claim that business needs are not well-articulated. The lack of a common innovation culture means that projects developed jointly by manufacturers and research institutes tend to be restricted to repairs and renovation of equipment (UNECE, 2019).

There is also an insufficient focus on commercializing ideas and inventions in the marketplace and limited technology transfer. However, there are a few technoparks and incubators and the Kyrgyz National University has plans to establish a technopark of its own but there is no law regulating technoparks or authorizing university laboratories to establish companies.

Although the country has had a High-Tech Park since 2011, this is not a material entity but, rather, a special tax regime for ICTs, gaming and Internet companies that also serves as a call centre (UNECE 2019).

Better data for sustainable development agenda

The president chairs the National Sustainable Development Council and the prime minister heads the committee set up in 2016 to co-ordinate implementation and monitoring of the *National Sustainable Development Strategy* to 2040. The *Taza Koom* (Smart Nation) Digital Transformation programme announced in 2017 is part of this strategy (MAPS Mission Team, 2019).[14]

In 2020, the government was in the process of amending the Statistical Law (2007) to provide a first definition of the national statistical system. The new law is expected to strengthen the National Statistical Committee's mandate for leading data collection and analysis to monitor progress towards the SDGs (MAPS Mission Team, 2019).

MONGOLIA

A difficult balancing act

Mongolia's economy is based largely on mining, unprocessed agricultural products and low-tech exports. Over 90% of its primary energy supply comes from coal (GCF, 2019). Ulaanbaatar is the world's third-most polluted capital city (IQAir, 2019).[15]

Mongolia will need to balance plans to develop existing mining industries with the desired introduction of more sustainable production and consumption patterns.

For instance, Mongolia intends to meet 100% of domestic energy demand by 2030 by raising the share of renewable energy to 30% of total energy consumption, according to its *Green Development Policy* (2014–2030), and by developing a nuclear power plant (Table 14.1).

It also details plans to develop industries for smelting copper and purifying gold, as well as mining petroleum, natural gas, oil shale and coal. The policy plans to balance this by, *inter alia*:

- creating a sovereign wealth fund from mining sector revenues to support long-term sustainable development;
- engraining transparent and responsible mining practices, enhancing environmental protection, restoration activities and the effectiveness of offset mechanisms;
- improving efficiency in the energy sector by 20% by 2030;
- expanding forest cover to 9% of the territory by 2030;
- protecting at least 60% of freshwater reserves and stream formation areas, while expanding protected areas to 30% of the country's territory by 2030;
- promoting sustainable agriculture and the development of an industrial processing cluster that is export-oriented and based on green technology;
- reducing solid waste in landfills by 40% by 2030; and
- allocating at least 20% of public procurement to the purchase of environmentally sound, effective and resource-efficient goods, works and services.

The *Mongolia Sustainable Development Vision 2030* (2016) also relies on the use of advanced technologies to liquefy and carbonate coal and shale to meet its target of reducing greenhouse gas emissions by 14% over 2015 levels by 2030 (Table 14.1).

One challenge will be to ensure that the country's sustainable development agenda is implemented across different sectors. For instance, the stated purpose of the *State Industrial Policy* (2015) is to ensure fair competition for stakeholders in priority industrial sectors (Table 14.2) and to develop safe, environmentally friendly and competitive manufactured products oriented towards export and import substitution. However, green industries do not figure among the priority sectors (Table 14.2). Responsibility for the development of wind and solar energy, for instance, falls to the *State Policy on Energy* (2015).

A focus on agro-food and industry

Like the *Green Development Policy,* the *Mongolia Sustainable Development Vision 2030* places strong emphasis on the agro-technical and food industry as well as other industrial sectors, along with boosting export-oriented processing through industrial clusters that deploy advanced technologies. Substantial innovation will be required to achieve the stated vision for a green economy laid out in both documents.

For instance, the government had introduced 'support tariffs' to cover the cost of electricity production from renewable energy sources but had to stop issuing new permits in 2018 over concerns that the existing electricity grid was struggling to accommodate the rapid growth in energy produced by wind farms. Renewable energy amounted to 3–4% of total electricity output in 2019 (GCF, 2019).

Table 14.2: **Priority sectors for Mongolia's *State Industrial Policy*, 2015**

Heavy industry	Light industry	Small and medium-sized enterprises
Oil production	Leather and hide production	Dairy production
Coal chemical production	Cashmere production	Construction material production
Coke chemical production	Wool production	Food production
Copper smelting	Wood production	Bio-preparations
Steel production		Information technology
Cement industry		

Source: communication by D. Battogtokh, Director-General, Strategy and Planning Department, Mongolian Ministry of Industry, May 2015

Despite the calls in the *Green Development Policy* and *Vision 2030* for green urban planning, environmentally friendly advanced manufacturing and pilot projects to cope with climate change, it may be difficult to balance support for the sustainable development of the mining sector with the goals of the country's Action Programme to 2020 (2016), which are: to achieve steady increases in oil and gold extraction, construct a copper smelting facility and provide greater support for metallurgical, coal and gas processing.

The Action Programme to 2020 focuses on, *inter alia*:

- implementing green growth policies to introduce advanced tech-friendly approaches to environmental management and human health, ensure re-use and recycling and place under special state protection no less than 50% of high-value ecosystems offering clean water supplies;
- establishing a joint investment fund with private sector participation to boost research expenditure;
- developing bio- and nanotechnology and increasing the variety and quantity of export-oriented products with a high intellectual content;
- reviewing the possibility of establishing a data centre in Mongolia that would serve as a high-speed information exchange network;
- implementing a national space communication satellite project and establishing a national network to ensure secure communications;
- developing value-added agricultural products for export;
- creating a legal environment for organic food and supporting its production through financial investment and fiscal policy;
- creating a favourable taxation, legal and business environment for priority export-oriented agricultural sectors to substitute for food imports;
- supporting the creation of small and medium-sized food-processing pilot factories equipped with advanced technology; and
- improving the legal environment and management of disaster prevention and implementing early warning systems.

Time to take stock

In 2019, three complementary assessments of the national innovation system were undertaken by the Mongolian University of Science and Technology, UNESCO and the Asian Development Bank (ADB) [2019].[16] Summarized below, these assessments lay the foundations for the planned successor to the original *Master Plan for Science and Technology 2007–2020*, which had been developed with UNESCO assistance.

At the time of the *Master Plan's* adoption in 2007, research spending accounted for 0.24% of GDP and research bodies were ill-equipped to operate under competitive market conditions. Research priorities were vague, leading to wastage of scarce resources, and Mongolia was dependent on imported foreign technologies and equipment.

The *Master Plan* proposed systemic reforms to stimulate investment in new knowledge and ensure constant technology upgrades, along with regular technology foresight exercises, to ensure the system could adapt rapidly to changing realities.

The *Master Plan* recommended greater financial support for public and private sector R&D to further national priorities and develop key technologies. GERD has actually dropped to 0.10% of GDP since 2015 and the intended funding boost from the non-government sector has not materialized (Figure 14.2).

Thirteen years on, what has the *Master Plan* achieved? It foresaw the establishment of a multistakeholder Strategic Industry Leaders Group to identify industries with the highest growth potential. This group has not yet been established but a list of priority areas for science and key technologies was laid out in a Cabinet resolution (#368) in 2015, including human development and environment, intensive agriculture, advanced industrial technology and high technology (ADB, 2019).

Under a second programme, the Mongolian Intellectual Property Organization was entrusted with drafting a law to protect government-financed research results. The 1998 Law on Technology Transfer was amended accordingly in July 2015 (ADB, 2019).

Research infrastructure still dependent on foreign investment

Under the *Master Plan*, research bodies were to be equipped with modern equipment and the personnel trained, to foster the development of advanced technology.

The quality of research-related buildings is effectively improving, thanks to relatively large construction and procurement projects implemented over the past five years or so. Mongolia is also introducing the open laboratory concept to optimize the use of research facilities, whereby external researchers pay a fee to use public and private laboratories (ADB, 2019).

The modernization of physical research infrastructure, nevertheless, remains heavily dependent on foreign assistance. Under the *Master Plan*, centres of excellence were to be established in biological resources, agriculture, medical research, mineral resources, biotechnology, nanotechnology, ICTs and renewable energy. A draft resolution was prepared to this end in 2011 but not approved.

The only centre to see the light of day has been Shastin Central Hospital in Ulaanbaatar, specializing in cardiology; it was established in 2013 with support from the Millennium Challenge Account and World Health Organization. In 2020, an information technology education and outsourcing centre at the Mongolian University of Science and Technology was under construction through a soft loan from the Government of India.[17]

Some laboratories are able to purchase modern equipment but have no budget for running costs. For instance, a team expedited by the Asian Development Bank reported in 2018 that the six laboratories of the Mongolian National University of Medical Sciences employed six full-time staff but appeared largely unused because running costs were six times the annual budget. 'Much of the equipment was covered with plastic sheeting,' they observed (ADB, 2019).

When the Ministry of Education, Culture and Science surveyed 700 staff from research institutes and universities in 2018, 74% of respondents described their laboratory facilities as unsatisfactory. Respondents also cited low levels of income for young researchers and a general lack of skills and professional qualifications (ADB, 2019).

Approved in December 2019, the *Action Plan for the National Programme for the Development of Human Resources in the Science, Technology and Innovation Sector* (2019) prioritizes evaluating and developing the system for skills training; one aim is to invite the diaspora to facilitate academic exchanges. Another focus of the action plan is to provide employees in the STI sector with solid social protection.

Joint research projects to fill funding gaps

The Mongolian Foundation for Science and Technology is the primary source of domestic research funding. Only about 5% of its total expenditure goes towards the purchase of physical research infrastructure.

Moreover, not all research sectors benefit equally. Research related to mining and animal husbandry has been boosted by international co-operation and private sector involvement but fields of lesser interest to industry lack equipment and other physical infrastructure (ADB, 2019).

This may be changing. A project coordinated jointly by the foundation and the Baseline Fund in Belarus breaks the mould by enabling researchers from both countries to undertake jointly funded research projects between 2019 and 2021 not only in agriculture but also in basic sciences, Earth sciences and human and social sciences (UNESCO, unpublished).

Agriculture and animal husbandry are just one focus of a three-year Joint Venture Research Project with China since 2019. There are also provisions for collaborative research in biotechnology, environmental protection, mining product development, IT and artificial intelligence (UNESCO, unpublished).

More targeted project funding

To ensure a better selection process for public-funded research projects, the *Master Plan* stipulated that funding should target research projects rather than organizations or staff. It also recommended a unified system to monitor and evaluate these projects. As part of this reform, accessible databases have been developed to enhance information-sharing and project monitoring and evaluation.

Launched in 2012, the Mongolian Statistical Information Service provides open data and a summary of Mongolia's progress toward the SDGs.[18] The security of national databases has been a priority, ever since a 2017 hacking attack on Mongolia's National Data Centre planted malware in government websites (Legezo, 2018).

The government has also introduced a scheme which awards research grants of up to 90 million Tughrik (*ca* US$ 33 640) to commercialize results over a two-year period. These grants are open to academics and research centres, independent research groups and public or private non-profit organizations. In 2017, 78 projects were awarded funding under this scheme (UNESCO, 2018).

An influx of PhD students

The *Master Plan* proposed awarding grants to enable 500 young scientists to complete their master's, doctoral and postdoctoral research at home or abroad. Since 2013, 12 young researchers have received 4 million Tughrik (*ca* US$ 1 480) annually and postdoctoral innovation grants have been awarded each year to ten researchers under the age of 45 years. Each receives 10 million Tughrik (*ca* US$ 3 740) per year for two to three years (UNESCO, unpublished).

The number of PhD students leapt by 23% between 2015 and 2018 (Figure 14.3), despite public expenditure on higher education shrinking from 11% to 6% of overall education expenditure (Figure 14.2), according to the UNESCO Institute for Statistics.

Women now dominate most scientific fields and have achieved parity in engineering (46% in 2017), a rare feat for any country (see chapter 3). Overall, researcher density has dropped since 2015 but there has been a 220% increase in the number of technicians per million inhabitants, albeit from a low starting point (Figure 14.3).

Since the Law on Science and Technology (2006), a student has the right to establish a 'start-up company' to gain job market experience and test business ideas. The Law on Technology Transfer (1998, amended in 2015) does not specify, however, when and under which conditions a patent, license or product design becomes a consumer product (ADB, 2019).

One focus of the National Programme for the Development of Human Resources in the Science, Technology and Innovation Sector (2019) is to empower employees of start-up companies at state-owned research institutions.

Science–industry ties to boost research spending

The *State Policy on Science and Technology* adopted by the Cabinet in September 2017 addresses many of the issues outlined above. For the first phase to 2020, the focus was on improving scientific infrastructure and beginning construction of the Nalaikh Construction Material Production and Technology Park, which got under way in 2018.

During the second phase to 2021, the emphasis is on training more scientists and technicians and supporting scientific creativity, while expanding international scientific co-operation. The policy also fixes the target of raising GERD from 0.13% of GDP in 2017 to 0.6% of GDP by 2020, 1% of GDP by 2025 and to 1.2% of GDP by 2030.

According to *Vision 2030,* the 1% target is to be reached through science–industry co-operation, with a special focus on geology, geochemistry and geophysics, medical research and early diagnosis systems and the establishment of a science and technology cluster and park.

Vision 2030 also outlines support measures for SMEs, including the provision of modern techniques and technologies to farmers, training for young professionals and an increase in the enterprise support fund to at least 200 billion Mongolian Tughriks (*ca* US$ 73.9 million) by 2025.

Meanwhile, the first phase of the *State Policy on Innovation* (2018–2025) is focusing on creating a legal framework to support start-ups in key economic sectors, such as through tax incentives. In the second phase from 2022 onwards, the emphasis will be on boosting the competitiveness of key industrial sectors and creating conditions for economic diversification.

TAJIKISTAN

Declining poverty

Although it has the lowest GDP per capita, Tajikistan became the fastest-growing economy in the region in 2017 (Figure 14.1). Poverty levels receded from 31.0% to 29.5% of the population between 2015 and 2017. Over the same period, the proportion of those with access to sanitation services rose from 70% to 82% (MEDTRT, 2018).

Despite healthy growth, the Tajik economy remains dependent on a small export base, with aluminium, gold, zinc ore and cotton making up 80% of exports. Tajikistan's ten longest rivers are a boon for agriculture, providing 60% of Central Asia's freshwater reserves. The agriculture sector accounts for 21% of GDP and half of all employment. The other main source of income is remittances (Price, 2018).

This narrow economic base makes Tajikistan vulnerable to external shocks, such as the economic crisis in the Russian Federation in 2014–2015, which led to a depreciation of the Russian rouble and a sharp drop in the value of remittances to Tajikistan (OECD, 2018b).

More reforms needed to empower private sector

UNCTAD (2016b) credits Tajikistan with having implemented significant market reforms. Further reform is needed, however, to remove persistent regulatory barriers that may be deterring inflows of FDI (Figure 14.1). Moreover, these modest levels of FDI tend to be concentrated in a handful of large projects; as of 2016, the extractive sector accounted for more than half of FDI inflows since 2009 (UNCTAD, 2016b).

Despite declining foreign investment, Tajikistan's industrial sector grew by 16% and 21% in 2016 and 2017, respectively, according to national figures (MEDTRT, 2018).

International support for infrastructure development has declined rapidly since 2015, from US$ 13.5 million to US$ 3.7 million in 2017. In order to stimulate foreign investment, UNCTAD (2016b) has recommended reducing tax complexity, fostering a stable institutional framework to promote competition and reforming labour regulations.

Tajikistan has also been promoting the emergence of micro-enterprises and SMEs by making it easier for entrepreneurs to access finance, especially for returning migrants, and by promoting exports in the agribusiness sector. These reforms would seem to have worked, since 300 such businesses opened in 2016–2017. According to the OECD (2018b), the country has made 'visible progress' on the demand side, running training programmes for returning migrants and supporting financial literacy. On the supply side, though, moves to facilitate the banking of remittances and introduce public support funds have been delayed by external and internal shocks.

Deeper reforms are needed to empower the private sector. A literature review conducted by the Institute of Development Studies found that many of the challenges faced by the private sector in Tajikistan 'have their root in weak governance', particularly in the financial sector, in state-owned enterprises and business-related divisions of the public administration. The fiscal system was also in urgent need of reform (Price, 2018).

Academy of Sciences still the research epicentre

According to Mamadsho Ilolov, President of the Academy of Sciences, some public–private and non-governmental initiatives have emerged but traditional structures remain dominant. The Academy of Sciences is the epicentre for science in the country; it organizes research activity across smaller institutes and implements related legislation (Ilolov and Sakina, 2017).

As of 2014, 100 institutions were involved in R&D. They employed 18 000 general staff and 20 756 researchers, according to national statistics. Three main mechanisms regulate the distribution of funding: core funding goes to institutes and centres to support research infrastructure; targeted funding supports large-scale research involving industry and SMEs; and thematic funding offers competitive grants for research projects by topic (Ilolov and Sakina, 2017).

Ambitious targets guide development efforts

Science remains a priority for the *National Development Strategy to 2030* (2016), which divides implementation into three five-year phases.[19] Its main goals are to ensure energy security, develop connectivity in terms of telecommunications and transportation, guarantee food security and expand productive employment (Price, 2018).

The strategy has broad ambitions. At the level of economic reform, it favours export promotion, import substitution and investment, to be accomplished by empowering the public administration, removing barriers to private enterprise, legally protecting property rights and improving vocational training. These reforms are expected to drive an average economic growth rate of 6–7% per year, nearly halving poverty to 15% of the population by 2030 (Price, 2018).

On the back of this expected economic growth, the strategy aims to reinforce social protection, ensure access to safe food, water supplies and sanitation services, reduce social and gender inequalities and create the conditions for environmental sustainability. In 2017, Tajikistan was 80% self-sufficient for wheat, meat and eggs but made a 'relatively low' contribution to all other foodstuffs. To ensure food security, the strategy is to reduce dependence on imports while boosting domestic production, so that farmers can satisfy 90% of demand by 2030 for staples such as bread, potatoes, eggs, rice and fruit (Rep. Tajikistan, 2017).

The strategy also prioritizes democratic governance and the rule of law. It considers the development of human capital, particularly in education and science, to be the backbone of the country's sustainable development (Price, 2018).

The Institute of Development Studies considers the construction of the Rogun Dam to be the *'de facto* centrepiece' of the *National Development Strategy to 2030*. This project is part of a broader strategy to harness the country's considerable hydropower potential. Hydropower stations already account for 95% of electricity consumption, yet only exploit 5% of the country's potential (MEDTRT, 2018). By 2017, 80 locations for new power stations had been selected and surveyed and work was being carried out on the 3 600 MW Rogun Dam.

In parallel, the *National Development Strategy to 2030* envisages expanding the fossil fuel sector to reach its target of increasing electrical power capacity to 10 GWt by 2030, an increase of 75% over 2017.

The strategy fixes three targets for GERD: 0.8% (2020), 1.2% (2025) and 1.5% of GDP by 2030. The strategy also fixes the target of having 0.6–0.65% of the population employed in the science sector by 2030. As an incentive, the salaries of scientists are to be raised to 25% higher than the average across the economy. How this investment is to be realized remains uncertain.

First major project for higher education

Tajikistan has one of the region's youngest populations, with 66% being under 30 years of age (Rep. Tajikistan, 2017).

In March 2016, Tajikistan launched the *Higher Education Development Project* together with the International Development Association, with funding of US$ 15 million. This is the first major project targeting the development of higher education in Tajikistan.

Implemented in partnership with the World Bank, the project involves: developing an external quality assurance system; modernizing educational curricula, especially in disciplines deemed important for labour market needs; and assessing the financing structure of the higher education sector, to ensure that it better incorporates national priorities.

TURKMENISTAN

Using gas receipts to diversify the economy

Wild fluctuations in global energy prices since 2014 have made Turkmenistan rethink its dependence on natural gas exports. Although increasing access to global gas markets remains government policy, diversifying and restructuring the economy is a growing priority (Rep. Turkmenistan, 2019). The Programme for Social and Economic Development spanning 2019–2025 prioritizes the industrial development of mining and the transformation of raw materials into products with high added value.

In building its export capacity, the government has initially targeted the gas and petrochemical industries, which form the bedrock of the economy, in line with the State Development Programme spanning 2010–2030.

The Galkynysh giant gas field has been developed, in co-operation with the China National Petroleum Corporation and Petrofac Limited, with plans to export natural gas to China, Iran and the Russian Federation.

Construction of a gas pipeline linking Turkmenistan with Afghanistan, Pakistan and India began in 2015. The consortium involves Turkmengas (85%) and, in equal part, Gail India Ltd, the Pakistani Inter State Gas Systems Ltd and Afghan Gas Enterprise.

In July 2019, agreements were signed with the Japan Bank for International Cooperation and other financial institutions for over US$ 152 million in loans to finance the turnkey construction of a gas turbine power station with a capacity of 432 MW in Lebap Province.

Making it easier to do business

In 2017, the non-state sector accounted for two-thirds (68.5%) of the economy. Chemicals, glass and textile (mainly cotton) manufacturing and agribusiness are all key primary industries.

The government is seeking to develop SMEs, curtail the informal economy and foster entrepreneurship. A package of measures has been introduced to simplify the procedure for registering new businesses, paying taxes and obtaining bank loans. Businesses oriented towards export and import substitution are now entitled to preferential bank interest rates. A range of traditional credit instruments have been adapted to the financing of start-ups (Rep. Turkmenistan, 2019).

To improve banking and government services, digital services are being introduced, including a 'single window' bureaucracy (Rep. Turkmenistan, 2019).

The *Concept for Development of a Digital Economy over 2019–2025* (2018), meanwhile, lays the groundwork for boosting employment in high-tech industries, mainstreaming innovation in the national economy, introducing advanced technologies into production systems and transitioning to an electronic document workflow. E-systems have already been introduced into hospitals and the education system.

One of the first steps towards a digital economy has consisted in opening centres of excellence at the Institute of Telecommunications and Informatics specializing in such areas as big data, artificial intelligence, blockchain, robotics, the Internet of Things, virtual and augmented reality, wireless communications and cybersecurity.

New institutions for science and education

Since 2010, about US$ 16 billion has been allocated to modernizing the country's education and science systems.[20]

Numerous schools, colleges, universities and institutes have been built, including specialized institutions. In 2019, the government announced the creation of the Institute of Market Economics and the Institute of Chemical Technology. These follow the new Institute of Public Utilities in 2017, Oguz Khan University of Engineering Technology in 2016 and the International University for Humanities and Development (MUGNiR) in 2014.

The Centre of Technologies at the Academy of Sciences was inaugurated in Ashgabat in June 2014. This modern centre has a range of laboratories specializing in environmental protection, drug development, nanotechnology, geographical information systems, the synthesis of new materials, biotechnologies, ICTs, energy production and energy-saving technologies and food processing. There are also a number of departments, including one with a focus on economics and another specializing in the introduction of technology into production systems.

The focus of these laboratories and departments largely mirrors the decree on Priority Areas of Science and Technology (2016) [Turkmenportal, 2015]: nanotechnologies and chemical technologies; new materials; energy research; biotechnologies; molecular biology; agriculture; ecology and genetics; ICTs; production technology for medical and pharmaceutical products; an innovative economy; and humanities.

The reference above to 'energy research' is vague. The government's 2010 list of priority research areas referred more explicitly to the 'development of the electric power industry, with exploration of the potential use of alternative sources of energy: sun, wind, geothermal and biogas.' Seismology is also absent from the new list of research priorities (Mukhitdinova, 2015).

Under the *Action Plan* for the *Concept for the Development of a Digital Education System* (2017), there are plans to create an Innovation Information Centre, supervised by the Ministry of Education, which will be responsible for integrating e-learning methods in education, including digital textbooks, manuals, audiovisual materials and interactive and multimedia programmes.

Cutbacks at the Academy

Ten years after reviving the Academy of Sciences and its reputed Sun Institute (now the Institute of Solar Energy), President Gurbanguly Berdimuhamedov issued a decree in 2019 for the establishment of the Science Development Fund of the Academy of Sciences. Through this fund, the state has allocated US$ 10 million to support scientific conferences, overseas visits and joint international projects. A further US$ 10 million has been earmarked for advanced training, through the Resolution on Financial Support for the Development of the Science System.

In parallel, the government announced that research undertaken by the Academy of Sciences would be self-financing for the next three years, citing the ongoing recession in the energy sector and economic slowdown for the cutbacks (Figure 14.1). This meant that the 26 research institutes attached to the Academy also lost state support, along with the public seismology service.

The Institute of Solar Energy suffered a different fate. It was transferred from the Academy of Sciences to the State Energy Institute, a university, to provide linkages between science and business.

In 2017, the Institute of Solar Energy had developed a new complex which combined living space with a greenhouse, a solar biogas plant, groundwater desalination plants powered by renewable energy sources and bioreactors for growing unicellular green algae (chlorella), which have health benefits.

Two sustainable cities in the making

Although Turkmenistan has not fixed any targets for alternative sources of energy, the introduction of innovative, resource-saving technologies into all sectors of the economy is a priority of the National Programme for Energy Saving 2018–2024. The construction of new facilities in the energy sector can only be approved upon certification, following a mandatory environmental impact assessment. In the manufacturing sector, the government reports the introduction of low-waste technologies, better sewage and water supply systems and groundwater treatment through the removal and recycling of industrial waste (Rep. Turkmenistan, 2019).

In return for government support, privatized public enterprises are expected to commit to protecting their employees and ensuring environmental security and protection (Rep. Turkmenistan, 2019).

Turkmenistan became a full member of the International Renewable Energy Agency in October 2018. A UNDP project to turn Ashgabat and Avaza into sustainable cities was launched the same year, with a focus on energy-efficient public lighting, waste management and sustainable forms of transportation, including hybrid vehicles (UNDP, 2018).

A drop in scientific output

The Law on the Legal Status of a Scientist (2009) was amended in 2013. It defines the rights and responsibilities of scientists, as well as those of state authorities and administrations, which are expected to guarantee scientific freedom and provide scientists with social protection.

The absence of official data makes it difficult to assess the extent to which the working conditions of scientists have effectively improved since the law was amended but scientific output has dropped since 2016 (Figure 14.4).

Learning from others

The Programme for the Development of Innovation, 2015–2020, focuses on learning from other countries how to introduce and adapt foreign technologies and develop innovative solutions. Joint laboratories are being created and co-operative projects implemented. Scientific exchanges include internships by Turkmen scientists at foreign institutions and interaction with international technology centres.

In February 2018, the Vnesheconombank of Turkmenistan signed an agreement with the German Commerzbank for over € 121 million in loans to finance the supply of agricultural equipment manufactured in France, Germany, Italy and the Netherlands for the Turkmen Ministry of Agriculture and Water Resources.

In 2019, state bodies signed about 20 memoranda of understanding with leading Korean organizations, including one between Turkmengaz and the Korean Organization of Industrial Enterprises to train Turkmen engineers. Another agreement focused on developing co-operation between Makhtumkuli Turkmen State University and Seoul National University.

The Turkmen government has also been engaging with EU training programmes such as Erasmus+ and Tempus (EEAS, 2019).

UZBEKISTAN

A strong state presence in the economy

Uzbekistan is one of the world's top three producers and exporters of cotton and has the world's fourth-biggest gold reserves. Uranium ore, mineral fertilizers and natural gas also bring major foreign exchange earnings, as do the chemical, textile, food, non-ferrous metallurgy and automotive industries. The country runs a large General Motors vehicle manufacturing plant under Daewoo and Chevrolet licenses and hosts Central Asia's only aircraft manufacturing plant.

The economy is, nevertheless, in need of modernization. More than 50% of enterprises are still under state ownership in the strategic sectors of banking, mining, energy, food and cotton. The country's infrastructure is ageing. Some 86% of extracted natural gas is used for domestic consumption, yet electricity generation (1 878 kWh per capita) amounts to just over one-third that produced in Kazakhstan (5 405 kWh per capita). Agriculture absorbs 90% of freshwater and contributes 26% of GDP (Figure 14.1) but productivity levels are relatively low, compared to countries such as Brazil or Turkey (Buyuk Kelajak, 2019).

Meanwhile, unfair competition in the area of intellectual property, including 'duplication' of the products of international companies, has discouraged foreign investors (Buyuk Kelajak, 2019). FDI contributed just 1.2% of GDP in 2018 (Figure 14.1).

Moves to improve the business climate

Following the first leadership change since the country gained independence in 1991, President Shavkat Mirziyoyev has embarked upon an economic modernization programme (Elci, 2019).

This reform got under way in February 2017, when the government announced a broad, market-oriented *National Development Strategy 2017–2021* which prioritized the privatization of state-owned enterprises and public–private partnerships; a better investment climate; support for entrepreneurship; and investment in modern technology and innovation.

In June 2018, the president approved the Tax Policy Reform Framework, which seeks to ease the burden on businesses and drive up income levels by lowering personal income tax to a flat rate of 12%. To attract foreign investment, the government has been scaling up reforms in the banking and financial systems, as well as in the public utilities sector, and has adopted a zero-tolerance policy for corruption. An anti-corruption law was adopted in 2017, followed by a 51-step Government Anti-Corruption Programme for 2017–2018. In May 2019, a 35-step Government Anti-Corruption Programme for 2019–2020 was approved (Buyuk Kelajak, 2019).

A focus on innovation-driven development

The *National Development Strategy 2017–2021* articulates the science development agenda. It identifies as priority areas for reform the commercialization of research results and the creation of new research laboratories and advanced technology centres. Research institutes and universities are to be encouraged to engage in public–private partnerships to establish technoparks.

The Ministry of Innovative Development (MoID) was created in November 2017 to lead the implementation of STI policies. This move reflects the new government policy placing innovation at the heart of the development process. Other key ministries are supporting this transformation, notably the Ministry of the Economy and Industry and the Ministry for Development of Information Technologies and Communications (Elci, 2019).

Several presidential decrees specify concrete measures to overhaul the science and research system, including funding for research institutes. For example, the presidential decree of November 2017 (#3365) has approved the Programme for Strengthening the Infrastructure of R&D Organizations and Stimulating Innovation by 2021.

This programme earmarks US$ 32.3 million for renovating research institutes, purchasing scientific and laboratory equipment and supplying consumables. It includes a set of supporting activities in five broad areas: improving the efficiency of research institutes and deepening their integration with university research; attracting young scientists; developing stronger science–industry collaboration; improving intellectual property protection and technology transfer services; and ensuring access to international research databases and information (Elci, 2019).

Companies given incentives to innovate

Some specialized tertiary institutions, such as the Tashkent Chemical Technological Institute, are trying to collaborate with companies by engaging students to work on the specific technological challenges companies face but they are also encountering hurdles. Uzbek businesses are simply not used to paying for research and investing in innovation. Most of the time, this work is not contract-based and lacks any commercial benefit for the tertiary institution involved (Buyuk Kelajak, 2019).

Moreover, Uzbek firms lack sufficient high-quality laboratory equipment and pilot plant infrastructure to allow promising laboratory results to be tested and adopted in an industrial environment (Buyuk Kelajak, 2019).

To date, Uzbek companies have been reluctant to invest in innovation, owing to the high cost of adopting new technology and promoting new products, a lack of skills and finance and an unwillingness to take risks. Uzbek companies are more focused on incrementally improving existing products and production lines.

At the same time, the corporate sector in Uzbekistan is booming: the number of newly registered joint ventures tripled between 2018 and 2019, offering potential for greater technology transfer in the coming years.

The government has introduced an incentive for companies to invest in innovation. Venture funds designed to co-finance high-tech entrepreneurial start-ups have been exempted from all types of tax and mandatory payments until 1 January 2023, in accordance with the presidential decree establishing the State Programme for the Implementation of the Action Plan for the Five Priority Directions of Development 2017–2021, adopted in February 2017.

MoID is prioritizing support for start-ups by setting up innovation centres and acceleration programmes. In parallel, it is working with the Academy of Sciences to identify and commercialize new technologies through MoID's Presidential Fund for the Commercialization of the Results of Scientific and Technical Activities (Elci, 2019).

The presidential decree of July 2018 (#3855) approved a list of 43 research projects for commercialization by research institutes and their line ministry. A further 40 technologies were selected for commercialization in 2020.

This decree indicated two ways for research institutes and universities to commercialize the results of their research and thereby generate revenue from the sale of innovative goods or services: via licensing agreements for the use of intellectual property rights by third parties and via joint ventures with commercial entities.

However, in practice, commercialization is being hampered by lack of experience. In the case of licensing agreements, vague rules and guidelines are proving an impediment. When it comes to determining the equity share of a research institute in a joint venture with a firm, it is a lack of expertise in valuing intellectual property that is impeding commercialization.

On 1 October 2018, the government introduced another incentive: additional one-time bonuses, equivalent to ten months of the minimum wage,[21] for the authors of inventions that were patented outside Uzbekistan. In addition, inventors and research teams now receive respectively 40% and 30% of the income earned by their research institute for an innovative product or service.

Protecting intellectual property a challenge

In February 2018, Uzbekistan adopted a resolution on *Measures to Improve Public Administration in the Field of Intellectual Property*, following a government analysis which concluded that intellectual property was being penalized by the failure to identify and punish intellectual property theft and other related offenses.

The analysis also pointed to high patent fees, an inefficient delivery system for public services and a lack of close interagency co-operation and qualified personnel.

Patent application processes are often lengthy and cumbersome, leading to a loss of know-how or relevance of the research by the time the invention is patented. Some Uzbek researchers report that they have patented and successfully commercialized their inventions in the Russian Federation but were unable to do so in Uzbekistan.

For their part, research institutes and universities point to an insufficient number of patent attorneys and overly bureaucratic patent application review processes as the major bottlenecks.

In addition, uncertainty over the ownership of intellectual property gives researchers little incentive to allocate time to commercializing the results of their research and increases the risks for early-stage investors.

Technology transfer offices have been established to help eliminate these problems but, without the right incentives and appropriate access to funding and expertise, these offices could easily become highly bureaucratic.

These challenges are not specific to Uzbekistan but are becoming more acute with the ongoing transition of Uzbekistan's innovation system.

Greater public support for research funding

Chronic underfunding for R&D is one of the country's biggest challenges. Currently, financial support is geared towards the creation of start-ups, technology transfer and training. There are also indirect policy instruments, such as fiscal incentives for companies in technology parks (Elci, 2019).

MoID has now begun reforming the science funding system. Prior to the ministry's inception in 2017, the government would fund research projects initiated by the scientific community once per year through a cumbersome procedure. Now, calls for proposals are announced online every two months and research grants are awarded on a competitive basis, taking into account the needs of the national economy.

Project funding used to cover researchers' salaries, primarily. MoID has tripled the size of the average grant to about US$ 80 000 and at least 50% of allocated funds are now used by beneficiaries to purchase research equipment. The ministry has also increased funding for field expeditions and laboratories for regional universities, in an attempt to diversify research topics and expand the geographical coverage of scientific facilities. This implies that more funding is going to institutions that do not fall under the National Academy of Sciences.

MoID manages an Innovation Development Fund that is financed through an allocation from the innovation budget of state-owned enterprises. Established by presidential decree in 2018, this fund supports the creation of new research institutes and universities, the registration of patents, short-term scientific trips and schemes to attract foreign scientists.

The ministry has also launched short-term (three-month) foreign internships for researchers. A total of 300 researchers went abroad in 2018–2019 and a further 250 in 2020.

The ministry is also supporting bilateral research projects with research institutions in Belarus, China, Germany, India, the Russian Federation and Turkey.

Although these higher levels of public financial support are welcome, more could be done to improve the mechanisms for fund distribution, commercialization and industry–science collaboration. There are examples of successful commercialization in the past, such as the locally produced medicines developed by research institutes, but companies struggle to introduce new or improved products that require an overhaul of production lines because this disrupts the ongoing production process and often requires heavy investment in new equipment.

Currently, research institutes receive three types of funding: core funds to maintain and upgrade facilities and equipment; funding for targeted research in priority areas; and competitive grant funding, which may target basic or applied research or innovation. Innovation grants, which specifically target commercialization, represent only about 2% of total grant funding. It is, thus, hardly surprising that research institutes would like to see innovation grants make up a much greater share of total grant funding to bridge the existing technological gap and cover additional costs related to marketing, intellectual property protection and so on.

The Academy of Sciences is leading the process to develop open laboratories. This is a positive development, since shared use of laboratory infrastructure helps research institutes to spread costs and ensure compliance with international standards, a prerequisite for expanding export markets and increasing protection from low-quality products produced abroad, such as poor-quality drugs.[22]

A roadmap for innovation

Although Uzbekistan is a net importer of high technologies and science-intensive products, these make up just 6% of total imports (Buyuk Kelajak, 2019). The government is in the process of creating new innovation centres in regions where opportunities for technology incubators are rare and plans to develop regional innovation ecosystems. These will complement the two active technology parks, Yashnabad and the Information Technology Park, as well as the handful of existing innovation centres offering pre-incubation programmes (Elci, 2019).

In January 2019, the government adopted an ambitious *Reform Roadmap*, developed with World Bank support, for becoming an upper middle-income country by 2040. This roadmap foresees the development of a *National Innovation Strategy* and the mobilization of financial resources for research grants to create partnerships with the private sector and foreign universities.

The *Reform Roadmap* came four months after the government's *Strategy for the Development of Innovation 2019–2021*, which affirms the ambitious goal of entering the top 50 in the Global Innovation Index by 2030.

To achieve this, the strategy envisages quadrupling GERD from the current 0.2% to 0.8% of GDP by 2021, striving for scientific excellence and strengthening the links between education, science and industry. The aim is also for Uzbek universities to rank among the top 1 000 universities in international rankings.

Another significant development has been the endorsement of the Law on Science and Scientific Activities in 2019. A similar bill on innovation should be approved by parliament in 2020.

Moves to make research careers more alluring

Meanwhile, the scientific community is ageing. As the older generation retires, researcher density has been dropping, a trend that continued between 2014 and 2018, as the number of full-time equivalent researchers dropped from 500 to 476 per million inhabitants. There was also a slight drop in researcher density by head count (Figure 14.3). This has prompted the government to introduce moves to attract younger scientists to a research career.

Since university teaching salaries remain very low, a presidential decree issued in April 2018 set about raising these, along with student scholarships. The decree also broadened tax exemptions for new educational institutions and made provision for soft loans to these.[23]

Only one-third of university teachers have academic qualifications. To broaden access to doctoral programmes, the quota for admission of doctoral candidates was doubled in February 2017 and procedures were simplified for assessing PhD dissertations. Five months later, a two-tier system of postgraduate education was introduced for the training of Doctors of Philosophy (PhD) and Doctors of Science (Soviet system) to make the doctoral programmes even more inclusive. In 2018, just 10% of the 18–25-year cohort was enrolled in higher education (Figure 14.3).

Academic research faces other challenges. These include the lack of a local peer-review system, outdated research methodologies and equipment and little experience of technology commercialization and entrepreneurship, born of their limited collaboration with industry. Commercialization funds have been established at universities to encourage innovation.

Research institutes currently outperform universities in terms of the quality of their output. To encourage universities and research institutes to develop ties, the positions of vice-rector for science and innovation at universities and deputy directors of research institutes have been merged since 2017.

CONCLUSION

Bold steps to overcome systemic challenges

The chronic underinvestment in R&D in Central Asia has spawned a range of systemic challenges that are holding back research and innovation. These include a vocational crisis in the research community and an exodus of skills.

The cultural divide between the business and scientific communities is another challenge. Disinterest in science among the business community has translated into a lack of demand for technology, creating a heavy burden for the state budget and a technologically backward economy. The scientific community, itself, communicates little with the manufacturing sector, thereby remaining detached from the needs of the real economy.

Complex tax regimes and the lack of tax rebates and loans for enterprises are discouraging innovation and making innovative enterprises unattractive targets for investment and lending. Innovators need financial incentives and a supportive legal and regulatory framework to commercialize their ideas.

The good news is that Central Asian governments are taking steps to overcome these obstacles. There are a growing number of technology parks which benefit from advantageous tax regimes, for instance. Uzbekistan has even placed innovation-based development at the top of its political agenda.

Central Asian scientists and engineers are enjoying more international exposure than in the past. For example, the international accelerator programme, Start-up Kazakhstan, is open to participants from the Commonwealth of Independent States and Europe and the Kazakh Tech Garden has opened offices in Silicon Valley (USA) and in the technoparks of Skolkovo and Novosibirsk (Russian Federation).

Governments are also working with international partners to access green finance, in order to embark on a more sustainable development path, such as through Uzbekistan's 'solar auctions'. One challenge will be to balance competing demands for innovation from the mining sector, which forms the bedrock of Central Asian economies.

Governments are also making an effort to improve the status of researchers through measures such as pay rises, competitive research grants, modern research equipment and joint research projects with institutional partners in countries such as Belarus, China, India and the Republic of Korea.

A need for foresight and critical thinking

Some systemic challenges can have minimal financial implications. One way in which governments can introduce greater coherence at little cost is by improving co-ordination among government agencies, to avoid research policies, 'green' development policies and industrial policies overlapping and even contradicting one another.

Independent think tanks or specialized government departments could conduct technology foresight studies to guide the national decision-making process. They could also undertake a regular evaluation of the status of policy implementation to ensure accountability and enable decision-makers to make the necessary policy adjustments. For instance, the activities of research institutes, universities and other scientific bodies could be assessed every three years to improve accountability.

Governments should not be wary of nurturing independent experts who can think for themselves. Having an independent expert community in the public sector would help to improve decision-making and lead to a higher standard of research, such as by ensuring that the process for selecting and evaluating scientific research was without bias.

The Organisation of Islamic Cooperation's *STI Agenda 2026* argues that the marginal role science plays today in the Islamic world is a result of the failure to uphold the Islamic tradition of nurturing critical thinking, integrity and creativity.

KEY TARGETS FOR CENTRAL ASIA

- Kazakhstan intends to slash government debt to 18.7% of GDP by 2028;
- Kazakhstan plans to use water-saving technologies on 15% of acreage and reduce its greenhouse gas emissions by 15% by 2030;
- At least 10% of Kyrgyzstan's electricity supply is to come from renewable sources by 2023 and 26% by 2030;
- Mongolia plans to devote 0.6% of GDP to R&D by 2020 and 1.2% by 2030;
- Mongolia plans to reduce its foreign debt to 40% of GDP by 2030;
- Mongolia intends to satisfy energy demands through the domestic supply and raise the share of renewable energy in total energy consumption to 30% by 2030;
- Tajikistan intends to expand hydropower output to 40.7–45 billion kWh by 2030;
- Tajikistan plans to allocate 0.8% of GDP to R&D by 2020, 1.2% by 2025 and 1.5% by 2030;
- Turkmenistan intends to achieve zero growth in greenhouse gas emissions by 2030;
- Uzbekistan intends to become a top-50 country in the Global Innovation Index by 2030;
- Uzbekistan plans to build 25 solar plants and 42 hydropower plants, while upgrading a further 32 hydropower plants, by 2021.

Yerbol Suleimenov (b. 1973: Uzbekistan) holds a PhD in Mathematics from the University of Manchester (UK). After initially working in central banking in Uzbekistan, Dr Suleimenov then served as Deputy Chair of the Science Committee of the Kazakh Ministry of Education and Science and as President of the country's Science Fund. He has also been Project Manager of the UNDP project for Institutional Support to the Regional Hub of the Civil Service in Astana, a hub for which he headed the Secretariat.

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ENDNOTES

1 See, for example, EEAS (2019).
2 On Transparency International's Corruptions Perception Index 2018, Mongolia ranked 93rd, ahead of Kazakhstan (124th), Kyrgyzstan (132nd), Tajikistan (152nd) and Uzbekistan (158th).
3 Kyrgyzstan's chemical industry suffers from under investment.
4 These are the International Treaty on Plant Genetic Resources for Food and Agriculture (2018), the Nagoya–Kuala Lumpur Supplementary Protocol on Liability and Redress to the Cartagena Protocol on Biosafety (2018) and the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity (2014).
5 In 2020, Kazakhstan was in the process of drawing up environmental legislation on the basis of principles devised by the Organisation for Economic Co-operation and Development.
6 The programme now covers Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka, Cambodia, China, DPR Korea, Indonesia, Laos, Malaysia, Myanmar, Philippines, Thailand, Vietnam, Mongolia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan.
7 See: https://www.switch-asia.eu/programme/facts-and-figures/
8 See: http://tazakoom.kg and https://digital.gov.kg
9 In 2016, the National Astana Laboratory at Nazarbayev University signed a Memorandum of Understanding with the Joint Institute for Nuclear Research in the Russian Federation to foster research collaboration.
10 Kazakhstan set up the National Fund in 2000 to buffer the oil and gas sector against external shocks. More than one-third of the value generated by oil and gas flows to the public sector in the form of taxes and duties. The bulk is directly transferred to the National Fund, managed by the National Bank of Kazakhstan. Most assets are denominated in foreign currencies and the portfolio is managed by foreign companies. Annual guaranteed transfers are made from the Fund to the central government's budget, as well as to targeted areas by presidential decree. In 2014–2015, targeted transfers of US$ 5.4 billion were used to support the recovery of the banking sector, provide bank lending to SMEs and finance infrastructure projects. Over the period 2015–2017, annual transfers of US$ 3 billion supported sustainable economic growth and employment under the State Programme for Infrastructure Development (Nurly Zhol) [OECD, 2018a, Box 1.1].
11 The State Programme for Industrial and Innovative Development (2015–2019) has replaced the State Programme for Accelerated Industrial and Innovative Development (2010–2014).
12 The State Programme for the Development of Education and Science for 2016–2019 builds on the State Programme for Educational Development 2011–2020; its successor covering the period to 2025 was awaiting approval in early 2020.
13 There are over 70 research institutes in Kyrgyzstan, 24 of which operate under the Academy of Sciences, 24 under the Ministry of Education and Science and 20 under various universities.
14 This committee comprises representatives of ministries, government agencies, international and non-governmental organizations and parliament.
15 The concentration of airborne particulate matter 2.5 microns in size (PM2.5) in Ulaanbaatar is 58 μg/m^3, almost six times the threshold recommended by WHO (IQ Air, 2018).
16 To inform this process, UNESCO conducted a survey (unpublished) in 2018 within its Global Observatory of STI Policy Instruments.
17 The Government of India's grant-in-aid programme had already funded the establishment of the Atal Bihari Vajpayee Centre for Excellence in Information and Communication Technology in Ulaanbaatar in 2003.
18 See: www.1212.mn and http://sdg.gov.mn
19 At the time of adoption of the National Development Strategy to 2030 in 2016, it was planned to raise US$ 118.1 billion to fund implementation: US$ 56.1 billion from the state budget, US$ 54.7 billion from the private sector and US$ 7.3 billion from development partners (Price, 2018).
20 Current investment in education and science in Turkmenistan has been framed by the Programme for Social and Economic Development, 2019–2025, the Programme for the Training of Scientific Personnel (2015) and the Programme for the Development of Innovation, 2010–2025.
21 The current minimum monthly wage in Uzbekistan is UZS 577 170 (*ca* US$ 60).
22 For example, having a laboratory certified as respecting Good Laboratory Practice would help a research institute to increase the quality and visibility of domestic research in chemistry, pharmaceuticals and interdisciplinary areas. It would also help the research institute to develop new pharmaceutical products that meet international standards, expand export markets and increase protection from low-quality medicines.
23 This presidential decree is entitled Measures to Improve the Remuneration System for Employees of Higher Educational and Scientific Research Institutions.
24 For Tajikistan and Turkmenistan, see: https://tinyurl.com/sd338vo and https://tinyurl.com/wmfwb8m

AT A GLANCE

Start-ups at the Azadi Innovation Factory in Tehran, established in 2017. Azadi covers an area of 18 500 m^2 and provides employment for 3 500 university graduates and young entrepreneurs. Start-ups cover a range of fields that include architecture and urban living, artificial intelligence, biotechnology, creative content, cybersecurity, fintech and insurance, nanopharmaceuticals and tourism. © Vice-Presidency for Science and Technology of Iran

- Combined with heightened domestic demand, the multiplication of technology incubators and accelerators since 2015 has led to exponential growth in knowledge-based firms and start-ups.
- Between 2014 and 2017, exports of knowledge-based goods grew by a factor of five, before slumping in 2018 following the restoration of US sanctions.
- A series of laws and policies adopted since 2015 have removed barriers to competition and enhanced the financial support system for innovation.
- Market incentives have not managed to boost overall commercial investment in research and development (R&D), however, which dipped from 35% to 28% of domestic expenditure on R&D between 2014 and 2016.
- The 39% unemployment rate among university graduates suggests a pressing need to adapt academic programmes to the needs of the job market.
- Despite attempts to boost domestic manufacturing and employment, the renewable energy sector still contributes less than 1% of the energy mix.

15 · Iran

Shuan Sadreghazi

INTRODUCTION

Five roller-coaster years

The previous *UNESCO Science Report* (Ashtarian, 2015) detailed Iran's plans for gradually weaning its economy off oil resources to accelerate the transition towards a knowledge economy. Events over the intervening years have incited the government to pursue this transition with greater ardour. The most visible expression of this policy is the heightened support for start-ups and other tech-based firms, which has stimulated innovation.

This trend can be divided into two stages. Up until the lifting of sanctions in 2016, the difficulty in accessing foreign technology had stimulated support for endogenous innovation. The government had put in place a number of policy instruments to support innovation, including the pivotal National Innovation Fund[1] (2012) and Nanotechnology Initiative Council (2002). It had also encouraged companies to source their materials from local suppliers as part of what it called the 'resistance economy' (Ashtarian, 2015).

Following the lifting of sanctions by the United Nations, USA and European Union (EU) in early 2016, in keeping with the *Joint Comprehensive Plan of Action*, or nuclear deal, agreed with six major powers[2] the previous year, Iranian scientists and engineers enjoyed greater exposure to foreign state-of-the-art technologies. For instance, the nuclear deal entitled Iran to submit a formal request to participate in a project[3] that may revolutionize energy production, if successful; this project is building an International Thermonuclear Experimental Reactor (ITER) in France. A team from ITER visited Iran in November 2016 to deepen its understanding of Iran's own nuclear fusion-related programmes (Coblentz, 2016).

Heightened exposure to foreign state-of-the-art technologies has added momentum to endogenous creativity. However, scientific interaction with the international community was curtailed in 2018 when the USA withdrew from the nuclear deal, shortly after the International Atomic Energy Agency (IAEA) had certified that Iran was in compliance with the agreement.

US sanctions were immediately restored and subsequently extended. The EU has attempted to preserve the nuclear deal by introducing an Instrument in Support of Trade Exchanges (INSTEX) for companies wishing to do business with Iran.

The re-imposition of sanctions has also penalized Iranian academics and students. In 2018, the international payments–transfer system known as SWIFT disconnected Iranian banks. This means that Iran-based academics and students are unable to pay conference registration fees or order books on international websites. Concerned at the prospect of unwitting violation of the sanctions, many journals and publishers have become reluctant to handle manuscripts signed by Iranian authors or entities (Kokabisagh *et al*., 2019).

Long-established scientific exchanges between Iran and the USA have also dried up since 2017. For example, workshops set up by the US National Academies of Sciences, Engineering and Medicine between 2010 and 2017 to bolster collaboration in fields that included energy and water resource management have been cancelled (Tollefson, 2018).[4]

Despite all the challenges, there is a silver lining. The impact of gruelling sanctions on oil exports has placed the potential of the knowledge economy on the government's radar. This was evident even before the previous batch of sanctions was lifted in 2016; however, government support for local knowledge-based companies and start-ups has moved into higher gear in the past few years, as we shall see later.

A body blow to tech exports

Perhaps the most glaring example of the immediate impact of the re-imposition of US sanctions on science and engineering has been the body blow delivered to Iran's burgeoning export market for medium- and high-tech products (Figure 15.1).

Between 2014 and 2017, exports of knowledge-based goods from Iran's science and technology parks and incubators had grown by a factor of five, before slumping in 2018. This decline in exports is associated with the economic problems encountered by companies and their difficulty in sourcing material and selling products after the re-imposition of sanctions.

The restoration of sanctions in 2018 has motivated companies to use local suppliers of knowledge-based goods and services.

Diversification into knowledge-based fields

The past five years have seen a boom in endogenous innovation. In 2015, Iran launched its first public innovation centres and accelerators to empower start-ups. By 2020, 49 innovation accelerators had been established with private equity and 113 innovation centres had been set up in partnership with science parks and major universities. Technology incubators,[5] meanwhile, have been providing graduate entrepreneurs with co-working spaces and mentoring on campus to help them launch their own start-up.

The government has been encouraging start-ups to diversify into various knowledge-based fields, with emphasis on developing local solutions and addressing the needs of industry. Since 2018, the Vice-Presidency for Science and Technology has published a series of books on global experiences in 20 tech-based fields, to alert entrepreneurs to opportunities for innovation. These fields span waste management, agriculture, water management and drought, air pollution, sports and physical health, digital health, social innovation, energy, tourism, insurance, education and mining.

Meanwhile, some large private companies have been diversifying their investment portfolios. Since 2015, they have established a total of 20 start-ups in such strategic fields as the digital economy, water, energy, lasers and photonics, cognitive sciences, aerospace, software, creative industries, agriculture and transportation. A prime example of this diversification is PersisGen, a specialized accelerator (Box 15.1).

By 2019, Iran had risen through the ranks from 106th (2015) to 61st out of the 129 countries featured in the Global Innovation Index (Figure 15.2).

Local drug production peaks

Iran's research strengths lie in biotechnology and nanotechnology. By 2018, there were 524 active biotech companies in Iran and sales of locally produced nanoproducts had increased twelve-fold in just three years (Figure 15.2). Iran's output in terms of publications on health leapt by 64% between 2012 and 2018, according to the Scopus database.

Local pharmaceutical production has climbed rapidly since 2015. The domestic market was worth US$ 4.5 billion in 2018,[6] with 70% of pharmaceutical companies being locally owned. By 2019, Iran was able to produce 95% of medicines destined for the domestic market, including two-thirds of their active ingredients.[7]

Iran exported pharmaceuticals to 17 countries in 2019, a considerable portion of which went to the EU. EU imports from Iran even peaked in the first half of 2019 at € 18 million, with Germany taking 92% of the stock, according to Eurostat (FDD, 2019). Iran's own imports of European pharmaceuticals amounted to € 320 million in 2019, about the same level as in 2014 (Ghasseminejad and Adesnik, 2019).

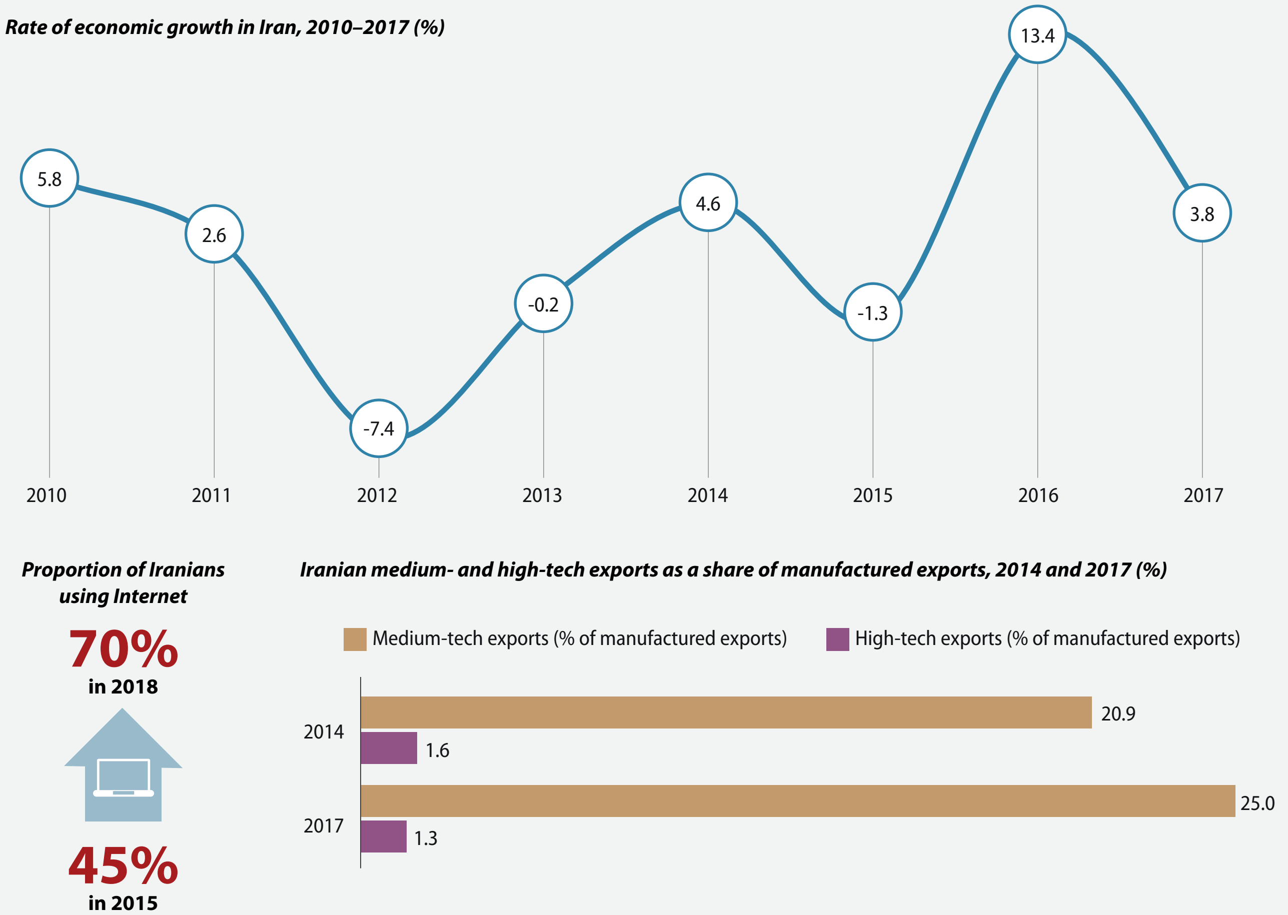
The volume of Iran's pharmaceutical exports had reached US$ 80 million by March 2018 before dropping back to US$ 50 million over the next 12 months (Financial Tribune, 2019).

A short-lived economic rebound

Endogenous innovation has been supported by the economic rebound triggered by the lifting of international sanctions in 2016. Iran posted growth of 13.4% that year and 3.8% the following year, equivalent to about US$ 447.7 billion (Figure 15.1). In the course of the first semester of 2017, recovery extended to the non-oil sector, facilitated by astute monetary and fiscal policies and a boom in the services and construction industries.

According to the Iranian Statistical Centre, the unemployment rate[8] had fallen to 10.6% by March 2020, showing a decline of 1.7% over the previous year, although the rate remained higher for youth and women, at 25.7% and 17.2%, respectively. Four out of ten university graduates are unemployed (39%), up by five percentage points since 2019.

Figure 15.1: **Socio-economic trends in Iran**



Source: World Bank's World Development Indicators (May 2020)

A broad mobilization against Covid-19

In 2020, the economy was ravaged by the Covid-19 outbreak. As Iranians were preparing to celebrate the Persian New Year in mid-March 2020, the number of confirmed cases was approaching the 30 000 mark. Iran has since scaled up its initial response to the crisis and improved co-ordination between government agencies and municipal bodies. In late March, Iranians began repurposing the country's production capacity for the manufacture of domestic personal protection equipment such as masks and hand sanitizer to meet the shortfall.

The National Innovation Fund and Vice-Presidency for Science and Technology also provided support for knowledge-based companies' Covid-19 response. Businesses were offered low-interest loans, for instance. A campaign was also launched called Corona Plus to incite start-ups to find solutions to the challenges posed by Covid-19. Companies were given financial incentives to help them produce medical equipment ranging from disinfectant and protective gear to ventilators and diagnostic kits, or to develop a cure.

Within a few weeks, the number of its Covid-19 testing laboratories had doubled from 22 to around 40. By mid-May, there were almost 120 000 confirmed cases, according to Johns Hopkins Coronavirus Resource Center.

A report by Iran's Parliamentary Research Centre (2020) has estimated that between 2.4 and 6.4 million may lose their jobs, at least temporarily, over Covid-19, 70% of whom lack any insurance cover. The government has been urged to take specific measures for vulnerable lower-income groups.

In addition to its significant impact on sinking oil prices – the government's main source of income – the Covid-19 outbreak has restricted exports of goods to Iran's neighbours. According to the the Central Bank of Iran, more than half of the country's income comes from regional trade channels. Since neighbouring countries closed their borders, Iran's exports have plummeted. In late March 2020, for the first time in six decades, Iran asked for emergency funds from the International Monetary Fund (IMF) to help it handle the situation.[9] The US opposed this request as part of its 'maximum pressure' campaign against Iran.[10]

According to the IMF (2020), GDP shrank by about 5.4% in 2018 and is expected to contract by 8.7% in 2019. The forecasted decline in economic growth would mean that, by the end of 2020, the economy would be 90% of its size just two years earlier, even without the Covid-19 epidemic.

Knowledge-based industries prioritized for support

The government faces the arduous task of cushioning these economic shocks (Hayaty *et al.,* 2018). It will be expected to define effective coping mechanisms for financial services and manufacturing, in particular, since the Iranian economy is characterized by a strong state presence in these sectors.

The government has stepped up efforts to sell its shares in large domestic enterprises, to compensate for the drop in income since sanctions were reimposed in 2018. The budget law for the year beginning on 21 March 2019 forecast revenue of US$ 2.5 billion from privatization.

However, the privatization drive has been encountering some resistance from state-owned companies. There are cases where shares sold on capital markets have been purchased by semi-state-owned entities, or where shares have been transferred to the private sector but not the concomitant responsibility for company management.

Moreover, banks and semi-state-owned enterprises tend to be bureaucratic and to require heavy collateral from start-ups applying for financial support.

The government has made it a priority to cushion the blow of sanctions to its burgeoning knowledge-based industries. For example, since 2018, the National Innovation Fund has been going through a major overhaul; it is evolving from a quasi-banking institution into a regulator and facilitator for financing knowledge-based companies, to help them overcome obstacles in the dominant financial sectors. For instance, the fund is being encouraged to co-ordinate its own programmes with those of other funds for research and technology and with the banking network. The National Innovation Fund is also introducing new investment schemes and streamlining its organizational structure and procedures (NIF, 2019).

For Iranian organizations, obtaining earmarked funds from the state budget does not guarantee that the totality will be

Chapter 15

Box 15.1: **PersisGen: Iran's first accelerator for medical biotechnology**

Launched in 2016, PersisGen is a biopharmaceutical company which designs, develops and produces biosimilars, vaccines and plasma-derived products. It also specializes in regenerative medicine through the use of stem cells.

PersisGen has an accelerator department which is the first of its kind in medical biotechnology in Iran.

The accelerator helps young researchers gain practical skills and establish independent knowledge-based companies. It mentors start-up teams, providing them with technical infrastructure and guidance on prototyping, technology buy-back and investment; it also signs contracts with start-ups for joint product development.

PersisGen is funded entirely through private equity. One of its primary private investors is CinnaGen, a pioneer in Iran's biomedicine industry that was founded in 2003. CinnaGen brings to the table its experience of joint research with the Fraunhofer Institute in Germany.

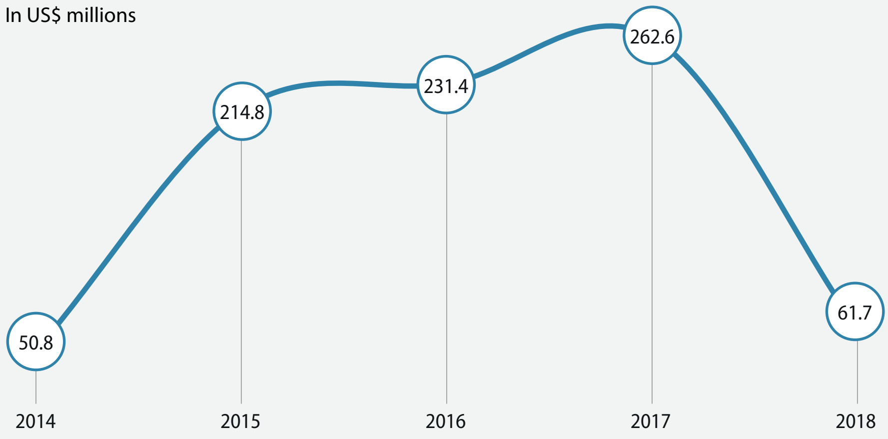
PersisGen has no foreign shareholders. It is supported by the Vice-Presidency for Science and Technology.

The economic savings for Iran of not having to import medical goods thanks to PersisGen's accelerator are projected to reach US$ 400 million annually by 2025. This forecast should not be unduly affected by the restoration of sanctions, since most of the anticipated production will be destined for the domestic market.

Source: persis.com

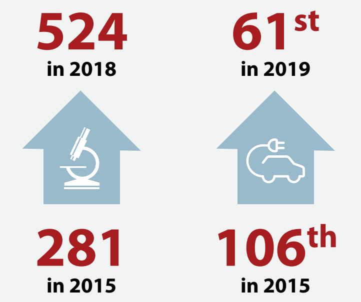
Figure 15.2: **Trends in innovation in Iran**

Exports of knowledge-based goods from Iranian science parks and technology incubators, 2014–2018
In US$ millions

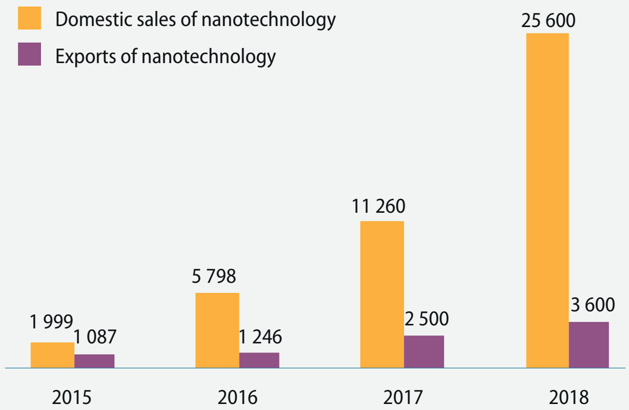


Iranian biotech companies

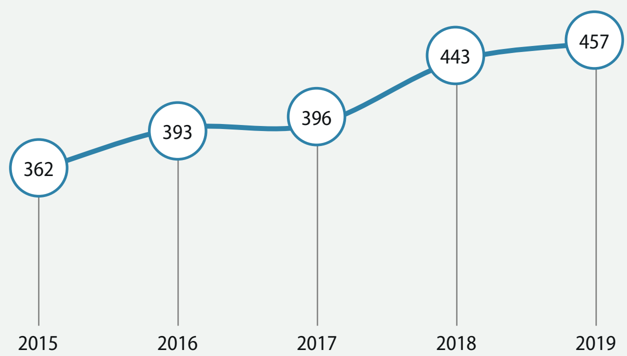
Iran's ranking in the Global Innovation Index



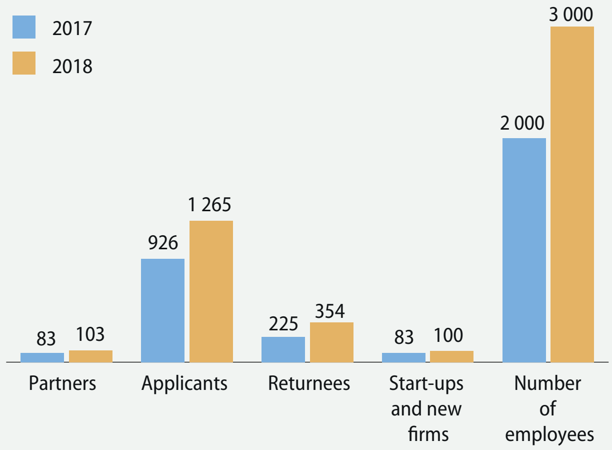
Sales of locally produced nanoproducts, 2015–2018



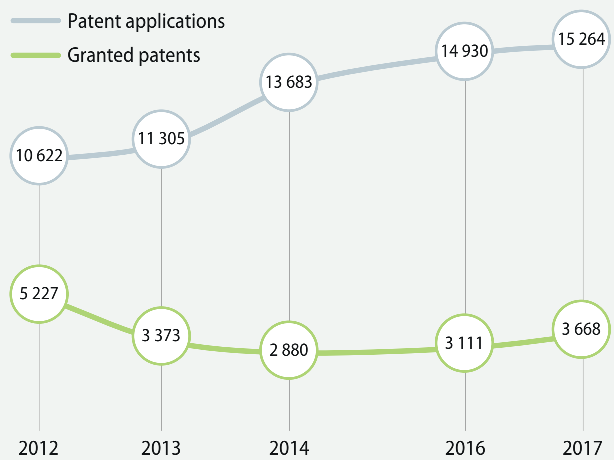
Number of IP5 patents granted to Iran, 2015–2019



Iranian returnees partnering with, or establishing, start-ups and new tech-based firms in Iran, 2017 and 2018



Trends in patenting at Iran's Intellectual Property Centre, 2012–2017



Note: Data are unavailable for 2015.

Note: Technology incubators are called growth centres in Iran. IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China

Source: World Bank's World Development Indicators (May 2020); Iranian Vice-Presidency of Science and Technology's Briefing on Science and Technology; for patents: prepared by Science-Metrix using PatentsView data; Iran Vice-Presidency for Science and Technology (2019); World Intellectual Property Organization; for data from Intellectual Property Centre: Implementation Committee for the National Comprehensive Scientific Map (2019) *Monitoring Report of Science, Technology, Innovation Indicators of the Islamic Republic of Iran*. See (in Persian): https://sccr.ir/Files/7164.pdf effectively transferred to them. By 2020, 87% of the amount destined for the National Innovation Fund had been secured. This fund has played a pivotal role by providing facilities for knowledge-based companies, such as for prototyping, hire-purchase, leasing, working and venture capital, office space, pre-order activities, industrial production plants, issuance of warrants and empowerment programmes.

TRENDS IN SCIENCE GOVERNANCE

A new generation of STI policies

The year 2010 was a turning point for science, technology and innovation (STI) policy in Iran. Up until this point, the emphasis had been on developing higher education and increasing the number of academic publications (1990–2000), followed by support for emerging technologies (2000–2010). The main result of this *first* generation of STI policies was greater academic productivity in emerging technologies, in particular, coupled with the creation of the first science and technology parks.

The founding of the Nanotechnology Initiative Council (2002) was a landmark of this period. These years also saw the adoption of the Competition Act (2007), followed by the establishment of the Competition Council in 2009 to serve as the main pillar of the law's implementation in the marketplace.

The *second* generation of STI policies dates from 2010 when the Vice-Presidency for Science and Technology drafted a bill that was subsequently enacted by parliament as the Law on Support for Knowledge-based Institutions and Companies and Commercialization of Innovation and Inventions (2011). This explicit focus on the knowledge economy was a first for Iran. The National Innovation Fund (2012) was a practical expression of this law. Initally, the aim was to support university spin-offs but this support has gradually expanded to encompass tech-based start-ups and some eligible large enterprises such as CinnaGen or PersisGen, which are privately owned.

The *third* generation of STI policies dates from 2015 when parliament gave another boost to entrepreneurship and innovation through the Law on Removing Barriers to Competitive Production and Enhancing the Financial System. It is this law[11] which led to the first innovation centres and accelerators in 2015.

This law was followed by the *Local Content Requirement Policy* (2016). It introduced a clause requiring international agreements and major national projects to 'include local technology and training.' This clause is now being implemented in national projects.

Another milestone has been the Law on the Expansion of Nanotech Utilization 2025 (2017). This law established a ten-year plan for transitioning from the stage of knowledge creation (technology push) to that of market expansion through the diffusion of nanotechnology in local industry and society (demand pull).

Notable in 2019 was the attempt to modernize public procurement procedures to leverage higher levels of local production, through the Law on Maximizing the Use of Local Capacity for Production and Services to address National Needs and Consolidate these Capacities to Enhance Exports.

Iran's judiciary established the Special Council for Dispute Resolution of Knowledge-based Companies and Elites in January 2020. It is based in Pardis Technology Park. A second council has been set up to address the legal problems faced by digital businesses.

For this third generation of STI policies, the Vice-Presidency for Science and Technology has shifted from a *national innovation system* approach, whereby government actors are the focal points of innovation, to developing an *innovation ecosystem* approach, whereby hubs of knowledge-based enterprises and tech-based start-ups are given support and their innovative capacity is linked to addressing national and industrial needs.

Three-step creation of innovation zones

Policies supporting what are called 'innovation zones' in Iran can also be broken down into three stages. The *first* stage entailed measures encouraging the creation of science and technology parks and incubators on university campuses.

By 2018, universities were hosting 45 active science and technology parks and 193 incubators. Pardis Technology Park is the largest. It hosts about 500 companies with a combined total of more than 6 000 employees. Pardis acccounts for 10% of the income and exports from Iran's science and technology parks.

The *second* stage has consisted in creating spaces within large cities where start-ups, investors and other actors of innovation can mingle and network. Abandoned factories have been renovated and rebranded as 'innovation factories' to house this new generation of entrepreneurs.

The first two innovation factories are Azadi and Highway, established in Tehran in 2017 and 2019, respectively, which are branches of the Pardis Technology Park. The start-ups and accelerators at Azadi and Highway are entitled to access facilities at the Pardis Technology Park.

Azadi (see photo, p. 394) covers an area of 18 500 m^2 and provides employment for 3 500 university graduates and young entrepreneurs. Start-ups cover a range of fields that include architecture and urban living, artificial intelligence, biotechnology, creative content, cybersecurity, fintech and insurance, nanopharmaceuticals and tourism (The Iran Project, 2019).

The Highway Innovation Factory can accommodate up to 500 employees. It opened with 20 start-ups working in the field of ICTs, medical devices, management, creative content development and agriculture (Tehran Times, 2019).

There are plans to establish another five innovation factories in large cities by 2022.

At the *third* stage of innovation platform creation, academic centres in urban areas are being turned into third-generation universities, also known as entrepreneurial universities. The aim is to bridge the gap with traditional universities and enhance the position of universities within the overall innovation ecosystem (Parliament Research Centre, 2013).

Sharif Innovation Zone is a prominent example of such an approach. By 2017, more than 500 start-ups had been established by students, graduates and faculty of Sharif University of Technology, according to the Platform Towards Developing Entrepreneurship.

A focus on the digital economy

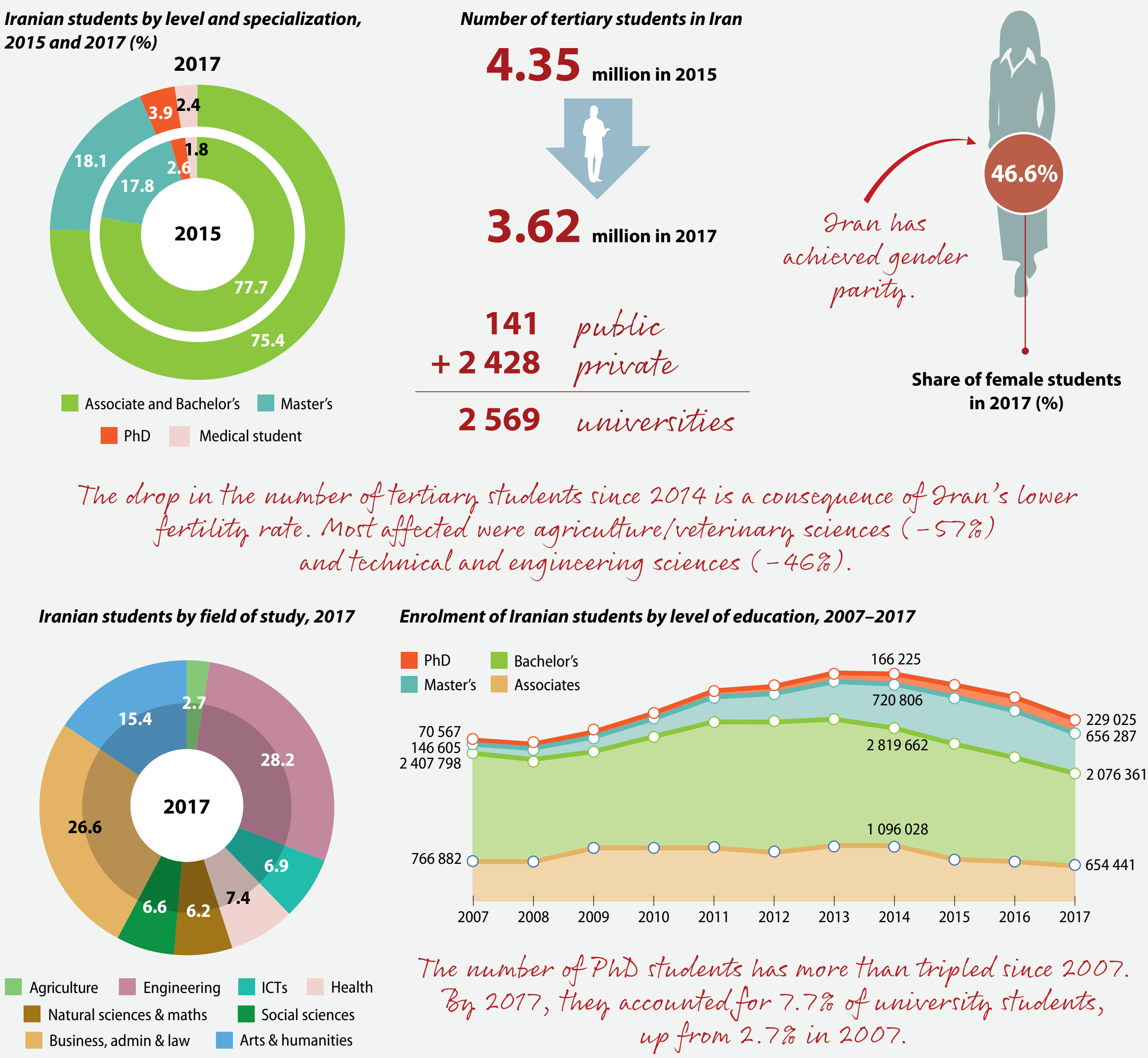
Since 2015, many universities and science parks have organized events to help university graduates develop both technical and soft skills. 'Start-up weekends', 'idea shows' and 'bootcamps' have become common events, with topics ranging from rural entrepreneurship, health, clean air and water to transportation, artificial intelligence, blockchain and cybersecurity. In 2019, the Vice-Presidency for Science and Technology issued an executive directive[12] advising universities to support bootcamps in fields related to the digital economy. Some 23 bootcamps on the digital economy are planned for 2019–2020 for university graduates in digital technologies like artificial intelligence.

The proliferation of these events is a positive sign of support for start-ups from Iran's leadership. However, there are concerns that these events offer little real support beyond awarding prizes and some modest funding. Having a nationwide network of professional mentors in various industries who could interact with start-up teams would help them move on from the gestation phase. Modules for the training of trainers could be developed to guide these mentors.

Sa'di, the famous Persian poet from 7th century, likens an action-less scholar to a honey-less bee. Perhaps Iranian STI policy-makers had this quote in mind when devising policy tools to enhance the impact of the first and second waves of STI policies described above.

For instance, the main outcome of the first and second waves of STI policies was a greater number of university graduates (Figure 15.3) and scientific publications (Figure 15.4) but this, alone, did not boost value creation to any significant extent. This is where the policy tools and

Figure 15.3: **Trends in higher education in Iran**



Source: Statistical Centre of Iran, see: www.amar.org.ir; UNESCO Institute for Statistics

Note: Associate level corresponds to the short-cycle diploma in Iran.

programmes of the third wave come in. By emphasizing ecosystem- and platform-building, they are more likely to yield greater value addition – although it is a bit early to say, at this stage.

These policy tools and programmes seek to empower innovative industries and digital industries. One such programme is IranLab, a start-up which organizes exhibitions of advanced, domestic laboratory equipment and materials where creative firms can meet potential customers. So far, there have been six IranLab exhibitions; there is also a permanent online marketplace for interested customers.

Another programme has been offering Market Support for Locally Built Advanced Machinery since 2018, reflecting the importance of this industry for Iran.

So far, more than 400 companies have benefited from this programme, leading to the manufacture of 600 novel products.

Another policy tool focuses on helping knowledge-based companies commercialize their products. Companies are offered supportive financial mechanisms, such as buyer credit, pre-purchase and prototyping credit. Such measures may be cumulated with other supportive regulatory mechanisms for knowledge-based entities, such as tax exemptions, low-interest financial services, exemptions from customs duty and social welfare insurance.

According to the World Bank (2020), Iran ranks 127th out of 190 countries for the ease of doing business but 178th when it comes to starting a business.

Making it easier for digital firms to do business

In 2016, an executive directive was devised to help the growing number of online businesses overcome bureaucratic hurdles. This led to the establishment of the National Union of Online Businesses in 2017, which provides its members with business licenses and other forms of support. This union has also proven useful for tackling certain regulatory barriers and other obstacles encountered by traditional businesses. For instance, in 2020, a parliamentary working group addressed the challenges faced by e-businesses and online services.

In the past five years, Iran's digital ecosystem has seen a boom in online platforms. For example, there are ride-haililng apps (Tapsi and Snapp), online marketplaces (Digikala, Divar), video streaming (Aparat) and an app-based distribution platform (Café Bazaar). Covid-19 has had a silver lining for Iranian online health and well-being start-ups. Since the outbreak, many new health apps have been advertised on billboards.

The growth in supply and demand with regard to online services correlates with the sharp increase in Internet penetration, especially mobile Internet, which has spiked at 70% in 2020, up from 40% in 2015.[13] Two-thirds (65%) of mobile phone connections now have Internet access.[14]

Giving officials a shrewd 'policy acumen'

Another type of complementary programme pursued more actively in the past few years aims to instil policy awareness and acumen in policy-makers to improve decision-making in prioritized areas of science and technology. Such programmes include the:

- national technology foresight programme (2015) for the energy, automotive, health and water sectors;[15]
- R&D surveys conducted biennially since 2015 by the Statistical Centre of Iran to gauge the level of investment by the business, academic, governmental and non-profit sectors;
- *Iran Innovation Survey* (2016), conducted annually by the Vice-Presidency for Science and Technology; and
- National Science and Technology Monitoring System, introduced in 2015 by the Supreme Council for Science, Research and Technology.[16]

SUSTAINABLE DEVELOPMENT AGENDA

High graduate unemployment

The United Nations' *Sustainable Development Report* (2019) ranked Iran 58th overall out of 162 countries, judging that the country was on track[17] to meet its targets for sustainable industrialization, infrastructure development and innovation (SDG9) but falling behind on climate action (SDG13) and on preserving terrestrial biodiversity (SDG15).

Iran ranks third in the Global Innovation Index (2019) for the percentage of the workforce employed in science and engineering. However, it is evident from the high rate of unemployment (39%) among university graduates[18] that more needs to be done to combine university education with career training; this will be a considerable challenge for a country with such a large talent pool (Figure 15.3).

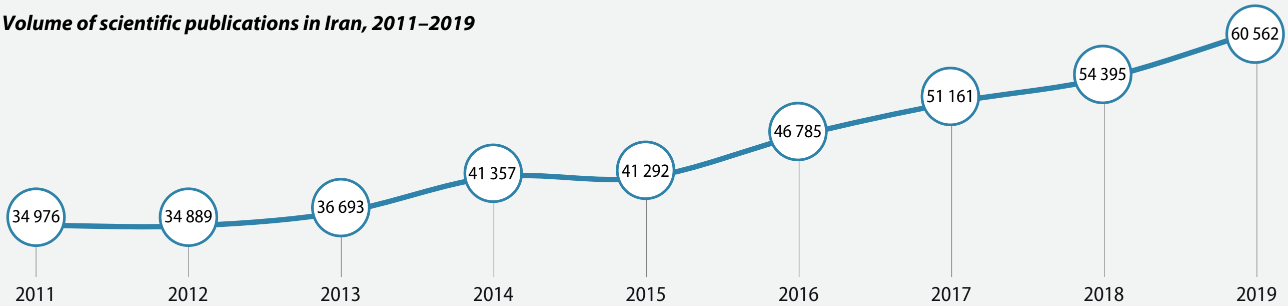
A number of factors explain the extremely high rate of unemployment among graduates. Firstly, there is a lack of statistics and other relevant information on the status of labour supply and demand in various fields of study, making it hard for students to anticipate market needs. This is exacerbated by the lack of co-ordination and communication between organizations and executive agencies in Iran with universities to identify labour market needs.

Universities also tend to rely excessively on purely theoretical education, coupled with weak training in practical and applied fields, especially when it comes to technical, engineering and agricultural disciplines. Universities are also accepting more students in the humanities than the labour market can absorb.

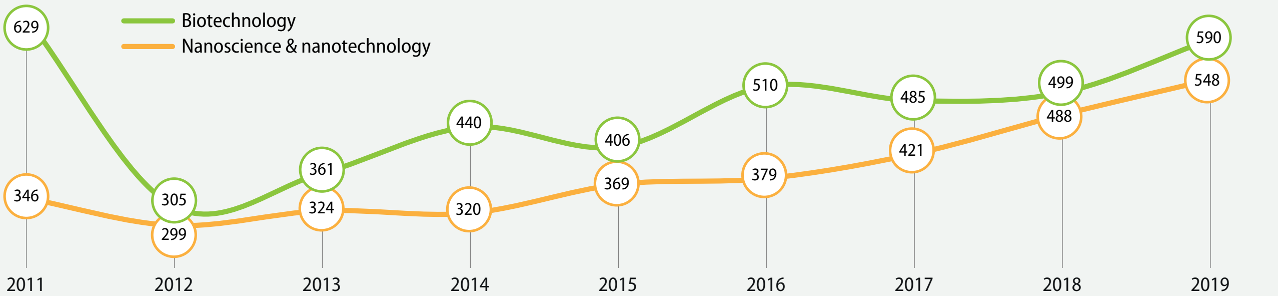
The spread of a culture of credentialism, whereby the obtention of a university degree is considered an end in itself, is not preparing graduates for the harsh realities of the job market. Students are finding that they lack marketable skills or that there are few job opportunities in non-industrial and less developed parts of the country. Upon confronting this reality, many graduates are opting to return to university to pursue a higher degree, in the hope of improving their employability. Habibi (2015) has analysed the phenomenon of graduate surplus and overeducation in Iran, which is also a major issue for other countries in the region.

Figure 15.4: **Trends in scientific publishing in Iran**

Volume of scientific publications in Iran, 2011–2019



Iranian publications in nano- and biotechnology, 2011–2019



Scientific publications per million inhabitants in Iran, 2011, 2015 and 2019

0.94

Average of relative citations for Iran, 2014–2016; the G20 average is 1.02

25%

Share of publications with foreign co-authors in Iran, 2017–2019; the G20 average is 25%

How has output on SDG-related topics evolved since 2012?

Iran published twice as much as expected, relative to global averages, on the topics of smart-grid technology, human resistance to antibiotics, desalination and national integrated water resource management.

The volume of output was also above average for hydropower, wind-turbine technologies and sustainable chemical waste management.

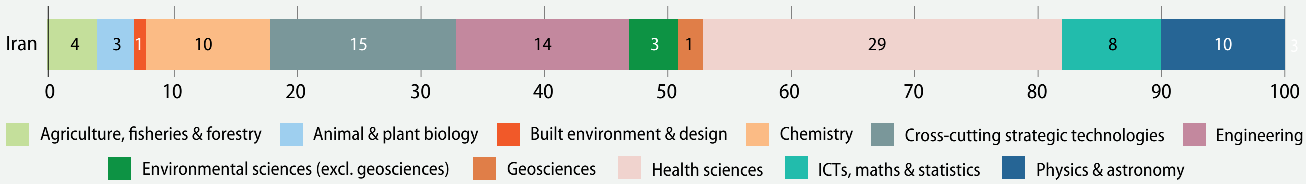
For many of these topics, the number of publications nearly doubled between 2012–2015 and 2016–2019. For example, this was the case for publications on smart-grid technology (from 1 136 to 2 158) and human resistance to antibiotics (from 592 to 1 045).

Output surged for the energy-related fields of greater battery efficiency (from 248 to 635), geothermal energy (from 76 to 171), photovoltaics (from 664 to 1 331) and biofuels and biomass (from 420 to 1 034).

Although output on radioactive waste management remains low, it doubled from 24 (2012–2015) to 53 (2016–2019) publications.

For details, see chapter 2

Scientific publications in Iran by broad field of science, 2017–2019 (%)



Iran's top five partners for scientific co-authorship, 2017–2019 (number of publications)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Iran	USA (9 833)	Canada (4 578)	UK (3 859)	Australia (3 673)	Italy (3 586)

The USA is Iran's primary scientific partner.

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

Domestic research spending stagnating

In 2017, Iran devoted 0.83% of GDP to gross domestic expenditure on research and development (GERD,[19] Figure 15.5). The National Research Institute for Science Policy had fixed an ambitious target for this indicator of 3% of GDP by the end of the *Fifth National Development Plan* (2011–2017) and 4% of GDP by the end of the *Sixth National Development Plan* in 2021 (Ashtarian, 2015).[20]

The inability to raise the GERD/GDP ratio is considered a major shortcoming of the *Fifth National Development Plan*. This trend is apparently due to the combined effect of an inadequate allocation of state budgets earmarked for research and the lack of interest in the private sector in augmenting its own financial investment in R&D. The plan had foreseen that public–private partnerships with a 50/50 share of investment would fuel demand-driven R&D.

Industrial R&D fell from 35% to 28% of GERD between 2014 and 2016. Visibly, market incentives have not proven strong enough to boost commercial investment in R&D.

The mere 2% increase in the 2020–2021 national budget for research centres and university research institutes makes achieving domestic spending targets any time soon even less likely.

One achievement of the *Fifth National Development Plan* is to have increased the number of research programmes, including joint research projects between Iranian and foreign research institutes. For instance, in November 2019, Iran's Vice-President for Science and Technology travelled to China with 70 knowledge-based Iranian companies to identify Chinese business partners.

A decline in local patenting

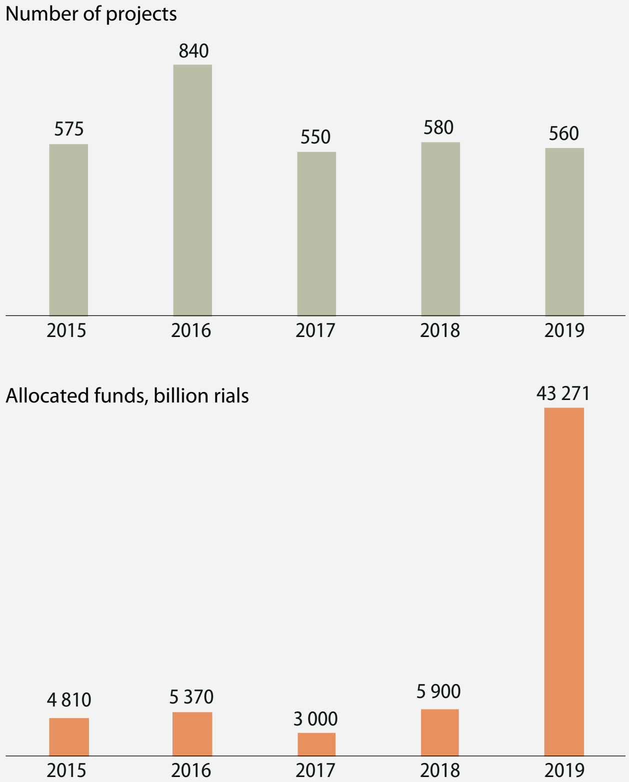
The number of patent applications submitted to Iran's Intellectual Property Centre has progressed, even if the number of patents issued locally shows a decline. Conversely, Iranian inventors are obtaining more patents than before from international patent offices (Figure 15.2).

According to the Global Innovation Index, Iran is one of the top three countries for the rate of improvement in innovation. Its most noted accomplishments relate to the quality of infrastructure, particularly as concerns the deployment of information and communication technologies (ICTs) to deliver public services. There have also been improvements reported in expenditure on education, state funding per pupil, patent applications, high-tech imports and exports of ICT services that include software development, telecommunications, film, radio and television recording and broadcasting (WIPO, 2019).

Continued growth in those indicators is, to some extent, the result of co-operation among relevant bodies in collecting

Figure 15.5: **Trends in research expenditure in Iran**

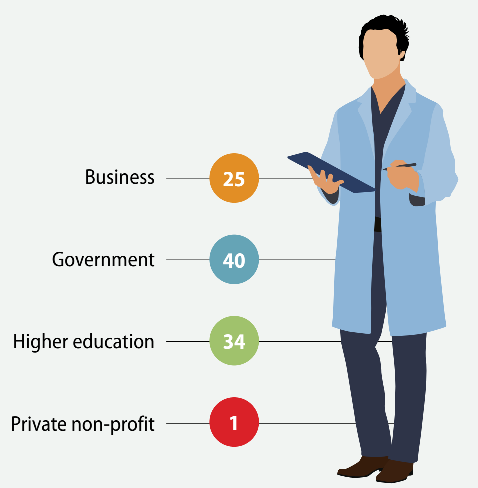
National Innovation Fund support for knowledge-based projects, 2015–2019



0.83%
GERD/GDP ratio, 2017

PPP$ 95 790
GERD per researcher (FTE, constant 2005 values), 2017

GERD performed by sector in Iran, 2017 (%)



Note: The Vice-Presidency's Office for Science and Technology considers that GERD may be closer to 1% of GDP, based on the report produced by the Iranian Statistical Office (2019). *Report on Executive Bylaw for STI Evaluation and Monitoring.*

Source: NIF (2019); Central Bank of Iran; for GERD: UNESCO Institute for Statistics

Banks and credit institutions lent 137.6 trillion rials (ca US$ 850 million) to 1 108 knowledge-based companies in 2019, a 74.5% rise over 2018.

and surveying data and publishing it internationally. This trend continued in 2019, in line with the *Comprehensive Scientific Plan* (2011) and the stance of the *Resistance Economy Council* within the Plan and Budget Organization.

The government is taking a three-pronged approach to improving the quality of scientific output. Firstly, it is gearing support towards the high end of the scale by identifying and supporting top-ranked scientists: 75 in 2017 and 77 in 2019.

Secondly, it is encouraging the diaspora to invest in Iran. So far, more than 1 400 Iranian professionals abroad have joined various local projects and initiatives. The diaspora has also launched more than 100 start-ups employing more than 3 000 skilled staff.

Thirdly, the government is helping Iranian inventors to apply for international patents to give them a greater chance of commercializing their invention.

Air pollution a downside of industrialization

According to the World Health Organization (WHO), Iran performs best in the Middle East for seven SDG indicators, including the vaccination rate and maternal health. Life expectancy at birth in 2016 was 75 years for men and 77 years for women.

The country performs well for the provision of water and sanitation and with regard to public policy on malaria and HIV but seems to underperform when it comes to air pollution.

Air pollution is one of the most visible downsides of Iran's efforts to industrialize and join global production chains. Each winter, periodic peaks in poor air quality cause schools (and sometimes universities) to close in Tehran and other large cities.

WHO recommends a concentration of airborne particulate matter of 2.5 $\mu g/m^3$. In 2018, Iran had an average concentration of 25 $\mu g/m^3$, with Tehran being the world's 23rd most-polluted capital city (26.1 $\mu g/m^3$) [IQAir, 2018]. On a more positive note, along with India, Iran has the greatest number of real-time air quality monitors in South Asia.

In 2016, Iran ranked 105th (out of 178 nations) on Yale University's (USA) Environmental Performance Index. Two years later, Iran had moved up 25 places in this index.

National plans contain measures for environmental protection, such as Act 190 on Green Management of the *Fifth National Development Plan* (2011–2017). However, the enforcement of environmental regulations remains a challenge (Tahbaz, 2016; Nabavi, 2018).

Being able to call upon foreign expertise, in accordance with multilateral environmental agreements, can also make a difference. For instance, a 2017 law stipulates that endangered wetlands must be restored, in line with Iran's obligations under the Ramsar Convention (Box 15.2). In 2018, for the fifth year in a row, Japan funded the ongoing restoration of a major wetland in northwest Iran, Lake Urmia. The United Nations Development Programme is partnering with the Iranian Department of the Environment for this initiative, via a project that is involving local communities in sustainable agriculture and biodiversity conservation.[21]

Greater ambitions for renewable energy

The majority of Iran's power plants are driven by fossil fuels, primarily natural gas (Figure 15.6).

In Iran's 20-year *Vision 2025* (2005) document, also known as *Iran 2025* (*Iran 1404* in the Persian calendar), the government was mandated to increase the share of renewable energy to 1.8% of the energy mix (about 20 000 MW), with hydropower being the designated priority.

However, Article 50 of the *Sixth National Development Plan* (2017–2021) is more ambitious; it aims to increase the share of plants powered by renewable energy to 5% by 2021.

This means that, by 2021, around 4 GW out of the current capacity of 85 GW should come from renewable sources. As of February 2020, 120 solar and wind power plants were in operation across Iran but these were producing a mere 800 MW of electricity, or just under 1% of the energy mix. Construction of other solar and wind power plants is ongoing

Box 15.2: **Stricter laws in Iran for environmental protection**

In January 2017, parliament approved bills mandating the administration to ensure the implementation of strategic environmental assessments and environmental impact assessments, within the framework of the *Sixth National Development Plan* (2017–2021).

The law tasks the administration with monitoring waste management projects on beaches, marine environments, forests and plains. 'Green' management methods are to be introduced by the public administration and external organizations in Iran.

The law prohibits any exploitation of forests for commercial and industrial purposes after current contracts expire in 2020. The administration must allocate a budget to cover the cost of shifting from logging to importing wood products.

The law calls for setting up wastewater treatment plants and conducting water reclamation projects, as well as managing industrial and household wastewater. By 2021, at least 20% of waste is to be disposed of each year in an environmentally friendly way.

The law also stipulates that 20% of endangered wetlands must be restored by 2021, particularly those listed under the Ramsar Convention.

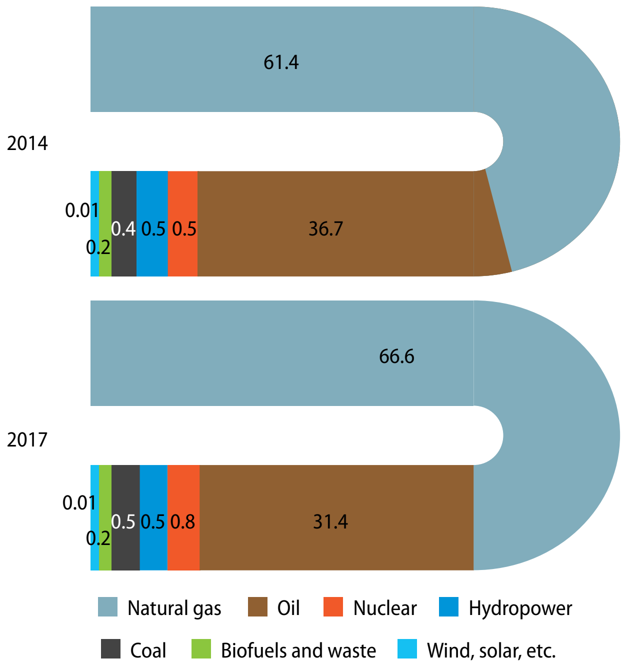
Medicinal herb-farming is also to be developed over 250 000 hectares by 2021.

A comprehensive plan is to be drawn up by 2018 to cope with sand and dust storms.

Some 10% of gas-powered motorcycles are to be replaced each year with electric ones.

Source: Tehran Times (2017)

Figure 15.6: **Breakdown of Iran's primary energy supply by source, 2014 and 2017 (%)**



Note: Values are not drawn to scale.

Source: International Energy Agency; epi.envirocenter.yale.edu

to supply the national power grid with an extra 362 MW of renewable energy, according to the Ministry of Energy.[22]

The main legal framework for developing, operating and selling renewable power is laid out in Article 61 of the Law on Modification of Energy Consumption Patterns, adopted in 2016, and the *Sixth National Development Plan* (2017).[23]

The Ministry of Energy has a dedicated renewable energy arm called the Renewable Energy and Energy Efficiency Organization (SATBA). SATBA is in charge of issuing licences for the establishment of renewable energy facilities; it also acts as the offtaker for the guaranteed purchase of the electricity generated by such facilites.

In 2015, the Ministry of Energy extended the duration of the guaranteed-purchase contracts from five to 20 years to spur investment. The Renewable Energy Organization of Iran (SUNA) then announced plans, in May 2016, to raise the amount of guaranteed prices for electricity generated at plants built with local skills and equipment, in an attempt to boost domestic manufacturing and employment in this sector (Kalehsar, 2019).

Moreover, according to a law approved by the government cabinet in 2016, which makes reference to Article 138 of the *Constitution*, all ministeries, government institutions and public non-governmental organizations, banks and municipalities are mandated to source 20% of their electricity consumption from renewable sources.

In addition, the Supreme Energy Council passed a law in 2018 on the Creation of a Market for Environmental and Energy Optimization. This law introduced incentives for consumers in the form of energy-saving certificates.

In the national budget for 2020–2021, there is a clause supporting the establishment of knowledge-based companies in the field of clean energy, in collaboration with eligible foreign firms.

The *Sixth National Development Plan* has also paid special attention to facilitating investment by foreign firms. In 2017, Iran signed two large contracts for the construction of solar power plants. The first involved the state-owned Amin Energy Developers and Norway's Saga Energy and would have produced a solar power plant capable of generating up to 2 GW of energy by 2022, at a cost of € 2.5 billon. The second concerned the British investor in renewable energy projects, Quercus, at a cost of € 500 million. However, by the end of 2018, the re-imposition of US sanctions had forced both companies to withdraw from these projects (Tsanova, 2018).

CONCLUSION

An effective coping mechanism

The reinstatement of sanctions following US withdrawal from the nuclear deal has hit the economy hard. However, there is also a sense of *déjà vu*. Iranians had already lived under sanctions for years.

In 2014, the country had developed a coping mechanism it dubbed the 'resistance economy,' to wean itself off its hard-hit oil-rent economy by seeking local solutions for those industries that could no longer count on imports of foreign materials and technologies.

Combined with heightened domestic demand, the multiplication of technology incubators and accelerators since 2015 has led to exponential growth in knowledge-based firms and start-ups. This proliferation of self-reliant businesses seems to have driven a form of dynamic decentralization that contrasts with the more inert top-down approach to central planning to which Iranians have become accustomed.

Despite the pain inflicted by sanctions, higher domestic demand for innovation and the desertion of the Iranian marketplace by foreign technology providers has created a potential opportunity for knowledge-based firms to climb higher in the value chain and gain a bigger market share. The brief respite between 2016 and 2018 when sanctions were lifted has also fostered endogenous innovation by giving companies access to foreign state-of-the-art technologies.

The next stage: better management and co-ordination

Building on this momentum will now require a shift in the mindset and skill-set of Iranian knowledge-based firms. They should also beware of the introspection trap. Regardless of the situation with regard to sanctions, finding new avenues for exports in uncharted waters should be perceived as an opportunity to reduce exposure to country- and region-specific risks through more diversified foreign markets.

Once tech-based firms have reached an appropriate level of maturity and competence, the introduction of incentives for them to enter global markets could be one solution for reducing their reliance on the insulated domestic market (Farnoodi *et al.,* 2020).

Although the vitality of the innovation ecosystem is plain to see, there is a need to add more 'substance' to it by laying greater emphasis on output and impact, rather than solely on input and one-off events like the Start-up Weekends that have become a common occurrence.

Many technology incubators and accelerators seem to have adopted the kind of management style that is a legacy of the public sector. This suggests that more attention should be paid to management training in these tech-based environments. Executive and on-the-job training for knowledge-based firms and start-up mentors would be helpful, especially for those incubators and accelerators situated outside large cities or which are not affiliated with prominent academic centres.

In cases where innovation centres are semi-privately owned or have close government ties, an 'ambidextrous set-up' could be employed to reduce the bureaucratic hurdles that these young teams encounter when fulfilling their administrative obligations. This would give young inventors the breathing space to give full rein to their creativity.

Prospects for the digital economy look promising, especially if investment is channelled into emerging technologies such as artificial intelligence, the Internet of Things and blockchain.

The diffusion of Industry 4.0 technologies in mature industries such as the automotive, oil and gas and petrochemical industries should also favour their integration in the knowledge economy.

The Innovation Paradox

Despite notable achievements in specific knowledge-based fields, Iran still faces the Innovation Paradox. In other words, it faces the challenge of turning knowledge into value at the industrial level and ensuring that this knowledge trickles down through society as a whole (Hamidi Motlagh *et al*., 2019).

Addressing this paradox calls for, *inter alia*, facilitating closer ties between the supply and demand side of the innovation system, such as by empowering innovation intermediaries who understand the needs of industry and are able to access networks across the value chain and by upgrading what are known as 'bridging institutions' to ensure that their reach extends beyond the ephemeral benefits of conferences, events and seminars.

Arguably one of the most notable institutional achievements of the past five years has been the overhaul of the National Innovation Fund. The fund has developed new financial tools like venture capital to nurture the knowledge economy, which is to be commended. However, more attention should be paid to promoting investment options that go beyond the provision of loans and facilities.

The remaining loopholes in the institutional chain of the funding system for the knowledge economy can be plugged by supporting intermediary institutions, credit institutions, developing venture capital megafunds and by establishing a knowledge economy bank.

A need for more effective career training

In higher education, meanwhile, the number of master's and PhD graduates has grown but there is a pressing need to revise academic programmes with an eye to developing the requisite skills for the job market. This is particularly vital for a country like Iran that has a large young population – one in four Iranians were under 15 years of age in 2019, according to the Iranian Statistical Centre – and a high share (39%) of unemployment among university graduates.

More needs to be done to move away from the culture of credentialism, whereby students perceive a university degree as an end in itself, with little regard for whether it will give them marketable skills. Universities need to combine their classic curricular programmes with effective career training and exposure to industry through more dynamic and engaging internship programmes, technical and vocational training at tertiary level and other means (Heshmati and Dibaji, 2019).

As demonstrated in the preceding pages, Iran has no shortage of policies and mandates pertaining to science, technology and innovation. Some might even say that the country has produced too much of a good thing. The challenge will be how to implement these policies effectively without becoming bogged down in red tape. Iran's innovation ecosystem has made sterling progress in the past five years. A little more synergy and coherence among the actors of this ecosystem would help it progress to the next level of maturity.

KEY TARGETS FOR IRAN

Iran plans to:

- raise the share of plants powered by renewable energy to 5% by 2021;
- increase expenditure on R&D to 4% of GDP by 2021.

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ENDNOTES

1 This was referred to as the Innovation and Prosperity Fund by Ashtarian (2015).
2 The six powers are China, France, Germany, the Russian Federation, UK and USA.
3 The ITER project involves the European Union, China, India, Japan, Republic of Korea, Russian Federation and USA.
4 Sanction-related travel restrictions have also affected non-Iranian scholars planning to attend scientific workshops and conferences in Iran.
5 Technology incubators are called growth centres in Iran.
6 In the present chapter, data for a specific year cover the 12-month period from March to March.
7 See: https://www.tasnimnews.com/en/news/2019/02/04/1939260/iran-producing-95-of-needed-pharmaceuticals-president-says
8 The Iranian Statistical Centre uses a methodology which estimates the number of people with jobs by counting one hour of work per week as employment.
9 See: https://time.com/5804706/iran-coronavirus/
10 See: https://www.nytimes.com/reuters/2020/04/22/world/middleeast/22reuters-health-coronavirus-iran-eu.html
11 A number of articles in this law are important for STI, including that supporting company patent registration and copyright protection (clause #4), that supporting investment in R&D by industrial and production units; (clause #31); that expanding the manufacture of knowledge-based products (clause #43); and that increasing the endowment for specialized research and technology funds (clause #44).
12 In Iran, directives are not compelling, since they have no mandatory clauses.
13 See: *The Global State of Digital 2020*: https://datareportal.com/reports/digital-2020-iran
14 ibid.
15 See: http://iranforesight.ir
16 See: www.atf.gov.ir/en
17 As of 2020, Iran had not yet submitted any voluntary national review on its progress in implementing *The 2030 Agenda for Sustainable Development*.
18 Graduates make up 15.6% of the unemployed in the general population but 39% of the graduate population.
19 The previous *UNESCO Science Report* (Ashtarian, 2015) cited a GERD/GDP ratio of 0.31 in 2010; this ratio is now considered to have been underestimated, owing to the limited number of firms surveyed at the time and the absence of data from some large universities and enterprises.
20 The *Fifth National Development Plan* was extended for a year to 2017, so overlaps with the start of the *Sixth National Development Plan* covering 2017–2021 (1396–1400 in the Persian calendar).
21 See: https://www.ir.undp.org/content/iran/en/home/presscenter/articles/2018/05/06/press-release-government-of-japan-renews-commitment-to-restoring-lake-urmia-for-the-fifth-year-in-a-row.html
22 See (in Persian): http://news.moe.gov.ir/News-List/51682
23 See: https://www.lexology.com/gtdt/tool/workareas/report/renewable-energy/chapter/iran

AT A GLANCE

Scientists from the company Evogene collecting field crop data as part of their contribution to the research consortium Phenomics, funded by the Israel Innovation Authority. These crop data will then be analysed through Evogene's GeneRator AI computational platform, which will leverage big data and artificial intelligence to decode the plant's biology, in order to guide the development of improved commercial crops. © Evogene

- Dubbed the 'start-up nation,' Israel has the most start-ups per capita in the world, enabled by a vibrant venture capital market. Industry 4.0 is a growing cluster, with 250 start-ups working in related areas.
- Through the Digital Israel programme, the government has committed to investing massively in areas such as artificial intelligence and data science, smart mobility, digital health and e-governance.
- The country's capacity to tackle social challenges in housing, transportation and health care is being constrained by the deficit.
- Sustainable development is a necessity for Israel. A water-poor country, it needs to develop new approaches to water management, since desalination is not without its drawbacks.
- There are concerns that production and jobs could migrate abroad, as Israeli intellectual property, know-how and technology is increasingly falling into the hands of foreign multinationals. Israel is the most research-intense country in the world but fewer than half of Israeli patents are owned by Israeli companies.

16 · Israel

Daphne Getz

INTRODUCTION

Rising deficit limiting options

Israel's macro-economy has performed well since 2015,[1] as reflected by the strong growth rate (Figure 16.1). At less than 5%, Israel's unemployment rate has been consistently lower than the average for members of the Organisation for Economic Co-operation and Development (OECD, 2018) and even dropped to 3.4% in 2020 in the weeks prior to the Covid-19 outbreak (CBS, 2020). Labour productivity remains relatively weak, however, and Israeli workers earn just three-quarters of the OECD average hourly wage (Figure 16.1).

The country faces social challenges in such vital areas as housing, transportation and health care, which will require significant government investment. This imperative coincides with the country's rising deficit (MoF, 2020), which limits options in terms of spending priorities.

The situation has been compounded by the political impasse following the 2019 elections, the third consultation in a year. Endowed with limited powers, the resultant caretaker government had been unable to demonstrate the requisite fiscal restraint to meet the deficit target of 2.9% of GDP, which is based on an anticipated economic growth rate of 5.3% (Kaplinsky, 2019). Although Israel has a stable government, following a power-sharing agreement concluded in April 2020, it will be challenging to meet the deficit target in 2020 despite the Covid-19 outbreak.

A flurry of Covid-19 solutions

Since the outbreak, the government has been encouraging the scientific and commercial sectors to develop innovative solutions. By May 2020, the Ministry of Science and Technology was supporting more than 80 related research projects, including on vaccine development and the social implications of the pandemic (MoST, 2020).

The government issued a compulsory license in 2020 for lopinavir/ritonavir, a drug that has proven effective in treating Covid-19 patients. In patent law, the compulsory license suspends the monopoly effect of a patent, allowing a generic producer to import the drug (Hoen, 2020).

An initiative led by the Ministry of Health is making use of an application (app) called *HaMagen* (The Shield) that can be voluntarily downloaded to a smartphone from the ministry's website. The application cross-checks the GPS history of a mobile phone with historical geographical data of coronavirus patients and notifies the user in the event of a match.[2] By early May 2020, 1.5 million Israelis had downloaded the app (Cohen, 2020).

Israel's Galilee Research Institute (MIGAL) has repurposed its research focus, in order to develop a human vaccine for Covid-19, using a grant of US$ 4 million that it had received previously to fund the development of a vaccine for Infectious Bronchitis Virus, an avian coronavirus.

Several government bodies have issued calls for proposals, through programmes which fast-track financial support of 50–75% of company expenditure for selected plans. For instance, the Israeli Innovation Authority, Ministry of Health and the Headquarters for National Digital Israel Initiative are offering companies research funds of NIS 50 million (*ca* US$ 14.5 million) to develop, test and implement related systems and products. The Israel Innovation Authority, Ministry of the Economy and Industry and the Manufacturers' Association have issued a joint call for proposals for factories to manufacture industrial products designed to prevent or treat Covid-19.[3]

According to the Israel Start-up Nation central database, more than 150 Israeli companies were developing technologies as of May 2020. Solutions include telemedicine technology, such as remote monitoring and analysis of patients' vital signs using radar, artificial intelligence (AI) and advanced optical sensor technology (IAI, 2020). Other examples are fast diagnostic kits (including voice diagnostics), wearables which monitor a patient's medical condition and virtual reality therapeutic support for quarantined patients. Potential medications are being developed by Kamada and Pluristem Therapeutics, among other firms. In May 2020, Pluristem was in the process of testing its placenta-based cell technology in clinical trials, which has been designed to mitigate the tissue-damaging effects of Covid-19.

SUSTAINABLE DEVELOPMENT AGENDA

Industry 4.0 is changing the world of work

One consequence of the political impasse in 2019–2020 has been the delay in implementing recommendations by the Committee for the Promotion of Employment to 2030. This committee had been appointed in 2017 by the Minister of Labour, Social Affairs and Social Services.

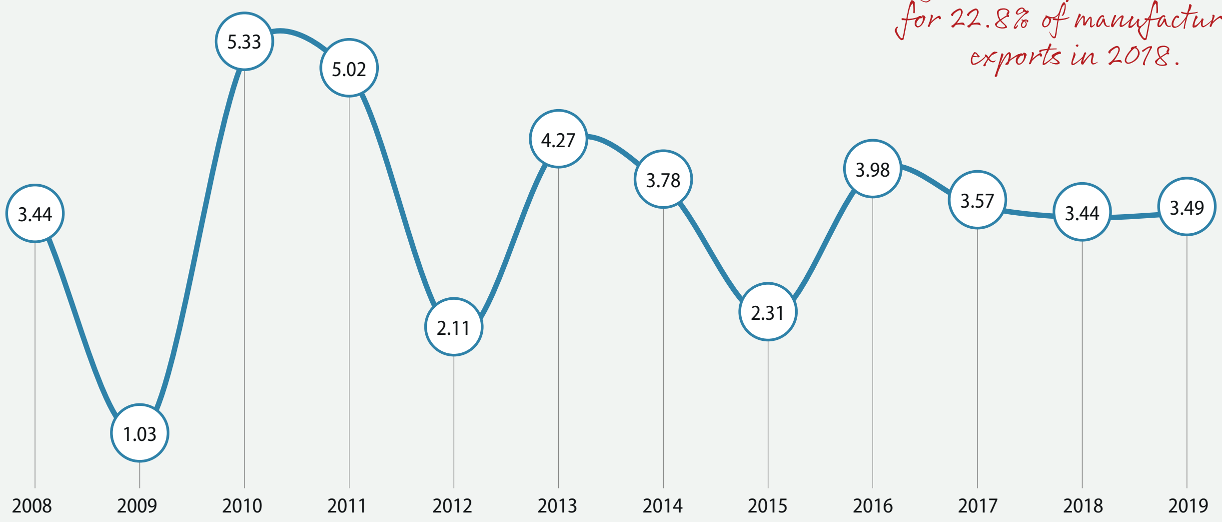
In its 2018 report, the committee acknowledged that the technologies of the Fourth Industrial Revolution (also known as Industry 4.0), including AI, machine learning systems and the Internet of Things, would not only affect all economic sectors but also 'shake up the world order as we know it.'

Professions in Israel are already changing. For example, there has been a decline in the number of conventional metalworking jobs and a concomitant rise in the number of jobs reliant on computer hardware. About half of all high-tech employees are non-ultra-Orthodox Jewish men under the age of 45 years.

In its 2018 report, the committee fixed fresh targets for increasing employment rates among Arab Israelis,

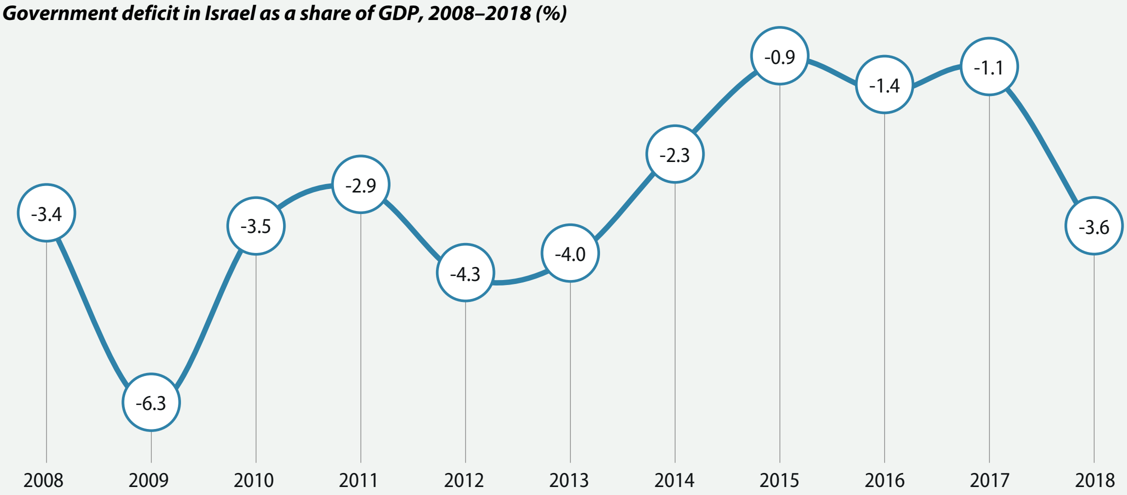
Figure 16.1: **Socio-economic trends in Israel**

Rate of economic growth in Israel, 2008–2019 (%)



High-tech exports accounted for 22.8% of manufactured exports in 2018.

Government deficit in Israel as a share of GDP, 2008–2018 (%)



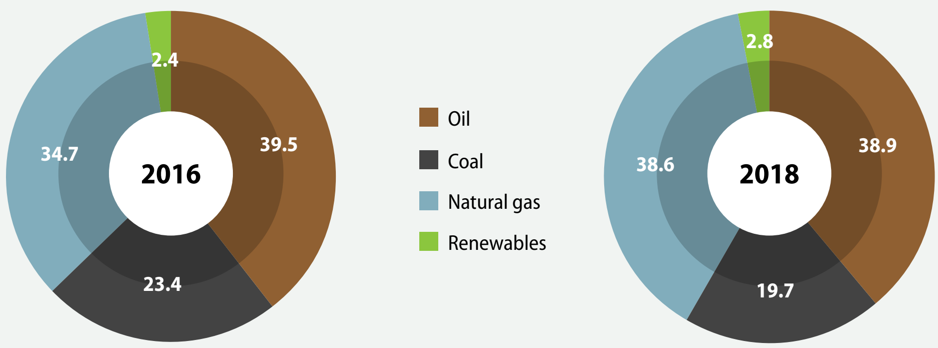
US$ 37.40

Average hourly wage in Israel in 2018; the average for OECD members is US$ 46.70

4.4%

Average unemployment rate in Israel over 2015–2019; the average for OECD members is 6.1%

Share of primary energy supply in Israel, 2016 and 2018 (%)



Source: Central Bureau of Statistics; Neaman Institute processing of OECD data; World Bank's World Development Indicators, May 2020; for employment rate and government targets for minority groups: MoLSASS (2018) the ultra-Orthodox (Getz and Tadmor, 2015), disabled people and those over the age of 60 years (MoLSASS, 2018).

The report recommended focusing on skills development in the non-academic segment of the population, notably through greater government spending on vocational training and the establishment of a Technology and Vocational Training Advisory Council.

The committee also called for lifelong learning to become part of the Israeli work culture, in order to make the economy more responsive to the constantly evolving job market (MoLSASS, 2019).

Heavy investment in Digital Israel

Israel is investing heavily in technologies such as AI and data science, smart mobility, digital health and e-governance through Digital Israel, a series of national programmes that include the Fuel Choices and Smart Mobility Initiative (Box 16.1).

Digital Israel is the concrete expression of the government's *Digital Policy* for 2017–2022. This NIS 1.5 billion (*ca* US$ 425 million) initiative aims to make Israel a global leader in this domain. The programme plans to leverage Israeli expertise in information and communication technologies (ICTs) to accelerate economic growth, reduce socio-economic disparities and make governance smarter, faster and citizen-friendlier. The programme is led by the Headquarters for the National Digital Israel Initiative, placed under the Ministry of Social Equality; this body collaborates with ministries, local authorities, companies and non-profit organizations.

In 2018, Israel embarked on a five-year National Programme for Digital Health. The stated aims are to create a new national economic growth engine, advance Israel's clinical and academic research and create a local digital health care system that is among the best in the world. The programme is backed by an investment of NIS 898 million (*ca* US$ 256 million) and implemented by multiple governmental bodies, including the Ministry of Health, the Ministry for Social Equality (Digital Israel), the Ministry of the Economy and Industry, the Israeli Innovation Authority and the Council for Higher Education (Prime Minister's Office, 2018).

Innovation in industrial symbiosis

In 2018, the Ministry of the Economy and Industry published the *National Strategic Plan for Advanced Manufacturing in Industry*. In addition to direct support at the factory level, the plan sets out a framework for investment, the development of a skilled workforce, infrastructure reinforcement and improved access to knowledge. Most of the programme's budget of NIS 0.5 billion (*ca* US$ 145 million) is allocated to small and medium-sized enterprises (SMEs) engaged in advanced manufacturing.

The same year, the Israeli Innovation Authority established an Advanced Manufacturing Division. This division runs the R&D Preparatory Incentive Programme for Companies in the Manufacturing Industry, providing grants for over 66% of the project budget for innovation in advanced manufacturing and a research and development (R&D) track in the Manufacturing Industry (MOFET), supporting 30–50% of the research expenses of approved programmes (MEI, 2018). A pilot project was launched in 2019 to test this approach (Box 16.2).

Box 16.1: **Israel investing in smart mobility**

The automotive industry is on the cusp of a profound disruption highlighted by four megatrends in mobility: connectivity, sharing, electrification and autonomy. The demand from the global automotive sector for innovative solutions has been met in Israel by a combination of supportive policy measures and technological competence in ICTs, advanced sensing and signal processing, big data and cybersecurity, among other areas.

The centrepiece is the Fuel Choices and Smart Mobility Initiative, established in 2010 and co-ordinated by an inter-ministerial unit in the Prime Minister's Office. This ten-year programme was endowed with a NIS 1.5 billion (*ca* US$ 436 million) budget. It is intended as a catalyst for reducing oil dependency in the domestic and global transportation sector and fostering an innovation ecosystem in smart mobility in Israel.

The programme established a Testing Centre for Connected and Autonomous Vehicles and a Smart Mobility Research Centre to encourage collaboration between academia and industry. Pilot projects test new technologies designed to reduce congestion and traffic accidents.

The programme has also devised a supportive regulatory framework, including government subsidies for the installation of particulate filters on heavy diesel vehicles; a hybrid taxi programme; the introduction of electric buses in Israel's public transportation fleet; financial assistance for the establishment of electric car-sharing programmes; government remuneration for the scrapping of old diesel vehicles; and the establishment and operation of low-emission zones, starting with Haifa from February 2018 onwards then Jerusalem in 2020 (Prime Minister's Office, 2018).

By 2020, the programme had nurtured the emergence of a vibrant auto-tech sector with over 500 active companies and 25 research centres in Israel operated by the world's automotive giants, the hallmark of which was the acquisition of the Israeli company Mobileye by Intel for US$ 15.3 billion in 2017.

Notwithstanding this, the rate of vehicle replacement has been somewhat pedestrian. Although 11% of private cars and 15% of taxis were hybrid or electric by 2019, this translated into just 5% of all the vehicles on Israeli roads; meanwhile, 99% of public buses were still being powered by diesel engines.

Source: compiled by author; CBS (2020) *Motor vehicles in Israel in 2019*. Central Bureau of Statistics: Jerusalem.

A total of NIS 20 million (*ca* US$ 5.8 million) has been allocated under this incentive programme to establish five innovation labs:

- The Alliance Open Innovation Lab (Renault–Nissan–Mitsubishi) in the automotive sector;
- Infralab in the smart infrastructure and construction sector;
- Let-lab in the Industry 4.0 and flow systems sector;
- PMatX Ltd in novel materials and (two- and three-dimensional) printing technologies in the electronics sector; and
- FoodNxt in the FoodTech, functional ingredients and nutraceuticals sectors.

The Innovation Labs Programme has two distinct target groups. The first are leading corporations interested in establishing innovation labs to practice open innovation. The second target group are Israeli entrepreneurs with a technological idea that they would like to transform into a product who wish to gain access to key technological infrastructure and the market expertise of leading corporate innovation teams, along with exposure to the corporation's network of customers and investors (IIA, 2019).

A focus on urban sustainability

In 2019, Israel's population passed the 9 million threshold, the consequence of decades of targeted immigration and natality policies. The country now has a high population density of 400 inhabitants per km^2, similar to that of the Netherlands. However, each inhabitant of the Netherlands has access to seven times more renewable internal freshwater than an Israeli (Box 16.3).[5]

For Israel, sustainable development is not a luxury. Rather, taking this path will be vital to overcome pressing socio-ecological challenges such as scarce water and land resources.

This scarcity has led the country to focus on urban sustainability, as outlined in its *Voluntary National Review* (2019). Innovation is one of Israel's most valuable resources. The government's vision is to expand its existing culture of innovation to give practical expression to the value of 'leaving no one behind' (Govt of Israel, 2019).

A government decision adopted in 2019 (#4631) has mainstreamed *The 2030 Agenda for Sustainable Development* into all strategic planning processes.

With better environmental protection and the introduction of sustainable consumption and production patterns being a particular challenge (Sachs *et al.*, 2019), the government allocated a five-year (2017–2021) budget of about NIS 120 million (*ca* US$ 34.9 million) to regional projects designed to reduce the negative impact of intensive agriculture on natural resources and support adaptation to climate change. Since 2012, 1% of the income from sales of land for housing has been allocated to the Open Spaces Protection Fund, which operates in accordance with the Israel Lands Authority Regulations. Over US$ 150 million has been distributed by the fund to more than 300 projects nationwide since 2013, most of it on a competitive basis. These projects may be submitted by any stakeholder group, including government agencies, local authorities, companies, civil society and universities.

By 2018, the waste recycling rate had increased to 24% but the remainder of waste was still being dumped in landfills (MoE, 2019). The Ministry of Environmental Protection is redirecting its waste management policy towards an integrated approach consisting of five levels: reduction at source, re-use, recycling, recovery and landfill. According to the *Strategic Plan for Waste Treatment* to 2030, 51% of all generated waste will be recycled by this date, 23% will be recovered for energy and the remainder will be landfilled (MEP, 2018a). The plan includes a US$ 1 billion budget to 2030 supporting the establishment of sorting, recycling and waste-to-energy facilities.

Israel ratified the *Paris Agreement* in November 2016 and committed to an unconditional target of limiting its greenhouse gas emissions to 7.7 tonnes of carbon dioxide equivalent (tCO_2e) per capita by 2030, a reduction of 26% over 2005 levels. An interim target of 8.8 tCO_2e per capita has been set for 2025; actual emissions in 2017 were about 9 tCO_2e per capita (MEP, 2019).

Israel is an energy island without grid connections to neighbouring countries. It suffers from severe urban air pollution, which amounted to 21.4 μg m^{-3} on average in 2017 (Health Effects Institute, 2019). The country is also expected to become increasingly vulnerable to extreme weather events related to climate change.

National policies aim to eliminate coal from electricity production by 2030.[6] This will be compensated by a rise in the

Box 16.2: Four Israeli pilot projects experimenting with industrial symbiosis

The Ministry of the Economy and Industry launched a pilot project in 2019 to promote industrial symbiosis, in order to support responsible consumption and production patterns across Israel's industrial sector.

Four companies operating in different regions won the tender for NIS 5 million (*ca* US$ 1.5 million). They are Daniron Consulting and Investments Ltd, 4S (concrete slabs and mining), the Good Energy Initiative and Aviv Management and Counselling. The by-products and waste from one plant will be used as raw material in the production process of another.[4]

By dividing the country into the Northern Region, Haifa and Sharon Region, Central Region and Southern Region, the ministry hopes to create specialization at the local level, as well as in industrial zones and city centres.

The pilot project will last for about a year, with the ministry planning to establish a long-term national project to promote industrial symbiosis with one of the partners having won the tender.

Source: compiled by author

share of natural gas in the energy mix. The discovery of natural gas reserves two decades ago has enabled Israel to become an energy exporter, with pipelines carrying natural gas to Jordan and Egypt (Getz and Tadmoor, 2015).

Within the Ministry of Energy's *Objectives Plan to 2030*, the government is also providing economic incentives to encourage industrial plants to connect to the gas grid.

Between 2010 and 2018, the share of coal dropped from 59% to 30% of total electricity production, balanced by the concomitant rise in natural gas from 39% to 66% of the total (Electricity Authority, 2018).

The share of renewable energy, meanwhile, increased from close to zero in 2010 to more than 4% of electricity production by 2019; 13% of consumed electricity is to come from renewable energy by 2025 and 17% by 2030. A research-based recommendation suggests investing revenue from natural gas in a sovereign wealth fund mainly targeting R&D in the field of renewable energy (Abu-Kalla *et al*., forthcoming).

In parallel, Israel is striving to reduce energy demand. Solar water heaters are already installed in 85% of Israeli households, reducing the country's annual electricity consumption by 4 million kWh a year (KRIC, 2012). As we saw earlier, the government has adopted a Fuel Choices and Smart Mobility Initiative to reduce dependency on fossil fuels in transportation while stimulating endogenous innovation (Box 16.1).

The government has approved sector-specific targets relative to anticipated consumption rates in 2030: a 17% reduction in electricity consumption and 20% reduction in the number of kilometres travelled by private vehicles.

Reducing Greenhouse Gases and Increasing Energy Efficiency (Government Decision #1403) was approved in April 2016; this scheme allocated NIS 500 million (more than US$ 200 million) over ten years in grants and state guarantees for bank loans to fund projects designed to improve energy efficiency and reduce greenhouse gas emissions, while prioritizing the use of Israeli innovative technologies. In late 2018, four banks won the tender to finance this type of project, which will multiply the state guarantee sevenfold (MEP, 2018b).

Another grant programme of NIS 300 million (*ca* US$ 87.3 million) covering the years 2016–2019 was operated by the Investment Centre at the Ministry of the Economy, with grants awarded on the basis of anticipated price savings, lower levels of greenhouse gases (less air pollution) and the number of kilowatt hours economized. By the end of 2018, a total of 98 local authorities and SMEs had been selected for the second phase (MEP, 2018b).

There has been public discussion on whether having a domestic source of natural gas has slowed the transition to renewables. As of late 2017, Israel was not on track to achieve its targets for reducing greenhouse gas emissions,[7] even though it has had a centre for renewable energy technology in the Negev Desert since 2008.[8]

A multisectoral process was underway in 2020 to come up with a vision and roadmap for transitioning to a low-emission, competitive and thriving economy by 2050.[9] This process is being led by the Ministry of Environmental Protection, in co-operation with the Israeli Institute of Democracy, the Ministries of Energy, Transport and Road Safety, Economy and

Box 16.3: **Israel is finding that desalination poses its own challenges**

Declines in freshwater quality and quantity in an already water-poor region have made it urgent for Israel to develop new approaches to water management.

Israel began desalinating water five decades ago (Avgar, 2018). Today, more than 35% of freshwater production comes from desalination (700 million m^3). By 2019, desalination provided 70% of domestic and municipal water. The government is targeting 1 100 million m^3 by 2030 (Government decision #3866).

The growing volume of desalinated water is creating challenges of its own. Lack of magnesium in the daily diet is associated with heart disease and this condition is becoming more prevalent in Israel in areas where desalinated water is the only source of drinking water, spurring discussion about whether to add magnesium to the water (Rosen *et al.*, 2018).

Desalination has also resulted in saltwater intrusion into aquifers and agricultural soil, owing to the use of reclaimed water for irrigation. Damming the Sea of Galilee to prevent it from flowing through the Jordan River into the Dead Sea has also led to a drop in sea level.

The vast use of reclaimed water has totally re-organized Israel's water supply and sanitation sector. In 2019, some 93% of wastewater was centrally treated and 86% was re-used in agriculture.

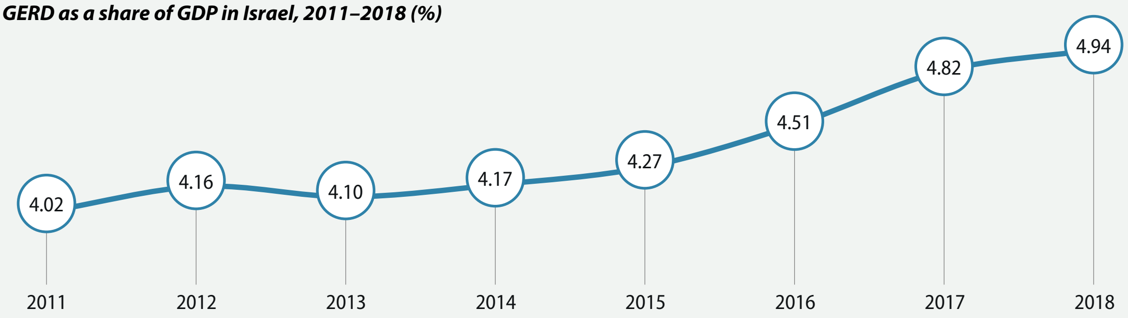
One emerging concern being investigated is the potential influence of contaminants such as pharmaceutical drugs and hormones on public health. These contaminants are not completely eliminated by wastewater treatment plants and might spread to crops and other agricultural products through irrigation. As Miarov *et al.* (2020) note, 'monitoring and regulation of these compounds are uncommon around the world and should be a priority due to Israel's high use of wastewater.'

Reducing demand will be vital to ensure sustainable management of the water sector in Israel. This will require a combination of technology, economic incentives, education and public awareness campaigns. Food security will benefit from producing more with the same amount of water. The national Agricultural Research Organization's Volcani Centre has been targeting crop species which consume little water and would, thus, be adapted to the local climate and soils; the centre has taken an approach typical of the Israeli research culture, a two-way flow of information between researchers and farmers.

Source: compiled by author

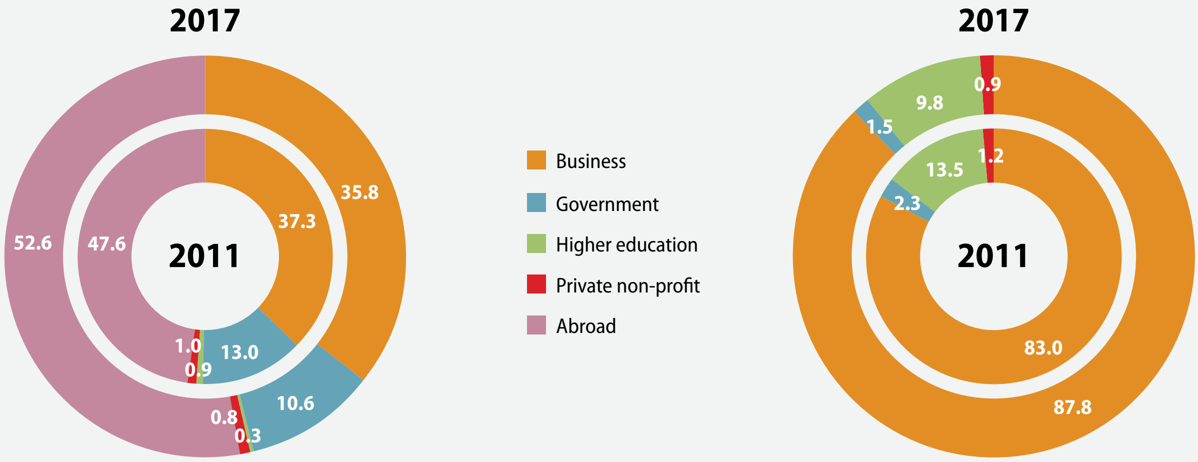
Figure 16.2: **Trends in research expenditure in Israel**

GERD as a share of GDP in Israel, 2011–2018 (%)



GERD in Israel by source of funds, 2011 and 2017 (%)

GERD in Israel by sector of performance, 2011 and 2017 (%)



Applications to Israel Science Foundation for all research grants

2 839
in 2019

2 110
in 2015

Share of government budget outlay for general university funds, at current prices

52.8%
in 2017

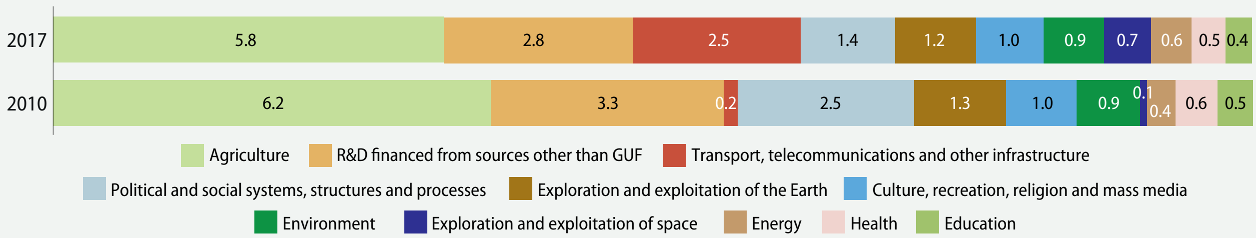
50.2%
in 2010

Share of government budget outlay on industrial production and technology, at current prices

32.4%
in 2010

29.4%
in 2017

Government budget outlay, by objective, at current prices, 2010 and 2017, (%)
Excluding general university funds, industrial production and technology and defence



Note: GUF stands for general university funds. The graphics on this page exclude defence R&D. The Israeli Central Bureau of Statistics only reports on military R&D performed by the business sector and has done so only since 2017. The research expenditure of companies engaged in defence R&D in 2017 amounted to NIS 6.7 billion, down from NIS 7.7 billion in 2016.

Source: Samuel Neaman Institute processing of OECD and Central Bureau of Statistics (2019) data; Data Centre of Israel Science Foundation, accessed April 2020; Israel Science Foundation (2020) *Annual Report 2019/2020*

Finance, among others, the Planning Authority and the OECD. Four task forces made up of experts drawn from the public and private sectors are studying different themes, such as the electricity, transportation and industrial sectors, building construction and cities. A fifth task force is drawn from civil society. As part of the process, a web platform has been set up to share information with the public.[10]

RESEARCH TRENDS

Foreign multinationals now fund half of research

Israel tops the world for research intensity. In 2018, domestic expenditure on civilian R&D amounted to 4.9% of GDP, the highest ratio among OECD member countries (Figure 16.2).

More than half (53%) of gross domestic expenditure on R&D (GERD) was financed by foreign multinational corporations and research centres in 2017, reflecting their growing influence on the national research effort.

The Israeli business enterprise sector remains the second-biggest player in the national innovation system after foreign multinationals. By 2017, Israeli firms were funding a slightly lower share of gross domestic expenditure on R&D but performing more than six years previously (Figure 16.2).

The share of foreign investment in research performed by the university sector is also high. By early 2020, Israel had received € 1.04 billion from the European Union's Horizon 2020 programme for research and innovation (2014–2020), 67% of which went to universities (IIA, 2020a).

In 2018, more than half of government spending on R&D was allocated to university research and to the development of industrial technologies. Research expenditure on health and the environment has doubled in absolute terms in the past decade but still accounts for less than 1.5% of total government expenditure on R&D. This places Israel at the bottom of the table among OECD countries for these fields, as well as for infrastructure development.

A steep rise in funding for academic research

The Planning and Budgeting Committee (PBC) is part of the Council for Higher Education (CHE). Between 2010 and 2019, PBC's annual budget grew from NIS 7.4 billion to NIS 11.4 billion (*ca* US$ 2.2 to 3.3 billion). The *Seventh Higher Education Plan* (2017–2022) gradually raises this budget to NIS 12.5 billion (*ca* US$ 3.6 billion) by 2022, the largest ever adopted by the PBC (CHE, 2012 and 2015).

This substantial budgetary increase reflects the PBC's philosophy that university research funds form the backbone of basic research and, thus, are essential to preserve Israel's international status. The multi-year plan focuses on the topic of research infrastructure as a major goal and has allocated dedicated budget additions of NIS 870 million (*ca* US$ 253 million) beyond the research funds budget (CHE, 2019a).

In addition to the aforementioned research funds, the PBC has approved a multi-year investment (2019–2022) to finance flagship research programmes in quantum science and technology (NIS 200 million or US$ 58 million), data science (NIS 150 million or US$ 43.6 million) and personalized medicine (NIS 100 million or US$ 29 million) [CHE, 2019b].

The Israel Science Foundation accounts for two-thirds of all grants for basic research available to Israeli researchers. Its core annual budget almost doubled from NIS 340 million to NIS 676 million (US$ 98.9 to 196.6 million) between 2011 and 2019, as part of plans to increase the number of applications for research grants. The success rate of awarded grants remained unchanged between 2011 and 2015 but the number of personal grant applications rose by 20%, from 1 200 to 1 500.

In parallel, universities added nearly 600 senior full-time equivalent (FTE) researchers to their faculty between 2013 and 2017, easily exceeding the target of 400 set in the *Sixth Higher Education Plan* (2011–2016).[11] The number of senior faculty members climbed from 4 832 to 5 426.

Given these cumulative trends, it is hardly surprising that Israel's publication intensity is now nearly double the OECD average (Figure 16.3).

Investing in the careers of the future

Another notable goal of the *Seventh Higher Education Plan* (2017–2022) has been to support national needs in the employment market. Over this period, NIS 2 billion (*ca* US$ 582 million) is being invested to increase by 40% the number of students enrolled in programmes sought after by the employment market, such as computer science, computer engineering, data engineering and electrical engineering; these funds will also go towards encouraging ultra-Orthdox Jews and Arab Israelis to enrol in higher education.

The number of students enrolled in fields of relevance to Industry 4.0 has already risen quite considerably since 2012 (Figure 16.4).

The Council for Higher Education also hopes to reduce the ratio of students to academic staff. In 2010, it set a goal of having a ratio of 21.5 students to every academic staff member in universities and 35.5 students to every staff member in colleges. By 2017, colleges had managed to reduce their ratio from 38.6 to 32.0. Progress has been slower in universities, with the ratio dropping from 23.4 to 21.7 over the same seven-year period (CHE, 2017).

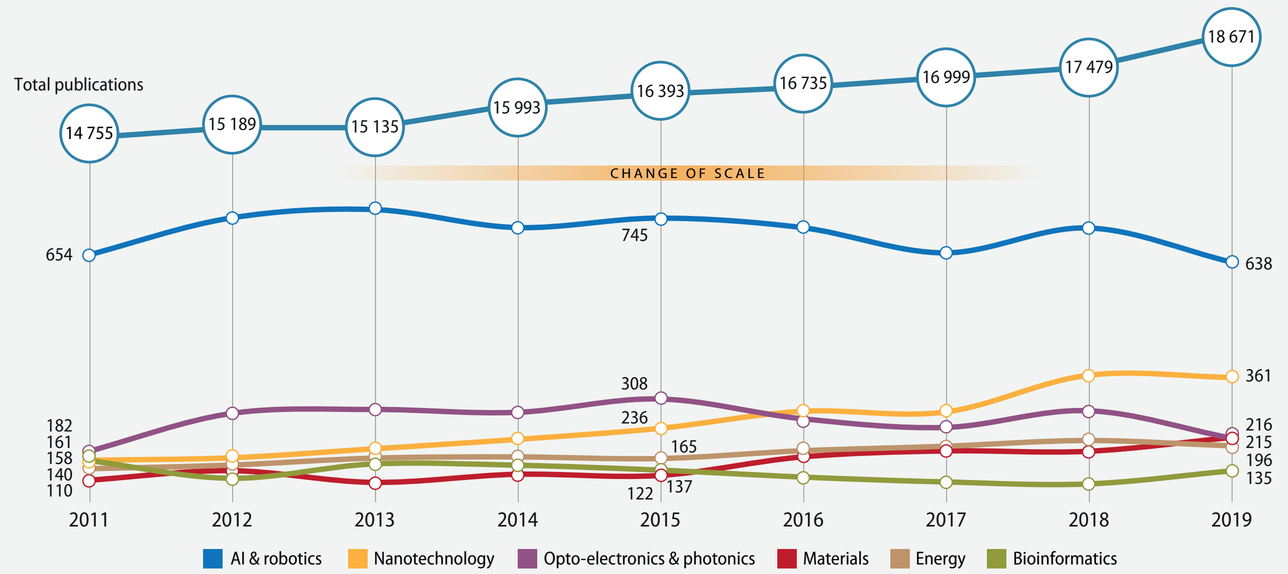
Getting more women into senior positions

The *Seventh Higher Education Plan* (2017–2022) has allocated NIS 70 million (*ca* US$ 20.4 million) to advancing the status of women in academia (see chapter 3). Although women now dominate each degree level overall, just 27% of women were studying high-tech subjects, on average, in 2017. Women are also still underrepresented at the senior faculty level, particularly in engineering and architecture, as well as mathematics, statistics and computer sciences, which have seen no improvement since 2011 (Figure 16.5).

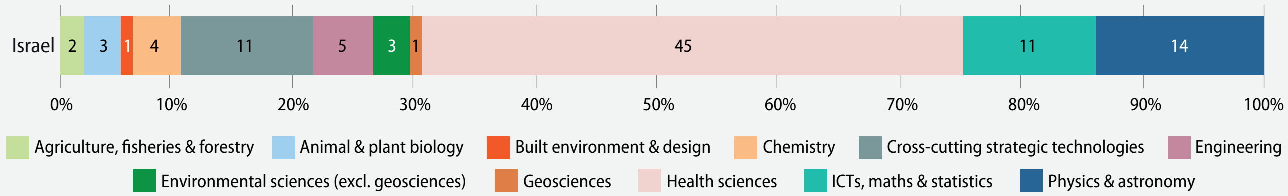
By 2017, women made up 32% of students enrolled in mathematics, statistics and computer sciences, according to the Israeli Central Bureau of Statistics. The PBC aspires to see women make up 35% of all students enrolled in bachelor's degree programmes in these and other high-tech subjects, such as electrical and electronic engineering, 'in the coming years'. The PBC hopes to achieve this by continuing to incentivize institutions to accept female students into

Figure 16.3: **Trends in scientific publishing in Israel**

Volume of scientific publications in Israel, 2011–2019



Scientific publications in Israel by broad field of science, 2017–2019 (%)



1.36

Average of relative citations for Israel, 2014–2016; the OECD average is 1.11

54%

Share of Israeli publications with foreign co-authors, 2017–2019; the OECD average is 34%

Scientific publications per million inhabitants in Israel, 2011, 2015 and 2019

How has output on SDG-related topics evolved since 2012?

Israeli scientists are publishing twice as much on the following topics as would be expected, relative to global averages: desalination, reproductive health and neonatology, water harvesting and transboundary water resources. This output reflects the policy focus on improving water management.

The intensity of Israel's output on desalination is more than double (2.1 times) the global average proportion on this topic. Moreover, there has been a slight increase in output, from 215 (2012–2015) to 255 (2016–2019) publications.

Among the selected topics with at least 50 publications during the period under study, hydrogen energy showed the fastest growth, with the number of publications nearly tripling from 58 (2012–2015) to 163 (2016–2019).

Although they form a small share of Israel's total scientific output (SI = 0.39), the number of publications on sustainable transportation has doubled from 62 (2012–2015) to 118 (2016–2019) [see Box 16.1].

SI = specialization index

For details, see chapter 2

Israel's top five partners for scientific co-authorship, 2017–2019 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Israel	USA (14 376)	Germany (5 832)	UK (4 704)	Italy (4 102)	France (3 619)

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

high-tech study programmes by distributing scholarships and grants to female students, holding seminars to expose women to high-tech topics and providing a support structure that includes catch-up classes and personalized tutoring.[12]

A focus on advanced digital technologies in academia

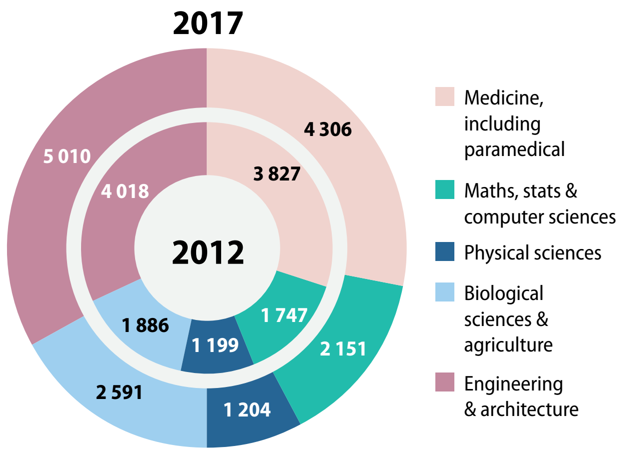
Israeli universities recognize that their educational programmes need to adapt to the rapidly evolving demands of the labour market. The Council of Higher Education has approved no fewer than 19 educational programmes in the field of data science at the bachelor's and master's level, as part of its *Multi-Year Academic Plan* for 2017–2022 (CHE, 2019c).

A second illustration of Israeli universities' efforts to become an incubator for cutting-edge future technologies is their investment in the field of AI. The Technion – Israel Institute of Technology has established a centre for advancing research in AI fields that include natural language processing, deep learning and hardware optimization for different learning algorithms (Technion, 2018). The new centre has been entrusted with the mission of fostering collaboration with researchers from the multinational corporation Intel.

Another example is the Centre of Knowledge in Machine Learning and Artificial Intelligence operating at the Hebrew University in Jerusalem. This centre is focusing on core scientific areas, such as computational neuroscience and computational biology, signal processing, computer vision, medical image processing and modelling, natural language processing and text-mining.

The efforts of Israeli universities to stand on the frontlines of technological advances often complement efforts in other sectors, as with collaborative research programmes to develop dual industrial and military technologies. There is, nevertheless, a need for universities and academic colleges to re-examine their educational programmes to ensure that these balance the provision of scientific knowledge with the development of marketable skills such as entrepreneurship, innovation and leadership in engineering (Bentur *et al*., 2019).

Figure 16.4: **University graduates in Israel in science and engineering, 2012 and 2017**



Source: Israeli Central Bureau of Statistics (2019) *Education-Statistical Abstract of Israel 2019*, No.70

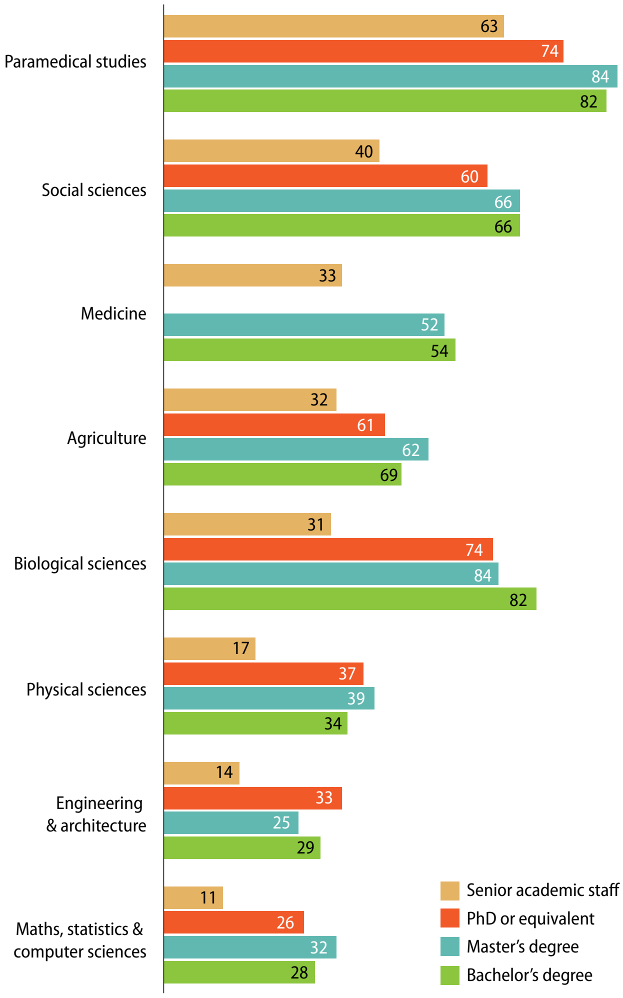
More capital for Industry 4.0 start-ups

Israel has earned the nickname of 'start-up nation' following the success of many Israeli start-up companies, including more than 6 000 founded since 2011. Israel has the largest number of start-ups per capita in the world, according to the World Economic Forum's 2018 *Global Competitiveness Report*. Thanks to government incentives and the availability of highly trained human capital, Israel has become an attractive location for the research centres of leading multinationals, as evidenced by their level of investment in the country.

Several government programmes now support entrepreneurship among minority groups. For example, the Israeli Innovation Authority operates the grant-based Diverse Start-up Track for entrepreneurs from the ultra-Orthodox community wishing to develop or upgrade innovative products or perfect local manufacturing processes (IIA, 2020b).[13]

Figure 16.5: **Representation of Israeli women in academic fields, 2017**

Share of women among Israeli university graduates and senior academic staff (%)



Note: In Israel, the degree of Doctor of Medicine is considered to be the legal and academic equivalent of a master's degree.

Source: Neaman Institute processing of Council for Higher Education and Israeli Central Bureau of Statistics data

The number of Israeli start-ups is still rising, although the pace has slowed. The information technology (IT) and enterprise software sector remains the most dynamic in terms of its capacity to leverage capital, having raised US$ 4.4 billion in 2019, an increase of almost 50% over the previous year. Companies specializing in life sciences also attracted more capital in 2019 than in previous years, raising US$ 1.4 billion in 2019.

Some of the leading tech clusters in Israel specialize in AI, the Internet of Things, cybersecurity and fintech (financial technologies); they are attracting a growing amount of capital investment (Figure 16.6).

Industry 4.0 is a growing cluster.[14] There were about 250 start-ups in the field in Israel in 2019, compared to 146 in 2014 (Engelstein, 2019). These 250 start-ups raised US$ 649.4 million in 2019. The majority of start-ups (142) specialize in industrial technologies (Figure 16.6).

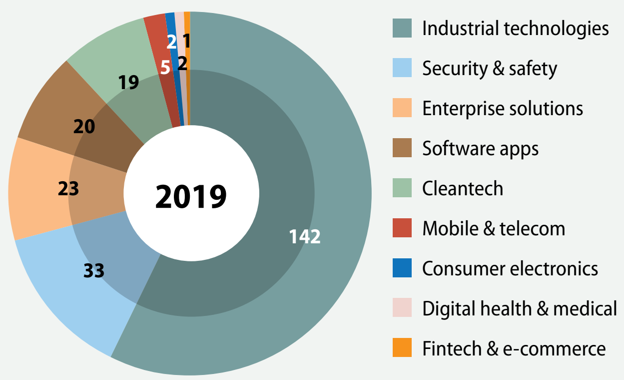
Israel's thriving high-tech industry is complemented by a vibrant venture capital (VC) market, which backed deals worth US$ 4 759 million in 2018. About 50% of all VC-backed deals involved an Israeli venture capitalist, either working solo or with others. According to the IVC database, 480 Israeli VC companies invested in Israeli high-tech firms in 2018 and 2019.

For most OECD countries, venture capital constitutes less than 0.05% of GDP. Israel and the USA are the exception; their venture capital industry accounts for more than 0.35% of GDP (OECD, 2018).

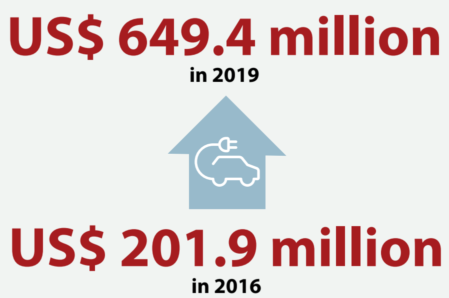
According to GKH, IVC and IATI (2019), there were 362 active multinationals in Israel in 2019 employing about 62 000 individuals. Of these, almost one-third (132) were active in the software sector. The leading clusters are operating in AI, machine learning, the automotive industry and big data (Figure 16.6). Intel is the leading multinational company, having filed 1 389 patent applications at the Israel Patent Office between 2013 and 2018.

Figure 16.6: **Trends in innovation in Israel**

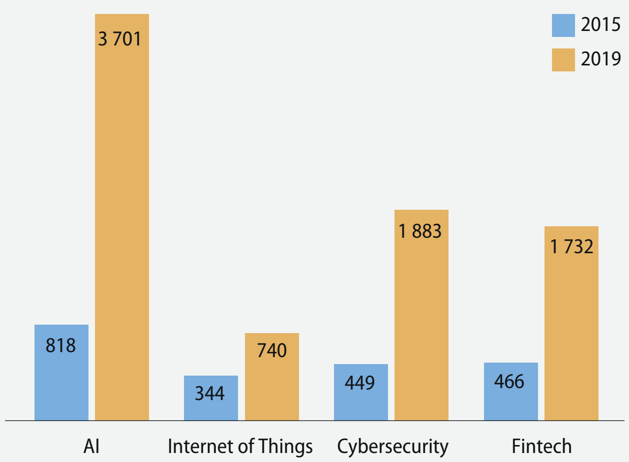
Number of Israeli Industry 4.0 start-ups by sector, 2019



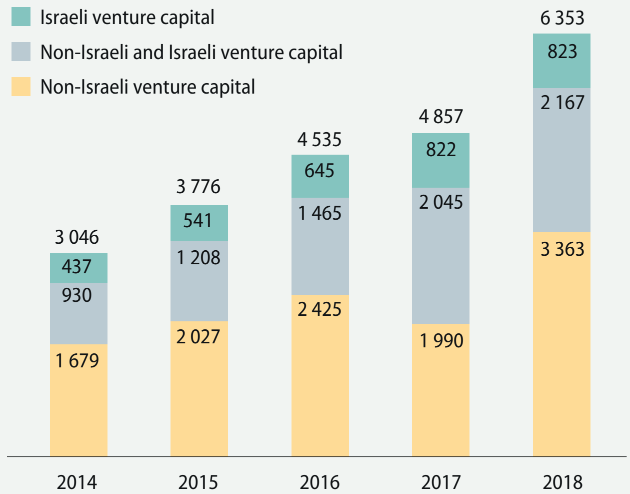
Capital raised by Industry 4.0 companies in Israel



Capital raised in Israel in selected tech clusters, 2015 and 2019
In US$ millions



Capital raised by Israeli high-tech companies from Israeli VCs and other VCs, 2014–2018
In US$ millions



Source: adapted from IVC Research Center & ZAG-S&W (2020) *Israeli High-Tech Funding Report*

Most intellectual property is still foreign-owned

Israel has a large volume of patents from the top five patent offices (Figure 16.6). However, over the past decade, the rate of transfer of Israeli intellectual property, know-how and technology into the hands of foreign research centres has substantially increased (Lemarchand *et al*., 2016). There has been a steep rise in the absolute number of distinct inventions being filed by foreign research centres at the Israel Patent Office and in their respective share of overall Israeli inventive activity.

There is a growing trend towards obtaining Israeli intellectual property by means of the acquisition of Israeli firms and start-ups. Consequently, acquired patents are beginning to account for a substantial share of the total patent portfolio of foreign research centres in Israel. The most active corporate buyers of Israeli companies since 2014 have been Google (10 acquisitions, including 4 acqui-hires), Microsoft (8 acquisitions) and Intel (5 acquisitions). Foreign corporate investment in 2019 amounted to US$ 983 million through 196 deals.

Fewer than half of the patents obtained by inventors from Israel are owned by Israeli companies. This means that knowledge is being created in Israel but then transferred to a foreign company. The potential consequences of this trend are that production and jobs could both migrate abroad (Cohen, 2019).

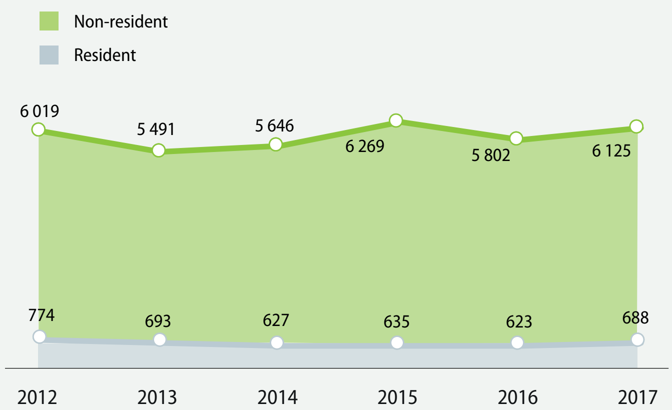
CONCLUSION

A tendency towards knowledge transfer abroad

Israel enjoys a unique combination of academic excellence and an entrepreneurial approach, resulting in the formation of many start-up companies.

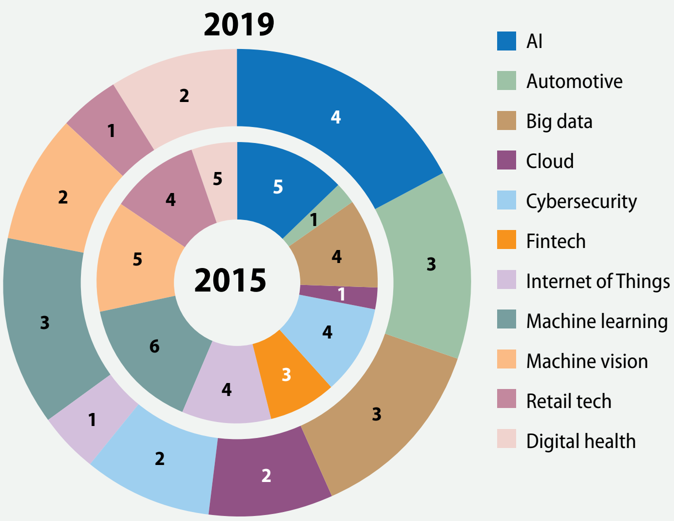
The country has long been considered an attractive investment for multinational corporations seeking to leverage the country's innovative academic and industrial

Applications to the Israel Patent Office by origin, 2012–2017

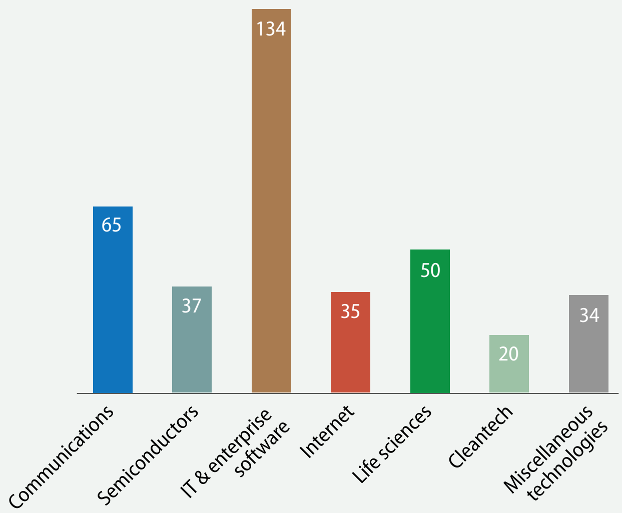


Number of IP5 patents granted to Israel, 2015–2019

Number of companies in top clusters of newly established multinational corporations, 2015 and 2019



Active multinational corporations in Israel by sector, 2020



Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China.

Source: IVC Research Center & ZAG-S&W (2020) *Israeli High-Tech Funding Report*; PATSTAT, data treatment by Science Metrix; Samuel Neaman Institute processing of data from GKH, IVC and IATI (2019)

R&D capabilities. Given that foreign investment in Israeli companies is on the rise, this trend is likely to become more entrenched in the years to come.

One concern for policy-makers should be the growing tendency for endogenous knowledge to be transferred to foreign companies, since there is a risk that this will lead to production and jobs migrating abroad.

More investment in basic research

The observed rise in investment in basic research is a positive sign. This trend signals that the government has come to appreciate that the next wave of Industry 4.0 technologies will originate from the basic research laboratories of Israeli universities, in intimate synergy with ICTs, rather than from the defence industry, as in the past (Getz and Tadmor, 2015).

One of the country's main missions will be to focus its innovative capabilities on the challenges that it faces in the fields of health care, transportation, water management and education, in particular. With STI policy shifting towards a mix of top-down and neutral approaches, Israel should be better-equipped in the years to come to direct innovation towards meeting these challenges.

KEY TARGETS FOR ISRAEL

Israel plans to:

- achieve a 17% reduction in electricity consumption relative to anticipated electricity consumption by 2030;
- consume 13% of electricity from renewable sources by 2025 and 17% by 2030;
- reduce the distance travelled by private vehicles by 20% relative to the anticipated amount of kilometres travelled in 2030;
- eliminate electricity production from coal by 2030.

Daphne Getz (b. 1943: Israel) holds a PhD in Physical Chemistry from the Technion. She has been a senior research fellow at the Samuel Neaman Institute for National Policy Research at the Technion since 1996. She heads the institute's Centre of Excellence in Science, Technology and Innovation Policies, as well as its information centre.

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ENDNOTES

1 The present report not only covers UNESCO member states. Israel's withdrawal from UNESCO came into effect on 31 December 2018.
2 See: https://www.health.gov.il/English/Topics/Diseases/corona/Pages/default.aspx
3 See: https://innovationisrael.org.il/en/news/government-israel-wages-war-coronavirus
4 See: https://www.gov.il/he/departments/news/industrial-symbiosis-pilot
5 In 2014, each inhabitant of the Netherlands had access to 652 m^3 of internal, renewable freshwater, compared to 91 m^3 for each Israeli, according to the Food and Agriculture Organization's Aquastat database.
6 These are: Israel's Intended Nationally Determined Contribution; the *National Plan for Implementation of the Greenhouse Gas Emissions Reduction Targets and for Energy Efficiency* (2019); the Ministry of Energy's *Energy Economy Objectives for the Year 2030* (2019); and the *National Master Plan for the Energy Economy* (2019).
7 See: https://www.gov.il/he/departments/publications/reports/reports_reducing_ghg_emissions_in_israel
8 One notable initiative is being implemented by Eilat-Eilot Renewable Energy, a non-profit organization. Fifteen solar plants already provide for 70% of the electricity demands of the Eilat and Arava region. By 2025, the organization aims to provide for all of the region's energy demands from renewable sources. See: http://www.eilateilot.org/
9 See: https://www.gov.il/en/departments/policies/israel_2050
10 See: https://yoursay.sviva.gov.il/
11 The figures for full-time equivalent (FTE) jobs include sabbaticals in Israel but exclude emeriti. Since 2016, the data include FTE researchers at Ariel University: 391 in 2017.
12 See: https://che.org.il/en/women/
13 Entrepreneurs from ultra-Orthodox communities can apply for a grant equivalent to 75% of the approved budget (up to NIS 2.5 million) for the first year and 70% of the approved budget for the second year (up to NIS 4.5 million).
14 Industry 4.0 here refers to the use of data collection and analysis to improve production processes and/or the introduction and connection of innovative production tools, such as advanced industrial robotics and additive manufacturing (industrial 3D printing), to existing production processes.

AT A GLANCE

The Smart Acres' vertical farm in the United Arab Emirates uses non-soil substrates to limit water use. Seen here in March 2021 is kale, or leaf cabbage, growing in one of the company's eight freight containers. Smart Acres plans to set up a research institute to develop a local potato seed with an international team to reduce costly imports of seeds. © Smart Acres

- Many Arab countries are focusing on industrialization and infrastructure development; for some, this extends to high-tech fields such as aeronautics, agricultural biotechnology and the space industry.
- However, all countries remain dependent on foreign core technologies.
- With education systems not delivering, some countries are focusing on skills development to support their ambition of developing a knowledge economy.
- Most countries have digital agendas to modernize public services and make it easier to do business.
- There is a desire to foster a science and innovation culture but investment in research remains static in most countries reporting data.
- Six countries accounted for nearly 90% of power generated from wind and solar resources in the region in 2017.
- Several countries are positioning themselves for Industry 4.0, with the development of strategies for artificial intelligence, the adoption of support programmes for research in related areas and plans for high-tech urban centres that are both digital and sustainable.

17 · The Arab States

Algeria, Bahrain, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Syria, Sudan, Tunisia, United Arab Emirates, Yemen

Esra Eisa Aleisa, Abdelkader Djeflat and Moneef Zou'bi

INTRODUCTION

Inadequate field data impeding poverty alleviation

Economic growth rates have declined in parts of the Arab region since 2015 and unemployment rates among the young, in particular, remain high (Figure 17.1). For years, young men and women have been relaying widespread calls for economic and political reforms, via Internet, social media and public demonstration.

The Covid-19 pandemic is likely to exacerbate poverty levels in the region. These had already risen since the Arab Spring of 2011, bucking the global trend towards a downturn in poverty levels over the same period. In Egypt, for instance, the share of the population living below the national poverty line rose from 26.3% in 2012 to 27.8% in 2015 (Arab Rep. Egypt, 2018). One of the main obstacles to tackling poverty effectively in the Arab region has been the lack of reliable data, owing primarily to inadequate field research in the social sciences.

The economic fallout from insecurity in Iraq, Libya, Syria and Yemen has been felt by all Arab countries, slowing the influx of foreign direct investment (FDI) and hurting real estate markets. The region accounts for 5% of the global population but 32% of the world's refugees (UNESCO, 2019). With the exception of Libya, the economies of the Maghreb have proved the most resilient, recording the region's highest combined average growth of just under 2.8% in 2017.

Military spending in the region has contracted slightly since 2015, according to data from the Stockholm International Peace Research Institute. However, six of the top ten countries for military expenditure as a share of GDP still came from the Arab region in 2019 (Figure 17.1).

Saudi Arabia and the United Arab Emirates (UAE) have both taken steps to acquire the requisite technological capabilities to build military equipment. Saudi Arabia's *2030 Vision* fixes the target of manufacturing locally 50% of the military equipment it imports by 2030. In February 2019, the UAE's Tawazun Economic Council announced the creation of a Defence and Security Development Fund with a starting capital of US$ 680 million (Samaan, 2019).

Countries have turned to tech for pandemic response

During the Covid-19 pandemic, Arab countries with a strong manufacturing base have been able to repurpose production lines to produce key equipment. By May, six textile factories in Morocco were manufacturing medical masks and other personal protective equipment exclusively, having converted their productive facilities for the purpose. By April, micro-enterprises and small and medium-sized enterprises (SMEs) in both Algeria and Morocco were manufacturing personal protective gear and the large Algerian textiles company GETEX SPA was producing 2 million masks.

The pandemic has also revealed some dormant innovative capacities. In March 2020, Morocco's Ministry of Industry vowed to manufacture a ventilator using only endogenous resources; by the following month, a prototype had been produced that was capable of operating with or without electricity. The pandemic has opened a wide space for start-ups, which have rushed to develop apps and other tools for prevention and geolocalization, drug and food distribution, among other areas.

Those countries with the most dynamic national research teams have been quickest off the mark to develop screening tests. The Lebanese National Council for Scientific Research (CNRS-L) issued a Flash Call for Covid-19 Management as early as March 2020. This led to the selection of 29 projects addressing topics such as vaccination policy, rapid test development and the use of artificial intelligence (AI) to support early diagnosis of the disease and measure its impact on the mental health of frontline workers. Saudi universities also mobilized research response teams to support the health care system, as at King Abdulaziz University in Jeddah.

In March 2020, the UAE opened a facility for Covid-19 in Masdar City that was capable of testing tens of thousands of people a day. At the time, the laboratory was the largest of its kind outside China. It resulted from a collaboration between UAE-based Group 42 and BGI, formerly known as the Beijing Genomics Institute.

Governments have had recourse to imported technology. Thermal (heat-seeking) drones have been utilized in some open spaces and markets in Saudi Arabia to identify people with a high body temperature, to help curb the spread of the virus (Alfaisal, 2020). Similarly, remotely controlled robots have been employed in Tunisia to enforce lockdown rules.[1]

In Bahrain, the government has enforced compliance with self-isolation rules through electronic tracker wristbands and the BeAware app, which monitors people's location via their mobile phone. Whenever a self-isolating individual moves more than 15 metres from their phone, an alert is sent to a monitoring station (Toumi, 2020).

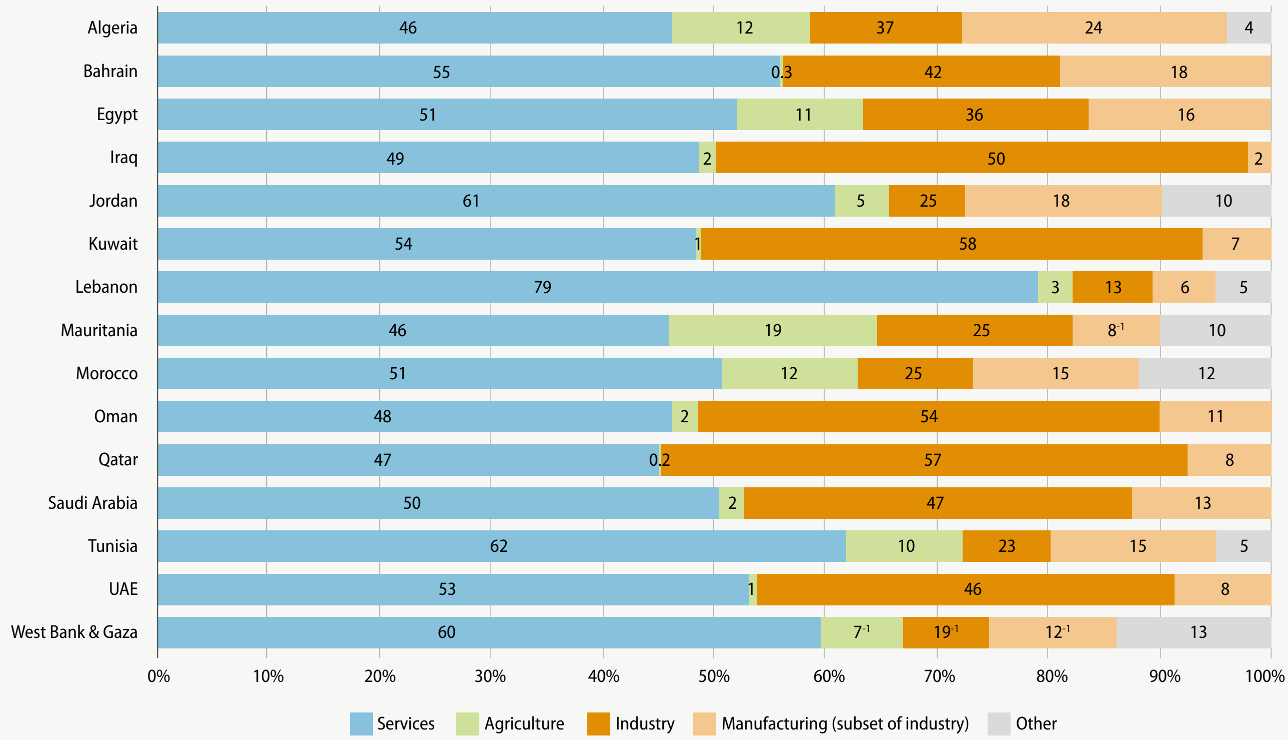
Monitoring committees heeding scientific advice

The Covid-19 pandemic has demonstrated the importance of heeding scientific advice. Most Arab countries have established ad hoc government committees staffed with scientific advisors to manage the crisis.

For instance, Lebanon's president announced the launch of the Expert Committee on the Novel Coronavirus Covid-19 on

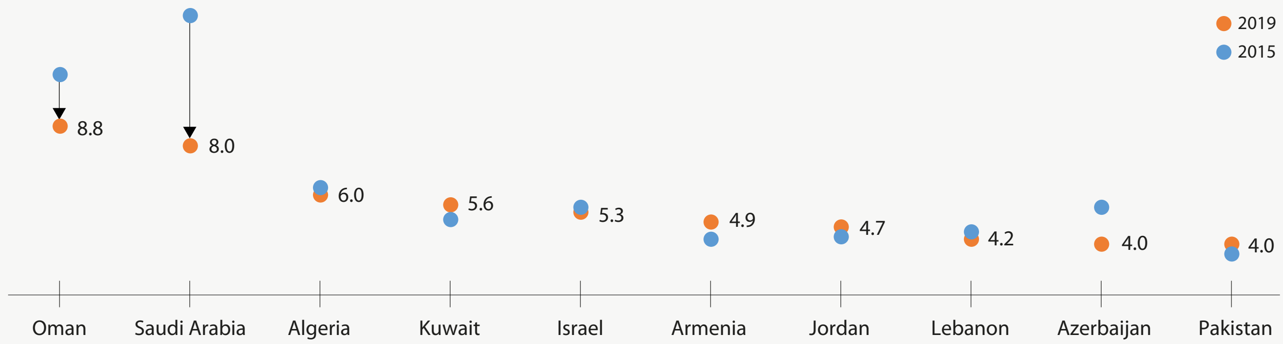
Figure 17.1: **Socio-economic trends in the Arab States**

GDP per economic sector in the Arab States, 2019 (%)

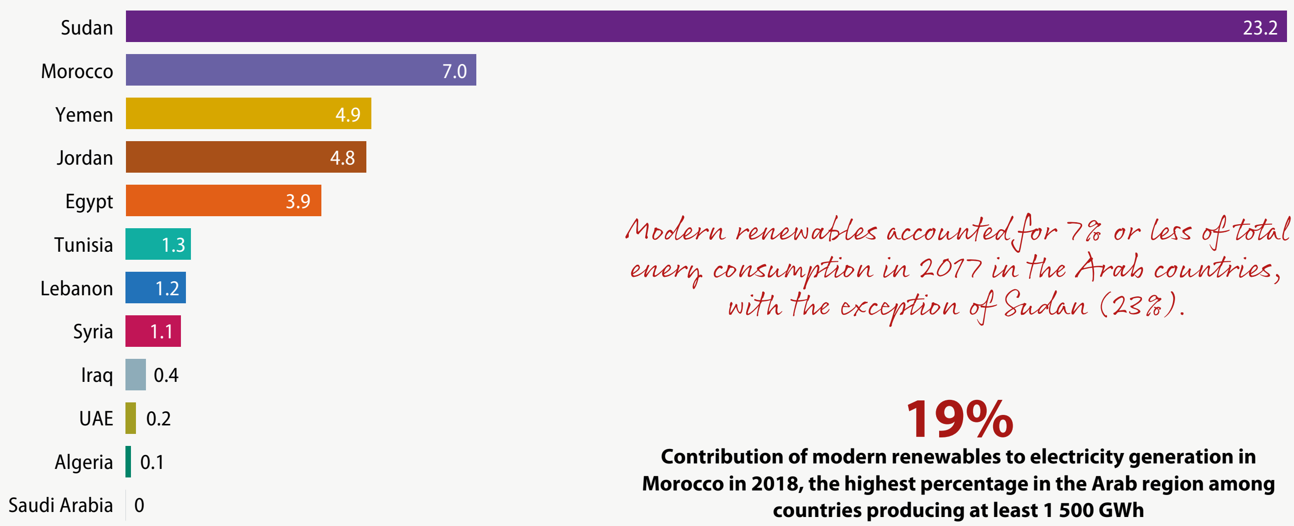


Note: The 'other' economic sector addresses activities outside of the International Standard Industrial Classification divisions 1–5 (agriculture), 10–45 (industry) and 50–99 (services).

Global top ten for military expenditure as a share of GDP, 2015 and 2019 (%)
Data labels are for 2019



Share of modern renewables in final domestic energy consumption in the Arab States, 2017 (%)

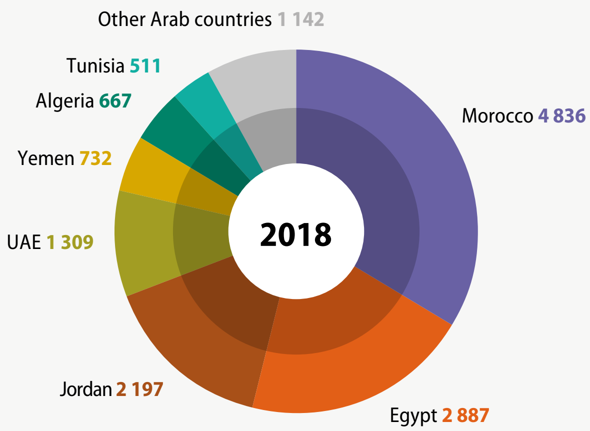


Modern renewables accounted for 7% or less of total energy consumption in 2017 in the Arab countries, with the exception of Sudan (23%).

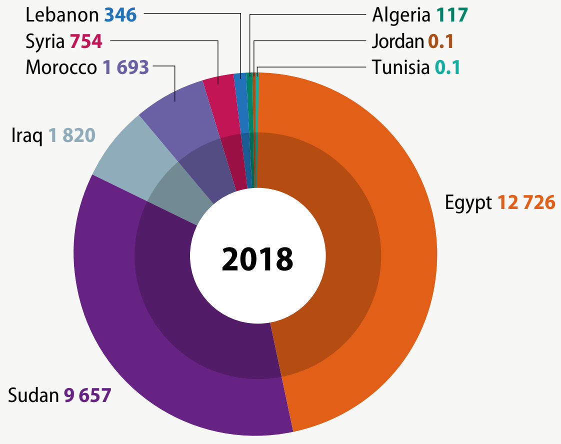
19%

Contribution of modern renewables to electricity generation in Morocco in 2018, the highest percentage in the Arab region among countries producing at least 1 500 GWh

Total electric power generated from hydropower, wind and solar resources in the Arab States, 2018
Calculated in GWh



Solar & wind



Hydropower

Wind and solar energy contribute 1% of Egypt's electricity, corresponding to 20% of electricity generated in the Arab region from these sources.

Selected socio-economic indicators for the Arab States, 2012–2019

	Average GDP growth rate (%)		GDP per capita (constant 2017 PPP$)	Average FDI inflows as a share of GDP (%)		Share of population using Internet (%)	High-tech exports as share of manufactured exports (%)	Unemployment rate (%)	Youth unemployment rate (%)
	2012–2015	**2016–2019**	**2019**	**2012–2015**	**2016–2019**	**2019**	**2018**	**2019**	**2019**
Gulf states plus Yemen									
Bahrain	4.09	2.77	45 026	5.31	1.24	99.7	0.4	0.7	4.6
Kuwait	2.22	-0.03	49 846	0.76	0.21	99.5	4.1	2.2	15.8
Oman	5.28	1.89	27 896	0.56	4.88	92.4	1.3	2.7	13.2
Qatar	4.18	1.26	92 651	0.24	-0.39	99.7	0.0	0.1	0.4
Saudi Arabia	3.97	0.92	46 962	1.29	0.62	95.7	0.6	5.9	28.6
UAE	4.73	2.08	67 119	2.55	2.78	99.1	10.8	2.3	7.3
Yemen	-5.24	-4.56	–	-0.24	-1.37	26.7^{-2}	8.0^{-3}	12.9	24.0
Mashreq plus Egypt and Sudan									
Egypt	2.92	4.85	11 763	1.51	2.95	57.3	2.3^{+1}	10.8	31.1
Iraq	6.18	4.14	10 881	-2.01	-2.41	75.0^{-1}	–	12.8	25.1
Jordan	2.74	2.01	9 906	5.21	3.27	66.8^{-2}	2.9	14.7	35.0
Lebanon	2.26	-1.30	14 717	5.75	4.69	78.2^{-2}	2.4	6.2	17.6
Sudan	2.64	1.03	3 958	2.89	2.92	30.9^{-2}	0.6^{-1}	16.5	31.4
Syria	–	–	–	–	–	34.3^{-2}	–	8.4	20.9
West Bank & Gaza	2.94	2.92	5 662^{-1}	1.04	1.64	70.6	0.9	26.2	42.0
Maghreb									
Algeria	3.42	1.67	11 350	0.48	0.85	49.0^{-1}	0.6^{-1}	11.7	29.5
Libya	19.17	10.39	15 174	0.70	0.00	21.8^{-2}	–	18.6	50.5
Mauritania	4.57	3.20	5 197	12.99	3.07	20.8^{-2}	0.0^{-2}	9.5	14.8
Morocco	3.69	2.65	7 515	3.11	2.22	74.4	4.0	9.0	22.1
Tunisia	2.76	1.70	10 756	2.53	2.03	66.7	7.4^{-1}	16.0	36.3

+n/-n: data refer to *n* years before or after reference year

Note: Palestine is designated as the West Bank and Gaza here, owing to data coverage issues. The unemployment rate is a modelled estimate by the International Labour Organization; the data cover youth aged 15–24 years. Data are unavailable for some countries. The share of modern renewables in final energy consumption does not reflect the share of renewables in energy produced for export.

Source: World Bank's World Development Indicators, December 2020; Stockholm International Peace Research Institute Military Expenditure Database; for electric power and energy consumption: International Renewable Energy Agency

29 February 2020, comprising exerts in health policy and management, virology and emergency medicine, among other areas.

Saudi Arabia formed its own Covid-19 Monitoring Committee, the same month. By mid-April, the government had approved about 35 policies, classed as proactive, reactive and supportive. Among supportive policies, one could cite a government pledge to provide all residents infected with Covid-19 with free health care and the launch of an online service to enable expatriates to return home.

In April 2020, Oman formed its own Technological Innovation Committee for Combating Covid-19, consisting of officials from institutions that include the Ministry of Health, the Telecommunications Regulatory Authority, Sultan Qaboos University, the Research Council and the Oman Technology Fund. Although relatively late to form in comparison with other Gulf states, this committee has set up specialized teams to produce innovative solutions for rapid diagnosis, the provision of e-health care, supply of medication and development of technologies in support of prevention (ONA, 2020).

Arab countries have adapted to remote learning

The pandemic has offered governments an opportunity to improve the provision of e-services.[2] It has also highlighted the technology gap among Arab countries. Pupils and students from the Gulf states, in particular, and those in urban areas were better placed to pursue their education from a distance, owing to better access to Internet and computer technology (Figure 17.1).

Most Arab States were able to adapt their education systems rapidly to online learning during the pandemic. When fellow Gulf states imposed an embargo on Qatar in 2017, students from these countries who were enrolled in Qatari university courses were able to pursue their learning remotely. Thanks to this experience, the government was quick to put remote learning systems in place in 2020 (QT-Online, 2020).

Bahrain, Oman, Saudi Arabia and the UAE also adopted fexible learning arrangements in 2020. Prior to the pandemic, more than 400 000 university students had engaged in online learning at some point, including through the Gulf's first virtual university, the Saudi Electronic University (est. 2013). Thanks to this existing capacity, Saudi Arabia was able to launch 22 educational channels within eight hours of the first lockdown.

Whereas a similar approach to online learning was adopted in Algeria, Egypt, Jordan, Morocco and Tunisia, Kuwait proved an exception. It paused all teaching at public schools and universities for at least six months without offering students the option of remote learning, despite having the necessary infrastructure in place. Private schools, which are mostly populated by foreign students, received more than twice as many hours of instruction as Kuwaiti citizens.

SUSTAINABLE DEVELOPMENT AGENDA

Rentier economies striving to move out of their comfort zones

In the past few years, several Gulf states have attempted to push back the boundaries of their long-standing comfort zones, firmly rooted in their rentier economies, by taking steps to encourage manufacturing and better governance. For instance, Oman's draft 2040 Vision sets the goal of raising the share of non-oil activities in the economy to 90% by 2040, when 'innovation will be the new engine of growth.' However, progress on these fronts has suffered from the effects of Yemen's prolonged crisis and the economic blockade of Qatar between 2017 and 2020, in particular.

The *Atlas of Economic Complexity* assesses the diversity of countries' industrial capabilities and know-how, ranking them according to prospects for growth. Over the 2014–2018 period, most Gulf states improved their ranking, suggesting that efforts to diversify their economies are paying off. Saudi Arabia's performance was the most impressive (69th to 36th place). Elsewhere in the Arab world, there was little change in the rankings of Egypt, Jordan, Lebanon, Libya and Tunisia but Morocco fell ten places to 91st position.

Education systems not delivering

Arab countries are conscious that, should they not manage to adapt their workforce to the new knowledge economy, they will face even higher unemployment rates. After relocating much of their production to the developing world in the 1980s, where cheap, unskilled labour was plentiful, industrial countries are now investing in advanced manufacturing technologies such as robotics, digital twins and three-dimensional (3D) printing, to revitalize their own domestic manufacturing sector.

This process is known as the Fourth Industrial Revolution (or Industry 4.0). It is generating technological and organizational changes in manufacturing that are already reducing demand for unskilled labour in both developed and developing countries. It will, thus, be vital for national education systems to give youth the requisite skills for this new world of work.

According to the 2018 edition of the Programme for International Student Assessment (PISA) conducted by the Organisation for Economic Co-operation and Development (OECD[3]), the ability of 15-year-old Arab students to use their knowledge of reading, mathematics and science to meet real-life challenges is almost invariably weaker than that of their peers from neighbouring Cyprus, Israel, Malta and Turkey.

Scores achieved by these Arab students fall below the average score for OECD countries. Although only six Arab countries participated in the PISA exercise, namely Jordan, Lebanon, Morocco, Qatar, Saudi Arabia and the UAE, these are also the countries least likely to have witnessed problems with their education systems. This suggests that the findings may reflect a far rosier picture of Arab education systems than exists in reality.

Perhaps even more worrying are the percentages of top and low achievers in all three subjects among participating Arab students. Top achievers accounted for just 3% of the

Arab students tested, with a low of 0.1% for Morocco and a high of 8% for the UAE. This compares with an average of almost 16% for the OECD and around 10% for their four neighbours.

The percentage of low achievers from schools in participating Arab countries ranged from over 60% (Morocco) to 30% (UAE). As a group, Arab students accounted for 42% of low achievers, compared to 22% for the four neighbouring countries and 13% for the OECD average.

The 2019 edition of the *Trends in International Mathematics and Science Study* found a similar pattern. It measures the performance of fourth and eighth graders. None of the seven participating countries (Bahrain, Egypt, Jordan, Kuwait, Oman, Saudi Arabia and UAE) exceeded the 500 benchmark (20% percentile), although Bahrain and the UAE scored consistently higher than the five others.[4]

Efforts to raise skills

In light of current performance, skills training has become a common focus area of strategic planning in the Arab States.

For instance, in Tunisia, about a dozen schemes have been developed since 2015 to improve the employability of graduates, such as the Decent Work Country Programme in Tunisia for 2017–2022 and the PAX-co scheme, under which training programmes are co-constructed by enterprises and public universities (MPTE, 2018). Vocational education and training has benefited from a 2017 law guaranteeing free access to initial training and improved responses to labour market requirements (MPTE, 2018).

Oman's *Five-Year Plan* and *Voluntary National Reviews* (2016 and 2019) describe the need to boost the employment rate of nationals as the country's most pressing priority. It is not alone: in the Gulf states, about 70% of those in employment are non-nationals, according to the International Labour Organization.[5] Job opportunities outstrip demand, with Omani nationals accounting for only about one-fifth of the workforce and being employed primarily in the public sector. The government is planning to give Omani graduates more marketable skills for industry. Launched in August 2018, Oman's National Youth Programme for Skills Development lies at the intersection between this challenge and the government's ambitions for the Fourth Industrial Revolution. By 2020, the government aims to train about 3 000 Omanis aged 15–29 years in related skills, such as programming, coding and critical thinking, including in relation to robotics and artificial intelligence (AI). Successful participants will receive a 'nanodegree', a new qualification recognizing the acquisition of Industry 4.0 skills.[6]

A dynamic digital marketplace

Arab entrepreneurs from Jordan and the UAE, in particular, have established online marketplaces that had millions of users by 2017 (UNESCWA, 2017a).

A growing number of start-ups are focusing on Industry 4.0 technologies. For instance, Proximie in Lebanon, which dates from 2017, enables surgeons to collaborate remotely, including via augmented reality (Medeiros, 2020). InstaDeep in Tunisia provides AI-assisted decision-making for companies. In 2019, the five-year old start-up raised US$ 7 million from the pan-African private equity firm, AfricInvest, a record amount for AI in Africa. In Morocco, the start-up Atlan Space, founded in 2016, uses AI and drones to monitor the environment. It received the Bank of Africa's African Entrepreneurship Award in 2019 (Mejri, 2020).

Digital economies not built on business alone

Of course, the adoption of digital technologies by businesses is, in itself, insufficient to realize truly inclusive digital economies. Other actors invariably also need to intervene, primarily those involved in education, vocational training and the media but also at the regulatory level. In recognition of the need to prepare the young for the digital economy, Morocco's Euromed University in Fes opened a School of Digital Engineering and Artificial Intelligence in September 2019, in partnership with the Polytechnic School in France. The initial intake comprised about 100 students at the bachelor level (Mejri, 2020).

Generally speaking, there is little available information on initiatives by firms to develop a digital business. It would be useful to conduct in-depth innovation surveys of firms to monitor progress in this area.

Digital technologies could also provide much-needed help for refugee communities and internally displaced populations, such as by enabling distance education, enhancing social cohesion and promoting entrepreneurship. Relief agencies operating in three Syrian refugee camps in Jordan have been experimenting with this approach (UNESCWA, 2020a).

Strategic plans for artificial intelligence

A number of Arab countries have developed strategic plans to capitalize on the potential of AI.

Saudi Arabia plans to position itself as a global hub for AI and data, including by creating an enabling regulatory environment.[7] On 30 August 2019, Saudi Arabia established a national Authority for Data and Artificial Intelligence by royal decree. This agency runs the National Centre for Artificial Intelligence, National Data Management Office and National Information Centre. The authority launched the *National Strategy for Data & AI* in October 2020. According to this strategy, 40% of the local workforce should have acquired basic skills in data and AI and there should be 15 000 local specialists in these fields by 2030.

The *United Arab Emirates' Strategy for Artificial Intelligence 2031* was adopted in October 2017, the same month in which the two federal ministers of state for Advanced Sciences and Artificial Intelligence were appointed. This strategy integrates AI in government services and targeted sectors, including transportation, health care and renewable energy.

Algeria, Egypt and Tunisia have all taken steps to develop their own national AI strategy. For example, the Tunisian Ministry of Industry and SMEs published an *AI Roadmap* in April 2019 which resulted in the holding of a smart industry forum the same year and the inclusion of AI as a priority focus of the National Programme for Research and Innovation, which funds 80% of industrial research (Mejri, 2020).

Plans for high-tech, sustainable urban centres

State institutions have several projects in the pipeline for smart urban centres which incorporate a host of novel technologies. One notable example is the new Saudi city of Neom, a futuristic city to be located near the borders of Egypt, Israel and Jordan that is one of the more prominent projects within Saudi Arabia's *Vision 2030* (2016).

Backed by US$ 500 billion from the Saudi Public Investment Fund, Neom is expected to serve as a hub for nine focal sectors, including technological and digital sciences, food production, biotechnology and advanced manufacturing (SCP, 2019). There are plans for autonomous transportation systems and electric vehicles, seaports and manufacturing plants that will make use of 3D printing and robotics. Robotics and AI are to be integrated in all aspects of daily life.

In January 2021, the kingdom unveiled plans for The Line, a 170-km long belt connecting smart cities without the need for cars or roads. Residents will be able to satisfy all of their needs within walking distance and will have access to nature. Communities will be hyper-connected through AI and powered by 100% clean energy.

The UAE's Masdar City has been under development since 2008 (Zou'bi *et al.*, 2015). Expectations were high for the artificial city, which was to be the world's most sustainable metropolis with a population of 40 000 by 2020. As of early 2020, the first phase has been completed, corresponding to roughly one city block with about 1 300 residents (Flint, 2020). According to Chris Wan, head of Masdar's design management team, the goal is no longer for the city to run entirely on renewable energy; by the project's completion in 2030, half of the city's power is expected to come from the electricity grid (Liu, 2018).

The Masdar Institute (est. 2007) has played a key role in incubating and running semiconductor manufacturing facilities. It has benefited from ongoing collaboration with the Massachusetts Institute of Technology in the USA.

Masdar City hosts the Mohamed bin Zayed University of Artificial Intelligence, inaugurated in October 2019, which is among the world's first to specialize in AI. The university offers master's and PhD programmes in machine learning, computer vision and natural language processing.

In Egypt, 12 new cities were built over the 2007–2018 period and a further 15 are planned. With Cairo counting among the world's densest cities and the national population projected to expand by 34 million between 2017 and 2030,[8] the government is seeking to relieve pressure on existing infrastructure and services by building new cities from scratch. Approved in 2015, the *National Urban Development Plan 2052* provides a framework for these efforts.

The Egyptian government has outlined a number of sustainability principles for its new cities: land per capita should exceed 15 m^2, solar panels are to be installed on 70% of rooftops and four-tenths of road surfaces are to be reserved for pedestrians and cyclists (Arab Rep. Egypt, 2018).

Sustainable smart cities are also planned for Algeria, Jordan and Morocco, among other countries (see Country profiles).

Water and food security remain challenges

Water scarcity, soil erosion and environmental degradation all present serious challenges for the region.

For example, the UAE is experimenting with indoor vertical farming, which uses non-soil substrates to limit water use and artificial lighting. About 97% of groundwater is currently used for agriculture, even though much of this is 'fossil' water left over from an earlier, wetter climate that is not being replenished (Aleisa and Al-Shayji, 2018; Garfield, 2018). In all, 89 hydroponic projects were active as of early 2020 (OBG, 2020).

The priority accorded to food security is reflected in the country's *National Food Security Strategy 2051* (2018). It outlines 38 initiatives to diversify sources of food imports and identify alternative supply schemes, among other objectives.

In Qatar, groundwater is being extracted at nearly four times the rate at which it is naturally replenished. With no surface freshwater, desalination provides 99% of the country's potable water (OBG, 2020). In order to expand water reserves, the Qatar General Electricity and Water Corporation inaugurated the Water Security Mega Reservoirs project in December 2018. It has expanded total water storage capacity by 67%. Its 15 concrete reservoirs are the world's largest potable water storage tanks; they are expected to cover storage requirements until 2026.

Access to clean drinking water has improved in Mauritania since 2015, with 72% of urban and 53% of rural populations benefitting by 2018. However, huge disparities remain, with only around 34% of the poorer segment of society having access (Govt of Mauritania, 2019). As of 2018, more than 20 water and sanitation projects were being implemented at a total estimated cost of US$ 542 million, funded both from the national budget and from external sources (Govt of Mauritania, 2019). Related research is being conducted at the World Bank-funded National Centre for Water Resources.

Ambitious plans for renewable energy

Several Arab States have set ambitious targets for developing capacity in renewable energy. For instance, Egypt's *Integrated Energy Strategy to 2035* (2016) plans to augment the share of renewables in the electricity mix from 2.3% (2016) to 42% by 2035, with emphasis on solar and wind energy.

Between 2010 and 2017, Algeria, Egypt, Jordan, Morocco, Tunisia and the UAE all made considerable progress in installing wind and solar power generation facilities. By 2017, these installations generated 12 407 GWh, or about 87% of power generated by the entire Arab region using this type of renewable resource (Figure 17.1).

In 2016, Morocco opened Noor 1 (160 MW), one of the world's largest concentrated solar power plants, as the first stage of the 580-MW Noor Ourzazate Solar Complex. Noor II and Noor III followed in 2018, bringing the total installed concentrated solar capacity at the complex to 510 MW.

Morocco's *National Energy Strategy* (2009) had set a target to 2020 of 42% for the share of renewables in total installed power capacity, which was extended to 52% by 2030 at the 21st session of the Conference of Parties (COP21) in 2015. According to the National Office for Electricity and Drinking Water, as of July 2019, renewables accounted for 35% of the 11 GW of total installed capacity.

The UAE has become a regional forerunner for renewable energy. Over the past four years, it has installed about 70% of the Gulf's renewable capacity, as solar and wind power have become a cheaper source of energy production than nuclear power (IRENA, 2021). The country has also boosted oil production by 800 000 barrels per day over the past decade (OPEC, 2021).

In April 2019, the 1.2-GW Noor Abu Dhabi Solar Power Project began operating commercially. Co-financed by eight commercial banks for Dh 3.2 billion (*ca* US$ 871.2 million) and built within 23 months, it claims to be the world's largest single-site plant of its kind.[9]

The Regional Center for Renewable Energy and Energy Efficiency (est. 2010) conducted a study of the Yemini solar sector in 2017 (Box 17.1), which has been credited as a 'rare success story' (Badiei, 2018).

Based in Egypt, this intergovernmental organization counts most of the Arab world among its 17 members. By collaborating with governments, the private sector and other actors, the centre aims to initiate dialogue on clean energy policy and facilitate investment in renewable energy, as well as capacity-building. For instance, since 2015, the centre has been implementing the Active Turbine Management Programme in Egypt, which has been assessing the optimum operation of wind turbines during bird migratory seasons.

The centre has also contributed to the formulation of the *Pan-Arab Sustainable Energy Strategy*, which was adopted by the Arab Ministerial Council of Electricity in 2019.

SUPRANATIONAL STRATEGIES FOR SCIENCE

A call to nurture thinking minds

There has been a flurry of activity in the past few years to accelerate progress towards knowledge societies and foster sustainable development. At its annual summit in September 2017, the Organisation of Islamic Cooperation (OIC), which groups 57 Muslim-majority countries, adopted its *STI Agenda 2026*.

This document emphasizes mechanisms for building collective competence in areas ranging from water, food and agriculture to energy and basic and applied sciences. It advocates large multinational projects and strengthening international linkages with 'the best in the world'.

The *STI Agenda 2026* observes that, 'notwithstanding some important gains in the past decade, a true scientific culture is conspicuous by its absence [in the Muslim world]'. The preamble recalls that 'science is disruptive and flourishes in an environment of irreverence'. It goes on to say that 'there should be no fears about the disruptive nature of knowledge and science, as this has been part of our heritage and traditions for centuries.'

Of the *Agenda's* 12 priorities, that of nurturing the thinking mind by building a culture of science and innovation tops the list. Recommendations and targets in this document are aspirational rather than prescriptive, with each government setting its own list of national targets to reflect its particular circumstances and ambitions.

The *STI Agenda 2026* will remain a stand-alone silo, however, unless a core group of countries commit to allocating the financial means needed to realize its ambitions. For instance, the *STI Agenda* invites member states to 'consider doubling the annual expenditure by 2025 on scientific infrastructure and research and development (R&D) in those countries which spend less than 0.3% of GDP and to aim for a target of 2.0% in countries which are at a relatively advanced level'.

Box 17.1: **Yemen embracing solar power for survival**

Power shortages linked to the ongoing conflict have led some Yemeni households to invest in solar power. By 2017, about 75% of households in urban areas and 50% in rural areas were equipped, at least partially, with solar panels, according to a study by the Regional Center for Renewable Energy and Energy Efficiency.

The authors estimate that US$ 1 billion was invested over 2011–2016 in the residential sector alone. Among the factors explaining this trend are the concomitant cost and unreliability of diesel-based generators and the falling cost of photovoltaic (PV) technology.

The Yemeni market is characterized by a large share of imported solar system components from Asian manufacturers, with minor imports from other countries, such as Germany and the USA.

A lack of technical understanding of the products within Yemen has led to problems; for instance, the use of car batteries in solar panels to store energy is considered the main cause of system failure.

Another challenge lies in the stringent conditions for loans, such as financial guarantees, which many customers are unable to provide. Three primary business models for financing have been developed for Yemen: the Internal Collateral Fund, which mimics the insurance model; the Aggregator Principle, by which large entities such as a farmer's co-operative enable smaller customers to make economies of scale and, thirdly, My Solar PV.

The My Solar PV scheme enables customers to avoid taking out interest-based loans, in line with the Islamic Sharia, which is of paramount significance in Yemen. The local bank purchases the solar system then sells or rents the unit in instalments to the end-user at a modest profit.

Source: RCREEE (2017)

Technology and innovation as enablers

In February 2019, the member states of the United Nations Economic and Social Commission for Western Asia (UNESCWA) adopted the *Beirut Consensus on Technology for Sustainable Development in the Arab Region*. Through this consensus, they 'affirm [their] commitment to work together on harnessing the power of technology and innovation to build a more peaceful, prosperous and just future for all in the Arab region.'

The consensus states a firm belief in technology and innovation as enablers for people-centred, sustainable and inclusive development. It notes that technology can be pivotal to the eradication of poverty and that advanced technologies like artificial intelligence could both contribute to, and detract from, job creation.

Member states commit to investing in technology and innovation through legislative and fiscal policy measures, stimulating technology transfer, improving the delivery of public services through e-governance and financing technological solutions to climate change. These goals are to be pursued at both the regional and national levels.[10]

In March 2017, the members of the Tunis-based Arab League Educational, Cultural and Scientific Organization (ALECSO) adopted the *Arab Strategy for Scientific and Technical Research and Innovation*, which emphasizes the need to draw on innovation and technology to attain inclusive sustainable development.

This follows the adoption of the *Arab Strategy for Science, Technology and Innovation*, endorsed by 22 Arab States in 2014. It identified water resources management and the use of nanotechnology in health, the food industry and for the environment as priority areas for collaboration (UNESCO, 2018).

Islamic Development Bank pivoting towards science

In May 2019, the Islamic Development Bank published its *Science, Technology and Innovation Policy for the IsDB*. The policy has been developed in partnership with UNESCO, to mainstream science, technology and innovation (STI) in the bank's operations and guide its investment policy.

Through this policy, the bank hopes to help member countries achieve their Sustainable Development Goals (SDGs) and support the formulation of national STI polices, especially in countries still lacking one. It also plans to help create an enabling environment, such as by updating public procurement frameworks, improving the investment climate and collecting data on R&D.

The policy includes indicators to measure member countries' progress over time in terms of research intensity, researcher population, volume of publications and share of international patent filing and so on.

The bank has also launched Engage, to foster solutions that further countries' SDG agenda (Box 17.2).

RESEARCH TRENDS

World-class researchers in short supply

The Fourth Industrial Revolution is blurring the boundaries between the virtual world and reality, services and industry, as biotechnology, nanotechnology, informatics and cognitive sciences converge to spawn new fields such as bioinformatics, bionanotechnology and nanorobotics. These fields are rooted in the basic science laboratories of universities, which means that any country wishing to understand these new technologies and develop their own must have an endogenous capacity in both basic and applied research.

This poses a dilemma for the Arab world, where world-class researchers are in short supply. Out of almost 6 100 highly cited researchers worldwide in 2018,[11] only about 90 were based at universities in the Arab world, mostly in Saudi Arabia, and just six of those came from the region, according to a study of publications in the Web of Science database (Clarivate Analytics, 2019).

This explains why Qatar, Saudi Arabia and the UAE, in particular, have been recruiting top scientists for their universities and research institutes. The UAE has taken this logic a step farther by granting scholars, scientists and doctors permanent residence. By 2018, the UAE had joined Tunisia in

Box 17.2: **Engage: funding innovation for sustainable development**

In February 2018, the Islamic Development Bank launched Engage, a digital platform promoting ways to use science and engineering to achieve the Sustainable Development Goals.

Engage offers innovators, small and medium-sized enterprise (SMEs), governments and non-governmental organizations alike three main services: match-making, technology transfer and calls for proposals in the field of innovation.

Engage has been endowed with US$ 500 million through the bank's Transform Fund, which provides seed funds for SMEs and start-ups, while supporting capacity-building and the commercialization of research. As with Engage, the Transform Fund is oriented towards development within the framework of the SDGs.

Following the outbreak of the Covid-19 pandemic in early 2020, the bank launched a call for innovative projects to respond to the crisis, financed by the Transform Fund. Proposals could focus on advanced technologies, such as the Internet of Things and big data, to monitor diffusion of the virus; innovative health supply chain management systems; low-cost rapid screening tests; or capacity-building to support health-care providers. New ideas with proof of concept would be eligible for US$ 50 000–100 000, whereas proposals to commercialize research would be eligible for equity participation of up to US$ 1 million.

Source: compiled by authors

having a researcher density well above the global average of 1 368 researchers per million inhabitants (Figure 17.2).

Other Arab countries are also training more researchers than before, notably Egypt, Morocco and Tunisia. The density of technicians remains low in the latter two countries, however, despite the vital role that technicians play in the Industry 4.0 manufacturing sector (Figure 17.2).

Led by Bahrain and Kuwait, all the Arab Gulf countries have managed to improve the gender balance in science and engineering (Figure 17.2). Kuwait has even achieved gender parity, placing it on a par with Tunisia for this indicator. In the Gulf, the most prestigious positions in science and engineering, nevertheless, remain dominated by men.

Research spending up in some countries

A common justification for low expenditure on research and development (R&D) by oil-rent economies is that their high GDP ensures adequate spending on research activity. However, this argument is countered by the fact that challenges facing the region, such as water and food security, economic diversification, social cohesion and the disruptive transformations engendered by the Fourth Industrial Revolution, require far more support for R&D than is currently being allocated.

Some Arab countries have tacitly acknowledged this necessity by boosting their own research intensity in recent years. This list is topped by the UAE (Figure 17.3), which devoted 0.69% of GDP to R&D in 2012 and 1.30% in 2018.

Egypt's research intensity has reached a plateau of 0.72% of GDP (Figure 17.3) since rising from 0.51% of GDP in 2012. The collection and analysis of data have benefited from the creation of the Egyptian Science, Technology and Innovation Observatory. Hosted by the Academy of Scientific Research and Technology, the observatory has published regular statistical reports on R&D since its inception in 2014. The observatory does not survey the business enterprise sector regularly, however.

Only in Oman and Tunisia does the business enterprise sector make a significant contribution to research expenditure, although data are missing for most countries (Figure 17.3).

In March 2018, Sudan established its own National Observatory of Science, Technology and Innovation, with support from the Egyptian observatory (UNESCO, 2018).

Sudan plans to raise its own gross domestic expenditure on R&D (GERD) to 2% of GDP by 2030 and Morocco's Higher Council for Education, Training and Scientific Research has recommended doubling the country's GERD/GDP ratio to 1.5% of GDP by 2025 (Zou'bi *et al.*, 2015).

In 2009, the Higher Council of Jordan launched the process of establishing its own observatory of STI, in collaboration with UNESCWA. As of September 2020, the observatory had yet to eventuate.

An Innovation Scoreboard for Arab countries

Although most countries recognize the importance of innovation to build a knowledge economy, they are being held back by a lack of available data. To remedy this, several countries have taken steps, with multilateral partners, to establish an Innovation Scoreboard for the Arab region, tailored to local needs.

As of May 2016, 41 indicators had been grouped into two categories: input and enablers and output and impact. The scoreboard includes 'back-up' indicators to account for a lack of available data.[12] Although a framework was established for the scoreboard, there has since been little progress.

Egypt and Saudi Arabia publishing half of Arab papers

Of the nearly 96 000 scientific publications produced by the Arab world in 2019, about half involved authors from Egypt and Saudi Arabia in equal proportions (see Table 1.3).

In 2016, Egypt was responsible for around 48% of research papers published in the Arab world, according to the Elsevier SCImago Journal Rank database. This may explain the rapid growth in scientific output in Egypt since 2011. The surge observed in Saudi Arabia and the UAE is no doubt largely attributable to the recruitment of world-class researchers in recent years.

Arab journals earn an average quality rating of 8.308, according to the Hirsch index. This is on a par with journals from Eastern Europe (8.740) but trails those from Western Europe (28.54) and North America (23.28).

Half of Arab journals specialize in medicine and health care. Of note is that only four out of 141 Arab journals are dedicated to agricultural and veterinary sciences, in a region where agricultural activity constitutes a key source of employment opportunities for much of the population.

A greater research focus on sustainability

According to a UNESCO study of 56 research topics related to the Sustainable Development Goals, publications from the region have grown since 2011 on topics such as photovoltaics, smart-grid technology and climate-ready crops (Figure 17.4; see chapter 2).

The European Union (EU) remains a close scientific partner for many Arab countries. Over 2017–2018, Algeria, Egypt, Jordan, Lebanon, Morocco and Tunisia signed agreements to participate in the EU's Partnership for Research and Innovation in the Mediterranean Area (PRIMA) programme running to 2028.[13] This programme is exploring new approaches to research and innovation in sustainable agriculture production and water availability. The EU is allocating € 220 million to the programme, with participating countries providing a further € 52 million.

This project has been hailed as a major advance in science diplomacy. Six calls for research proposals were launched in February 2020 on water management, the agrifood value chain, the water–ecosystem–food nexus and farming systems.

A wider range of scientific partnerships

Although Western countries remain close partners, over half of Arab countries counted Saudi Arabia and one-quarter Egypt among their closest collaborators over the 2017–2019 period. Kuwait, Libya and Yemen even counted both countries among their top five collaborators (Figure 17.4).

There is a growing diversity of scientific partners. Iraq now counts Iran among its closest collaborators, for instance, and India, Malaysia and Pakistan figure among the top five collaborators for other Arab countries. Chinese scientists have become close collaborators for their peers in Egypt, Qatar, Saudi Arabia, Sudan, Syria and the UAE.

There is potential for greater intra-Arab collaboration, since half of all journals published in the Arab world are open access, compared with just 11% in Western Europe and 5% in North America, according to the Elsevier SCImago Journal Rank database in 2019.

Between 2015 and 2019, Saudi Arabia registered the greatest increase in the number of granted patents, followed by Egypt, the UAE and Qatar. The rest of the region actually recorded negative growth over the same period (Figure 17.5).

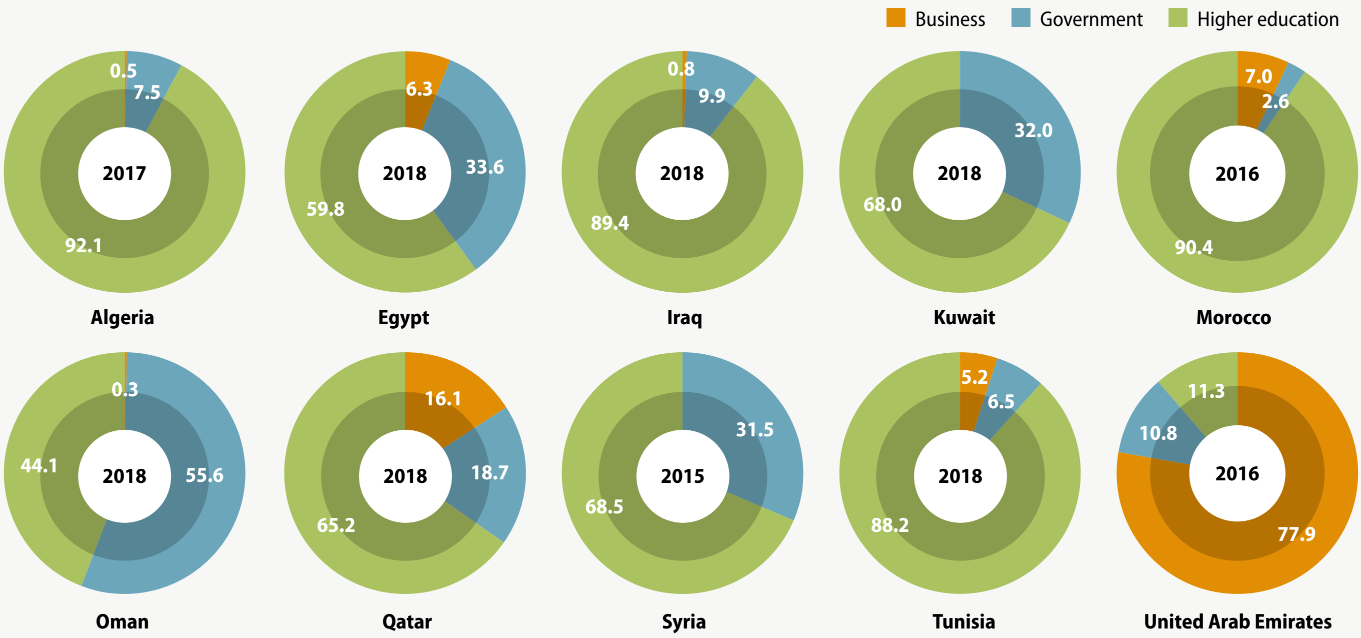
Figure 17.2: **Trends in human resources in the Arab States**

Distribution of students in the Arab States by programme, 2018 or closest year (%)

	Agriculture	Engineering	ICTs	Health	Natural sciences & maths	Social sciences	Business, admin. & law	Arts & humanities
Algeria	1	19	2	6	11	16	19	25
Bahrain	0	13	5	8	3	6	43	17
Lebanon	2	15	4	12	9	5	28	25
Mauritania (2017)	1	3	2	5	21	7	32	29
Palestine	1	10	4	14	4	8	30	29
Qatar		13	4	7	5	12	26	33
Sudan (2015)	3	11		12	15	22		34
Tunisia (2017)	2	20	12	10	7	7	23	20

Note: Data are unavailable for some countries and the share of unspecified students is over 5% for others. In the table, the non-allocated shares concern Algeria (2%), Bahrain (5%), Lebanon (1%), Palestine (2%), Sudan (4%) and Tunisia (2%).

Researchers (FTE) by sector of employment in the Arab States, 2018 or closest year (%)



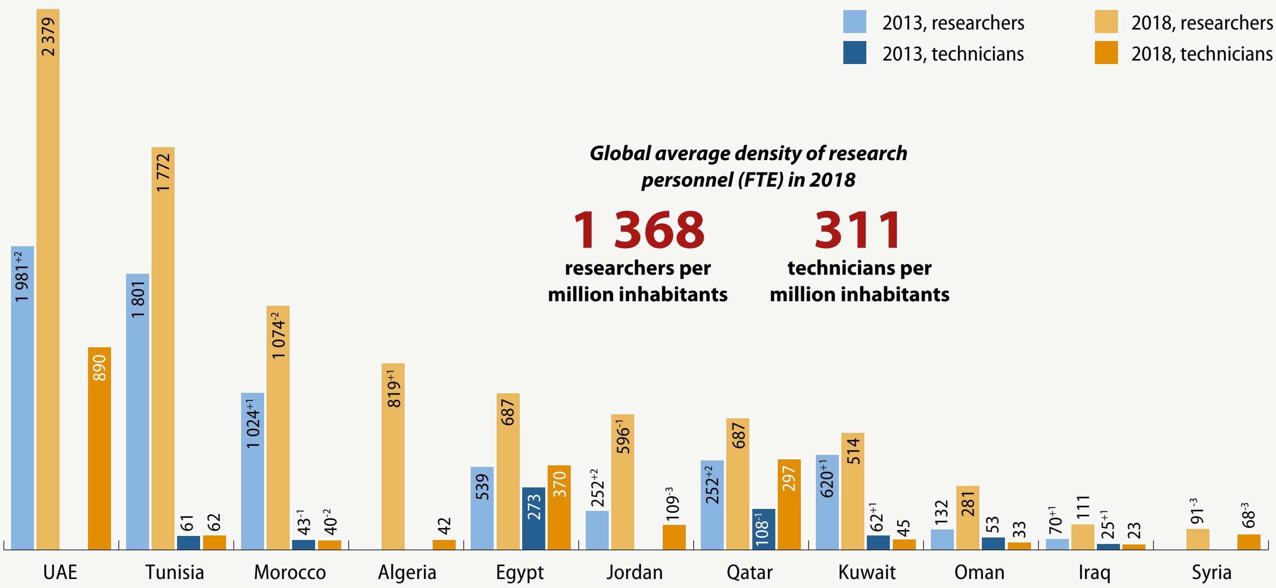
COUNTRY PROFILES

ALGERIA

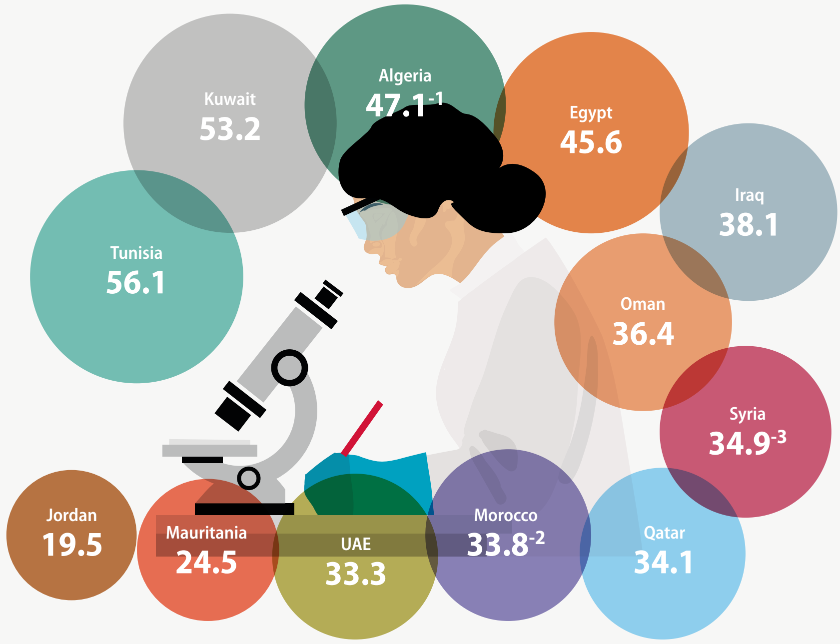
Algeria is the world's sixth-largest gas exporter. Hydrocarbons were responsible for 19.7% of GDP in 2017 (AfDB, 2020) and an estimated 40% of the public budget in 2018 (Abouzzohour *et al.*, 2020). With oil prices on the decline since 2014, the government attempted to cushion the impact by drawing on its oil stabilization fund to support public finances but this fund ran dry in early 2017 (OBG, 2018a). Protests taking place nationwide over 2019–2020 led to the election of a new president in December 2019.

In 2015, the government instituted a five-year investment plan which identified the following priority industries: manufacturing; iron and steel; mechanical and metals;

Researchers and technicians (FTE) per million inhabitants in the Arab States, 2013 and 2018



Share of female researchers (HC) in the Arab States, 2018 or closest year (%)



Expenditure on higher education as a share of GDP

1.28% in Oman, 2016

0.82% in Jordan, 2018

+n/-n: data refer to *n* years before or after reference year

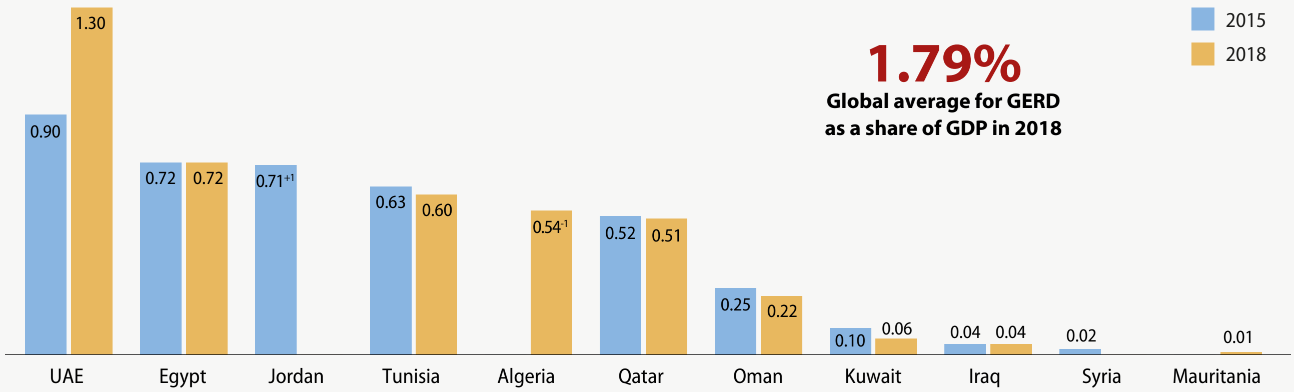
Note: Data are unavailable for some countries.

Source: UNESCO Institute for Statistics

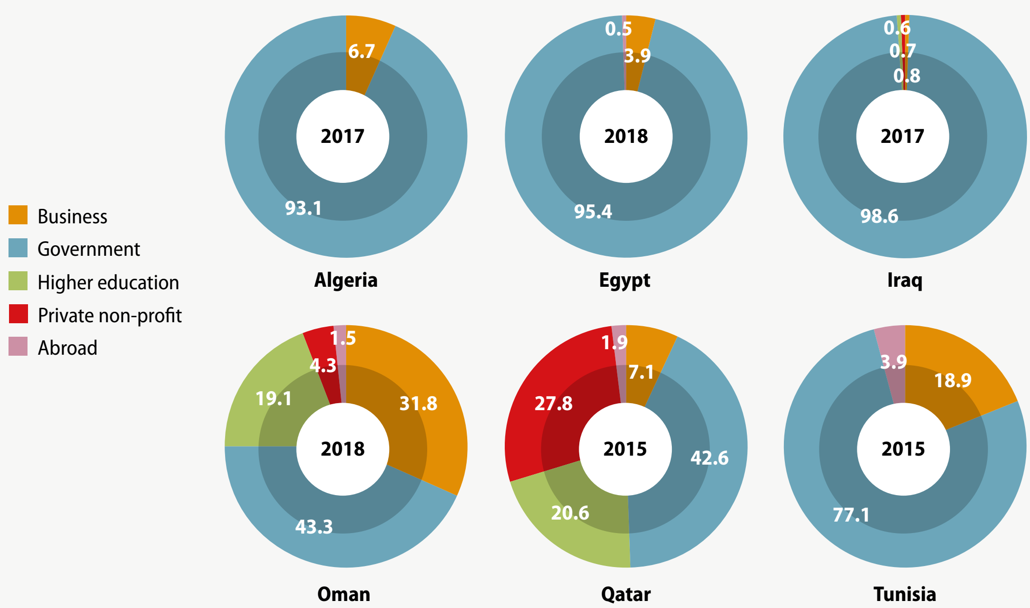
Chapter 17

Figure 17.3: **Trends in research expenditure in the Arab States**

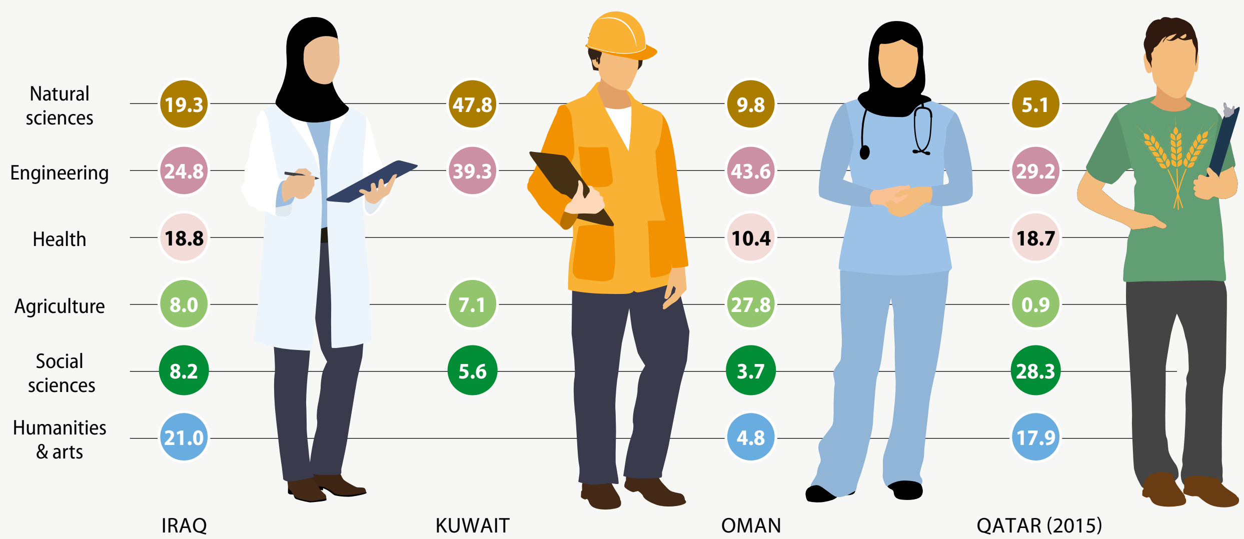
GERD as a share of GDP in the Arab States, 2015 and 2018 (%)



GERD by source of funds in the Arab States, 2018 or closest year (%)



GERD by field of science in the Arab States, 2017 or closest year (%)



+n/-n: data refer to *n* years before or after reference year

Source: UNESCO Institute for Statistics

electrical and electronics; agribusiness; chemicals; plastics and pharmaceuticals; and construction materials (OBG, 2018a).

The non-oil economy grew by 2–3% each year over 2016–2019 (World Bank, 2020a). Agro-industry is Algeria's most developed industrial segment, accounting for 38% of industrial value added in 2017. In the same year, 716 new agro-industrial investment projects were established. Cement is one of the fastest-growing segments; in 2018, output surpassed domestic demand for the first time (OBG, 2018a).

Research projects initiated by foreign firms and involving local universities are emerging in both the agrifood and cement industries. For instance, since 2013, the R&D unit of the giant cement producer Lafarge has worked with local development laboratories (*centres de développement locaux*) in various parts of the country to develop new product applications, construction systems and building methods, using local building materials. These projects tend to hire local researchers.

An orientation law for SMEs

Algeria has begun implementing a new innovation strategy built on the following pillars: placing firms at the centre of innovation; supporting innovative SMEs; integrating science and innovation policies into government decision-making; and fostering stronger linkages between firms and the scientific research community.

In January 2017, parliament adopted the orientation law for the development of SMEs. It aims to boost public and private R&D through incentives and financial support. The decree of application led to the establishment of the Agency for the Development of SMEs and Promotion of Innovation in July 2018, with a mandate to support business incubation, foster technology transfer and assist SMEs in reaching foreign markets (OBG, 2018a). The law also led to the establishment of several Innovation and Technology Transfer Centres, to promote synergies between research and industry.

Towards the goal of establishing 1 million new companies over 2015–2019, set out in the government's investment plan covering the same period, parliament passed a law (#17-02) in June 2017 to support new businesses, promote innovation and improve SMEs' export capacity and competitiveness. For instance, under the law, subcontracting companies are eligible for exemptions from value-added and profit tax. The law also lays the groundwork for establishing two funds to support SMEs, the SME Credit Guarantee Fund and a seed capital fund (OBG, 2018a).

A new Delegate Ministry for Start-ups and the Knowledge Economy has been established under the authority of the Office of the Prime Minister. This delegate ministry has overseen the creation of an investment fund to finance start-ups, as well as a High Council of Innovation to support strategic orientation. It has also co-ordinated the elaboration of a legal framework to define and label concepts relating to start-ups, incubators and the knowledge economy and has allocated dedicated spaces for business incubation, as well as 25 planned FabLabs.

A new Council of Scientific and Technological Research

The Directorate-General for Scientific Research and Technological Development, which operates under the authority of the Minister for Scientific Research, defines and funds the five-year National Priority Research Programme. The most recent of these covers the 2018–2023 period (Figure 17.6). It identifies the following priority research areas, which were first outlined in an interministerial decision of 27 June 2016:[14]

- renewable energy;
- biotechnology;
- materials science; and
- environmental sciences.

April 2020 saw the inauguration of the new Council of Scientific and Technological Research, which is to operate under the direct authority of the prime minister; it comprises 45 members appointed by the president. The council will determine major directions for science policy, evaluate existing policies and help integrate STI into the country's socio-economic development. It is also tasked with evaluating the results of R&D (APS, 2020).

In February 2020, the new *Government Action Plan* was submitted to parliament; it targets financial reform, an overhaul of the tax system, training programmes to meet labour market needs and the development of capacities in renewable energy, among other things. The plan also acknowledges the need to develop capacities in science and technology, in order to build a knowledge economy.

The *Action Plan* sets the target of developing capacity in renewables to produce 15 GW of electricity by 2035. This lowers the bar slightly from the level set by the *Renewable Energy and Energy Efficiency Development Plan* (2015), which had sought to raise the share of renewables in total power generation to 27% by 2030, through 22 GW of additional capacity (Petrova, 2020).

The government announced plans in May 2020 to develop 4 GW of solar photovoltaic capacity by 2024, under the Tafouk 1 project. This project will see the construction of solar plants in more than ten provinces (wilayas), covering a total area of around 6 400 ha, for a total cost of US$ 3.2–3.6 billion (Petrova, 2020). Algeria currently benefits from some 20 solar power plants installed in the Sahara and highlands.

Algeria's Centre for the Development of Renewable Energies conducts R&D programmes on energetic systems using solar, geothermal and biomass energy. Half of the patents filed by research centres are made by this centre.

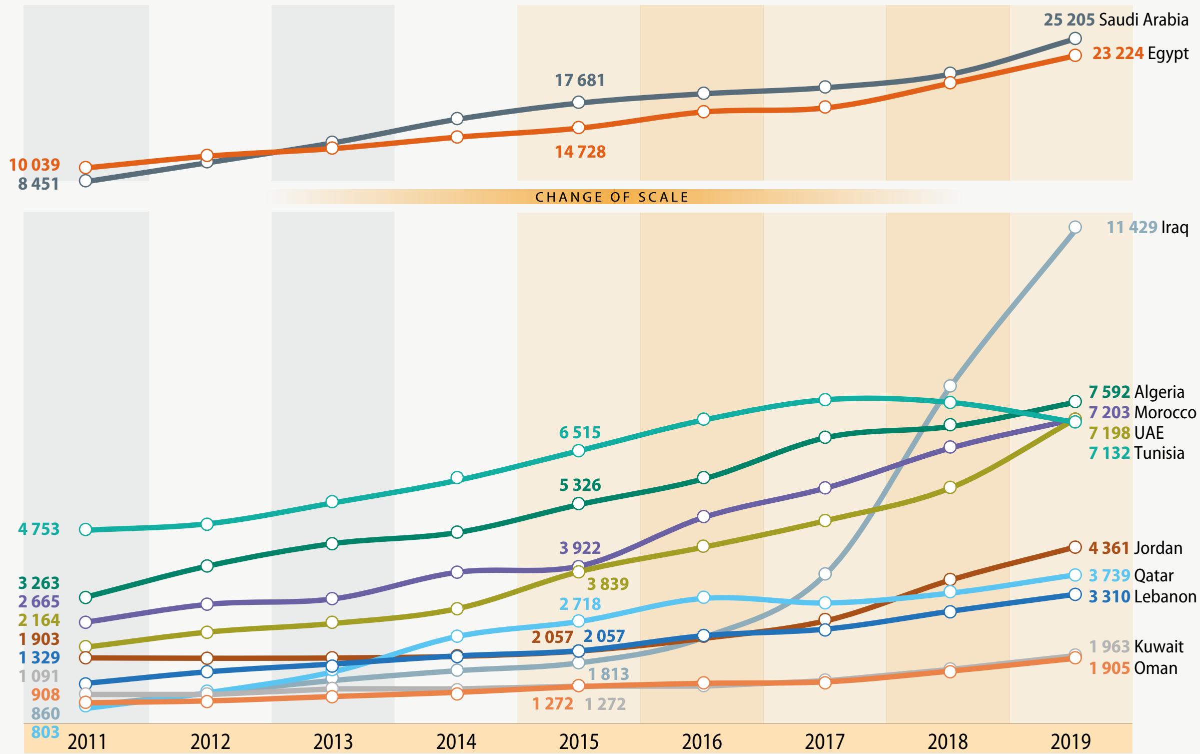
E-payment terminals made compulsory

The *e-Algérie* (2013) strategy targets the digital economy. It has 13 major thrusts, including those of accelerating the use of digital technologies in public administration and the business sector, developing the digital economy, strengthening telecommunications infrastructure and fostering research and innovation.

Several legislative reforms have been designed to support the digital economy. A law adopted in February 2015 (#4) fixed the rules for electronic signatures and certification. This was followed, in June 2018, by a law (#4) on postal and electronic communications which makes it mandatory for

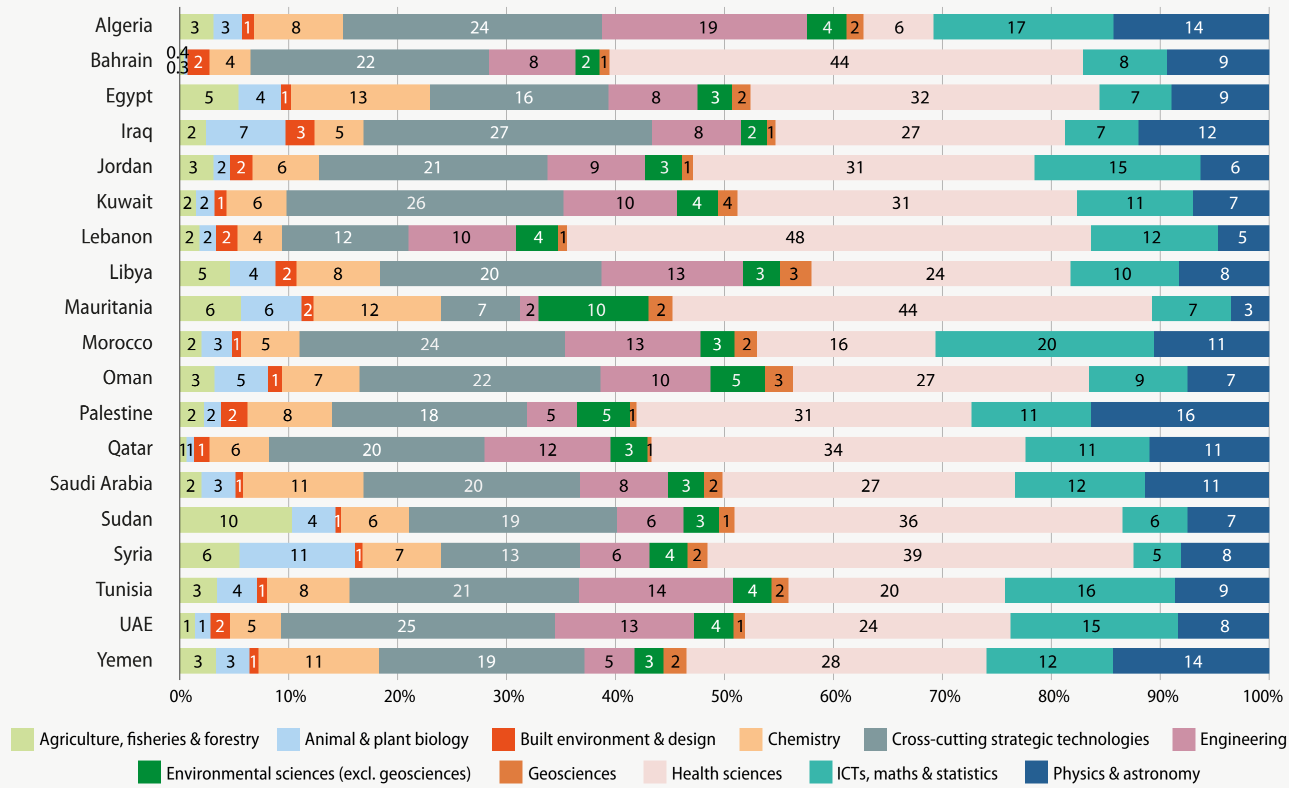
Figure 17.4: **Trends in scientific publishing in the Arab States**

Volume of scientific publications in the Arab States, 2011–2019



	2011	2012	2013	2014	2015	2016	2017	2018	2019
Sudan	503	469	586	531	568	756	719	898	894
Palestine	340	341	396	447	418	429	640	689	812
Bahrain	280	259	360	354	312	377	421	542	683
Yemen	234	254	291	311	281	322	408	478	614
Syria	444	503	433	404	395	398	397	421	510
Libya	241	293	381	395	405	355	405	434	477
Mauritania	31	31	37	38	37	52	45	60	74

Scientific publications in the Arab States by broad field of science, 2017–2019 (%)



Volume of scientific publications from Arab States

95 817
in 2019

58 447
in 2015

64%
Cumulative growth rate for Arab publications, 2015–2019

1.06
Average of relative citations in the Arab States, 2014–2016; the G20 average is 1.02

54%
Average share of papers with foreign co-authors in the Arab States, 2017–2019; the G20 average is 25%

How has output on SDG-related topics evolved since 2012?

Arab countries are publishing more on the following topics than would be expected, relative to global averages: desalination; wind-turbine technologies; water harvesting; photovoltaics; wastewater treatment, recycling and re-use; human resistance to antibiotics; sustainable withdrawal and supply of freshwater; eco-industrial waste management; eco-construction materials; smart-grid technologies; and national integrated water resources management.

The region published nearly four times the global average intensity on desalination, with output surging from 1 468 (2012–2015) to 2 218 (2016–2019) publications. Qatar's output doubled from 90 to 202 publications and Egypt's output rose from 270 to 462 publications. Saudi Arabia contributed about 30% of regional output on this topic.

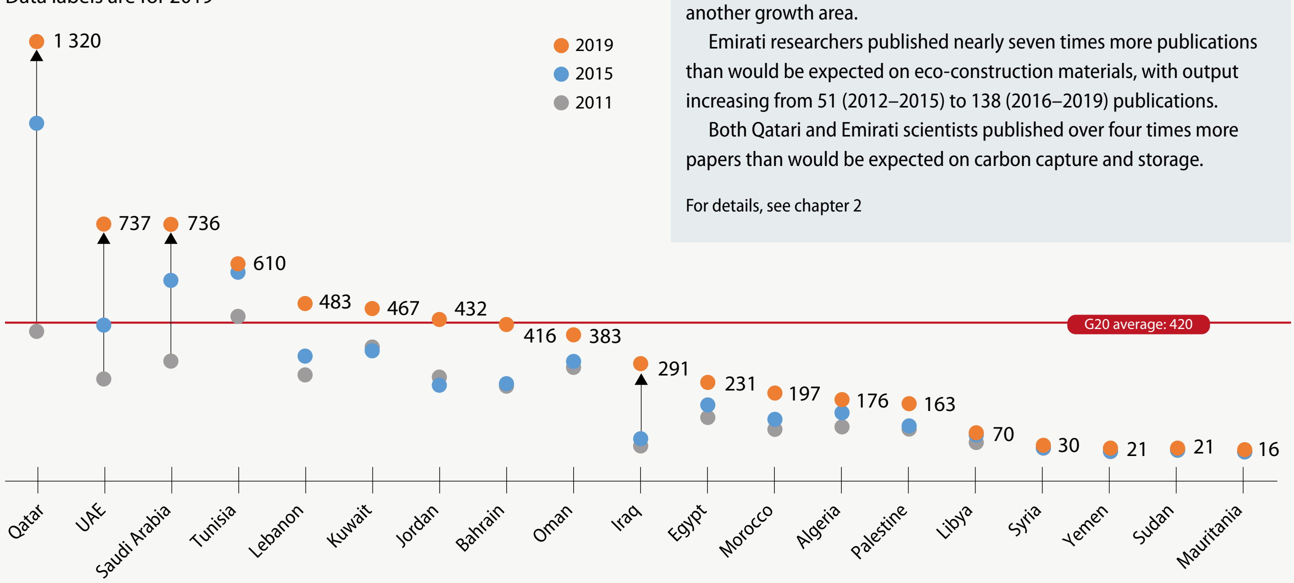
Regional publications on photovoltaics doubled from 2 208 to 4 537 over the same period. Regional output doubled on other energy-related topics, such as sustainable transportation, smart-grid technologies, battery efficiency and biofuels and biomass. Climate-ready crops were another growth area.

Emirati researchers published nearly seven times more publications than would be expected on eco-construction materials, with output increasing from 51 (2012–2015) to 138 (2016–2019) publications.

Both Qatari and Emirati scientists published over four times more papers than would be expected on carbon capture and storage.

For details, see chapter 2

Scientific publications per million inhabitants in the Arab States, 2011, 2015 and 2019
Data labels are for 2019



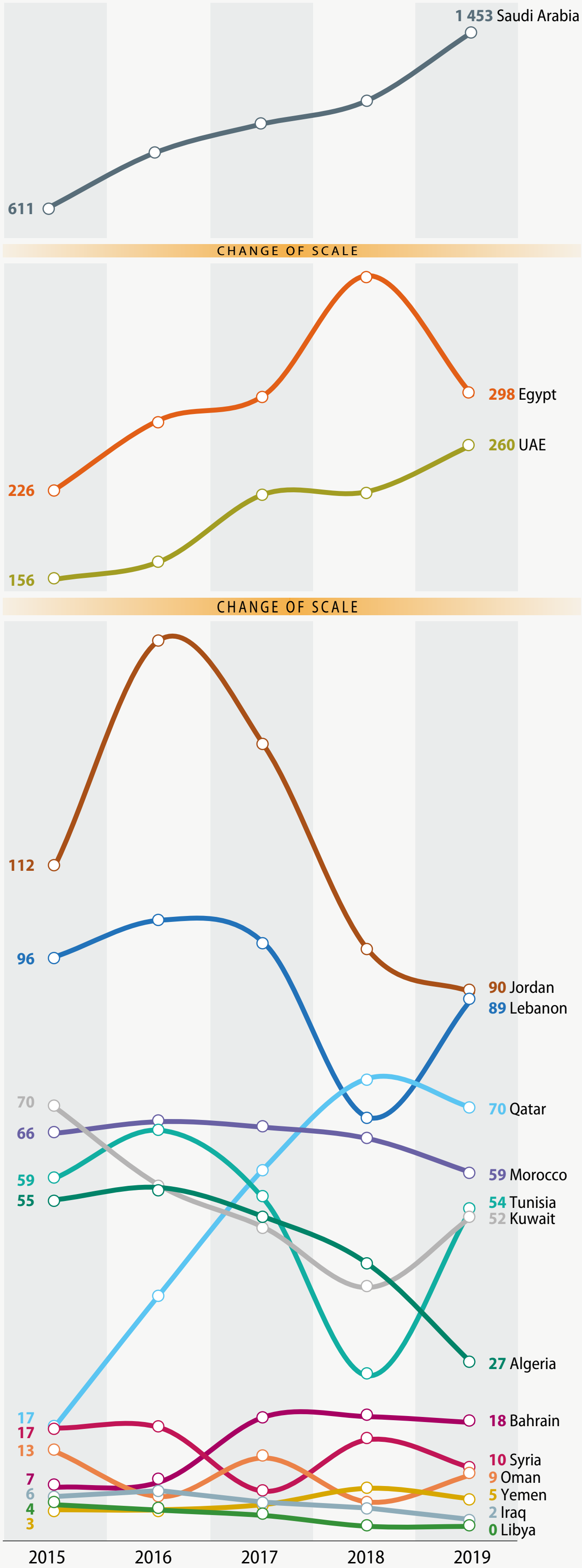
Top five partners for scientific co-authorship in the Arab States, 2017–2019 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Algeria	France (5 153)	Saudi Arabia (980)	Spain (870)	Italy (678)	USA (578)
Bahrain	Saudi Arabia (241)	Egypt (171)	USA (169)	UK (123)	India (119)
Egypt	Saudi Arabia (11 523)	USA (6 151)	Germany (3 193)	China (3 074)	UK (2 865)
Iraq	Malaysia (2 116)	UK (1 812)	USA (1 174)	Australia (785)	Iran (717)
Jordan	USA (1 549)	Saudi Arabia (1 025)	UK (664)	UAE (617)	Germany (539)
Kuwait	USA (890)	Egypt (465)	Saudi Arabia (435)	UK (407)	Iran (273)
Lebanon	France (2 476)	USA (1 773)	UK (574)	Canada (519)	Italy (496)
Libya	UK (236)	Malaysia (216)	Egypt (185)	USA (123)	Saudi Arabia (100)
Mauritania	France (68)	Senegal (51)	Morocco (37)	Tunisia (25)	UK (24)
Morocco	France (3 388)	Spain (1 133)	USA (1 059)	Italy (756)	Canada (746)
Oman	India (733)	UK (473)	Pakistan (444)	USA (438)	Saudi Arabia (410)
Palestine	USA (329)	Turkey (285)	Malaysia (270)	UK (265)	Germany (256)
Qatar	USA (2 895)	UK (1 627)	China (1 195)	Australia (828)	Italy (822)
Saudi Arabia	Egypt (11 523)	USA (9 023)	China (6 118)	India (5 856)	Pakistan (5 691)
Sudan	Saudi Arabia (609)	China (454)	UK (236)	Malaysia (216)	USA (215)
Syria	USA (105)	France (85)	Germany (77)	UK (72)	China (63)
Tunisia	France (5 701)	Saudi Arabia (2 358)	Spain (1 074)	Italy (912)	USA (658)
UAE	USA (3 451)	UK (1 782)	Canada (1 421)	Saudi Arabia (1 253)	China (1 161)
Yemen	Saudi Arabia (505)	Egypt (410)	Malaysia (353)	India (132)	USA (113)

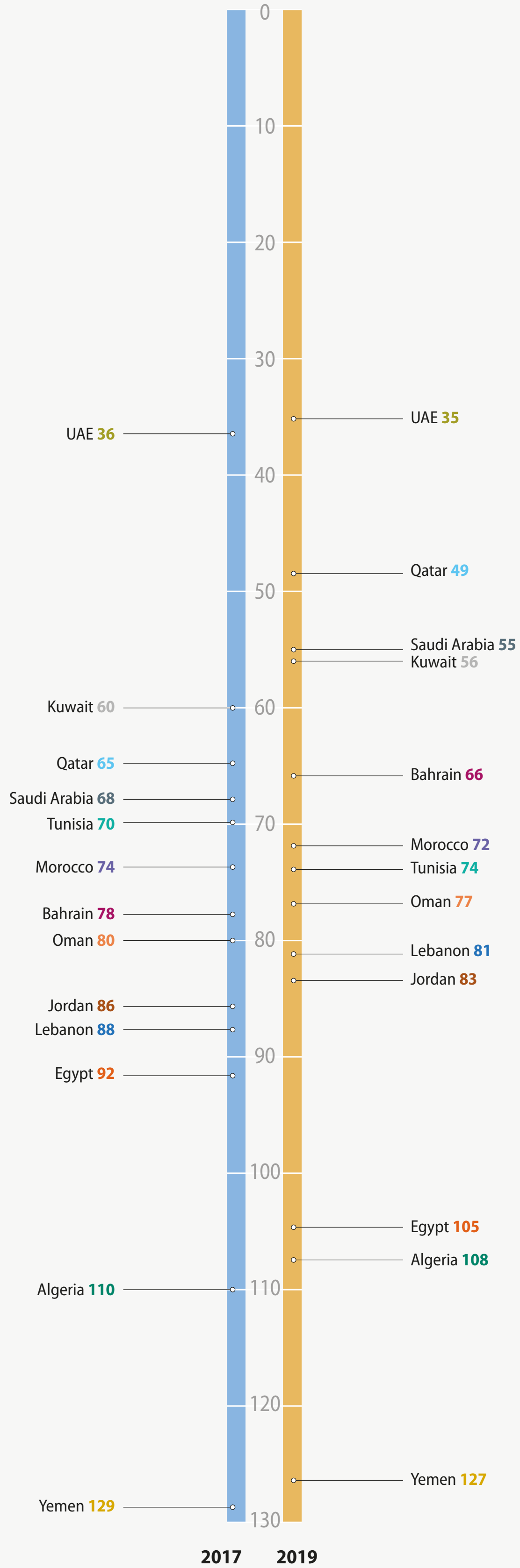
Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

Figure 17.5: **Trends in innovation in the Arab States**

Number of IP5 patents granted to Arab inventors, 2015–2019



Global Innovation Index rankings of the Arab States, 2017 and 2019



Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China. The Global Innovation Index is a composite index produced by Cornell University (USA), INSEAD graduate business school (France) and the World Intellectual Property Organization.

Source: PATSTAT; data treatment by Science-Metrix; Global Innovation Index © Cornell INSEAD WIPO shop-owners to have electronic payment terminals, or face a financial penalty (OBG, 2018a). This resulted in a 52% increase in the number of digital transactions taking place in 2019 over the previous year.

These reforms helped Algeria to move up seven places in the World Economic Forum's 2019 *Global Competitiveness Report* over the previous year. Despite these advances, much of the population still has limited access to financial payment systems, as a result of overregulation in the banking and telecommunications sectors. E-commerce is also yet to take off (Arezki, 2019).

The year 2016 saw the introduction of 4G to the Algerian market; by the following year, there were 9.9 million subscribers to this technology (OBG, 2018a).

To improve telecommunications, Algeria launched the domestically made satellite Alcomsat 1 in December 2017, with support from China. Algeria now has six satellites in orbit, tying with Nigeria and South Africa, according to the Algerian Space Agency.

Algiers to be a Smart City by 2035

The Algiers Smart City project was launched in mid-2017, with the goal of transforming Algiers into a 'completely intelligent city' by 2035. According to Mohamed Taouche, head of the project, the aim is to promote synergies and co-operation in technology with international actors, provide support for start-ups and develop the 'technological ecosystem' (Ghezlaoui, 2019).

By February 2018, the project had received over 150 proposals from stakeholders in 15 countries, including corporations and start-ups, to launch projects within the Smart City framework. In April of the same year, the project reached a milestone by launching the Experimental Laboratory and the Technology Innovation Hub. The laboratory provides an environment in which to test chosen proposals before launching at scale, whereas the innovation hub offers mentoring and serves as a physical space for international and local partners to meet (OBG, 2018a).

The Hassi Messaoud smart city is presently under construction. Expected to become a 'model ecological city' serving a population of 80 000, it will count a green belt, wastewater treatment plant and technical landfill centre, according to the Minister of Environment and Renewable Energies in late 2018.[15]

Investment in technoparks

The National Agency for the Promotion and Development of Technoparks (est. 2004) secured a loan of DZD 15 billion (*ca* US$ 116 million) in 2018 to invest in its technoparks in Oran, Algiers, Annaba and Ouargla, to be repaid by 2030. Algiers' Sidi Abdellah technopark is to receive more than one-third of this loan, part of which will be invested in the construction of a second data centre (OBG, 2018a).

Innovation hubs have also emerged spontaneously in certain territories, such as Sétif and Bordj Bou-Arreridj. They specialize in information and communication technologies (ICTs) and electronics but remain small-scale (Djeflat, 2017).

BAHRAIN

A vibrant fintech ecosystem

Bahrain's *Government Action Plan (2015–2018)* identified six key focus areas for sustainable development:

- cities, housing and urban development;
- environment;
- population and social issues;
- education, scientific research and productive work;
- economic diversification and sustainability; and
- peace and security.

This mid-term plan builds upon the *Bahraini Economic Vision 2030* (2008), which had identified the financial sector as the country's main non-oil growth engine, to be supported by high-potential sectors such as tourism, business services, manufacturing and logistics.

The financial sector accounted for 17% of GDP in 2018. With favourable regimes for taxes, custom duties and utility costs on offer, a vibrant fintech ecosystem has emerged. Over 2017–2018, the Central Bank of Bahrain introduced the country's first regulatory sandbox, a 'light-touch regulatory environment' in which to test innovation in fintech, as well as a FinTech and Innovation Unit which is tasked with creating a supportive regulatory environment for financial services (Bahrain FinTech Bay, 2018).

Established in February 2018, the Bahrain FinTech Bay purports to be the Arab States' largest fintech hub. It serves to accelerate early-stage Bahraini fintech companies and entice foreign companies from the same sector to establish regional head offices in the country (Bahrain FinTech Bay, 2018).

A surge in start-ups

The number of Bahraini start-ups grew by 46% over 2015–2018 (BEDB, 2018). The launch of StartUp Bahrain, a platform bringing together start-ups, corporations, investors and others, dates from 2016.

Tamkeen is the country's primary labour fund. Over 2018–2020, it supported 1 500 budding entrepreneurs and 4 000 institutions with an annual budget of BHD 60 million (*ca* US$ 160 million).

Expansion of cloud services

In 2019, Bahrain expanded its digital infrastructure with the launch of the region's first Amazon Web Services data centre, a cloud service platform that offers computer power and database storage, among other things. This follows the government's *Cloud First* strategy (2017), which commits state entities to adopting cloud technology with the aim of having 1 500 government employees ready to use the cloud by 2019 (OBG, 2019). Digital infrastructure has paved the way to a burgeoning digital economy, which contributed an estimated 8% to GDP in 2018 (McKinsey, 2018).

Bahrain has one of the Arab States' most advanced telecommunications sectors.[16] The fourth *National Telecommunications Plan* (2016–2019) foresees the creation of

Figure 17.6: **STI policies in the Arab States**

TUNISIA

Explicit STI policy
Strategic Plan for Scientific Research 2017–2022 (2017)

Other related policies
- *National Priority Research and Innovation Programmes* (2018–2020)
- *AI Roadmap* (2019)

Ministry and/or other body responsible for STI
- Ministry of Higher Education and Scientific Research

LIBYA

Explicit STI policy
National Strategy for Science, Technology and Innovation (2014)

Other related policies
- *Libya 2020 Vision* (2014)

Ministry and/or other body responsible for STI
- National Planning Council

LEBANON

Explicit STI policy
Science, Technology and Innovation Policy (2006)

Other related policies
- *Charter for Research Ethics* (2016)

Ministry and/or other body responsible for STI
- National Centre for Scientific Research

PALESTINE

Explicit STI policy
Palestinian STI Policy Framework Document (2016)

Other related policies
- *National Policy Agenda 2017–2022*
- Open Data Policy (draft)
- National Policy for Digital Transformation (draft)
- Policy Agenda to Support the Palestine ICT Start-up Ecosystem (draft)

Ministry and/or other body responsible for STI
- Palestinian Ministry of Education and Higher Education

MOROCCO

Explicit STI policy
National Strategy for the Development of Scientific Research towards 2025 (2015)

Other related policies
- *Digital Morocco 2020* (2016)

Ministry and/or other body responsible for STI
- Ministry of National Education, Vocational Training, Higher Education and Scientific Research

MAURITANIA

Explicit STI policy
(No explicit STI policy)

Other related policies
- *National Strategy for Accelerated Growth and Shared Prosperity for the period 2016–2030*

Ministry and/or other body responsible for STI
- Ministry of Higher Education, Scientific Research and Information and Communication Technologies

ALGERIA

Explicit STI policy
(No explicit STI policy)

Other related policies
- *National Priority Research Programme 2018–2023* (2018)
- *Renewable Energy and Energy Efficiency Development Plan* (2015)
- *e-Algérie* (2013)

Ministry and/or other body responsible for STI
- Ministry of Higher Education and Scientific Research

EGYPT

Explicit STI policy
National Strategy for Science, Technology and Innovation 2030 (2019)

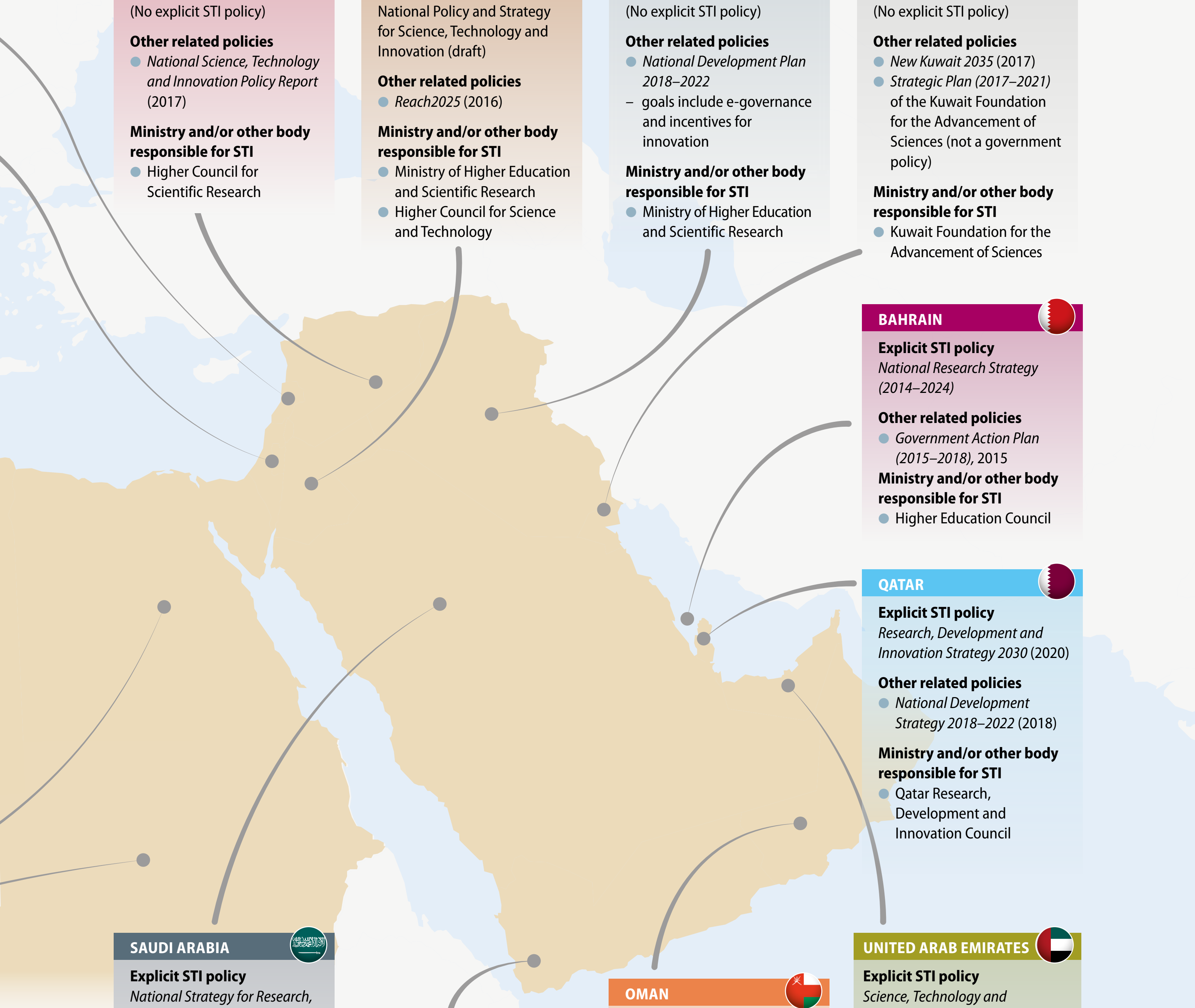
Other related policies
- *Egypt Vision 2030* (2016)

Ministry and/or other body responsible for STI
- Ministry of Higher Education and Scientific Research

SUDAN

Explicit STI policy
Science, Technology and Innovation Policy (2017)

Ministry and/or other body responsible for STI
- Ministry of Higher Education and Scientific Research
- National Observatory of Science, Technology and Innovation (est. 2018)



SYRIA

Explicit STI policy
(No explicit STI policy)

Other related policies
- *National Science, Technology and Innovation Policy Report* (2017)

Ministry and/or other body responsible for STI
- Higher Council for Scientific Research

JORDAN

Explicit STI policy
National Policy and Strategy for Science, Technology and Innovation (draft)

Other related policies
- *Reach2025* (2016)

Ministry and/or other body responsible for STI
- Ministry of Higher Education and Scientific Research
- Higher Council for Science and Technology

IRAQ

Explicit STI policy
(No explicit STI policy)

Other related policies
- *National Development Plan 2018–2022*
  – goals include e-governance and incentives for innovation

Ministry and/or other body responsible for STI
- Ministry of Higher Education and Scientific Research

KUWAIT

Explicit STI policy
(No explicit STI policy)

Other related policies
- *New Kuwait 2035* (2017)
- *Strategic Plan (2017–2021)* of the Kuwait Foundation for the Advancement of Sciences (not a government policy)

Ministry and/or other body responsible for STI
- Kuwait Foundation for the Advancement of Sciences

BAHRAIN

Explicit STI policy
National Research Strategy (2014–2024)

Other related policies
- *Government Action Plan (2015–2018)*, 2015

Ministry and/or other body responsible for STI
- Higher Education Council

QATAR

Explicit STI policy
Research, Development and Innovation Strategy 2030 (2020)

Other related policies
- *National Development Strategy 2018–2022* (2018)

Ministry and/or other body responsible for STI
- Qatar Research, Development and Innovation Council

SAUDI ARABIA

Explicit STI policy
National Strategy for Research, Development and Innovation (2019)

Other related policies
- *ICT Strategy 2019–2023* (2019)
- *Strategy for Data & AI* (October 2020)
- *National Industrial Strategy to 2030* (2018)

Ministry and/or other body responsible for STI
- King Abdulaziz City for Science and Technology
- Ministry of Education

YEMEN

Explicit STI policy
(No explicit STI policy)

Ministry and/or other body responsible for STI
- Ministry of Higher Education and Scientific Research

OMAN

Explicit STI policy
(No explicit STI policy)

Other related policies
- *National Industrial Strategy 2040* (2018)
- *National Energy Strategy 2040* (2015)
- *Digital Oman Strategy* (2003)

Ministry and/or other body responsible for STI
- Research Council
- Ministry of Technology and Communications

UNITED ARAB EMIRATES

Explicit STI policy
Science, Technology and Innovation Policy (2015)

Other related policies
- *Strategy for the Fourth Industrial Revolution* (2017)
- *United Arab Emirates' Strategy for Artificial Intelligence 2031* (2017)

Ministry and/or other body responsible for STI
- National Science, Technology and Innovation Committee

UN Disclaimer

a National Broadband Network providing all businesses and 95% of residences with ultra-fast broadband. A working group has also been set up to develop and deploy a 5G action plan; it held its first meeting in April 2018 (OBG, 2019).

A strategy to boost research

The *National Research Strategy (2014–2024)* sets five objectives, among which are to strengthen university research capacity, improve integration with international research institutions and address the following national research priorities: financial services; banking and insurance; health services and public health; and ICTs.

Targets include raising GERD to 1% of GDP by 2020 and boosting the number of PhDs and students enrolled in science and engineering.[17]

Between 2015 and 2018, the number of PhD graduates increased from 13 to 32, possibly thanks to the provision of new graduate programmes, which are offered free of charge by public universities. However, the share of graduates overall in natural sciences, mathematics and statistics declined slightly over the same period to 15.6%. In 2019, Bahrain's gross enrolment ratio at tertiary level stood at 55.6%.

EGYPT

Sweeping changes to subsidies

In November 2016, Egypt embarked on a programme of economic reform supported by the International Monetary Fund.

This programme was preceded by a substantial cutback in fuel and electricity subsidies, in line with Egypt's national sustainable development strategy. Energy subsidies outstripped the health budget by a factor of five in 2014, situating these among the highest in the world. One-third benefitted the wealthiest quintile of the population (Arab Rep. Egypt, 2018), perhaps owing to their comparatively higher energy consumption and greater access to subsidized energy products (Breisinger *et al.*, 2019). The share of fuel subsidies in the total government budget fell from 20% to 11% between 2012 and 2017 (Arab Rep. Egypt, 2018).

In parallel, the government reformed the food subsidy system to target beneficiaries better and expanded tax reforms to increase revenue and reduce tax evasion.

Between 2012 and 2016, the overall budget deficit shrank from almost 13% to 10.9% of GDP, even as public investment rose slightly (Arab Rep. Egypt, 2018). Between 2016 and 2019, Egypt had the second-highest average economic growth rate of any Arab country (Figure 17.1).

Seventeen new industrial parks

Egypt has been negotiating trade agreements with regional blocs. In February 2019, the government ratified the African Continental Free Trade Area Agreement. In September 2017, its free trade agreement with the Southern Common Market (Mercosur) entered into force. In 2020, the government was in the process of negotiating a free trade agreement with the Eurasian Economic Union. The government is interested in benefiting from the Russian Federation's experience of establishing industrial zones, in order to replicate the model in Egypt.

Over the 2015–2020 period, the Industrial Development Authority established 17 industrial parks in 15 governorates, at a total cost of nearly EGP 10 billion (*ca* US$ 600 million). The Authority operates under the purview of the Ministry of Trade and Industry (Al-Aees, 2020).

Megaprojects to upgrade infrastructure

In line with *Vision 2030* (2016), the government is implementing at least three dozen national 'megaprojects' to upgrade infrastructure. One is expanding the area of arable land by 18.8% by 2030, through the reclamation of marginal or desert lands. Another added 865 km of roads over 2014–2018. A third, the Golden Triangle project, is exploiting mineral resources in the Upper Egypt area (Arab Rep. Egypt, 2018).

Egypt is partnering with various countries and organizations to finance and implement these projects, including the Russian State Atomic Energy Corporation (Rosatom) for the El-Dabaa Nuclear Power Plant and the Industrial and Commercial Bank of China for the New Administrative Capital. Construction of this city east of Cairo got under way in April 2016. It will initially accommodate seven million people, while hosting governmental agencies and foreign embassies (Embassy of Egypt, 2016).[18]

The government is investing EGP 275 billion (*ca* US$ 17 billion) in the development of the Suez Canal Economic Zone, which it aims to transform into a hub for international commerce. This investment will also be used to build schools and hospitals in the Sinai Peninsula (Embassy of Egypt, 2018).

Economic development hinges on energy sector

For the International Renewable Energy Agency (IRENA, 2018), 'Egypt's economic development hinges on the energy sector'. It considers that Egypt could realistically and cost-effectively supply 53% of its electricity mix from renewables by 2030. Egypt has the advantage of hosting the intergovernmental Regional Center for Renewable Energy and Energy Efficiency in Cairo.

As of 2018, total installed electricity capacity from renewable energy sources amounted to 4.8 GW, which breaks down into 2.8 GW from hydropower and the remainder from wind, solar and bio-energy sources (IRENA, 2018).

The second phase of the Benban solar park megaproject was completed in November 2019. The government estimates the cost of the plant at US$ 2.8 billion, with companies from several countries contributing to its construction (Arab Rep. Egypt, 2018).

Egypt signed preliminary contracts with Rosatom in November 2017 for the construction of four reactors for the 4.8 GW El-Dabaa Nuclear Power Plant, which will be the country's first. Construction is set to begin in 2020 with the aim of commissioning the first reactor in 2026.

Greater integration of women in the economy

In February 2016, the government released *Egypt Vision 2030*, the country's first sustainable development strategy, which is to serve as the framework for all sectoral policies through to 2030. The vision is for a competitive and diversified knowledge economy, characterized by justice and social integration, with a balanced natural ecosystem.

One aim is to integrate women better in the economy. Following implementation of the Egyptian Financial Inclusion Programme, the share of women with bank accounts rose from 9% in 2015 to 27% in 2017, surpassing the 2030 target of 18% set by the *National Strategy for the Empowerment of Egyptian Women 2030* (2017) [Arab Rep. Egypt, 2018].

The Central Bank of Egypt has outlined plans to promote gender-inclusive finance. As of early 2020, the bank is working towards a unified definition for women-led businesses, a gender-disaggregated database to measure trends in financial inclusion and the provision of further incentives to banks to lend to microfinance institutions (Abulnaga, 2020).

Cashless payments are expected to take off in Egypt, with the approval of Law No. 18 of 2019, which mandates the use of cashless payments by public and private entities. For instance, the law obliges public authorities and entities to pay salaries, financial dues and dividends through cashless means.

A strategy to create an enabling environment for STI

In 2019, the government released the *National Strategy for Science, Technology and Innovation 2030.* Its stated mission is to create an enabling environment for STI and 'an atmosphere of excellence-based scientific competition', so as to contribute to economic growth and sustainable development.

The strategy points to a number of weaknesses in the research system, which include poor economic returns on scientific research; a lack of co-ordination between scientific institutions, which leads to overlap of research areas; brain drain; and a reluctance in the private sector to fund scientific research. The national innovation system is also overregulated, governed by a heavily centralized bureaucracy and confronted with constantly shifting sectoral strategies.

The strategy sets the following seven strategic goals to address these problems and others:

- update laws and regulations relating to scientific research;
- improve the co-ordination of the research system;
- cultivate human resources and improve infrastructure;
- promote quality scientific research;
- support investment in scientific research and foster linkages with industry;
- develop a 'science culture' and link education to scientific research; and
- strengthen and benefit from international co-operation.

To develop human resources, the strategy aims to raise the number of study grants and scholarships available to postgraduate students and researchers, as well as to introduce training courses and workshops.

To improve linkages with industry, the strategy envisions new financing programmes based on public–private partnerships.

In the area of international co-operation, the strategy aims to establish a permanent representation office for STI with the European Union and African Union.

In 2018, the president signed the Law of Incentives for Science, Technology and Innovation (#23); it provides a legal framework for public universities and research institutions which establish start-ups to commercialize their research.

Most research activity takes place in state-run universities and research centres supervised by the Ministry of Higher Education and Scientific Research. Egypt hosts 219 research centres, the largest number in the region; these operate under the auspices of various ministries. Some specialized research centres are being reorganized under the umbrella of the Ministry of Scientific Research's Supreme Council of Scientific Research Centres and Institutes, to ensure that they target national priorities and harmonize their activities more effectively.

Since the Zewail City of Science and Technology was established in 2012, staff scientists have published 1 623 papers in international journals. Most of these papers have been in the physical sciences.

IRAQ

Foundations of governance to be strengthened

Decades of tumult have seen economic sanctions, armed conflict and civil strife erode Iraq's educational and science systems. The government's *Voluntary National Review* (2019) of its progress towards the Sustainable Development Goals highlights challenges such as a lack of political stability, ineffective governance and a scarcity of relevant data.

Agriculture and industry have struggled to compete with imported goods, even as high exchange rates for the local currency have made imported components expensive, pushing up production costs.

Non-oil industry was the sector most impacted by conflict and low-oil prices over 2014–2016 but this sector returned to growth in 2017, as a consequence of the improved security situation and reconstruction effort (World Bank, 2018a).

The government has an opportunity to use oil revenue to finance economic reform, one of the main strategic objectives of the *National Development Plan 2018–2022,* along with establishing the foundations of good governance. This plan anticipates a government investment of IQD 132 trillion (*ca* US$ 111 billion) to achieve its targets, which include raising the agriculture sector's share of GDP to 5.2% by 2022, improving the health system and augmenting net enrolment at secondary level to 45%. In 2018, one in three (32%) pupils completed the upper secondary level of schooling.

Comprehensive STI strategy still pending

A 2019 market assessment of the technology sector's businesses in Iraq by the United Nation's International Organization for Migration concluded that website design and telecommunications were relatively developed technology sectors in Iraq, whereas e-commerce, e-banking and digital payments remained underdeveloped (IOM, 2019).

Unrest has continued to impede the efforts of the Ministry of Higher Education and Scientific Research to develop a comprehensive STI strategy (Bizri, 2018). This ministry has proposed establishing a National Council for Scientific Research but this is yet to be implemented.

JORDAN

A better environment for business

Over the 2018–2019 period, the government enacted a range of economic reforms that have improved access to credit, facilitated tax-paying and addressed issues of insolvency. These reforms were reflected in its much-improved ranking (75th) in the Word Bank's *Doing Business 2020* report, Jordan having climbed 43 places since 2017. Though still high, the trade imbalance fell by one-third to about US$ -5.8 billion over 2015–2019. A number of economic challenges remain, including a high unemployment rate (Figure 17.1).

SMEs account for about four-tenths of Jordan's nominal GDP and 98% of all operational companies (OBG, 2018b). The US non-profit Building Markets (2019) found that Jordanian- and refugee- or migrant-owned SMEs created an average of 15 and 18 jobs per year, respectively.

The *National Entrepreneurship and SME Growth Strategy* (2015) covered the period to 2019. It proposed establishing a structure to co-ordinate the implementation of policies and programmes in support of entrepreneurship and SMEs. According to the OECD (2019), as of 2019, 'limited progress' had been made in establishing this structure.

The government adopted the *Jordan 2025* framework strategy in 2015. It defines its central goal as being to improve citizens' welfare and the provision of basic services. It also aims to achieve economic self-reliance and financial stability, as well as to improve productivity and competitiveness. Among the 400 measures listed by the strategy, notable is the objective of: 'activating' the Renewable Energy and Energy Efficiency Fund, established in 2010; completing the country's high-speed fibre optic network; and rehabilitating environmentally degraded areas that include the Zarqa River basin and Phosphate Hills near Russeiffeh.

Reach2025: blueprint for the digital economy

In May 2019, the government created the Ministry of the Digital Economy and Entrepreneurship, thereby expanding the mandate of the former Ministry of Information and Communication Technology to focus on the digital economy and related areas.

One flagship of the new ministry is the Youth, Technology and Jobs project, approved by the World Bank in March 2020, with grants totalling US$ 200 million. The project aims to raise the number of digitally skilled youth by establishing a National Skills Council for Information and Communication Technology, developing curricula for technical schools and providing selected tech hubs with financial support. The project will also expand the provision of e-government services.

Box 17.3: **SESAME: a ray of unity**

The Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME) is the first major international research centre in the Middle East and neighbouring countries.

Situated in Allan, Jordan, it has eight members: Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, Palestine and Turkey. UNESCO has worked with these members to bring this project to fruition since the first stone was laid in 2002.

As a user facility, SESAME hosts visiting scientists who use synchrotron technology for advanced research.

Since SESAME was officially inaugurated in May 2017, six beamlines have been commissioned, with plans for a seventh. The absorption spectroscopy and infrared beamlines became available to users in 2018, followed by that for powder diffraction in mid-2020. In January 2020, construction began of the tomography and soft X-ray beamlines. Funding is being sought to construct the sixth for macromolecular crystallography.

Demand is high. The number of proposals almost tripled to 151 between the first call in December 2016 and the third in November 2019. One particularly encouraging proposal in the third call emanated from Palestine for a joint project with Cyprus, Greece and Turkey.

Between July 2018 and February 2020, experiments were conducted for 62 proposals from 12 different countries, many of them collaborative projects. Experiments have centred on, for example, novel materials for batteries, shock features in Martian and lunar meteorites, the possible use of herbs for treating Alzheimer's disease, ancient manuscripts from the Qur'an and the presence of arsenic in rice grains and rice farm soils in Iran. Since 2018, experiments undertaken at SESAME have spawned the publication of several papers in quality scientific journals.

SESAME is now in a position to support others: on 19 January 2020, it hosted another organization's workshop on its premises for the first time, that of the Association of Arab Universities.

SESAME's solar power plant was inaugurated in February 2019, making SESAME the world's first large accelerator complex to be fully powered by renewable energy and the world's first carbon-neutral accelerator laboratory. This makes SESAME economically as well as environmentally sustainable.

SESAME is a signatory of the United Nation's Climate Neutral Now pledge.

In November 2018, SESAME became the first Associate of the League of European Accelerator-Based Photon Sources.

Source: Clarissa Formosa-Gauci, UNESCO; see: https://www.sesame.org.jo/

Prior to these initiatives, the government had launched its *Reach2025* action plan at the Middle East and North Africa Information and Communication Technology Forum in 2016, billed by the ministry as the new blueprint for the digital economy. Focusing on smart specialization, public sector innovation, start-ups and infrastructure for the digital economy, among other things, it projects that 5 000–7 000 businesses could be added to the digital economy by 2025, creating 130–150 000 jobs and contributing an additional 3–4% of economic growth each year.

Reach2025 identifies six key sectors with the potential to drive Jordan's digital economy: health; education; energy and clean tech; the financial sector; transportation; and communication and security. The action plan envisions creating a seed fund and 'catapult' for the digital economy, namely, a network of specialized centres of excellence that offer the Internet of Things and cloud computing services.

Amman to become a smart, sustainable city

In November 2017, the European Bank for Reconstruction and Development signed a memorandum of understanding with the Greater Amman Municipality to support the city's endeavour to become 'smart' and sustainable (Zgheib, 2017). The following year, the US Trade and Development Agency signed a grant worth about US$ 900 000 to support the development of a Smart City Roadmap for the decade to come.

According to the government's *Voluntary National Review*, US$ 10 billion was spent in the ten years to 2017 on public–private partnerships in electricity generation, renewable energy, water, transport, wastewater treatment and other areas (Govt of Jordan, 2017).

National Centre for Innovation established

At 0.71%, Jordan's GERD/GDP ratio is the third-highest for the Arab States reporting recent data (Figure 17.3). The *Science, Technology and Innovation Policy and Strategy* covering the period 2013–2017 specified 24 projects offering incentive schemes for researchers and innovators, as well as the establishment of technology incubators.

This strategy is to be replaced by the *National Policy and Strategy for Science, Technology and Innovation* for 2021–2025. Twenty-one programmes will be implemented to achieve its five strategic objectives:

- promote interdisciplinarity and knowledge-sharing among researchers and innovators;
- expand scientific and technological services;
- maximize national and international funding and strengthen international co-operation;
- develop entrepreneurship and innovation programmes; and
- evaluate and analyse the national innovation system to inform decision-making.

The *National Innovation Strategy (2013–2017)*[19] led to the establishment of the National Centre for Innovation in 2019, an online platform that co-ordinates innovative projects, collects data and allows public and private stakeholders to engage with one another directly. The Middle East and North Africa Transition Fund financed its first two years of activity to the tune of US$ 2.47 million (Bennett, 2018).

The priorities for scientific research designated by the Higher Council for Science and Technology for the 2011–2020 period include 148 topics related to inclusive, sustainable development. Ten topics relate to basic and applied sciences, with a focus on life sciences, as well as engineering and ICTs. Eighty-four topics concern the social sciences.

Jordan is home to the Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME), a major interdisciplinary science project that has been boosting science diplomacy and scientific collaboration (Box 17.3).

KUWAIT

Plans to become a financial and trade hub

Kuwait's oil reserves are the world's sixth-largest, accounting for 90% of export revenue and about 40% of GDP in 2017 (Govt of Kuwait, 2019).

New Kuwait 2035 (2017) aims to transform the country into a 'financial and trade hub regionally and internationally'. Its 164 strategic programmes are guided by seven goals: a sustainable, diversified economy; an effective civil service; a sustainable living environment; developed infrastructure; high-quality health care; creative human capital; and a strategic global position. Finance, information technology and renewable energy are identified as priority sectors.

In December 2018, the head of the Central Bank announced the roll-out of a Kuwait National Payment System which will include a government e-banking service and new digital currency, the Digital Kuwaiti Dinar (Ellia, 2018).

One motivation for these industrial zones is the high cost and scarcity of industrial land, the distribution of which is controlled by the government (Alkhoja and Zakout, 2019; OBG, 2019).

Currently, SMEs only contribute about 3% to GDP (OBG, 2019). As part of its industrial diversification strategy, the government has endowed the National Fund for SME Development (est. 2013) with US$ 6.1 billion. The fund covers up to 80% of SMEs' capital needs, coupled with tax and customs exemptions, training and technical support (Govt of Kuwait, 2019).

Renewable energy to offset rising demand

New Kuwait 2035 aims to raise the share of renewables in electricity generation capacity to 15% by 2030, equivalent to a capacity of about 4 500 MW. This would reduce the need for gas imports to satisfy Kuwait's voracious appetite for energy (OBG, 2019), among the highest, per capita, in the world (Govt of Kuwait, 2019).[20] This project has since been delayed on account of the political turbulence in the country.

Demand for energy is expected to rise, once construction is completed of the new port at Mubarak Al Kabeer and the twin cities of South Saad Al Abdullah and South Sabah Al Ahmad take form (OBG, 2019).

The 1.5 GW Al Dibdibah solar plant had been considered a stepping stone towards the 2030 target when plans were first put forward in 2018. However, the government called off the tender in July 2020, citing the impact of the Covid-19 crisis (Reuters, 2020).

A leap planned in research intensity

Kuwait lacks a dedicated science policy or ministry (Figure 17.6). The Director-General of the Kuwait Institute for Scientific Research, Dr Samira Omar, has informed the present authors that, as a result, efforts to develop STI are fragmented and directionless.

This has implications for all aspects of the national innovation system; for instance, although there are some funding opportunities for SMEs, there is a lack of targeted programmes to support knowledge-intensive start-ups and the activities of accelerators and incubators are insufficiently co-ordinated. Researcher density declined over 2013–2018 (Figure 17.2).

In March 2016, the Kuwait Foundation for the Advancement of Sciences presented its new *Strategic Plan (2017–2021)*, which sets the target of raising research intensity to 1% of GDP by 2020 from a 0.3% baseline. The plan also envisages founding a National Research Council which would be responsible for identifying priority research areas. In addition, it proposes establishing five talent academies to support gifted students, in co-operation with the Ministry of Education.

The Kuwait Institute of Scientific Research (est. 1967) carries out applied research in three broad areas: oil, water, energy and construction; environment and life sciences; and techno-economics. Its eighth strategic plan covering the years 2015–2020 emphasizes technology roadmapping to develop 'system solutions' in areas that include oil, energy, water and life sciences.

In 2019, Kuwait University inaugurated the Shdadiyah campus, the largest of its kind in the Arab region. There are plans to establish about 400 engineering and more than 800 science labs at this campus over the period to 2025. The university has been striving to boost international collaboration in aerospace sciences and is collaborating with the European Organization for Nuclear Research (CERN), alongside the Kuwait Foundation for the Advancement of Sciences.

Since it was established in 2018, the Kuwait Space programme has launched its first suborbital single-stage rocket using liquid bipropellant, in collaboration with the US National Aeronautics and Space Administration. The rocket has reached low latitudes as an initial experiment.

LEBANON

Compounded crises

Lebanon is dealing with the fallout from 'compounded crises' (World Bank, 2019a). Following the mass public protests of 17 October 2019, capital inflows ground to a halt, which led to banking, debt and exchange rate crises. This, in turn, pushed up prices for essential goods (World Bank, 2020b).

The situation has deteriorated further since, as a consequence of the Covid-19 pandemic and the tragedy of 4 August 2020, when chemicals stored in a warehouse exploded, destroying much of the port and centre of Beirut and claiming at least 154 lives (Ramzy and Peltier, 2020).

Universities in Lebanon have since implemented austerity measures, introducing budget cuts that have limited access to facilities, equipment and funds for research.

Capital Investment Programme

With gross public debt estimated at 153% of GDP in 2017, Lebanon has one of the highest debt-to-GDP ratios in the world (World Bank, 2018b). At the same time, the World Bank judges the country's infrastructure to be 'amongst the poorest regionally and globally,' after years of inadequate public investment. Deficiencies are especially prominent in the electricity, water supply, waste management and transport sectors (World Bank, 2018b).

Successive plans have sought to tackle these deficiencies. In 2016, the Ministry of Energy and Water presented its second *National Energy Efficiency Action Plan* to 2020. The *Plan* included a list of energy-saving goals for the housing, industrial, agricultural and transport sectors and set the target of achieving a 12% share of renewable energy in electricity generation by 2020 but provided little detail of specific measures.

In April 2018, the incoming government presented the Capital Investment Programme at the CEDRE conference[21] in Paris. It comprises more than 280 infrastructural projects to be implemented over three cycles between 2018 and 2030, at a total estimated cost of US$ 22.8 billion (World Bank, 2018b).

The bulk of this investment is earmarked for transportation. To modernize Lebanon's power supply, which is intermittent for 92% of households, the programme foresees an investment of US$ 5.6 billion to 2030 in 17 projects. The lion's share of this investment would finance two gas-fired plants at El–Zahrani and Salaata producing a total of 1 000 MW. To improve industrial competitiveness, the programme foresees establishing the Tripoli Special Economic Zone, to provide industry with infrastructure and low-cost municipal lands (World Bank, 2018b).

At the CEDRE conference, Lebanon secured aid pledges of about US$ 11 billion to implement the programme, conditional upon reducing the budget deficit by 5% by 2023. The government's 2019 budget includes cuts to public spending to achieve these targets, including to electricity subsidies.

An initiative to guarantee investment

In 2013, the Central Bank, the Banque du Liban, issued Circular 331 in an effort to kickstart the entrepreneurial ecosystem, curb brain drain and support local employment. Through this circular, the Central Bank guarantees to reimburse banks for up to 75% of their investment in a start-up, should the start-up go bankrupt. By May 2017, US$ 300–320 million had reportedly been raised and half of this sum had been invested (Daoud, 2017). According to Hassen (2018), Circular 331 helped to reduce the funding barrier faced by Lebanese entrepreneurs.[22]

However, the present financial crisis has compromised the advances made by burgeoning start-ups and investments have most likely stalled.

The Beirut Digital District, which provides co-working spaces, concentrates many of the country's start-ups. As of 2017, the district reportedly hosted 70 companies employing 1 200 people (Les Echos, 2017) and had begun a process of expansion (Daoud, 2017) that has likely stalled in 2020.[23]

A survey conducted over 2017–2018 of tech start-up founders, co-founders or partners found that navigating the regulatory framework and accessing local talent were the two greatest impediments to entrepreneurship (ABI, 2018). With regard to the wider innovation system, the main barriers identified were a weak collaborative culture, a lack of funding for researchers at the prototyping stage, an insufficient number of incentives and reward mechanisms and poor intellectual property protection at the national level (Berytech, 2020).

Research expenditure likely to fall

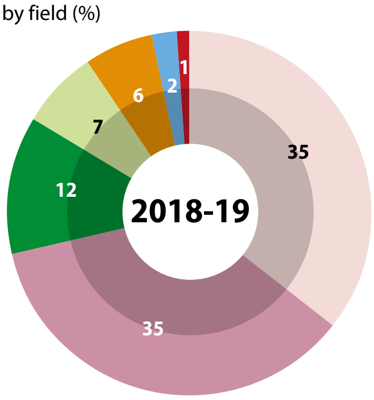
Lebanon's *Science, Technology and Innovation Policy* (2006) continues to serve as the country's main strategic plan in related areas (Zou'bi *et al.*, 2015).

Through its Grant Research Programme, the CNRS-L allocated an estimated US$ 2.5 million to support 249 projects over 2014–2016. The number of projects varied little for the call covering 2018–2019 (239) but the amount of funding doubled to US$ 5 million. The bulk of the budget allocation was evenly distributed between basic sciences and engineering, on the one hand, and medical sciences, on the other (Figure 17.7).

This growth in expenditure follows a restructuring of the Grant Research Programme in 2017. Project costs are

Figure 17.7: **Projects funded by Lebanon's National Centre for Scientific Research, 2018–2019**

Distribution by field (%)



Note: The National Centre for Scientific Research makes biennial calls for research proposals.

Source: National Centre for Scientific Research of Lebanon

now shared by the CNRS-L with one of the 16 participating universities. There had been plans to raise funding for 2019–2020, with a focus on: applied AI and data analytics; crisis and emergency management; environment and waste management; and the social sciences and humanities. However, officials at the CNRS-L forecast a steep decline in expenditure over this period.

National charter for research ethics

In July 2016, Lebanon became one of the first Arab countries to adopt a national charter for research ethics, when the CNRS-L released the *Charter of Ethics and Guiding Principles of Scientific Research in Lebanon*.

The *Charter* states that research should comply with international standard-setting instruments like the *Helsinki Declaration* on medical research. It also calls upon institutions to ensure that research projects targeting human subjects directly receive special approval from the host institution's ethical committee.

The CNRS-L also contributed to drafting the *Charter of Ethics of Science and Technology in the Arab Region* (2019), the result of an 18-month multistakeholder consultation process (Box 17.4).

In March 2019, the CNRS-L and the Lebanese National Commission for UNESCO launched the National Observatory for Women in Research to boost women's participation in scientific research and, thereby, help build a knowledge society (Al Akhbar, 2019).[24]

LIBYA

Void has been filled by budding entrepreneurs

Armed conflict reignited in 2015 in Libya. With minimal governance and broken public institutions (World Bank, 2019b), Libya counts among the world's most fragile states; in 2017, approximately 1.3 million people were in need of humanitarian assistance, according to the United Nations High Commissioner for Refugees.

Libyan research institutes have endured immense structural damage and university laboratories have experienced a shortage of spare parts and consumables. There have been some improvements, though, as concerns the exercise of intellectual freedom and internal academic mobility (LOOPS, 2019).

Libya 2020 Vision, released in 2014 by the Libyan Institute for Advanced Studies, identified STI as being fundamental to the country's development agenda, alongside openness, human rights, gender empowerment and six other elements. *Libya 2020 Vision* foresaw developing a strategy for STI and technology transfer, dedicating more resources to R&D and improving the quality of science teaching.

The *National Strategy for Science, Technology and Innovation* was duly approved by the National Planning Council in 2014 but the present authors have been unable to confirm the status of implementation.

Within the Ministry of Economy and Industry, the Permanent Technical Committee for Measuring Innovation plans to develop indicators and standards against which to

Box 17.4: **The *Charter of Ethics of Science and Technology in the Arab Region***

In November 2019, the *Charter of Ethics of Science and Technology in the Arab Region* was launched at the World Science Forum organized by UNESCO and the Government of Hungary in Budapest.*

The *Charter* outlines the ethical responsibilities of the various actors participating in the chain of production, transfer, localization and deployment of science and technology and related knowledge. These actors include institutions such as: universities and research centres; individual scientific workers, including technicians; governments; the productive sector; and society at large, the ultimate consumer of the fruit of scientific research.

The *Charter* identifies means by which to: frame the role of science and technology as part of a development agenda; support an enabling environment in which science and technology can thrive; protect science and those who work in related areas; and steer science and technology away from non-ethical practices that could bring harm to a person, animal, society or the environment.

For example, scientific workers are urged to refrain from undertaking research that compromises environmental sustainability or neglects the welfare of animals used in experimentation. Funding agencies are urged to refrain from impeding the publication of funded research results or putting pressure on a researcher that conflicts with the objectivity of their work. Institutions are urged to establish ethics committees in all disciplines to supervise the implementation and evaluation of the *Charter* and the commitment of scientific workers to it.

The *Charter* has its roots in a regional consultation which took place in 2017 in Beirut, Lebanon, at which about 50 ethics experts from ten Arab countries, representing universities, research institutions and research councils, agreed that the UNESCO Regional Bureau for Science in the Arab States, based in Cairo, should co-ordinate the drafting process. The *Charter* was subsequently developed in collaboration with the League of Arab States and ten specialized institutions from as many countries.**

On 31 March 2019, the Council of the League of Arab States adopted a resolution approving the *Charter of Ethics of Science and Technology in the Arab Region* as a guide and called upon the Arab States to disseminate it among their research institutions.

Source: compiled by Jana El Baba, UNESCO; read the *Charter* in Arabic, English or French: https://tinyurl.com/yb2v43d4

* The launch took place under the patronage of Her Royal Highness Princess Sumaya bint El Hassan, President of the Royal Scientific Society of Jordan and UNESCO Special Envoy for Science for Peace, who had accompanied and supported the *Charter* since its inception.

** These are the National Council for the Evaluation of Scientific Research and Technological Development (Algeria); Academy of Scientific Research and Technology (Egypt); University of Technology (Iraq); Royal Scientific Society (Jordan); National Council for Scientific Research (Lebanon); Moulay Ismail University (Morocco); Palestine Academy for Science and Technology; Prince Mohammad Bin Fahd University (Saudi Arabia); Khartoum University (Sudan); and Institut Pasteur de Tunis (Tunisia).

measure domestic innovative activity. The committee enlisted the support of Expertise France in September 2020 (Box 17.5).

To support innovation and entrepreneurship, the Ministry of Planning has maintained collaborative links with the European Union, through the European Neighbourhood Instrument[25] (Box 17.5).

MAURITANIA

National science council established

Food insecurity became critical in Mauritania in 2018 after severe arid seasons over 2015–2017. The World Bank notes that fiscal reforms adopted since 2016 have restored the macro-economic balance and raised tax revenues. However, economic challenges remain, including with regard to the labour market, which is characterized by the marginalization of youth and informal employment (World Bank, 2019c).

Mauritania's *Strategy for Accelerated Growth and Shared Prosperity* (2016–2030) aims to improve governance, reform the education system and reduce unemployment (Figure 17.1). It identifies priority areas for research that include agriculture and fisheries, extractive industries, handicrafts, tourism, clean energy and ICTs.

In 2016, two-thirds (67%) of Mauritanian researchers worked in agriculture and fisheries. Despite this focus, research expenditure in this sector remained relatively low, at just 0.49% of the value contributed to GDP by the agricultural sector (ASTI, 2018).

The government has prioritized public–private partnerships as a means of embedding technology and innovation in the private sector and promoting greater investment in research. To this end, it established an Interministerial Committee for the Development of Public–Private Partnerships in 2016. This was followed by a law in February 2017 (#6) creating a special legal regime for public–private partnerships.

In April 2015, the government created the National Council for Higher Education and Scientific Research, with a mandate to set priority areas for research and higher education and serve as a repository for related data (Sawahel, 2015).

The Higher Council for Research and Innovation, chaired by the prime minister, was established in June 2016. It is responsible for preparing a national policy for science and research, forging university–industry linkages and promoting scientific co-operation with Mauritania's neighbours and beyond the region (Sawahel, 2016).

MOROCCO

Expanding the aeronautics and automotive industries

Although the share of industry and manufacturing in GDP has remained roughly level in Morocco since 2015, key industries

Box 17.5: **European support for Libyan entrepreneurs**

The conflict in Libya has driven out foreign companies and curbed imports, creating space for local firms and generating demand for local products and services. In parallel, the drop in the supply of public-sector jobs has spurred more young people to start their own business.

Some start-ups have addressed market failures induced by the conflict, such as Flouzi's online payment app created to mitigate the effects of the liquidity crisis.

Since 2014, the French technical co-operation agency, Expertise France, has been supporting young Libyan entrepreneurs through a series of projects involving European and Libyan partners.

The first of these is the Support to Libya for Economic Integration, Diversification and Sustainable Development (SLEIDSE) project, implemented by Expertise France over the 2016–2017 period with € 7.6 million in funding from the European Union.

SLEIDSE has established entrepreneurship and innovation centres at 11 universities* and trained staff at four pilot chambers of commerce in Benghazi, Misrata, Sabah and Tripoli on how to support young entrepreneurs. The project has also trained 500 start-up teams in various economic sectors.

In parallel, the French government has provided € 1.5 million to create the Janzour Coding Academy and the first Entrepreneurship Certificate to be awarded jointly by universities and chambers of commerce.

Another outcome of the SLEIDSE project is the Libus Online Entrepreneurship School, developed in co-operation with the International Trade Centre.

Under the Social Entrepreneurship Initiative, financed by the EU to the tune of € 500 000, Expertise France has organized 'bootcamps' to nurture an entrepreneurial spirit and creative thinking.

The EU also invested € 11 million in the Private Sector Development Programme (EU4PSL) [2019–2022] to give small and medium-sized enterprises (SMEs) better access to finance. The programme has reactivated the National Credit Guarantee Fund with LYD 300 million (*ca* € 194 million) in capital from the Libyan government and with the participation of seven Libyan commercial banks.

Libyans have been entitled to participate in the EU's Horizon 2020 research and innovation programme and in the student exchange programme Erasmus+. Between 2017 and 2019, ten research grants and 18 Erasmus fellowships were awarded to Libyans through these programmes.

Another project has been funded by UK Aid. It contributed € 2 million over 2018–2020 to the STREAM business incubator, accelerator and FabLab, which was established by Expertise France in Tripoli and is managed by Libyana Mobile Telecom.

Over the same period, UK Aid invested € 1.5 million to create a microfinance institution, Nama Tamweel, to be managed by the Assaray Trade and Investment Bank.

Source: Mohamed Ahmed Alwasad, Senior Advisor for Entrepreneurship and Innovation Policy, Expertise France; see: https://tinyurl.com/Expertise-France-Libya

* These are the Universities of Almargeb, Benghazi, Gharyan, Jufra, Misurata, Robruq, Sebha, Sirt, Tripoli, Zawia and Zintan.

have improved their export performance, including those with higher added value.

This is the case of the aeronautics assembly and component manufacturing sector, one of the country's fastest-growing sub-sectors. It saw the value of exports nearly double to MAD 14.7 billion (*ca* US$ 1.5 billion) over 2014–2018.

According to the Office des Changes, automotive exports increased by 69% over the same period. With the opening of a US$ 630 million automotive manufacturing plant in June 2019, Morocco had an annual production capacity of about 700 000 cars by late 2019. The new plant is expected to boast an annual production capacity of 200 000 vehicles by 2023 (OBG, 2020).

This sector is also a major recipient of FDI, some of which goes towards technologies such as batteries, cameras and electrics. In 2017 alone, 26 investments were made in this sector for a total value of US$ 1.45 billion (UNCTAD, 2018).

Target reached for job creation in industry

The *Industrial Acceleration Plan 2014–2020* (2014) has guided Morocco's efforts to diversify the economy and support emerging industries such as aeronautics and automotive manufacturing. Its goals include transferring informal activities to the formal sector, improving the competitiveness of SMEs and establishing linkages between smaller suppliers and multinational manufacturing companies (OBG, 2020).

Other milestones have been reached under the plan. By August 2017, Morocco had reportedly created 97% of the 500 000 new jobs in industry that it had targeted to 2020. A new *Industrial Acceleration Plan* for 2021–2025 was announced in December 2019; it will focus on integrating SMEs into the value chain and preparing for the technological changes brought about by Industry 4.0 (OBG, 2020).

A Green Park for solar research

Morocco is also developing wind and solar energy. The aim is partly to reduce dependence on energy imports, which accounted for 92% of energy consumption in 2018, but also to meet Morocco's 2016 unconditional commitment under the *Paris Agreement* to reduce greenhouse gas emissions by 17%, compared to the business-as-usual scenario (Govt of Morocco, 2020).

By 2018, renewable sources still only accounted for 3% of total energy consumption and one-third of installed electrical capacity, however (Govt of Morocco, 2020).

In 2017, the Green Energy Park opened in Benguerir, a sustainable city situated 50 km north of Marrakech that has been under development since 2009, with the well-equipped Mohammed VI University at its heart. Built on an 8-hectare site, the Green Energy Park has been designed by the Research Institute for Solar Energy and New Energies (IRESEN). The park houses laboratories specializing in areas such as solar photovoltaics and desalination using solar energy. Morocco is also developing two solar parks with a total capacity of 320 MW, Noor Tafilalet and Noor Atlas (Govt of Morocco, 2020; Zou-bi *et al.*, 2015).

The number of scientific publications on wind-turbine technologies has tripled from 148 (2012–2015) to 477 (2016–2019) and almost quadrupled for solar photovoltaics (from 145 to 569), according to the UNESCO study of 56 research topics (see chapter 2).

Striving to improve STI co-ordination

The Permanent Interministerial Committee has earmarked strategic sectors such as mineral resources, renewable energy and high-tech exports as priority areas for research (Bizri, 2018).

In December 2018, the Mohammed VI Polytechnic University hosted the first Forum on Artificial Intelligence for Africa, co-organized by the Moroccan government and UNESCO (see also Box 20.4).[26]

Morocco's *National Strategy for the Development of Scientific Research: towards 2025* (2009), its innovation strategy *Maroc Innovation* (2009) and its *Vision for Education, 2015–2030* have striven to improve co-ordination among the key players of the national innovation system while diversifying support for research. Accomplishments, thus far, include:

- the creation of the Innov Invest Fund in 2018 to support business incubators, via a World Bank loan (MAD 500 million, *ca* US$ 57 million) [Govt of Morocco, 2020];
- the creation of 26 collaborative platforms since the inception of the National Programme for University–Industry Interface in 2004;[27] and
- an increase in publication intensity overall and for cross-cutting strategic technologies since 2012 (Figures 17.4 and 17.8).

Although applications to the national patent office surged by 167% over 2015–2019, applications from abroad were largely responsible for this trend, since domestic patent applications actually declined by 14% over the same period. Numbers were also down in 2019 at the top five patent offices (Figure 17.5). This suggests that the national innovation system is less effectively converting research results into concrete applications (OMPIC, 2020).

The lack of private investment in research and the ageing research workforce remain challenges for the national innovation system (Govt of Morocco, 2020). According to the Minister of Education, Vocational Training, Higher Education and Scientific Research, expenditure on R&D surged from 0.3% of GDP in 2016 to 0.8% in 2017, although these figures have not been independently verified (Ouadghiri, 2019).

The legal framework for public–private partnerships was updated in 2014, to support large infrastructure projects, then again in 2019 to extend these partnerships to local administrations and other public entities. In January 2020, the government launched a call for bids for three new industrial parks in the Casablanca-Settat region, to be developed via public–private partnerships (Hatim, 2020).

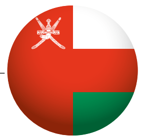
New agency to address digital divide

The *Digital Morocco 2020* strategy (2016) has provided the framework for accelerating the digital transformation, cementing the country as a digital hub and improving digital governance and skills.[28] Targets include placing half of all government administrative procedures online and ensuring that one-fifth of SMEs have Internet access (OBG, 2020).

The Digital Development Agency (est. 2017) regulates digital projects and oversees reforms, including that of narrowing the urban–rural digital divide. This divide is visible in ownership rates of a computer or tablet: 36% in rural areas and 72% in urban areas. In 2018, only 17% of Moroccan bank account-holders made a digital transaction in 2018, compared to 80% of account-holders in Tunisia (OBG, 2020).

In May 2019, the Digital Development Agency launched the Al Khawarizmi programme. Endowed with a budget of MAD 50 million (ca US$ 5.6 million), the programme promotes R&D in AI and big data through calls for research proposals. It is also encouraging entrepreneurship and fostering the diffusion of digital tools through means such as digital parks and a smart factory (Mejri, 2020).

OMAN



Innovation to be the new growth engine

Oman's *Ninth Five-Year Plan* for 2016–2020 aims to diversify the country's oil-rent economy through five main sectors: manufacturing; transport and logistics services; tourism; fisheries; and mining. The plan targets annual growth of at least 5% for each of these sectors. Growth in value-added manufacturing actually declined in 2016 before becoming negative in 2017.

The draft Oman 2040 Vision takes up where the Oman 2020 Vision left off. Although the ultimate aim is to embrace the knowledge society, the document does not specify priority areas of technology or concrete measures to develop the national innovation system. Rather, it is left to Oman's Research Council and other institutions to identify sectoral priorities themselves in their own planning documents, on the basis of Oman 2040 Vision.

Preparing the groundwork for Industry 4.0

The government has identified readiness for Industry 4.0 as the third key determinant of success in reaching the SDGs, after those of promoting local development and fundraising (Govt of Oman, 2019). In the *National Industrial Strategy 2040* (2018), the government outlines plans to improve industrial competitiveness, partly by upgrading the use of technology in the manufacturing sector to automate production processes.

Implemented by the Oman Broadband Company, the *National Broadband Strategy* (2014) has achieved its target of providing high-speed, fibre-to-the-home Internet access to about 80% of homes in Muscat, the capital city, and 30% in other urban areas (OBG, 2020).

The *Digital Oman Strategy* (2003) has prioritized e-governance and business support. As of 2020, the process of digitizing government services is still ongoing. Since 2019, more than 50 government departments have been participating in an initiative to digitalize their services by 2022. According to the Ministry of Technology and Communications, about 160 public e-services were launched in 2019 (OBG, 2020). Many of these are delivered through the Altakamul app, a single access point for government services.

Other key initiatives include the Oman Technology Fund (est. 2016), which had invested in 53 innovative enterprises in the information technology sector with strong growth potential by 2018 (Govt of Oman, 2019). Its three subfunds target start-ups, mid-stream businesses and global venture-capital companies (OBG, 2020).

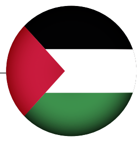
To help drive the digital economy and ensure cybersecurity, the Oman ICT Group was founded in early 2019 through the country's largest sovereign wealth fund, the State General Reserve Fund. The role of the ICT Group is to fund and oversee projects while supporting SMEs specializing in robotics, blockchain, the Internet of Things and related areas[29] (ITA, 2020b; OBG, 2020).

Blending oil tech and renewables

Thanks to enhanced oil recovery technology and innovation in 3D seismic imaging, Oman has maintained high oil production rates (OBG, 2020). A prime example of this is the Miraah Solar Thermal Project, the first phase of which got under way in February 2018. The project will eventually produce more than 1 000 MW of solar power to generate 6 000 tonnes of steam a day and, thereby, extract heavy oil from the Amal field (Govt of Oman, 2019).

The *National Energy Strategy 2040* (2015) sets the target of raising the share of renewables in electricity generation to 10% by 2025. As of 2018, wind and solar energy accounted for less than 1% (Figure 17.1).

PALESTINE



An STI policy framework

Policy-making in Palestine is presently guided by the *National Policy Agenda 2017–2022*, which is framed by three pillars:

- finding a 'path to independence';
- implementing government reform, which includes restructuring local government to make it more responsive, improving public services through e-governance and rolling out a nationwide land registry; and
- advancing its sustainable development agenda.

The policy agenda identifies manufacturing, agriculture, tourism and Gaza's industrial base as priority productive sectors. However, the government considers that its relations with Israel have severely impeded its development agenda (Govt of Palestine, 2018).

The Palestinian Authority published the *Palestinian STI Policy Framework Document* in 2016, with UNESCO support. The document outlines a series of principles for establishing a co-ordinated national innovation system. It does not outline a specific roadmap.

Palestine imports about 91% of its electricity. A household earning the average income spends 10% of its income on energy, five times the proportion in Lebanon or Jordan (Govt of Palestine, 2018).

In 2018, the Palestinian Investment Fund (est. 2000) committed to investing US$ 35 million over four years to install solar power systems on the rooftops of 500 public schools, for a total power generation capacity of 35 MW. The project is being implemented in collaboration with the Palestinian Ministry of Education and Higher Education (Govt of Palestine, 2018).

Three policies ready for approval

Three key policies have been drafted and, as of December 2020, were awaiting government approval.

The Open Data Policy seeks to improve government efficiency, co-ordination and the provision of public services, as well as raise public trust in government. These objectives are to be achieved via a government open data platform and by developing the capacity of public institutions to disseminate data.

The objectives of the National Policy for Digital Transformation include improving the provision of e-services, promoting R&D and expanding Internet access.

The Policy Agenda to Support the Palestine ICT Startup Ecosystem, meanwhile, lays out an action plan to define a legal regime for start-ups, incentivize the establishment of start-ups and create a framework for public–private co-operation. Measures foreseen include simplifying the process for registering a business, offering tax exemptions for start-ups and providing support for R&D conducted by start-ups.

Regulatory environment hampering innovation

Entrepreneurs in Palestine are up against a complex and antiquated regulatory environment. The Innovative Private Sector Development project, implemented by the World Bank for US$ 13 million over 2018–2023, is helping the government to improve the environment for entrepreneurship by, among other things, setting up an automated company registration system and developing a licensing system supportive of home-based businesses.[30]

According to the Palestine Economic Policy Research Institute, most entrepreneurs are unable to turn to financial institutions for loans, owing to high interest rates and the need to give up large equity stakes.

Other institutions are increasingly filling the financing gap. Microfinance institutions in Palestine had a US$ 170-million portfolio in 2016, almost double the value in 2013 (PEPRI, 2018).

Some venture capital firms are also financing entrepreneurship and the digital ecosystem in the West Bank and Gaza; these reportedly invested about US$ 150 million in over 40 Palestinian companies over 2012–2018 (PEPRI, 2018).

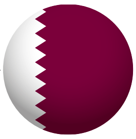
Sadara Ventures (est. 2011), is billed as the first venture capital firm to target the Palestinian tech sector.

With few job opportunities available to women in the public and private sectors, some have turned to entrepreneurship. Nearly four in ten microfinance borrowers were women in 2016 and women led 23% of start-ups in Gaza and the West Bank, above the 12% of start-ups led by women in New York (PEPRI, 2018).

In 2020, the Ministry of Telecoms and Information Technology held two specialized training sessions and one hackathon on robotics and AI. About 2 400 students participated in the hackathon and 120 received training in programming and in practical skills for the labour market.

Over 2021–2022, two further hackathons and ten training programmes on AI are planned.

QATAR



Remapping of international relations

Qatar's development agenda was put to the test in June 2017, when Bahrain, Egypt, Saudi Arabia and the UAE imposed an air, land and sea embargo. This reshaped regional trade routes; Qatar turned to Oman and Kuwait for imports and strengthened trade links with India, Iran, Morocco and Turkey (OBG, 2020). In January 2021, the four countries restored diplomatic ties with Qatar.

The national innovation system was one casualty of the embargo. Prior to 2017, generous funding from the Qatar Foundation for Research, Development and Innovation,[31] coupled with a high standard of living, had made Qatar an attractive destination for researchers (Huggett and van Hiltern, 2016). Following the embargo, the foundation was forced to cut back its support for research (Elmes, 2017). Scientific output declined over 2016–2017, before recovering in 2018 (Figure 17.4).

Qatari campus leaders have indicated that the embargo, nevertheless, came with a silver lining. It forced the government to diversify its relations regionally and globally, engendering greater self-sufficiency, including in the manufacture of food products and medicines (Bothwell, 2018).

In science, too, Qatar has diversified its international relations. For instance, new partnerships have been developed with the National Institute for Materials Science in Japan and Bahcesehir University in Turkey, to strengthen academic collaboration and facilitate the exchange of faculty members and students.

Growth in industry and infrastructure

The *National Development Strategy 2018–2022* prioritizes the development of infrastructure, economic diversification, quality education and training and social protection. This mid-term strategy is aligned with the *Qatar National Vision 2030* (2008).

According to the Qatar Chamber (2019), an NGO representing the business community, 380 industrial facilities were established over 2015–2019, attracting US$ 3.5 billion in investment. The number of manufacturing plants for machinery and equipment surged by 82% and 74 agrifood facilities were established, the largest infrastructural growth of any sector (OBG, 2020).

The Qatar Free Zones Authority opened the Umm Al Houl and Ras Bufontas free zones near key transport hubs in 2019. Businesses in these zones are eligible for 20-year exemptions from income and corporate tax. The authority has identified logistics, chemicals and 'new technologies' as priority sectors (OBG, 2020).

Since successfully bidding to host the 2022 Fifa World Cup in 2010, Qatar has plunged tens of billions of dollars into related infrastructure. For instance, the new Doha Metro opened in May 2019; 1 588 km was added to the road system in 2018 alone; Hamad International Airport, which opened in 2014, signed contracts in February 2020 for a major expansion process; and Hamad Port, the main seaport, opened in September 2017 (OBG, 2020).

In 2018, Qatar became one of the first countries to enjoy a commercially available 5G network (Barton, 2020). The government-led Qatar Smart Programme, better known as TASMU, is targeting five priority sectors: health care, transport, environment, logistics and sport. Over 2017–2022, the programme is investing QAR 6 billion (*ca* US$ 1.6 billion) in related projects (OBG, 2020), such as software to help buses reduce their carbon emissions through optimized routes (QL, 2017).

A first solar plant on the cards

Qatar is the world's leading exporter of natural gas. Production at the North Field is expected to rise by 64% between 2019 and 2027.

The government's budget statement for 2020 reflects these priorities, with 43% of expenditure being directed towards major projects and the next spending priorities being health care and education (OBG, 2020).

Qatar is beginning to develop its solar power capacity. In January 2020, a QAR 1.7 billion (*ca* US$ 467 million) contract for the country's first solar photovoltaic power plant was awarded to a special purpose vehicle, Siraj-1, following a competitive bidding process. Siraj-1 comprises Siraj Energy, a joint venture between several Qatari state-owned entities, as well as the Marubeni Corporation (Japan) and Total Solar International (France). The plant, located in Al Kharsaah, is expected to have a capacity of 800 MW (OBG, 2020).

Ambition to raise spending and ethical standards in research

Published in May 2020, the *Qatar Research, Development and Innovation Strategy 2030* outlines a vision of a locally empowered and globally connected national innovation system, to enhance Qatar's resilience and prosperity. It sets the target of raising research intensity to 1.5%, with the business sector accounting for two-thirds of overall expenditure.

Research and innovation are to focus on key national challenges, which include a relatively high prevalence of diseases such as diabetes and congenital disorders, reducing greenhouse gas emissions, improving air and water quality and raising domestic food production capacity.

The regulatory environment is to be reformed to raise ethical standards, protect intellectual property and enable effective management of data, among other things. One key measure in the pipeline is a funding policy for STI which would include a government commitment to expenditure, in line with the *Qatar Research, Development and Innovation Strategy 2030*.

According to this, there are multinationals operating in Qatar that work in research-intensive sectors but few of these are actually conducting R&D locally. The strategy seeks to incentivize multinationals' engagement with the national innovation system, although it does not outline specific measures to this end.

Qatar leads the Arab States for publication intensity on several cross-cutting technologies, including AI and robotics, energy and materials science (Figure 17.8).

A score of start-ups incubated in four years

Qatar's Science and Technology Park (est. 2009) has been touted as the country's premier hub for business innovation.[32] It incubates companies in health sciences, energy, environmental sciences and ICTs, among other areas.

The park's Product Development Fund is a cost-sharing mechanism for local start-ups and SMEs that covers up to 50% of the cost of product and service development targeting local market needs.

Twenty local firms have been incubated at the park's tech-focused Incubation Centre since 2016, including Meddy, which has since become Qatar's largest online platform for booking medical appointments.

As of October 2020, international companies registered in the park have invested QAR 4.3 billion (*ca* US$ 1.2 billion) in research and innovation.

SAUDI ARABIA

Non-oil exports: half of GDP by 2050

Home to 17.2% of the world's proven oil reserves, Saudi Arabia is one of the world's largest oil producers (BP, 2019).

The release of *Vision 2030* (2016) followed the sharp drop in oil prices over 2014–2016. It envisions Saudi Arabia becoming a 'global investment powerhouse' with a diversified industrial base and better business environment. To support this policy, the Public Investment Fund's assets are to be carried from SAR 600 billion (*ca* US$ 160 billion) to more than SAR 7 trillion (*ca* US$ 1.9 trillion).[33]

By 2030, the share of non-oil exports in GDP is to rise from 16% to 50%. Gas is set to play a greater role in the economy, with plans to develop the Jafurah onshore gas field approved in February 2020 (OBG, 2020).

Fintech focus of venture capital fund

Vision 2030 is being implemented through 13 Vision Realization Programmes, including the National Industrial Development and Logistics Programme (NIDLP) announced in 2019. It is set to invest SAR 1.7 trillion (*ca* US$ 453.2 billion) to create 1.6 million jobs by 2030 in four targeted growth sectors: mining, industry, logistics and non-oil energy (OBG, 2020). By 2030, the contribution of SMEs to GDP is to rise from 20% to 35%.

Outlined in the NIDLP delivery plan for 2018–2020, the *National Industrial Strategy* to 2030 itself identifies seven priority sectors: machinery and equipment; renewable energy generation; pharmaceuticals; medical supplies; automotive industry; chemicals; and the food industry. In 2016, the government established the Industrial Clusters agency, to attract investment and oversee the implementation of the *National Industrial Strategy*. In 2017, 56 new industrial plants were licensed.

Efforts to improve the business environment have paid off; the World Bank identified Saudi Arabia as the most improved country in its *Doing Business 2020* report.

In October 2019, Riyad Bank became the country's first bank to establish a venture capital fund focused on fintech. Through the Digital Partnership Programme, the bank will invest SAR 100 million (*ca* US$ 26.7 million) in building partnerships between entrepreneurs and tech companies and supporting tech start-ups in fintech (FF, 2019).

The electric vehicles industry is among those being funded by the Public Investment Fund. In 2018, the US-based company Lucid Motors raised more than US$ 1 billion from this fund to support product development. In January 2021, the company was in talks to establish a factory for electric vehicles near Jeddah (Edelstein, 2021). The country's first charging station was commissioned in August 2019 by Saudi Automotive Services Co (SASCO).

First solar plant operational

As of early 2020, renewables account for less than 1 GW of installed power capacity. The National Renewable Energy Programme (est. 2017) has been pursuing a target of 9.5 GW by 2023 but, in January 2019, the Renewable Energy Project Development Office (REPDO) raised this target to 27.3 GW by 2024 and 58.7 GW by 2030. Of this capacity, 40 GW is to come from solar energy and 16 GW from wind farms (E&U, 2020a; OBG, 2020).

REPDO is attached to the Ministry of Energy. As of October 2020, it had launched 12 projects through three rounds, for a total of 3.4 GW. Eleven of these concern solar energy; a 400-MW wind farm at Dumat Al Jandal is also under construction (REPDO, 2020). The country's first 300-MW solar plant in Sakaka has been operational since November 2019.

Saudi Arabia is the largest producer of desalinated water in the world. It aims to hoist production from 60% to 90% of urban needs by 2030 (OBG, 2020). Desalination is a costly process and many plants operate using energy derived from fossil fuels.

In 2015, Advanced Water Technology, the commercial arm of the King Abdulaziz City for Science and Technology, partnered with the Spanish firm Abengoa to build one of the world's first large-scale solar-powered desalination plants near Al Khafji City. Inaugurated in November 2018, the plant can treat 60 000 m^3 of seawater per day.

National Cybersecurity Authority established

The Ministry of Communications and Information Technology has released a five-year roadmap for innovation and the digital economy, the *ICT Strategy 2019–2023*. The strategy targets growth of 50% in the ICT sector by 2023, through a more technically skilled workforce, a more research-intensive start-up ecosystem and greater co-ordination.

In the wake of a high-profile cyberattack on Saudi Aramco in 2012 and that on the Ministry of Labour in January 2017, the government set up the National Cybersecurity Authority in October 2017. This entity outlined minimum cybersecurity standards for the public and private sectors in October 2018 (OBG, 2020).[34]

By Royal Decree, the independent National Digital Transformation Unit was founded in 2017, to accelerate the digital transformation and help achieve *Vision 3030* (2016).

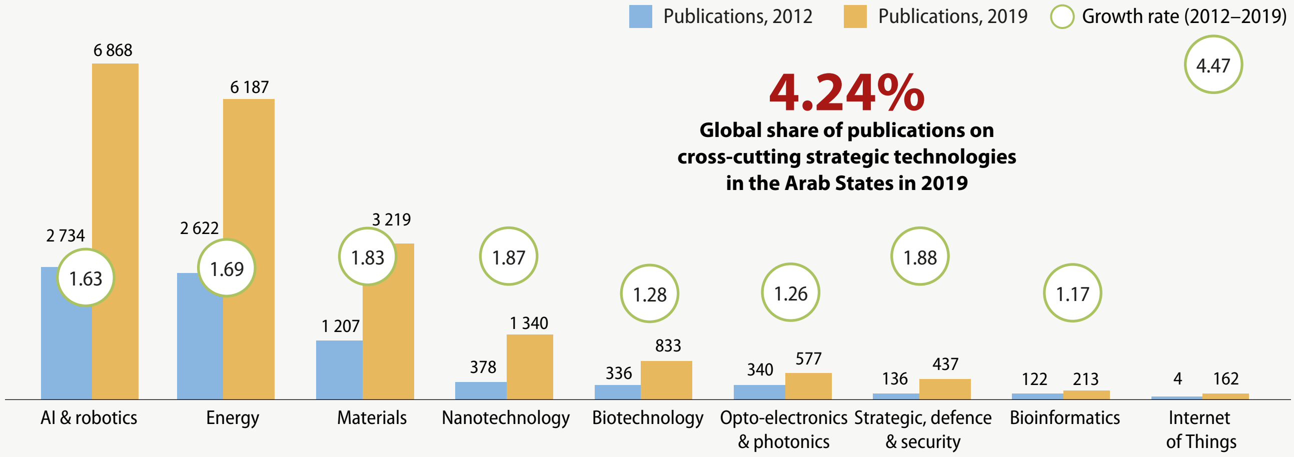
A Research Products Development Company

The *National Strategy for Research, Development and Innovation* was published in 2019, within the framework of the NIDLP. It identifies several challenges for the national innovation system, including a weak capacity to lower the lifecycle of products and market them competitively, along with the 'non-existence' of national programmes for distributing research funds. Saudi Arabia's four technology transfer offices are deemed too few in number to meet demand.

The Research Products Development Company was established in 2015. Touted as the national centre for technology development and commercialization, this entity develops and tests prototypes and helps to prepare inventions for their commercial launch.

Figure 17.8: **Trends in publishing on cross-cutting strategic technologies in the Arab States**

Volume of scientific publications on cross-cutting technologies in the Arab States, 2012 and 2019

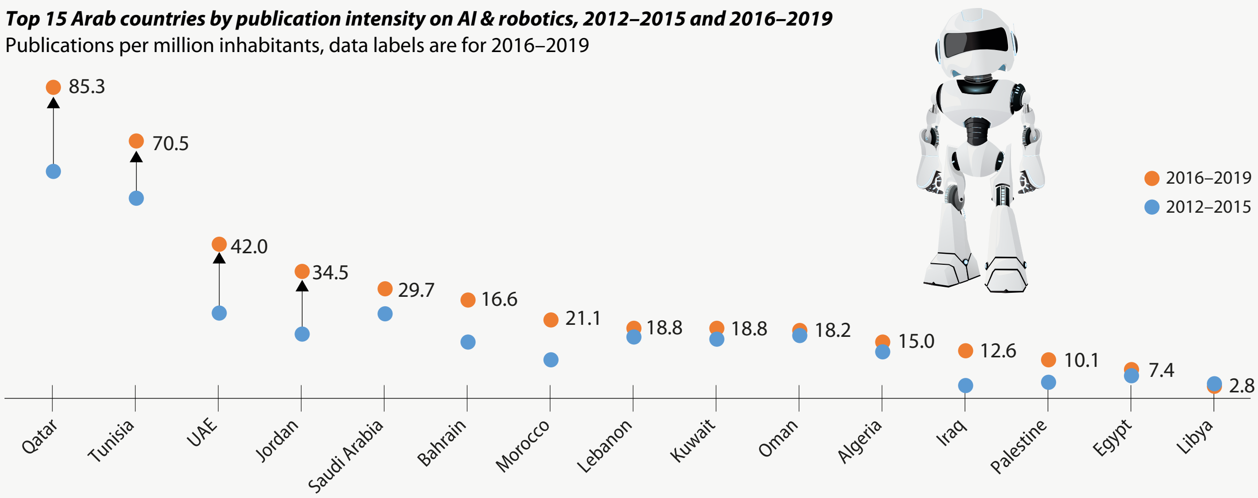


From 2011 to 2019, Saudi Arabia (26%) and Egypt (20%) accounted for the largest shares of publications on cross-cutting strategic technologies in the Arab States.

Iraq's contribution to regional output on cross-cutting strategic technologies tripled from 3% over 2012–2015 to 9% over 2016–2019.

5 977
Publications on AI & robotics by Tunisian researchers over 2011–2019, the leader by volume among Arab countries

Top 15 Arab countries by publication intensity on AI & robotics, 2012–2015 and 2016–2019
Publications per million inhabitants, data labels are for 2016–2019



The *National Strategy for Research, Development and Innovation* makes a number of recommendations; these do not, however, amount to a government commitment. Recommendations include: offering grants and tax incentives to promote industrial R&D; defining clear regulatory guidelines for intellectual property ownership; and establishing technology transfer offices at local universities.

In 2007, the King Abdulaziz City for Science and Technology (KACST) launched the Badir Programme for Technology Incubators and Accelerators. Over 2007–2017, the programme served 200 start-ups (Rahal, 2017) and, according to an external impact assessment, contributed SAR 2.1 billion (*ca* US$ 560 million) to the economy (IntIBM, 2018).

The Kingdom plans to allocate US$ 2.1 billion by 2030 to boost its space programme, as part of its economic diversification strategy.

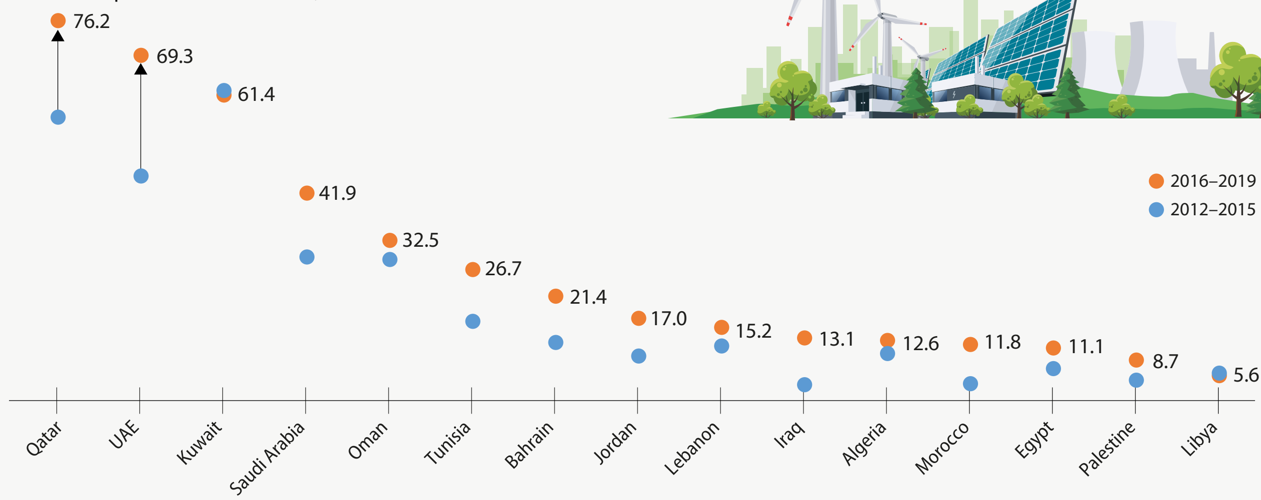
Research output on the rise

Saudi Arabia leads the Arab States for the volume of scientific publications and has the third-highest publication intensity, following years of strong growth (Figure 17.4). This performance can be linked to the policy whereby Saudi universities recruit highly cited foreign scientists.[35]

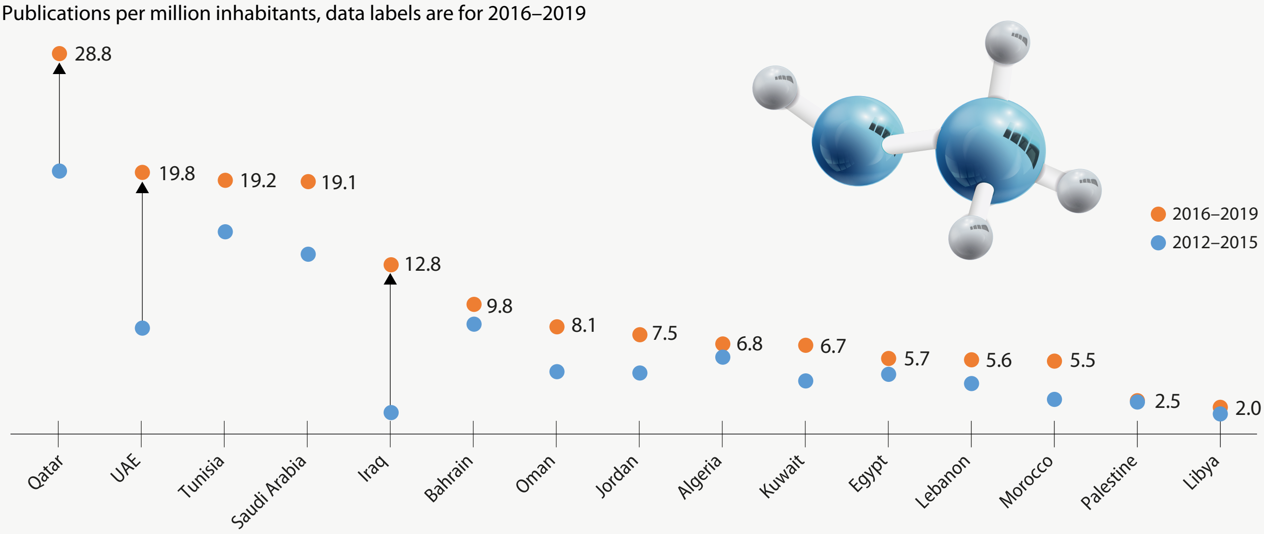
First geostationary satellite launched

In February 2019, the European launcher Ariane carried the first Saudi geostationary satellite for telecommunications

Top 15 Arab countries by publication intensity on energy, 2012–2015 and 2016–2019
Publications per million inhabitants, data labels are for 2016–2019



Top 15 Arab countries by publication intensity on materials science, 2012–2015 and 2016–2019
Publications per million inhabitants, data labels are for 2016–2019



Note: Countries produced the greatest output on these three cross-cutting strategic technologies: AI and robotics, energy and materials science. The growth rate was calculated as the number of publications during 2016–2019 divided by the number of publications during 2012–2015 to buffer the variability among individual years. See the statistical annex for complete data for all countries, freely available from the *UNESCO Science Report* web portal.

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

(SGS-1) into space. It had been built by the US firm Lockheed Martin, which had trained engineers from KACST.

Saudi Arabia hosts two of the Arab States' best-performing universities: KACST and King Abdullah University of Science and Technology (KAUST). *Among Vision 2030*'s targets is for three Saudi universities to join KACST and KAUST among the top 200 universities in international rankings by 2030.

Now that there is available local expertise, the government has reduced financial support for postgraduate students to attend university in the USA by 12%, according to the National Science Foundation. In 2017, 35 000 Saudi women were studying abroad in about 60 countries on government scholarships (Arab News, 2017).

Workforce with skills in data and AI

Promoting the country's global positioning in AI is one target of the *National Strategy for Data & AI* (2020). The government is thus planning to host the world's first Global AI summit. To build related skills, educational tracks in data science and AI are to be created at primary and secondary levels and at universities, to be linked to professional training programmes. The regulatory framework is to be reformed to make possible the roll-out of open data 'by default', by 2025, which requires a legal framework that ensures security, data protection and privacy.

Saudi Arabia's new smart cities, in general, and Neom, in particular, are considered to be strong 'test-beds' for the trial of AI and data-related initiatives (see Plans for high-tech, sustainable urban centres, p. 428).

New institutions with a focus on industry 4.0

In November 2019, the government signed an agreement with the World Economic Forum to establish a local branch of the Centre for the Fourth Industrial Revolution, attached to KACST. The network of centres links governments, business, start-ups and other actors to pilot innovative approaches to technology governance. The Saudi Arabian branch will focus on AI, blockchain, data policy, the Internet of Things, smart cities and robotics and mobility.

In September 2020, KACST signed an agreement with the Ministry of Industry and Mineral Resources to establish an Advanced Manufacturing and Production Centre to promote co-operation in Industry 4.0-related areas.

SUDAN

A potential 'food basket' for its neighbours

In October 2017, the USA lifted sanctions on Sudan and ended an economic embargo. Regional and international banks had been avoiding transactions with Sudan for fear of incurring fines. This had contributed to currency depreciation and a rise in unemployment and poverty. Although the removal of sanctions is expected to improve the operational environment, Sudan still has a debt burden estimated at 93% of GDP (AfDB, 2018).

Manufacturing is the most productive sector. Sudan has a comparative advantage in agriculture, agroprocessing, animal husbandry and the wool and leather industries. With sound policies to support agriculture and the agrifood industry, Sudan's geographical position and emerging sensitivity to environmental sustainability could help the country position itself as a 'food basket' for its Arab and African neighbours (AfDB, 2018). To realize this ambition, Sudan will need to develop its human capital and infrastructure.

STI policy targets rise in expenditure

Sudan's *Science, Technology and Innovation Policy* (2017) is the culmination of a presidential initiative launched in 2008 with support from UNESCO. Its goal of building a knowledge society is to be achieved by mainstreaming STI in wider development policies. Another objective is to resuscitate the Council for the Development of Scientific Research, Technology and Innovation, which had existed between 1971 and 2009 (UNESCO, 2018).

The Ministry of Higher Education and Scientific Research has been mandated to pilot the implementation of this policy. Formerly the Ministry of Higher Education, it assumed its current portfolio after the Ministry of Science, Technology and Innovation was abolished in 2015.

Over 2017–2018, the ministry drafted bills to revive the Council and establish the Fund for Scientific Research (UNESCO, 2018).

There are several points of convergence between the *Science, Technology and Innovation Policy* and the *Arab Strategy for Science, Technology and Innovation*, endorsed by 22 Arab States in 2014. Both identify water resources management and the use of nanotechnology in health, the food industry and for the environment as priority areas for collaboration (UNESCO, 2018).

The *Science, Technology and Innovation Policy* aims to multiply research intensity ten-fold from 0.2% (2017) to 2% of GDP by 2030. Available sources indicate that the government raised research funding by around 30% for the 2018/2019 fiscal year (UNESCO, 2018).

Sudanese universities and research centres boast a sizeable body of specialists trained in high-ranking universities overseas. The country's expatriate communities across the world are lending a hand to their compatriots through both personal and institutional links, such as via the Council of Sudanese Experts and Scientists Abroad.

SYRIA

Technology transfer offices on the agenda

The United Nations Economic and Social Commission for Western Asia has described the ongoing conflict in Syria as 'one of the most destructive since the Second World War'. As of 2019, more than 11.7 million people within the country were in need of some form of humanitarian assistance. Damage to infrastructure was estimated at US$ 11.7 billion in 2018, with the housing, mining, security, transport, manufacturing, electricity and health sectors the hardest hit (UNESCWA, 2020b).

In 2017, Syria's Higher Commission for Scientific Research (est. 2005) published its first comprehensive report on *Science, Technology and Innovation in the Syrian Arab Republic*.

It outlines priority research areas across 15 sectors, including agriculture, energy, industry and health (Bizri, 2018).[36] Over 2018–2020, 42 research projects were conducted across these 15 sectors, based on needs assessments conducted in collaboration with relevant ministries.

A *National Plan for Enabling Scientific Research in the Syrian Arab Republic* was approved in early 2019. It proposed various legal reforms, including incentivizing private-sector investment in R&D. As of December 2020, new laws are reportedly being formulated.

The Higher Commission for Scientific Research has plans to establish technology transfer offices at all Syrian research institutions, which would, in turn, establish and co-ordinate start-up incubators while connecting researchers with investors.

There are also plans to establish research units attached to government ministries. A national technology transfer office would serve as a link between local offices and these research units. According to Dr Majd Jamali, Secretary General of the Higher Commission for Scientific Research, these plans could receive government approval in early 2021.

Despite the ongoing crisis, scientific output increased by 29% over 2015–2019, a marked improvement over 2011–2014, when there was little change (Figure 17.4).

TUNISIA

Investment in infrastructure

The Tunisian economy grew by only 1.7%, on average, over the 2016–2019 period (Figure 17.1), as a result of continuing political change that limited investor confidence (World Bank, 2020c).

There are indications that the informal economy has prospered in Tunisia since 2011, with the government estimating the cost of tax evasion at TND 25 billion (*ca* US$ 9 billion) in 2018 and the share of the informal sector in the workforce at about 42%. A digital payment system, proposed by the government in March 2018, could help to limit tax evasion and corruption by eliminating cash payments from public offices (OBG, 2019).

Major infrastructure development projects are under way, including a new highway linking Tunis to Jelma, approved in June 2019; a railway connecting Tunis and Kasserine, supported by the European Bank for Reconstruction and Development to the tune of US$ 112 million; and the Enfidha deepwater port, where work is due to be completed by 2022. The Oxford Business Group estimates that the government has invested about US$ 6.5 billion in large infrastructure projects since 2016 (OBG, 2019).

Electronics cluster to promote research

FDI inflows to the industrial sector increased by about 16% over 2017–2018, amounting to about four-tenths of total inflows over the same period. Investors were drawn, primarily, to electronics, especially in the automobile and aeronautic subsectors (OBG, 2019).

Foreign electronics companies have been drawn to Tunisia by the cost-competitive and highly skilled workforce. Some 41 electronics companies with cumulative annual sales of about US$ 1.2 billion launched their own cluster in May 2017. Going by the name of ELENTICA, the cluster entered into a partnership with the Ministry of Higher Education and Scientific Research (MESRS) in October 2018, with the goal of promoting scientific collaboration and installing research centres in ELENTICA companies. These research centres will focus on areas such as the Internet of Things, smart cities, renewable energy and smart-grid technology, electric cars and e-farming (OBG, 2019).

Other tech-based sectors are experiencing rapid growth. Exports in the aeronautics sector skyrocketed over 2010–2018 from TND 85 million to TND 1.5 billion (*ca* US$ 544 million). In the pharmaceuticals sector, meanwhile, exports more than tripled to TND 192 million over 2012–2018 (OBG, 2019).

Ambitions for renewable energy production

The *Renewable Energy Action Plan 2030* (2016) sets the goal of boosting the share of renewable energy in electricity production to 30% by 2030, from a 4% baseline in 2015. The government has reportedly since fixed a target of launching tenders for renewable energy projects with a total capacity of 3.5 GW by 2030 (ITA, 2020a).

In the eight months to August 2020, renewables accounted for only 2.7% of domestic electricity production, according to the Ministry of Industry, Energy and Mines. New renewable energy projects are, nevertheless, on the horizon. In May 2018, the government launched a call for several solar and wind projects for a total capacity of 1 GW; by July 2020, the tenders for solar projects to produce 500 MW had been awarded to three developers (ITA, 2020a).

The Research Centre for Renewable Energy (est. 1983), which operates under the umbrella of MESRS, is responsible for providing relevant expertise on renewables and otherwise supporting development of the sector.

STI policy to 2040 under development

MESRS is presently developing a national STI policy to cover the period to 2040. The policy will be informed by a strategic dialogue document, which will gather input from the private and public sectors, that is due for release in March 2021. The STI policy should follow in 2022, with industrial diversification being one of its focus areas.

Pending such a policy, the *National Development Plan 2016–2020* fixed the target of raising expenditure on R&D to 1.2% by 2020. Over 2015–2018, research intensity actually declined (Figure 17.3).

The *National Development Plan* also set the goals of creating a new generation of innovative institutions and directing research towards areas of national priority. These research areas were subsequently defined by MESRS' *Strategic Plan for Scientific Research 2017–2022* (2017). It has three overarching objectives: to promote academic excellence; innovative and pioneering companies; and innovative and prosperous regions. Its six thematic priorities for scientific research are:

- emerging democratic society: education, culture and youth;
- governance and decentralization;
- the circular economy;

- water, energy and food security;
- quality health care; and
- the digital economy.

Subsequent research programmes, such as the MESRS National Priority Research and Innovation Programmes (2018–2020), have been aligned with this strategy.

MESRS conducted reviews of its programmes in 2015, 2018 and 2020. The latest review found that there was an insufficient number of programmes with a focus on technology transfer. It also found that programmes had been hindered by complex procedures and a lack of involvement of the business sector.

One programme with a focus on the commercialization of research results is the PAQ–PAES programme,[37] launched by MESRS in 2019. It finances young graduates up to a maximum of TND 100 000 (*ca* US$ 37 000) to help them launch spin-off projects or start-ups based on their research. The programme also provides training.

Technology transfer offices were established at several universities and research centres in 2015 to improve university–industry linkages, protect intellectual property and provide researchers with commercial guidance (UNESCWA, 2017b).[38]

In 2016, a UNESCO Chair in Science, Technology and Innovation Policy was established at the National School of Engineering in Tunis. It provides placements for graduate students in private companies to give them experience that they may subsequently apply to create their own business.

Greater Internet penetration an achievement

Digital Tunisia 2020 (2014) has five thrusts:

- to digitize government services;
- develop telecommunications infrastructure for high-speed Internet;
- cultivate a 'digital culture' in the private sector;
- foster entrepreneurship; and
- improve the regulatory framework.

Digital Tunisia fixes the targets of achieving 50% mobile broadband penetration and increasing the value of digital exports from TND 950 million (*ca* US$ 344 million) to TND 5 billion (*ca* US$ 1.8 billion).

Internet penetration has increased fairly rapidly since the approval of the strategy in 2014 (Figure 17.1), since only 44% of Tunisians had Internet access in 2013.

Paid leave for budding entrepreneurs

Parliament unanimously passed the Start-up Act into law in April 2018. It provides a number of legal and financial incentives for qualifying early-stage enterprises, such as corporate tax exemptions and mechanisms for financial support. About 250 start-ups have received support, financial or otherwise, within the framework of this act.

The Start-up Act raises the ceiling of the Technology Card, which allows for remote currency transactions, from €3 380 to € 33 800. It is also purportedly the world's first legal framework to grant aspiring entrepreneurs year-long leave, extendable to two years, to set up a new business. This opportunity is open to both public and private sector employees. A state-funded salary is to be provided during the first year of the business' operations (INSME, 2020; OBG, 2019).

In June 2019, the World Bank committed to a US$ 175 million loan for two projects. The first of these runs to 2026. It is providing funds for equity and quasi-equity investment in SMEs and start-ups, along with support for incubators and accelerators. The second project, running to 2025, is financing the digitization of social security and education systems. The Ministry of Communication Technologies and the Digital Economy is overseeing the implementation of these twin projects (World Bank, 2019d).

Most of Tunisia's international scientific collaboration takes place under the umbrella of EU co-operation programmes, through bilateral projects with European partners (Figure 17.4). For instance, within the Horizon 2020 framework, a support programme on the green economy and climate change was launched in 2017. Tunisia has achieved a success rate of 18% for Horizon 2020 project proposals, according to the MESRS, which is higher than the average for EU countries. Under the Erasmus+ programme, 12 new capacity-building projects were launched in 2017 and a funding agreement was put in place.

UNITED ARAB EMIRATES

Tomorrow 21

The *UAE Centennial Plan 2071* (2017) will kick off in 2021. It has four pillars:

- a future-focused government;
- excellent education, with a focus on science and technology, space science and engineering;
- a diversified knowledge economy; and
- a happy and cohesive society.

As a constitutional federation, the emirates that make up the UAE have their own strategic frameworks, in additional to those at the national level. Counted among these is Abu Dhabi's *Ghadan 21* (*Tomorrow 21*) programme. Inspired by the volatility of oil prices since 2014, it was adopted in September 2018 to improve the business environment and foster economic growth to 2021. Ghadan 21 is an economic accelerator programme endowed with AED 50 billion (*ca* US$ 14 billion) in funding.

In its first year, *Ghadan21* oversaw an overhaul of the emirate's business licensing framework and the launch of Hub71, an ICT cluster funded to the tune of AED 1 billion (*ca* 272 million). Hub71 provides start-ups with funding, office space, health insurance and subsidized housing; it is the fruit of a collaboration between the government-run Mubadala Investment Company and tech-focused multinational corporations such as Microsoft (USA) and Softbank (Japan).[39]

The *Abu Dhabi Economic Vision 2030* (2008) remains the emirate's blueprint for diversifying the economy through investment in the following priority sectors where the emirate has a comparative advantage: tourism, manufacturing, health care, logistics, financial services, education, aerospace and telecommunications.

There are signs that the strategy is beginning to pay off. Non-oil goods accounted for 19.5% of Abu Dhabi's total trade in goods in 2018, a marked improvement on the 3.9% share from 2010. As of 2019, construction is the largest non-oil sector, followed by finance and manufacturing (OBG, 2020).

Food and energy security a priority

In April 2020, the Abu Dhabi Investment Office, a government body founded in 2018 to support start-ups and SMEs, announced plans to allocate US$ 100 million to four agritech firms as an initial investment in a larger US$ 272 million programme in support of agritech. The four firms are developing an indoor tomato farm (Madar Farms); a research centre (Aerofarms); an irrigation system compatible with sandy soil; and more efficient fertilizers (Peters, 2020).

The country's *Energy Strategy 2050* (2017) aims, *inter alia*, to raise the contribution of non-fossil fuels to 44% of the energy mix, leaving natural gas (38%), 'clean' coal (12%) and nuclear power (6%) to make up the remainder.

With the start-up of its first reactor in August 2020, Barakah has become the first operational nuclear power plant in the Arab region. The plant is the fruit of a joint venture since 2009 with a consortium led by the Korea Electric Power Corporation which is building four commercial reactors in Barakah totalling 5.6 GW. Upon completion, the Barakah plant is expected to meet about one-quarter of the country's electricity needs.

The *Dubai Clean Energy Strategy 2050* (2015) sets the target of supplying three-quarters of the emirate's total power supply from nuclear and renewable energy by 2050. According to the Dubai Electricity and Water Authority (DEWA), solar power accounted for 9% total energy generation by 2020, thanks largely to the Mohammed Bin Rashid Al Maktoum Solar Park (E&U, 2020b).

In 2016, DEWA launched the Dubai Green Fund. It invests directly in environment-focused businesses, including through loans with advantageous interest rates. In 2017, the fund raised AED 2.4 billion (*ca* US$ 650 million) to support 'green' companies (DEWA, 2018).

More researchers and expenditure

Vision 2021 (2010) set ambitious goals for the country, such as tripling research expenditure and ranking in the top ten of the Global Innovation Index by 2021. It ranked 36th in 2019 (Figure 17.5). The target for research expenditure was achieved in 2018, however, when it amounted to AED 19.8 million, a 217% increase over 2010.

The UAE has reached out to foreigners to boost its endogenous research capacity. In 2019, it introduced the Gold Card Visa scheme, which grants residency to foreign scientists, researchers and doctors. Even by 2018, the country had the highest number of researchers per million inhabitants in the Arab world (Figure 17.2).

Industry 4.0 a policy focus

The government launched the *UAE Strategy for the Fourth Industrial Revolution* in 2017. It outlines a vision of integrating Industry 4.0 technologies in key areas that include education, health, food security, urban planning and defence. In health, the strategy highlights personalized medicine, robotic health care and wearable and implantable technologies. To achieve food and water security, the focus will be on bio-engineering science and advanced renewable energy technologies.

Various tech companies operate from Dubai's free zones, which offer tax breaks and reduced customs duties. As of late 2019, Dubai Internet City (est. 2000) hosted about 1 600 companies (OBG, 2020); counted among them are the regional headquarters of multinationals including Microsoft and IBM.

In May 2018, the telecoms operator Etisalat inaugurated a commercial 5G network in the UAE, one of the first of its kind in the Arab region. Etisalat is rolling out its 5G with support from Huawei and Swedish tech company Ericsson (OBG, 2020).

The *Science, Technology and Innovation Policy* (2015) sets out 24 focus areas, including semiconductor process development; AI and robotics, the Internet of Things, big data; additive manufacturing (3D printing); and advanced materials for aerospace manufacturing, maintenance and testing. This policy indicates that *Vision 2021*, which identified STI and R&D as 'pillars of a knowledge-based, high productive economy', sets its own direction and 'purpose'.

In March 2020, DEWA opened a Research and Development Centre at the Mohammed Bin Rashid Al Maktoum Solar Park, which is exploring possible applications of 3D printing, in addition to research on solar photovoltaics (DEWA, 2020).

In October 2019, the government inaugurated its new AI Lab offering government employees access to computer services and training in how to use machine learning and predictive models to generate datasets.

The Chinese company UBTech Robotics, meanwhile, has allocated US$ 362 million to setting up AI teaching labs at more than 1 000 primary and secondary schools across the country (OBG, 2020). UBtech has developed a humanoid service robot that can complete household tasks, such as cleaning a tabletop.

The Dubai government aims to boost the use of electric vehicles by rolling out 42 000 electric vehicles across the country by 2030 and, in parallel, setting up a laboratory to build a community of users.[40] In 2015, DEWA launched the EV Green Charger Initiative to improve charging infrastructure for electric vehicles, which had been identified as a barrier to uptake. By October 2018, 200 charging stations had been established.

Towards a paperless, blockchain-powered government

The *Emirates Blockchain Strategy 2021* (2018) sets the goal of integrating this technology into half of government digital transactions by 2021 to cut processing costs and the volume of printed documents.

In the same vein, through the *Dubai Paperless Strategy*, the government aims to digitize all government services by 2021 and make these accessible via a single digital platform.

The Emirate of Dubai, meanwhile, is pursuing its own *Dubai Blockchain Strategy* to make it 'the first blockchain-powered government'. The public bodies Smart Dubai and the Dubai Future Foundation launched this initiative in late 2016. The following year, the Smart Dubai office announced that it would be striving to transition as many government services and transactions as possible to blockchain (OBG, 2018c).

A legal framework for the nascent space industry

With opportunities opening up globally in space transportation and space tourism, the UAE sees the space industry as a sector with considerable economic potential. In December 2019, the Space Law came into effect; it aligns the legislative and regulatory environment of the country's space sector with international treaties.

Several commercial satellites have been launched, including one assembled by the Mohammed bin Rashid Space Centre and launched in October 2018 from Japan's Tanegashima Space Centre. The most ambitious project thus far, however, is undoubtedly the Hope Probe's mission to Mars (Box 17.6).

The UAE also led the process to establish the Arab Space Cooperation Group, the Arab States' first regional body for space co-operation. At the signing of its charter in March 2019, the group comprised 11 Arab countries.[41] Its first project involves developing a climate-monitoring satellite, with the launch planned for 2022.

YEMEN

Places of learning damaged or destroyed

Yemen is enduring one of the world's worst ongoing humanitarian crises. Half of the population lives in areas directly affected by conflict that are deprived of such basic services as health care, education and energy (Box 17.1). The United Nations Office for the Coordination of Humanitarian Affairs estimates that 80% of the population requires some form of humanitarian assistance.

The premises of universities and affiliated centres have been either completely or partially destroyed (Seitz, 2017), further limiting Yemen's low research output (Figure 17.4). According to Yemen's Ministry of Higher Education, more than 43 government scientific centres affiliated with Yemeni universities have had to suspend operations, owing to damage to their facilities (Sarih, 2018).

Several non-profit organizations, including the Council for At-Risk Academics, the World Academy of Sciences and the Organization for Women Scientists in the Developing World, are lending a helping hand to scholars displaced by conflict, such as by assisting them in finding research positions abroad (Zakham and Jaton, 2019; see also The integration of refugee and displaced scientists creates a win–win situation, p. 20).

CONCLUSION

Common priorities, different strokes

Despite their socio-economic differences, the Arab States share common priorities. With water scarcity, soil erosion and environmental degradation all presenting serious challenges, more governments are embracing science-based solutions, such as indoor vertical farming and desalination. Countries have set strikingly ambitious targets for the development of renewable sources of energy, with several megaplants either planned or under development.

Another commonality has been the adoption of an ambitious digital agenda to modernize public services and foster innovation and entrepreneurship. Jordan, for instance,

Box 17.6: **Hope Probe heading for Mars**

Although the Emirati space programme is still in its infancy, the country has already established a space agency, designed a series of satellites and sent its first astronaut into space in little over a decade. On 14 July 2020, it launched the Hope Probe on a two-year mission to explore Mars' atmosphere and climate.

The UAE is partnering with leaders in space technology to realize its agenda. KhalifaSat, an Earth observation satellite, was designed in partnership with the Korean company Sartrec. It was launched in 2018 in Japan, using a rocket manufactured by Mitsubishi Industries. The Russian Soyuz spacecraft carried 36-year-old astronaut Hazza Al Mansouri to the International Space Station in 2019.

The Hope Probe lifted off from the Tanegeshima launch site in Japan on 14 July 2020. Although the Mars mission was funded by the United Arab Emirates Space Agency, the probe itself was designed and manufactured through a partnership between the Mohammed bin Rashid Space Centre and the Laboratory for Atmospheric and Space Physics at the University of Colorado Boulder in the USA.

This is the first mission to Mars by any Arab or Muslim-majority country. The probe's name reflects the government's hope that the mission will inspire more youngsters in the Arab world to study engineering.

Piloting the endeavour from the Mohammed bin Rashid Space Centre is deputy project manager and lead scientist Dr Sarah Al Amiri. She is also Chair of the United Arab Emirates Council of Scientists and Minister of State for Advanced Sciences in the Cabinet.

At 33 years of age, Dr Al Amiri is part of a new generation that is passionate about space science and technology. The average age of employees at the Mohammed bin Rashid Space Centre is 27 years and about four in ten employees are women. Most staff work in scientific and technical departments.

The space industry reflects the government drive towards an 'emiratization' of the country's skilled workforce. Two-thirds of the staff at Yahsat, the Abu Dhabi satellite communication company, are Emirati and half hold technical qualifications.

Source: adapted from Webster (2019)

has created a new ministry to implement its blueprint for the digital economy.

For the Gulf states, their digital agendas are part of a broad strategy to emerge from long-standing rentier systems by expanding non-oil sectors and fostering a knowledge economy. Saudi Arabia and the UAE figure among six Arab states which have established space agencies or related institutions. Along with Algeria, Egypt and Morocco, they are now operating their own satellites, although none has a rocket launching capability yet.

Algeria, Morocco and Tunisia, meanwhile, share the common goal of supporting manufacturing and assembly industries with high added value, with a focus on the aeronautics, automotive and electronics industries.

Governments recognize the transformative potential of the Fourth Industrial Revolution. Saudi Arabia and the UAE have dedicated strategic plans in place and at least four other countries – Egypt, Algeria, Morocco and Tunisia – have committed to developing the same. Strategies to develop artificial intelligence are a corollary of this approach. Several countries are also developing smart cities which, crucially, are also striving to be 'green'.

Innovation flourishes in an open environment

However, countries must take care not to attempt to run before they can walk. Before they can embrace the Fourth Industrial Revolution, they will need to train an endogenous skilled workforce, including a critical mass of technicians. The performance of Arab schoolchildren in international assessments suggests that education systems in the Arab States are weaker than those of their neighbours. This should be cause for concern.

The Fourth Industrial Revolution is disruptive, by definition. It is a product of the disruptive nature of knowledge and science. Decision-makers and educators must be prepared to nurture the young thinking mind, if they hope to build an endogenous culture of science and innovation.

The Arab world has an advantage over many other regions, in that it has a more balanced talent pool; women made up 43% of Arab researchers in 2018 (see chapter 3). The challenge now will be to remove the cultural obstacles that Arab women encounter on the path to leadership positions.

Another challenge concerns research funding. The past five years have witnessed a significant expansion in higher education yet, despite generous public funding for universities, the proportion allocated to R&D remains low. This has consequences: innovative technologies are not being developed or exported by Arab countries. Even when contract research from oil and gas companies provides universities with substantial funding, the fruits of this research tend to be self-serving, contributing little to wider society, or in terms of university rankings.

This signals that Arab universities need to depart from their traditional funding models for education to direct funds towards creating effective research communities whose output is of societal benefit. Only then will countries be able to participate fully in the Fourth Industrial Revolution.

Public investment in R&D should, first and foremost, serve to create viable research communities in the public and private sectors. Unless R&D targets capacity-building or problem-solving, it will remain a drain on resources. For example, R&D will be vital across the region to diversify the economy and the energy mix, as well as to ensure food and water security.

Overall, there is a need to embrace an interdisciplinary approach to problem-solving, to reap the full benefits of science. The current limited research output in the social sciences and humanities in some Arab countries may be impeding implementation of their development agenda.

There is also a need for universities to integrate, rather than segregate, students in the economic, scientific, engineering and literary streams, to ensure that future leaders all speak the same language. This physical proximity between students with complementary skillsets can have the added advantage of creating a fertile terrain for the emergence of innovative start-ups.

Blind spots in STI policy-making

Two-thirds of Arab countries have an explicit STI policy (Figure 17.6). These strategies tend to acknowledge the need to support R&D, promote commercialization and establish linkages with societal needs. However, achieving these goals will require investment in R&D, which is limited in all but three countries. In fact, over 2015–2018, most countries reporting data saw a dip in their investment levels (Figure 17.3).

Another vulnerability is the limited information available on the observed impact of policies, even though it is essential to ensure accountability and ground future policy-making in lessons learned from the past. Few countries collect regular data and, among those that do, surveys tend to exclude the business enterprise sector, creating a policy 'blind spot'.

There is, more generally, a chronic lack of attentiveness to the immense potential of science, technology and innovation. This manifests itself in a lack of specialized committees for science and technology in most parliaments, as well as the focus on supply, rather than demand – or, in other words, on inputs, rather than outputs. These inputs are, for the most part, sourced externally, suggesting the need to do more to develop an endogenous research base.

Even the region's most prosperous economies continue to rely massively upon the purchase of packaged technology inputs from abroad. There even appears to have been a regression in technology transfer in recent years. This complacency towards technological dependency augurs ill for the development of modern, innovative industries.

Experts can advise policy-makers on how to invest effectively in technology transfer but only as long as that advice does not fall on deaf ears. Such advisory mechanisms also need to be institutionalized, in preference to an ad hoc arrangement in times of crisis.

By appointing Covid-19 scientific committees, Arab governments have seen first-hand the advantages of being able to rely on local experts to monitor and control the progression of the virus. They should be encouraged to make such committees permanent fixtures. With their broad-based expertise, academies of sciences can play such a permanent role, providing political leaders with guidance as and when required.

A time for radical policy change

The combination of political turmoil, armed conflict, mass migration and the Covid-19 pandemic should provide impetus for radical policy change across the region. The lack of meaningful multisectoral reform over the past decade in some countries has led to economic stagnation, making the adoption of new governance models a necessity.

The young will not accept anything less than meaningful reform. Moreover, this process will need to be participatory, bringing together decision-makers in central government, local communities, civil society and the scientific community. Such a process should also call upon the diaspora, which has not been adequately consulted on new STI policies adopted in recent years.

One imperative for policy-makers will be to ensure that the implementation of this agenda benefits all segments of the Arab population. Currently, impoverished local communities find themselves largely left to their own devices when it comes to basic services such as education, health care, environmental protection and crisis management. The national voluntary reviews being undertaken by some countries should help to inform this reform process.

All that glitters is not gold

The measures taken by governments in recent years to combat high levels of youth unemployment, including among tertiary graduates, have been largely palliative, without due regard for analysing the structural causes of this chronic problem. Policy-makers are encouraged to adopt pragmatic, realistic projects that are of tangible socio-economic benefit for the population, in general, and youth, in particular.

Future policies will need to lay the foundation for fair, effective and informed management of public resources and improved basic services, with special emphasis upon quality education at all levels, health care services and much wider employment opportunities for youth, in particular, in both traditional and novel productive sectors. Some Arab countries have already taken a step in this direction by defining their central goal as that of improving citizens' welfare and the provision of basic services.

Failure to tackle these challenges will inevitably result in the further marginalization and alienation of vast segments of the Arab population.

The ongoing crises in countries such as Iraq, Lebanon, Syria and Yemen are a solemn reminder that, as long as instability persists, government attention will be absorbed by crisis management, relegating STI policy to the status of an afterthought.

KEY TARGETS FOR THE ARAB STATES

- Algeria is aiming to achieve 15 GW of installed electricity capacity from renewable sources by 2035;
- Egypt aims to expand the surface area of arable land by 18.8% by 2030;
- *New Kuwait 2035* aims to raise the share of renewables in electricity generation capacity to 15% by 2030;
- Bahrain set a target to 2021 to expand green space in its governorates by 50% over 2016 levels;
- Morocco aims to reduce greenhouse gas emissions by 17%, compared to the business-as-usual scenario;
- Oman's draft 2040 Vision sets the goal of raising the share of non-oil activities in the economy to 90%;
- Oman is seeking to raise the share of renewables in electricity generation to 10% by 2025;
- In Saudi Arabia, 40% of the local workforce is to have acquired basic skills in data and AI and 15 000 local specialists are to have been trained in these fields by 2030;
- Saudi Arabia plans to achieve 58.7 GW of installed power capacity from renewables by 2030;
- Sudan plans to devote 2% of GDP to R&D by 2030;
- The Dubai Clean Energy Strategy 2050 (2015) sets the target of supplying three-quarters of the emirate's total power supply from nuclear and renewable energy by 2050;
- Dubai's government services are to be fully digitized by 2021.

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ENDNOTES

1 See: https://tinyurl.com/pguardrobottunisia

2 This was reflected in Saudi Arabia's improved ranking in the United Nations Department of Economic Social Affairs' *E-Government Survey 2020*, where it moved up 9 places over the 2018 edition to rank 43rd. Bahrain leads the Arab region in this index.

3 With the exception of the score by Cyprus with regard to reading and related skills, scores by the Arab countries' neighbours, as well as average scores for all participating countries, exceed those attained by the Arab countries listed in this table.

4 See: https://timssandpirls.bc.edu/

5 See: https://www.ilo.org/beirut/areasofwork/labour-migration/lang--en/index.htm

6 A Royal Decree (#8) issued in January 2021 renamed the Oman Academic Accreditation Authority the Oman Authority for Academic Accreditation and Education Quality Assurance. Public and private schools and higher education institutions are to adhere to criteria set by this body, which is to report to the Council of Ministers.

7 According to the strategy, Saudi Arabia is well-positioned to become a world leader in data science and AI, given its portfolio of sectors 'with tech appetite', the investment capacity of the Public Investment Fund and the country's young population, which is 'deeply entwined with the digital economy'.

8 Egypt's population was estimated at 96 million people in 2017. At the current growth rate (2.6%), the population could exceed 130 million by 2030 (Arab Rep. Egypt, 2018).

9 See: https://tinyurl.com/y5t3x9ca

10 The themes of the consensus are: enabling technological ecosystems; dynamic educational systems for decent employment opportunities; technology-driven social inclusion; supportive governance; environmental sustainability; conflict mitigation and disaster risk reduction; and financing technology for sustainable development.

11 The list of 6 100 researchers consists of those recognized for their exceptional research performance, demonstrated by production of multiple highly cited papers that rank in the top 1% by citations for field and year. See: http://hcr.clarivate.com/

12 These indicators are presented in the summary report from the National Experts Meeting of 21 September 2016. See: https://www.cmimarseille.org/ar/node/3091

13 They are participating alongside thirteen other countries: Croatia, Cyprus, France, Germany, Greece, Israel, Italy, Luxembourg, Malta, Portugal, Slovenia, Spain and Turkey.

14 *Journal Officiel No. 54* of 14 September 2016

15 See: https://tinyurl.com/hassimessaoud

16 Bahrain ranked 4th in the United Nations Department of Social and Economic Affairs' 2018 global index for telecommunications infrastructure.

17 The first of their kind in the Gulf region, two initiatives implemented in Bahrain over the 2018–2020 period set out to make science education more enticing for the young: the Cleverplay project and the Compact Muon Solenoid experiment at the European Organization for Nuclear Research (CERN). Cleverplay targets primary school children and is Bahrain's first education service provider with a focus on science.

18 The Industrial and Commercial Bank of China is providing a US$ 3 billion loan for the construction of a central business zone in the New Administrative Capital.

19 This strategy focused on the following areas: medical services and pharmaceuticals; ICTs; clean technology; architecture and engineering services; education and career guidance services; and banking and financial services.

20 In 2015, Kuwait consumed 8.9 tonnes of oil equivalent energy per capita (OBG, 2019).

21 The CEDRE acronym stands for the Conférence économique pour le développement, par les réformes et avec les entreprises.

22 Over 2013–2017, the value of investments in digital enterprises in Lebanon reportedly increased from US$ 7 to US$ 53 million (ABI, 2017). In 2016, Circular 419 was issued; it allows banks to invest up to US$ 600 million collectively in Lebanese tech start-ups, equivalent to about 4% of the capital of Lebanese banks (ABI, 2018).

23 Located in the Beirut Digital District, the UK–Lebanon Tech Hub is a collaboration between the Banque du Liban and the British Embassy in Beirut. Established in 2014, the hub helps start-ups gain a foothold in European and global markets; it reported adding 1 370 direct and indirect jobs to the economy over 2014–2017 (BW, 2017).

24 According to its administrators, the Lebanese National Observatory for Women in Research will study the experiences of female researchers and identify barriers they face; evaluate and streamline the research output of Lebanese women through targeted conferences and seminars; and allocate funds to support research programmes related to women, among other things.

25 See: https://tinyurl.com/European-neighbourhood-Libya

26 The UNESCO AI Forum for Africa, held in Morocco in December 2018, recommended holding regional fora on artificial intelligence across Africa, in the Statement issued on the outcome. The first regional forum covering East Africa was initially planned for Kenya in 2020 but has been postponed to 2021, due to the Covid-19 pandemic. Read the Statement: https://tinyurl.com/AI-forum-Africa-Statement

27 See (in French): https://tinyurl.com/university-industry-partners

28 In September 2019, the Euromed University in Fes opened a School of Digital Engineering and Artificial Intelligence, in partnership with the Polytechnic School in France (Mejri, 2020).

29 As of June 2020, the ICT Group comprises four public sector companies: the Oman Broadband Company, the Oman Technology Fund, Space Communication Technologies Company and Oman Tower Company.

30 See: https://projects.worldbank.org/en/projects-operations/project-detail/P164412

31 The Qatar Foundation for Research, Development and Innovation, Qatar National Research Fund and National Natural Research Foundation remain the top funding agencies for scientific research in Qatar. The country's Science and Technology Park is part of the Qatar Foundation for Research, Development and Innovation.

32 The Qatar Science and Technology Park hosts the Gulf Organization for Research and Development and the Qatar Mobility Innovation Centre, as well as multinational corporations that include ConocoPhillips, Cisco and Siemens.

33 This fund complements the Saudi Industrial Development Fund (OBG, 2020).

34 Saudi Arabia ranked 13th out of 175 countries in the International Telecommunication Union's 2018 Global Cybersecurity Index, with a particularly strong performance in capacity building and co-operation.

35 This policy began during the rule of the late King Abdullah bin Abdulaziz Al Saud, who was a strong proponent of education and research (Zou'bi *et al.*, 2015).

36 The other sectors are: water resources and irrigation systems, telecommunications, creating an enabling environment, building and construction, transport, social and cultural development, local and regional development, finance, tourism, population, environment.

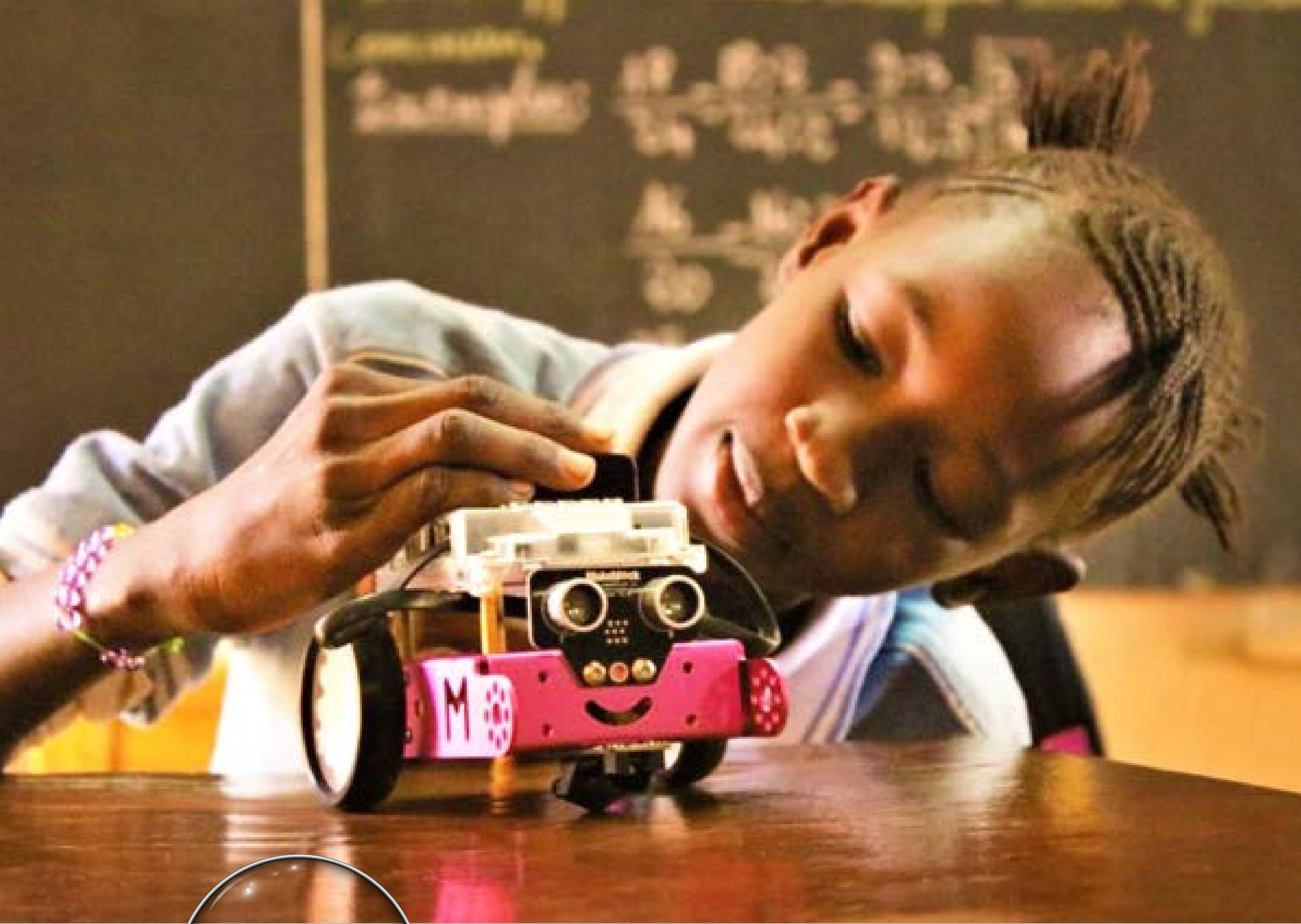
37 The full title of Tunisia's PAQ–PAES programme, in French, is Programme d'Appui à la Qualité–Pré-Amorçage et Essaimage Scientifique. PAQ is a programme of the Ministry of Higher Education and Scientific Research.

38 Technology transfer offices were established in 2015 at the Universities of Monastir, Sousse, Sfax, Gabes, Carthage and Jendouba (UNESCWA, 2017b).

39 Abu Dhabi's Ghadan 21 (Tomorrow 21) programme has also allocated AED 9 billion (ca US$ 2.4 billion) to a scheme that guarantees up to 70% of the value of domestic bank loans to domestically owned SMEs (OBG, 2020). SMEs account for 90% of employment in Abu Dhabi; the government is seeking to expand their contribution to the economy from 16% (2018) to 23% (2021) of GDP (OBG, 2020).

40 With Directive #1 of 2016, the Dubai Supreme Council of Energy set the target of raising the proportion of electric and hybrid vehicles to 10% by 2030. See: https://tinyurl.com/DEWA-EVGreencharger

41 Membership of the Arab Space Co-operation Group comprises Algeria, Bahrain, Egypt, Jordan, Kuwait, Lebanon, Morocco, Oman, Saudi Arabia, Sudan and the UAE.



Workshop in robotics and coding at RobotsMali. Inaugurated in March 2018, this educational centre for children, teenagers and university students also runs courses on artificial intelligence, electronics and the Internet of Things. Classes are also offered in entrepreneurship, marketing, design and project management.

AT A GLANCE

- Faced with increasingly capricious weather patterns that are playing havoc with food security, West African countries are developing expertise in climate science with the support of international partners.
- With the African Continental Free Trade Area on the horizon, countries are racing to restructure their economies and modernize infrastructure. Electrification is a key element of this strategy, with numerous projects under way to develop solar power.
- Through their digital agenda, countries such as Cabo Verde, The Gambia, Ghana, Nigeria and Senegal are preparing for the day when much of intra-African trade may take place on the Internet, including through the creation of locally led data centres.
- With more than half the population below the age of 20 years, governments are investing in physical and virtual universities to cope with the growing demand for higher education.
- Ghana, Côte d'Ivoire, Nigeria, Mali, Senegal and Togo are hosting a growing number of technology hubs but these are struggling to raise sufficient capital.

18 · West Africa

Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, The Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo

George Essegbey, Almamy Konté, Natewinde Sawadogo and Willie Siyanbola

INTRODUCTION

The region's biggest economy slows

West African economies have performed quite creditably since the end of the commodities boom in 2014. Several even posted some of the highest growth rates in Africa in 2019 (Figure 18.1). The notable exceptions are Liberia (-2.3%), which is still recovering from the Ebola outbreak of 2014, and the region's biggest economy, Nigeria (2.2%), which alone accounts for two-thirds of the subregion's GDP and half its population. At the time of writing (mid-2020), it is not yet possible to determine the impact of the Covid-19 pandemic on West Africa.

Nigeria's economy slumped between 2015 and 2018 (Figure 18.1). Oil receipts plummeted in the face of vacillating global markets for crude oil and faltering oil production resulting from poor environmental management in the Niger Delta. In parallel, the economy of the three northern geopolitical zones has been paralysed by growing insecurity tied to the Boko Haram insurgency, tensions between herdsmen and farmers, banditry and kidnapping.

By contrast, the relatively high level of exports of goods and services in 2019 for Benin, Cabo Verde, Ghana and Guinea, in particular (Figure 18.1), signals a drive by these countries to lessen their dependence on primary commodities by diversifying the economy through industrialization and value addition in extractive industries. Big challenges remain, however, with regard to digital and physical infrastructure (roads, railways, etc.), industrial capabilities and innovation.

Will the planned adoption of a single currency boost intraregional trade? Sylla (2019) suggests that the decision by the Economic Community of West African States (ECOWAS) in June 2019 to adopt the 'eco' is premature. Noting the asymmetry of ECOWAS economies, he observes that just 5% of exports contribute to intraregional trade among members of the Central African Economic and Monetary Community, despite more than 70 years of sharing the CFA franc.

STATUS OF REGIONAL ECONOMIC AND SCIENTIFIC INTEGRATION

Continental Free Trade Area taking shape

At the continental level, too, intra-African trade remains modest, even if it is growing. Intra-African exports accounted for 17% of total African exports in 2017 (UNCTAD, 2019), compared with 68% in Europe and 59% in Asia.

This could change with the advent of the African Continental Free Trade Area (Essegbey *et al.,* 2015). The continent took a monumental step towards realizing this dream in July 2019, when Nigeria officially signed up to the project.

Now that all 54 African countries are on board, the project can enter its operational phase. The ultimate goal is to create the world's biggest single market for goods and services and customs union, with freedom of movement extending to people and capital – something that would be good news for the continent's scientists and engineers.

The entry into force of this agreement should remove barriers to investment and trade, including in agricultural goods and the digital market.[1]

Two agreements adopted in the capital of Equatorial Guinea in 2014 lay the groundwork for this metamorphosis: the *Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods* and the *African Union Convention on Cyber Security and Personal Data Protection* (the *Malabo Convention*).

Rising food insecurity prioritizes commitments

This is not the first time that the African Union (AU) has committed to greater investment in agriculture – the *Malabo Declaration* comes on the heels of the *Maputo Declaration* in 2003, which established a Comprehensive Africa Agricultural Development Programme. It *is* the first time, however, that the AU has established a country scoreboard. This scoreboard contains no fewer than 43 indicators for measuring progress towards the *Malabo Declaration's* targets to 2025. Four of these figure in Table 19.2.

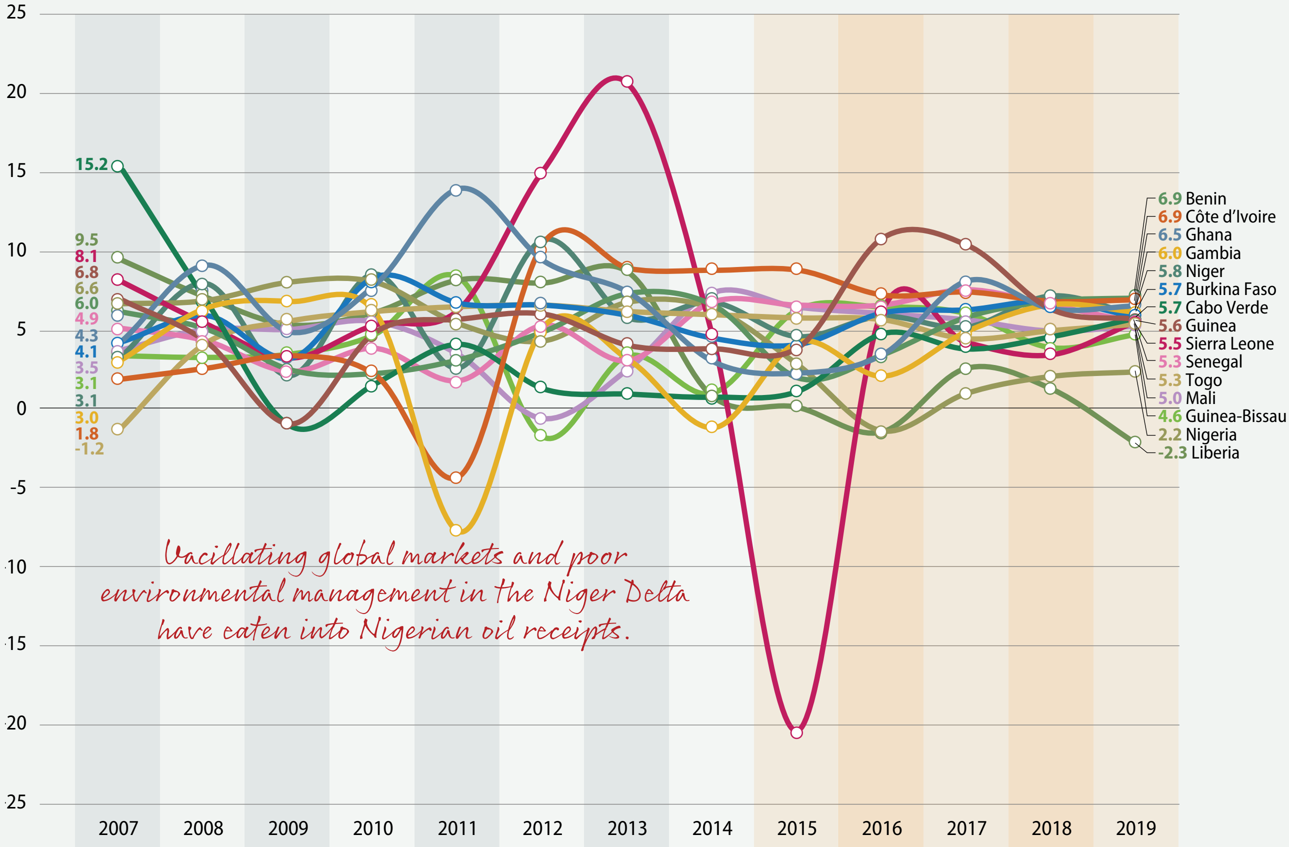
A first *Biennial Review Report and Scorecard* was presented to the AU's General Assembly in January 2018. It found that 20 out of 47 countries were on track to fulfil the commitments of the *Malabo Declaration*, which include 'ending hunger, tripling intra-African trade in agricultural goods and services, enhancing the resilience of livelihoods and production systems, and ensuring that agriculture contributes significantly to poverty reduction'.

The AU Commissioner for the Rural Economy and Agriculture, Josefa Sacko, commented that the scoreboard corroborated the findings of the 'recent status report on food security, which show that the numbers of food-insecure people are increasing in Africa' (AU, 2018). She was referring to a 2017 report which observed a rise in the prevalence of hunger in Africa, after many years of decline (FAO, 2017). The 2018 edition of the same report confirmed the trend, observing that Central and West Africa were faring the worst and that, 'today, a fifth of Africans are undernourished' (FAO and UNECA, 2018).

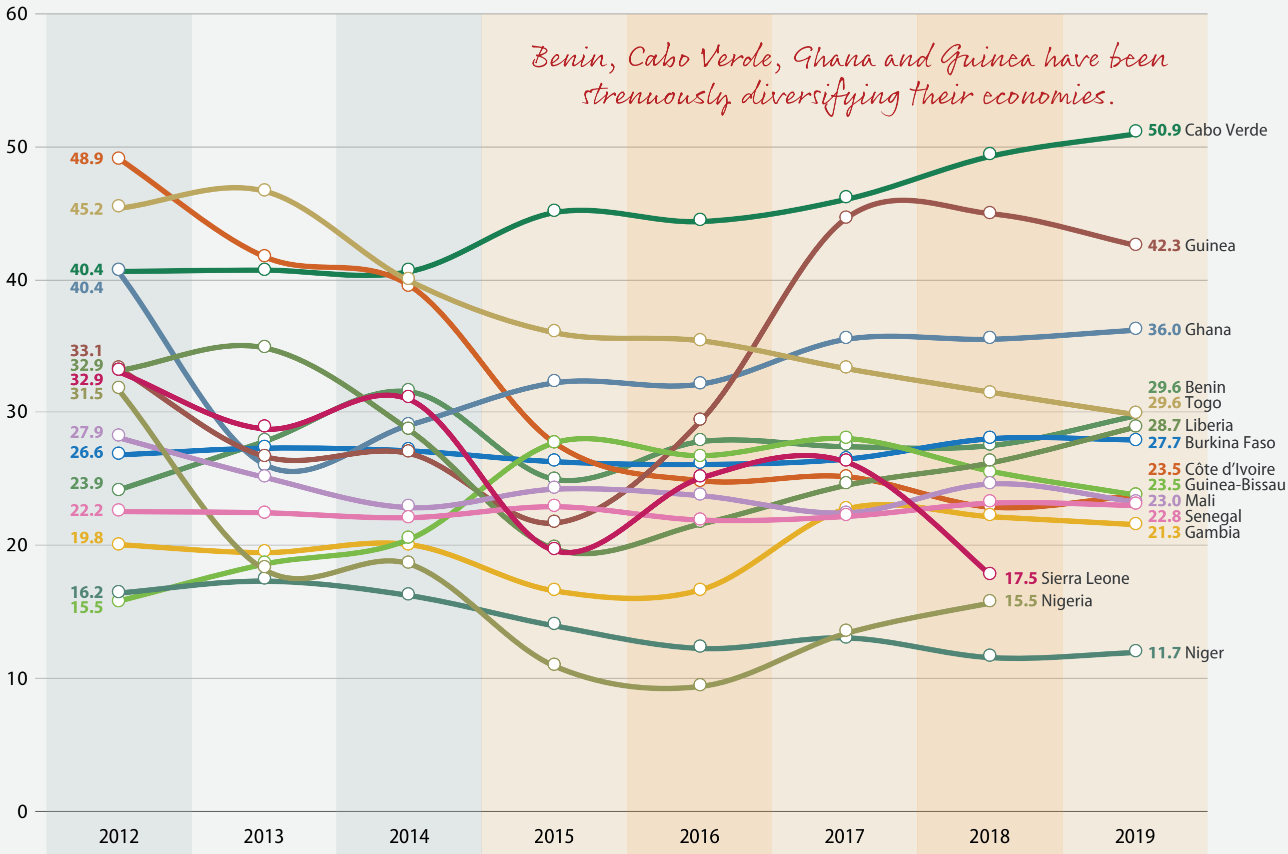
The report attributed this deterioration to a slowdown in economic growth in 2016, owing to weak commodity prices for oil and minerals, in particular, as well as 'worsening environmental conditions and, in many countries, conflict and climate variability and extremes, sometimes combined.'

Figure 18.1: **Economic trends in West Africa**

Rate of economic growth in West Africa, 2007–2019 (%)



Exports of goods and services as a share of GDP in West Africa, 2012–2019 (%)



Source: World Bank's World Development Indicators, August 2020

High fertility rates threaten sustainability

West Africa has the highest fertility rate on the continent (Table 19.1). Slower population growth would put less pressure on natural resources, as well as on countries' education, health and agricultural systems.

Meeting in Ouagoudougou, Burkina Faso, on 22 July 2017, the presidents of the national parliaments of ECOWAS members issued a joint declaration with Chad and Mauritania inviting their member states to lower fertility rates to three children per woman by 2030, by extending access to family planning, combating early marriages and lowering child mortality.

The declaration acknowledged the potential for economic growth of the 'demographic dividend' but only as long as the fertility rate could be *maîtrisée* (brought under control). Failing that, the signatories noted, the high fertility rate risked compromising countries' chances of reaching their Sustainable Development Goals (SDGs).

The *Declaration of Ougagdougou* also recalled the commitment ensconced in the AU's 2001 *Abuja Declaration* for the continent to devote at least 15% of the national budget to health care and urged its members to reach this target by 2025. So far, Sierra Leone alone has achieved this ratio (see Table 19.2).

Internet access a gateway to the digital marketspace

Once up and running, the Continental Free Trade Area will bring opportunities for the development of a digital market, with much of intra-African trade likely to take place on the Internet (Samme-Nlar, 2018).

Currently, fewer than one in five people have Internet access in two-thirds of ECOWAS countries, even though penetration rates have risen since 2013 (Essegbey *et al.,* 2015, see Table 19.2). Three countries have made great strides in just four years: Cabo Verde (from 38% to 57% penetration), Côte d'Ivoire (19–47%) and Ghana (15–39%) [see Table 19.2].

The majority of West African countries have now adopted a domestic 'digital agenda' which prioritizes accelerating Internet penetration and digitalizing the economy and public services. For instance, the Nigerian government renamed the Ministry of Communication Technology the Ministry of Communications and the Digital Economy in October 2019 to reflect its commitment to embarking on a large-scale digital literacy programme to make Nigeria a regional hub for software engineers and services.

A focus on protecting digital data

For digital businesses to flourish, they will need to be able to collect and move personal data, such as bank details, billing addresses and customer names. This continent-wide digital trade will have to be regulated, in order to protect personal data and computer software and hardware. This is the intention of the *Malabo Convention* (2014). For the convention to enter into force, 15 African countries will need to ratify it. As of May 2020, only eight had done so: Angola, Ghana, Guinea, Mauritius, Mozambique, Namibia, Rwanda and Senegal. A further 11 have signed the *Convention*.[2]

The *Malabo Convention* calls on countries to develop regulations to protect domestic data. Currently, there is no unified approach (Samme-Nlar, 2018). A 2015 survey by the AU Commission found that only eight states had a national strategy on cybersecurity, 11 had cybercrime laws and 13 a national computer emergency response team.

By definition, data protection needs to cross borders. The lack of harmonized data regulations across the continent makes it difficult for both domestic and multinational organizations to comply with those regulations already in place.

This has implications for the development of companies that rely heavily on data, such as Google, which set up Africa's first centre for artificial intelligence (AI) in April 2019 (see p. 483).

In May 2018, the AU Commission published *Privacy and Personal Data Protection Guidelines*, which it had developed jointly with the Internet Society. These guidelines set out 18 recommendations for different stakeholders, including from an Africa-wide perspective (Samme-Nlar, 2018). The guidelines followed a memorandum of understanding between ECOWAS and the International Telecommunications Union in June 2015 to elaborate regional cybersecurity initiatives through ECOWAS.

An *African Digital Transformation Strategy*

In October 2019, African ministers with a communication portfolio adopted the *Sharm El Sheikh Declaration* proposing a continental *African Digital Transformation Strategy*.[3] Ministers urged member states to consider this strategy as the continent's common digitalization agenda, with a Digital Single Market by 2030. They invited member states to ratify the *Malabo Convention* and to set up a cashless financial system to nurture online marketplaces and combat corruption.

Member states were also urged to establish a working group on AI and to adopt a common African stance on AI. Ministers proposed setting up a think tank on AI to assess and recommend collaborative projects aligned with *Agenda 2063: the Africa we Want* and the Sustainable Development Goals.

Regional science policy making a difference

In 2012, the ECOWAS Commission adopted an all-encompassing *Policy on Science, Technology and Innovation* (ECOPOST) to 2020, accompanied by an *Action Plan* (Essegbey *et al*., 2015). ECOPOST was originally crafted to run parallel to the region's *Vision 2020* document but its lifespan has since been extended to 2024 to coincide with the expiry date of the AU's *Science, Technology and Innovation Strategy for Africa* (STISA–2024) and to reflect the rapidly evolving landscape for science, technology and innovation (STI) in the region and globally.

One of the key recommendations of ECOPOST has been the establishment of the ECOWAS Academy of Sciences. This decision was ratified by the conference of ministers from the subregion in December 2018. Concept notes have since been developed and a technical meeting bringing together national academies of sciences was planned for 2020 to finalize plans for the West African Academy of Sciences. Once in place, the new institution will host another project, the creation of the ECOWAS Journal of Science, Technology and Innovation.

Elusive sustainable funding for research

One key issue for West Africa concerns how to ensure sustainable research funding. Although the AU established the African Scientific and Research Innovation Council in

Abuja in January 2016, it serves purely as a technical advisory body to support implementation of *STISA-2024*.

In Abidjan, in November 2017, members of African academies of science, university rectors and heads of research institutes had appealed to policy- and decision-makers attending the AU–EU Summit to create an African Research Council to ensure sustainable research funding (MESRS, 2018a).

Another issue is the dearth of reliable statistics on research and development (R&D). At the request of the ECOWAS Commission, the African Observatory of Science, Technology and Innovation (AOSTI) has compiled datasets on scientific publications and patenting in the subregion (AOSTI, 2016; 2020).

Further to the recommendations of science ministers from the region, the ECOWAS Research and Innovation Support Programme (PARI) has been created to provide a platform for collaboration and networking among researchers and facilitate their mobility, while also encouraging them to design solutions to common problems.

PARI contributes to *STISA-2024*, the AU's *Agenda 2063* and *Agenda 2030 for Sustainable Development*. Since 2018, PARI has awarded an annual grant to researchers from the subregion through a rigorous competitive process. To qualify for a grant, the team must include researchers from at least two of the three blocs of English-, French- and Portuguese-

Box 18.1: **Building research capacity to tackle climate change in West Africa**

The programme for a West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) is the fruit of a partnership between the ECOWAS Commission and the German government since 2012. Funded by the German Federal Ministry for Education and Research, WASCAL is co-ordinated by the Centre for Development Research at Bonn University and headquartered in Accra (Ghana).

WASCAL aims to become a leading provider of climate services to West Africa, by strengthening research infrastructure and research capacity in multidisciplinary fields. There are three main thrusts: a Climate Research Programme, a Graduate Studies Programme and the establishment of observation networks.

The Climate Research Programme focuses on sustainable agriculture and climate-smart landscapes, vulnerability to climate extremes, the land-use, land-cover and land-degradation nexus and rural–urban and cross-border migration.

The Graduate Studies Programme has established MSc and PhD programmes in climate science at selected universities in the ten participating West African countries: Benin, Cabo Verde, Côte d'Ivoire, The Gambia, Ghana, Mali, Niger, Nigeria, Senegal and Togo (Figure 18.2). Several of these universities host centres of excellence (Table 18.1). The programme pools expertise, with staff exchanges between the West African institutions and their affiliates in Germany. By 2017, it had produced 258 graduates at PhD and master's levels, according to the 2018 *Annual Report*.

The observation networks are being established by WASCAL's Competence Centre in Ouagadougou (Burkina Faso), which is also developing a range of data products and services: high-resolution climate simulations over West Africa; land-surface and land-use data, as well as other products derived from remote sensing; and climate data and scenarios derived from climate modelling. One challenge with existing climate models is how to downscale them to local levels for greater accuracy.

The observation networks are multidisciplinary. For instance, the Climate Service Unit at the Competence Centre has been charged with setting up an observation network in participating countries to amass quality information on weather and the hydrological cycle, as well as changes in land use and biodiversity and human coping strategies.

The Competence Centre also provides vital infrastructure. It is equipped to receive satellite data from the remote sensing observation network, for example. Among its less sophisticated research equipment are sensors used by the 50 automatic weather stations in the region, or the soil moisture probes that have been providing continuous measurements since 2012. The collected data are shared with the national weather services of participating countries, upon request.

In 2017, WASCAL scientists and alumni launched an annual book series on regional climate change to inform policy-makers. The first volume focused on flooding, with chapters on the physical science basis of climate hazards, community vulnerability and response strategies.

In April 2018, WASCAL launched a pilot project in Climate Change and Renewable Energy in Accra (Ghana) and Lomé (Togo). Feasibility studies were conducted, in collaboration with Ghana's Council for Scientific and Industrial Research and the University of Lomé to evaluate the potential of solar energy, biomass, hydropower and hybrids in these two countries.

The pilot project also analysed the institutional framework in Togo and Ghana, as well as the impact of climate change on the resource base and the best options for effective greening of the economy in rural areas. The findings have provided policy-makers with evidence-based information for the ongoing development of sustainable renewable energy programmes in these countries.

It is hoped to extend this pilot project to other WASCAL countries – and to convince the remaining five members of ECOWAS to participate in the broader WASCAL programme.

WASCAL has a sister centre based in South Africa, the Southern African Scientific Service Centre for Climate Change and Adaptive Land Management (SASSCAL). Also launched in 2012 and supported by Germany, it involves Angola, Botswana, Namibia, South Africa and Zambia.

Source: adapted from wascal.org

speaking member states and the research must be multi- or transdisciplinary.

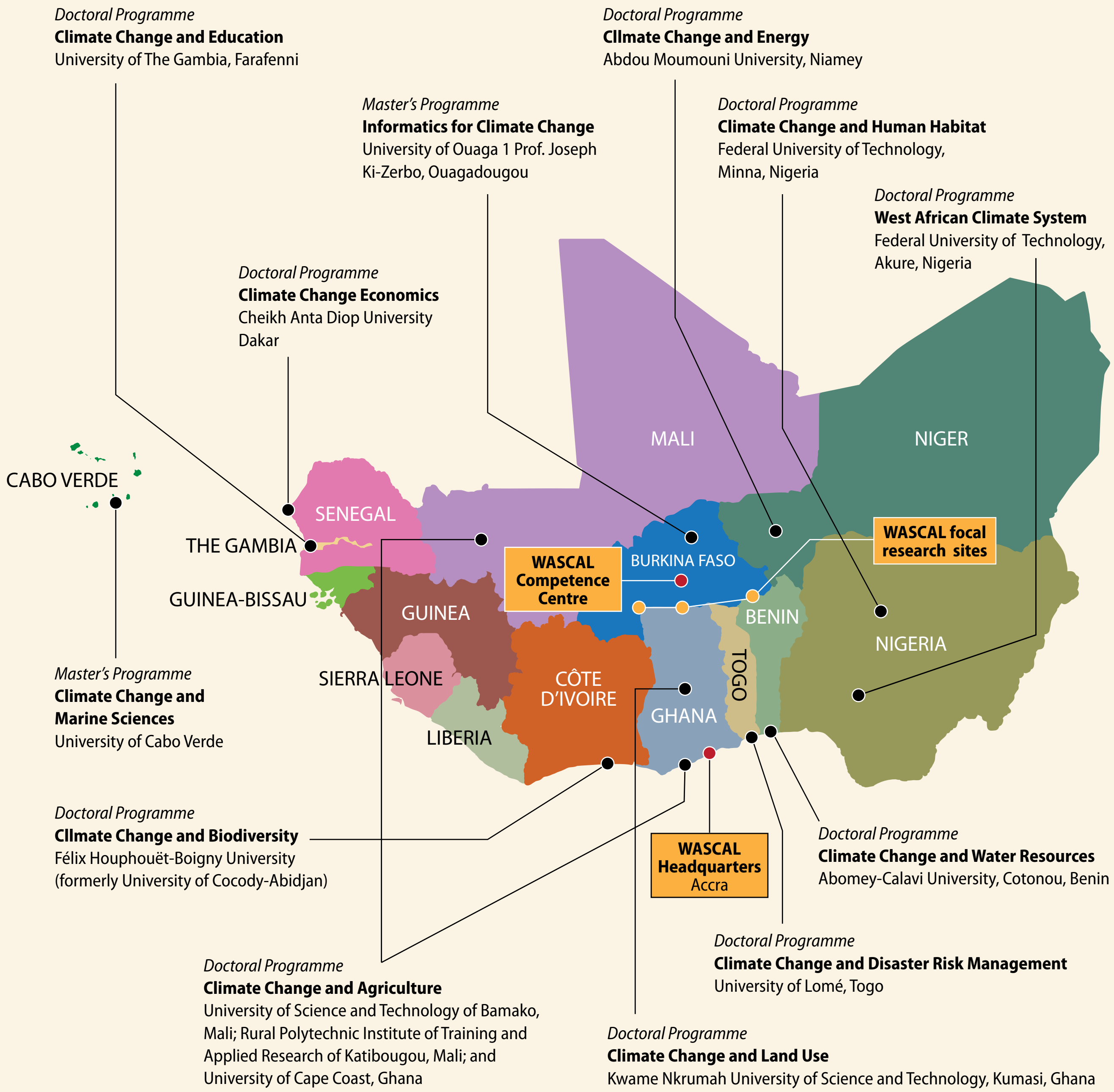
A single PARI grant for US$ 100 000 and two grants of US$ 150 000 each were awarded in 2018 and 2019, respectively. The ECOWAS Commission plans to increase the value of each grant to US$ 200 000 in 2020.

In 2012, the ECOWAS Commission signed an agreement with the German government establishing the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL), in order to further implementation of both *ECOPOST* (2012) and the *ECOWAS Agricultural Policy* (2005), which are closely linked (Box 18.1).

The ECOWAS Commission is also investing in an Earth observation satellite in collaboration with the Nigerian National Space Research and Development Agency (NASRDA). ECOWAS and NASRDA signed a Memorandum of Understanding in 2017 which resulted in the formulation of the ECOWAS *Strategy on Space Sciences and Geomatics*.

In 2018, the ECOWAS Centre for Renewable Energy and Energy Efficiency, hosted by Cabo Verde, launched a project aimed at Improving the Governance of the Renewable Energy and Energy Efficiency Sector in West Africa, in co-operation with Deutsche Gesellschaft für Internationale Zusammenarbeit and with the financial support of the European Union and Germany.

Figure 18.2: **The Graduate Studies Programme of the West African Science Service Centre on Climate Change and Adapted Land Use**



Centres of excellence turning out graduates

Since 2014, some 22 centres of excellence have been established in selected member states, thanks to US$ 500 million in World Bank loans (Essegbey *et al.,* 2015). The original 19 were joined by three institutions in Côte d'Ivoire in 2016. More than 21 000 students have, so far, enrolled in the programmes offered by these centres (Table 18.1).

The project has also contributed a great deal towards enhancing research and education infrastructure. In March 2019, the World Bank (2019a) approved a total of US$ 143 million in International Development Association credits and grants to help Burkina Faso, Djibouti, Ghana, Guinea and Senegal step up the quality and provision of applied research and higher education in science, technology, engineering and mathematics (STEM).

In another project, this time led by UNESCO, eight West African universities were provided with infrastructure for information and communication technologies (ICTs) between 2012 and 2015.[4] Each campus received a lab equipped with at least 200 computers, a data centre, high-speed Internet access (fibre-optic communicaton), universal portals to manage the academic credits accumulation and transfer service system, a print on demand facility, a publishing unit and training for technicians. The project also created a regional virtual library and a virtual higher education institute offering online lectures (UNESCO, 2016).

SCIENCE POLICY ISSUES

Most countries now have explicit STI policies

A mid-2019 assessment by the ECOWAS Commission found that countries had implemented about 70% of ECOPOST, based on progress reports received from ten of them. In most countries, STI tends to be part of a broader ministerial portfolio but Nigeria has a dedicated Ministry of Science and Technology. In Liberia, STI is still handled by the Ministry of Education (Figure 18.3).

Since the adoption of ECOPOST in 2012, a growing number of West African countries have formulated STI policies linked to their national development plans. Only six of them are yet to develop an explicit STI policy (Figure 18.3). Sustainable development is the underpinning vision, which would appear to be an effort to synchronize the AU's *Agenda 2063* with the global *Agenda 2030 for Sustainable Development*.

What remains to be seen is whether the level of commitment to mobilizing and investing the requisite public resources can translate these intentions into reality. Currently, only Burkina Faso (0.61% of GDP in 2017) and Senegal (0.58% of GDP in 2015) are approaching the AU's target of devoting 1% of GDP to research and development (R&D) [Figure 18.4]. Recent data are unavailable for most West African countries, despite the key role these data play in decision-making.

Rising isolationism hastens need for financial autonomy

Another concern is the rising conservatism in global politics and deepening trend towards introspective policies in some of the advanced countries which have traditionally been sponsors of training in Africa. This trend suggests that African countries need to be more proactive in funding capacity-building and research themselves, rather than relying on external support to such a large extent. This is all the more urgent in the face of the widening technological gap, as convergent technologies such as bionanotechnology, robotics or bioinformatics evolve at breakneck speed in advanced countries, fuelled by big data, highly trained computer scientists and supercomputers. IBM researcher Tapiwa Chiwewe has observed that, even in South Africa where he is based, few computer departments at universities are doing research on AI (see Box 20.4).

Data collection is still not a priority for many West African countries. Only five have published data since 2015 on researcher density, despite this being one of the two indicators for SDG9.5, along with the ratio of gross domestic expenditure on R&D (GERD) to GDP. The data reveal a leap in Senegal between 2010 and 2015 in researcher density. Senegal also counts the highest share of women in the research pool (Figure 18.4; see also Chapter 3).

Scientific productivity has grown in most countries since 2015. This is particularly true for Ghana, which leads the region for publication intensity. There has also been a notable rise in Nigeria[5] and in the countries affected by Ebola outbreaks in 2014 (Guinea, Liberia and Sierra Leone), which publish mostly in health sciences (see Figure 2.1).

Generally speaking, there is still little scientific output in agriculture and geosciences, despite the importance of farming and mining for many countries (Figure 18.5). The low level of patenting by residents of Ghana and Nigeria, the region's economic powerhouses, reflects the low commercialization of research results and limited returns on innovative activity (Figure 18.5).

A first mega-incubator

The number of tech hubs in Africa has more than doubled since 2016 to 744 (see Figure 20.2). Almost half of these are located in just five countries: Egypt, Kenya, Morocco, Nigeria and South Africa. This impressive growth and the perceived potential of Africa's tech hubs has attracted interest from the likes of Google, Facebook, Goldman Sachs, Y Combinator, Rocket Internet and the World Bank (Kazeem, 2019).

In spite of the influx of seed funds and grants, many tech hubs are still struggling to raise sufficient capital. The near absence of local business angels and seed capital remains the biggest challenge. For instance, in Nigeria, almost 80% of investment in tech hubs comes from offshore sources. This dearth of investment, according to Coetzee (2019), is related to three phenomena: local investors prefer traditional, straightforward investments in real estate and struggle with the concept of software space and international investors fail to understand local needs.

Weak Internet connection also poses a big challenge; broadband penetration remains very low (see Table 19.2), particularly outside urban areas. This problem is compounded by an unstable power supply and policy environment. Tech hubs also need a clear idea of their *raison d'être*, be it creating jobs, developing digital skills, facilitating foreign direct investment, or a combination of these.

Figure 18.3: **Status of STI policy development in West Africa, 2019**

CABO VERDE

STI policy
(No explicit STI policy)

Related policies and/ or funds
- *Strategic Plan for Sustainable Development* (2017–2021)

Ministry responsible for STI
- Ministry of Education (via Office of Science, Technology and Innovation)

THE GAMBIA

STI policy
- *National Science, Technology and Innovation Policy* (2015–2024)

Related policies and/ or funds
- *National Development Plan (2018–2021)*

Ministry responsible for STI
- Ministry of Higher Education, Research, Science and Technology

SENEGAL

STI policy
- *Development Plan for Higher Education and Research (PDESR)* [2013–2017]

Related policies and/ or funds
- Fund for Scientific and Technological research (FIRST)
- Fund for Agricultural and Food Research
- Fund for Scientific and Technical Publications

Ministry responsible for STI
- Ministry of Higher Education, Research and Innovation

BURKINA FASO

STI policy
- *National Policy for Scientific and Technological Research* (2013–2025)

Related policies and/ or funds
- *National Innovation Strategy* (2016–2025)
- *National Fund for Research and Innovation for Development* (FONRID, 2011)

Ministry responsible for STI
- Ministry of Higher Education, Scientific Research and Innovation

MALI

STI policy
- *National Policy for Science, Technology and Innovation (PNSTI)* [2017–2025]

Related policies and/ or funds
- *Action Plan* for PNSTI (2017)
- Competitive Fund for Research and Technological Innovation (2011)
- *Strategic Framework for Economic and Sustainable Development* (2016–2018)

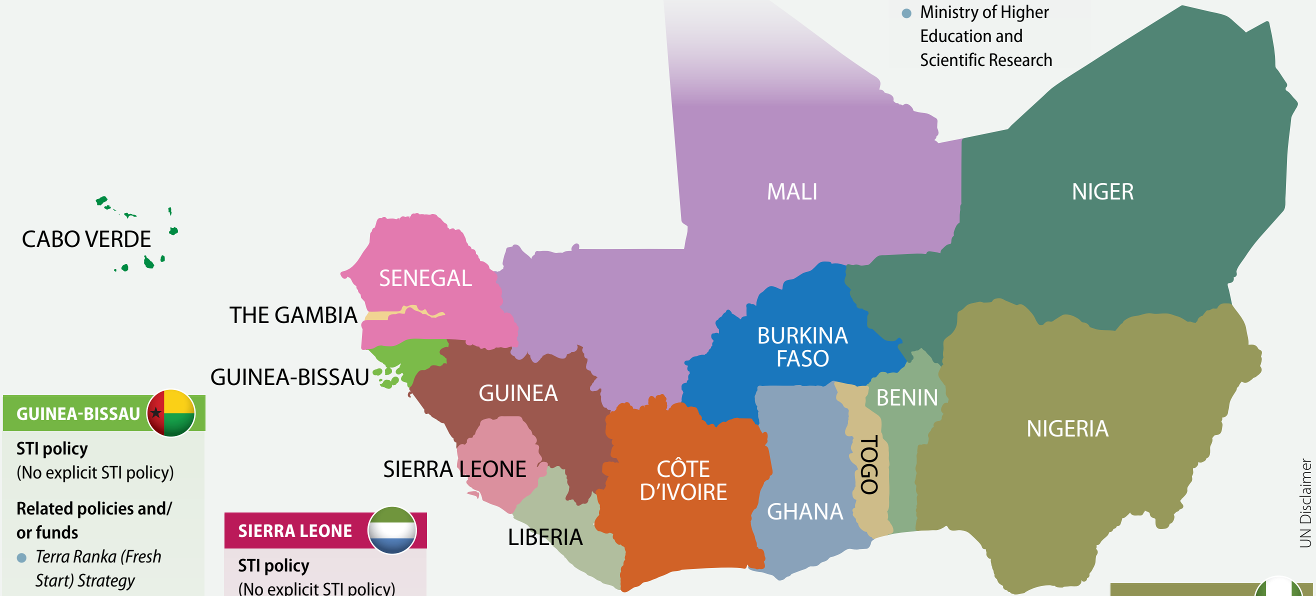
Ministry responsible for STI
- Ministry of Higher Education and Scientific Research

NIGER

STI policy
- *Niger Science, Technology and Innovation Policy* (POSTINI), adopted in 2018

Related policies and/ or funds
- Support Fund for Scientific Research and Technological Innovation (FARSIT)
- Intellectual Property Support Fund (FAPI)

Ministry responsible for STI
- Ministry of Higher Education, Research and Innovation



GUINEA-BISSAU

STI policy
(No explicit STI policy)

Related policies and/ or funds
- *Terra Ranka (Fresh Start) Strategy* (2015–2020)
- Sectoral Programme for Education (2017–2025)

Ministry responsible for STI
- Ministry of Higher Education and Scientific Research
- Ministry of Education (shared responsibility)

SIERRA LEONE

STI policy
(No explicit STI policy)

Related policies and/ or funds
- *Medium-Term National Development Plan* (2019–2023)

Ministry responsible for STI
- Ministry of Education, Science and Technology

CÔTE D'IVOIRE

STI policy
(No explicit STI policy)

Related policies and/ or funds
- *Strategic Support Programme for Scientific Research* (PASRES)

Ministry responsible for STI
- Ministry of Higher Education and Scientific Research

GHANA

STI policy
- *National Science, Technology and Innovation Policy* (2017–2022)

Related policies and/ or funds
- Coordinated Programme of Economic and Social Development Policies (2017–2024)

Ministry responsible for STI
- Ministry of Environment, Science, Technology and Innovation

BENIN

STI policy
- *Development Plan for Higher Education and Research* (2013–2017)

Related policies and/ or funds
- National Fund for Scientific Research and Technological Innovation

Ministry responsible for STI
- Ministry of Higher Education and Scientific Research

NIGERIA

STI policy
- *Science, Technology and Innovation Policy* (2012–2020)

Related policies and/ or funds
- *Economic Recovery and Growth Plan* (2017–2021)

Ministry responsible for STI
- Ministry of Science and Technology

GUINEA

STI policy
- *Action plan for Higher Education and Scientific Research* (2016–2020)

Related policies and/ or funds
- *National Plan for Economic and Social Development* (PNDES)

Ministry responsible for STI
- Ministry of Higher Education and Scientific Research

LIBERIA

STI policy
(No explicit STI policy)

Related policies and/ or funds
- *Education Sector Plan*, 2017–2021
- Innovation Fund for Entrepreneurship (LIFE, operational since 2015)
- *National ICT Policy* (2018–2023)

Ministry responsible for STI
- Ministry of Education

TOGO

STI policy
(No explicit STI policy)

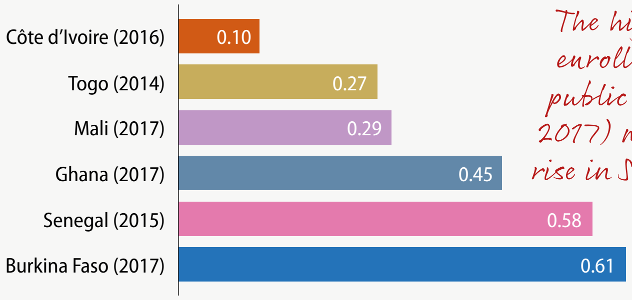
Related policies and/ or funds
- *National Development Plan* (2018–2022)

Ministry responsible for STI
- Ministry of Higher Education and Research

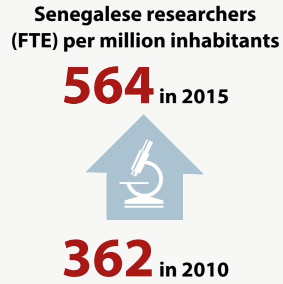
Source: compiled by authors

Figure 18.4: **Trends in GERD and researchers in West Africa**

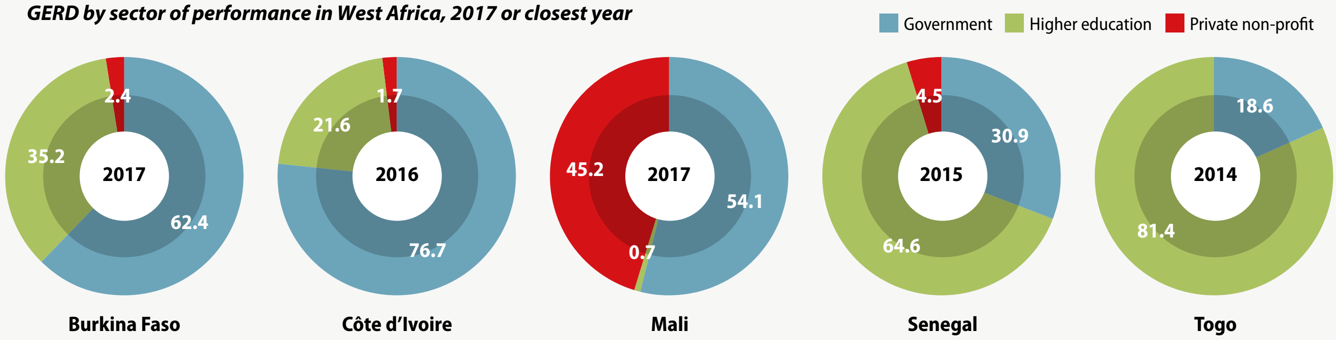
GERD as a share of GDP in West Africa, 2017 or closest year (%)



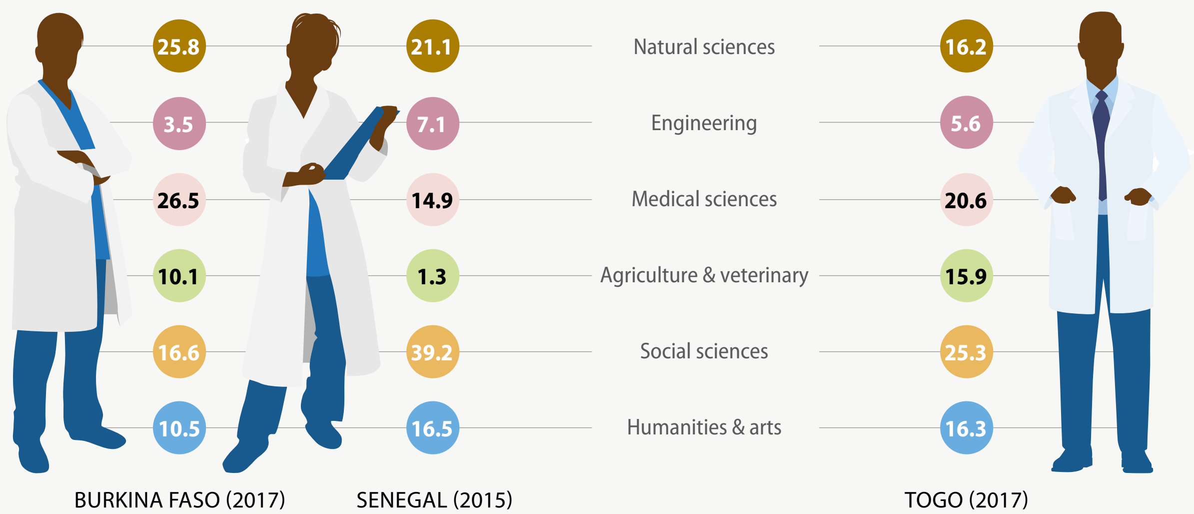
The high share of students enrolled in STEM fields at public universities (32% in 2017) may explain the sharp rise in Senegalese researchers.



GERD by sector of performance in West Africa, 2017 or closest year

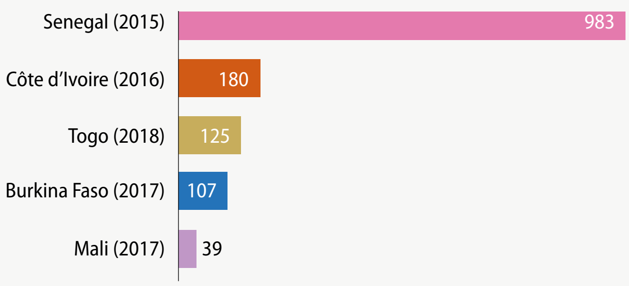


Researchers by field of science (HC) in West Africa, 2017 or closest year (%)

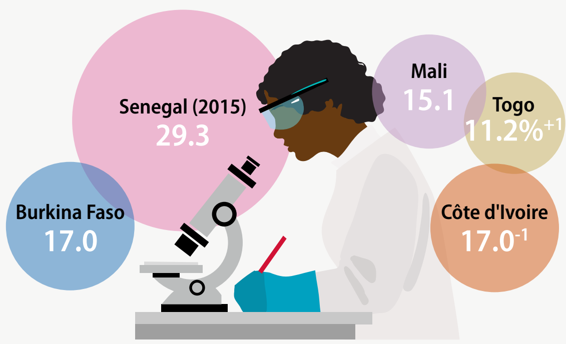


Note: For Burkina Faso, the share of unclassified researchers is 7.1%. For the missing countries, recent data are either unavailable or the share of unclassified researchers is too high for the statistics to be meaningful.

Researchers (HC) per million inhabitants in West Africa, 2018 or closest year (%)



Share of women researchers (HC) in selected West African countries, 2017 or closest year (%)



-n/+n: data refer to *n* years before or after reference

Note: Recent data are unavailable for most West African countries.

Source: UNESCO Institute for Statistics; Rep. Ghana (2019)

Nigeria is presently home to the largest number (101) of tech hubs in Africa, half of which are based in Lagos. Ghana, Côte d'Ivoire, Senegal and Togo also host more than 20 each (see Figure 20.2).

The French-speaking countries now have some of the fastest-growing ecosystems for tech hubs, due in part to the efforts of business angels to bridge the investment gap with their English-speaking neighbours. French-speaking countries are currently enjoying financial support from France, Senegal and the African Development Bank to boost small and medium-sized enterprises (SMEs) and the subregion's digital ecosystem.

In 2019, the Nigerian CcHub acquired the Kenyan iHub, creating West Africa's first 'mega-incubator'. Since its inception in 2011, CcHub has incubated more than 120 early-stage ventures. Whereas CcHub has adopted a commercial model, charging for workspace and creating its own Growth Capital Fund – Nigeria's first fund targeting social innovation – iHub's donor-funded model ultimately proved unsustainable (Jackson, 2019).

Table 18.1: Enrolment in centres of excellence in West Africa, 2014–2018

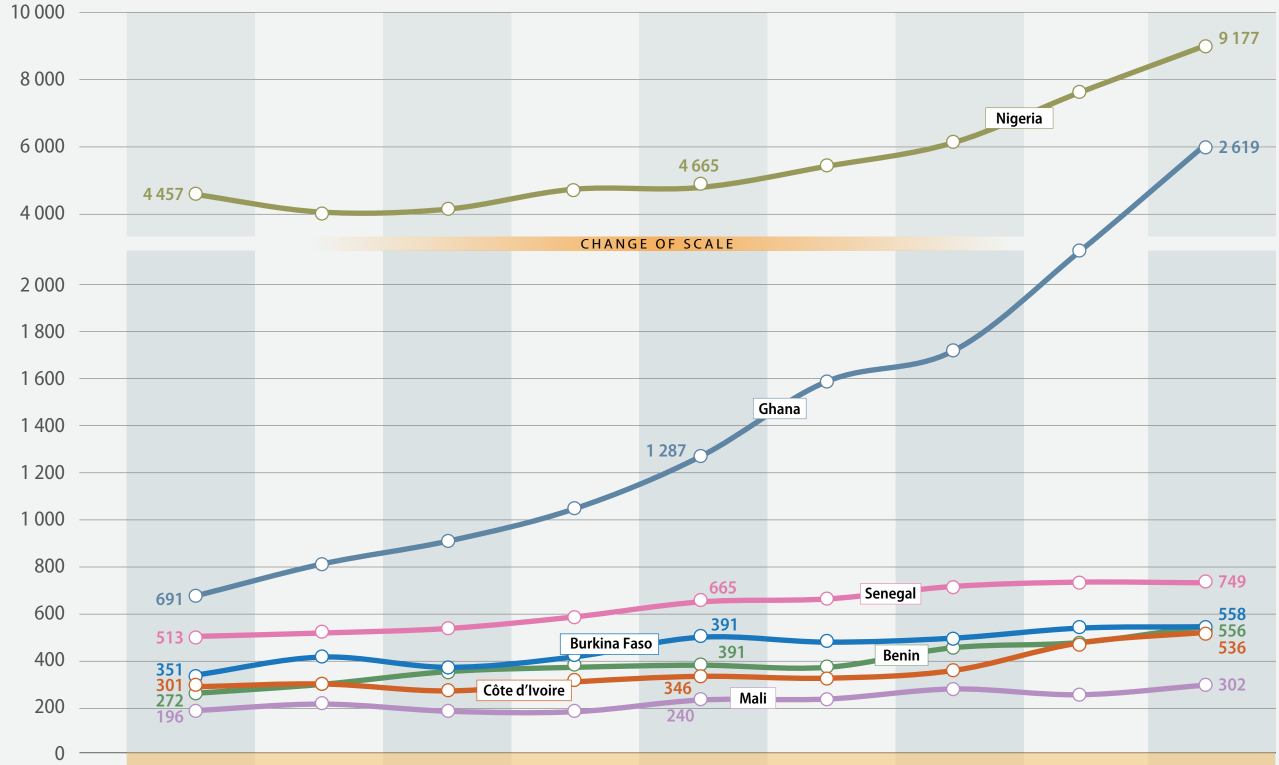
Country	Lead institution	Focus of centre of excellence	PhD	Master's	Short-term	Total, 2014–2018
Benin	University of Abomey-Calavi	Applied mathematics and informatics	220	616	61	897
Burkina Faso	International Institute of Water and Environmental Engineering (2iE)	Water, energy, environmental sciences and technologies	53	1 569	515	2 137
Cameroon	University of Yaoundé	Information and communication technologies (ICTs)	130	971	839	1 940
Côte d'Ivoire	Felix Houphouët-Boigny National Polytechnique Institute	Sustainable mining	12	230	28	270
Côte d'Ivoire	Felix Houphouët-Boigny University	Climate change, biodiversity and agriculture	86	43	0	129
Côte d'Ivoire	Higher School of Statistics and Applied Economics	Statistics and applied economics	0	416	113	529
Ghana	Kwame Nkrumah University of Science and Technology	Water and environmental sanitation	112	277	489	878
Ghana	University of Ghana	Plant breeding, seed science and technology	44	36	1 020	1 100
Ghana	University of Ghana	Cell and molecular biology of infectious pathogens	70	116	132	318
Nigeria	Redeemer's University	Genomics of infectious diseases (malaria, Lassa, Ebola)	29	41	439	509
Nigeria	University of Port Harcourt	Oilfield chemicals research	126	494	615	1 235
Nigeria	Ahmadu Bello University	Neglected tropical diseases and forensic biotechnology	81	239	461	781
Nigeria	Federal University of Agriculture	Agricultural development and sustainable environment	57	142	151	350
Nigeria	Bayero University, Kano	Dryland agriculture	91	260	501	852
Nigeria	Benue State University	Food technology and research	105	308	689	1 102
Nigeria	University of Benin	Reproductive health and population studies	59	451	762	1 272
Nigeria	Obafemi Awolowo University	Science, technology and knowledge	87	327	1 007	1 421
Nigeria	University of Jos	Phytomedicine research and development	161	586	716	1 463
Senegal	Cheikh Anta Diop University	Maternal and infant health	193	168	504	865
Senegal	University Gaston Berger	Mathematics, informatics and ICTs	204	1 110	42	1 356
Togo	University of Lomé	Poultry sciences	55	115	446	616
Togo	African University of Science and Technology	Materials science and engineering	79	115	1 081	1 275
		TOTAL	**2 054**	**8 630**	**10 611**	**21 295**
		Share of total enrolment (%)	**9.6**	**40.6**	**49.8**	

Note: In November 2019, the World Bank approved funding to create new centres of excellence and consolidate existing ones in Benin, The Gambia, Niger, Nigéria and Togo. For background, see Essegbey *et al.* (2015).

Source: https://ace.aau.org/; Aticken and Stenseth (2019)

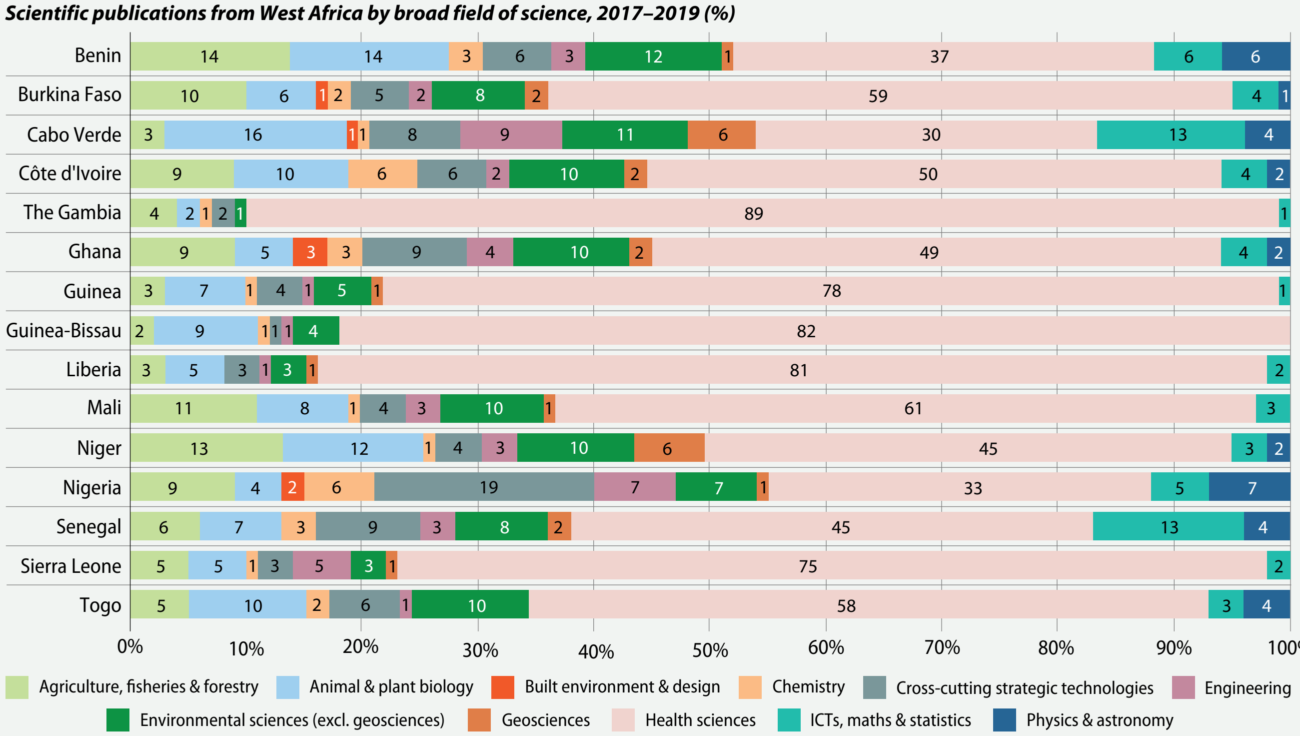
Figure 18.5: **Trends in scientific publishing and patenting in West Africa**

Volume of scientific publications in West Africa, 2011–2019

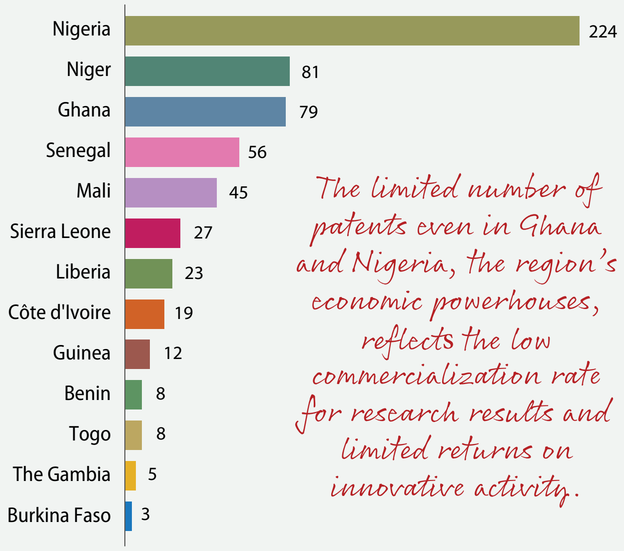


	2011	2012	2013	2014	2015	2016	2017	2018	2019
Togo	96	85	106	141	144	141	133	181	197
The Gambia	92	122	141	152	160	163	177	136	180
Niger	103	97	92	123	161	154	145	171	177
Sierra Leone	30	39	36	62	98	133	139	134	141
Guinea	35	38	38	62	98	119	129	91	118
Liberia	15	17	15	22	45	63	66	80	88
Guinea-Bissau	29	34	37	57	35	50	54	49	61
Cabo Verde	4	16	24	31	31	34	39	31	44

Scientific publications from West Africa by broad field of science, 2017–2019 (%)



Number of IP5 patents granted to West African inventors, 2015–2019



How has output on SDG-related topics evolved since 2012?

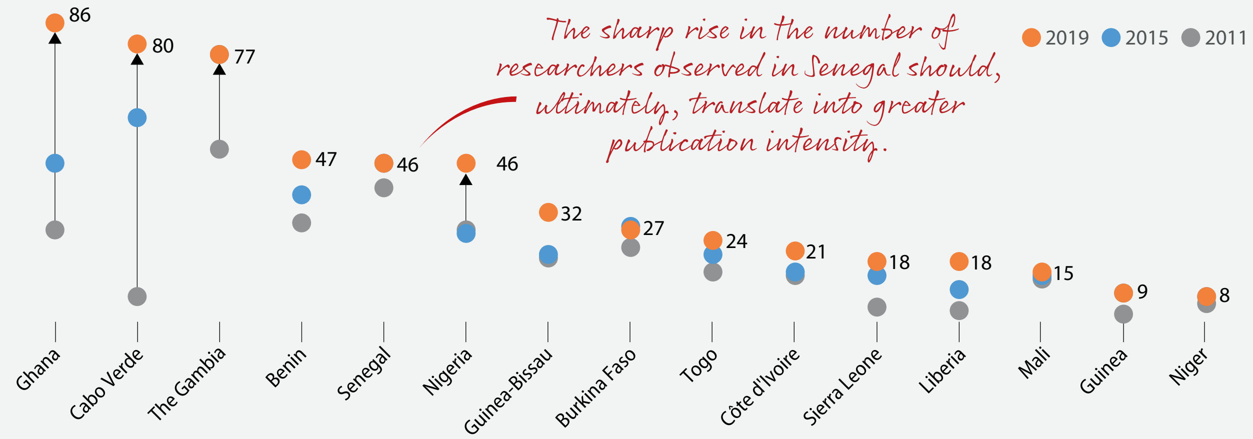
West African scientists are publishing more on the following topics than would be expected, relative to global averages: help for smallholder food producers (Benin's intensity is 56 times the global average), water harvesting (46 times the global average for Niger), climate-ready crops, the impact of climate-related hazards on local communities, medicines and vaccines for tuberculosis (58 and 39 times for Guinea-Bissau and The Gambia, respectively), tropical communicable diseases (49 and 41 times for Mali and The Gambia, respectively), HIV research, traditional knowledge (46 times for Benin), sustainable use of terrestrial ecosystems and agro-ecology (28 times for Benin).

The 2014–2015 Ebola outbreak in Liberia, Guinea and Sierra Leone left its mark on scientific output. Liberia's output on new or re-emerging viruses that can infect humans quadrupled from 33 (2012–2015) to 133 papers (2016–2019), an intensity 144 times the global average.

Health-related topics still dominate, even though output is declining on topics such as tropical communicable diseases and HIV. The fastest-growing areas are agro-ecology, the sustainable use of terrestrial ecosystems and help for smallholder food producers, where output doubled or tripled in many countries between 2012–2015 and 2016–2019. Moreover, Nigerians quadrupled their output on eco-construction materials from 23 (2015–2015) to 95 (2016–2019) publications.

For details, see chapter 2

Scientific publications per million inhabitants in West Africa, 2011, 2015 and 2019
Data labels are for 2019



Top five partners for West African countries for scientific co-authorship, 2017–2019

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator(s)
Benin	France (403)	USA (233)	Belgium (172)	UK (155)	Germany (151)
Burkina Faso	France (484)	USA (318)	UK (265)	Germany (190)	Ghana (163)
Cabo Verde	Portugal (63)	Spain (28)	Brazil (23)	UK (18)	USA (16)
Côte d'Ivoire	France (502)	USA (217)	Switzerland (163)	UK (152)	Germany (146)
The Gambia	UK (339)	USA (180)	South Africa (82)	Netherlands (75)	Australia (74)
Ghana	USA (1 422)	UK (1 016)	South Africa (699)	China (631)	Nigeria (459)
Guinea	France (117)	USA (102)	UK (79)	Belgium (66)	Switzerland (52)
Guinea-Bissau	Denmark (98)	UK (51)	Portugal (38)	USA (24)	Sweden (23)
Liberia	USA (150)	UK (55)	Nigeria (44)	Ghana (39)	Germany (36)
Mali	USA (314)	France (232)	UK (162)	Burkina Faso (126)	Kenya (103)
Niger	USA (129)	France (122)	Burkina Faso (75)	UK (73)	Senegal (66)
Nigeria	South Africa (2 765)	USA (2 122)	Malaysia (1 939)	UK (1 890)	India (819)
Senegal	France (862)	USA (442)	UK (227)	South Africa (146)	Germany (139)
Sierra Leone	USA (161)	UK (144)	China (57)	South Africa (44)	Ghana/Switzerland (40)
Togo	France (144)	Burkina Faso (91)	USA (80)	Benin (72)	Côte d'Ivoire (62)

Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China.

Source: Scopus (excluding Arts, Humanities and Social Sciences) and PATSTAT; data treatment by Science-Metrix

COUNTRY PROFILES

BENIN

Better-paid but little left over for research

Although broader development policies refrain from explicitly mentioning higher education and research, sectoral policies like the *Development Plan for Higher Education and Research* (2013–2017) have been developed. The *National Development Plan* for 2018–2025 states that, 'by 2025, Benin will have a sub-sector of higher education and scientific research which provides qualified human resources and research results adapted to national development problems'. The plan sets out to improve the quality of higher education by developing academic and pedagogical training; strengthening training programmes and methods; fostering equity in higher education; and strengthening universities' infrastructure and pedagogical equipment.

Some progress has been made, since the number of private universities rose from two to seven between 2012 and 2016 and four public universities were created through mergers, over the same period. Two of the latter are multidisciplinary. The third specializes in agriculture and the fourth in STEM.

Over this period, university lecturers also received a salary rise, although many were approaching retirement. Public universities are currently facing funding difficulties, with the bulk of budgets being absorbed by running expenses, rather than investment in equipment or R&D.

The *Development Plan for Higher Education and Research* (2013–2017) focused on pursuing development priorities by strengthening research capacities and improving the quality of research output. In 2018, the *Strategic Plan* for 2018–2022 noted that the *Development Plan* had not lived up to expectations, as it was not based on a broader national vision of scientific research and innovation expressed by law.

Benin faces the same problem as other West African countries when it comes to designing policy documents. Formulation is centralized and the policy itself neglects funding for its implementation. This shows the contradiction in policy design led by the World Bank: in the discourse, there has been a positive shift in development policy but this affirmation is belied by the shortcomings of policy implementation.

BURKINA FASO

'Federative' research programmes providing missing link

In 2016, the freshly elected Kaba Thiéba government set out to address the challenges of the post-insurrectional period (Essegbey *et al*., 2015) through a five-year *National Economic and Social Development Plan* (PNDES, 2016–2020). The *Plan* consists of three mains areas, each with a set of strategic objectives which together address 86 out of the 169 targets for the Sustainable Development Goals to 2030.

The *Plan* is innovative, in that it explicitly sets two strategic objectives around higher education and scientific research. The former aims to 'increase the supply and improve the quality of education, higher education and training in line with the needs of the economy', whereas the latter means 'to promote research and innovation for the structural transformation of the economy'.

The *Plan* will be able to capitalize on over 20 years of formal science and higher education policies that have never been adequately implemented, since they contradicted the government's market-driven development policies that had been aligned with the World Bank's structural adjustment framework since 1991.

The national research system will be reconfigured in the next couple of years as the older generation of researchers retires. This demographic trend offers a golden opportunity to modernize the country's innovation system. The government led by Prime Minister Christophe Dabiré since February 2019 is in the process of revising the *National Policy for Scientific and Technological Research* (2013–2025), in order to iron out inconsistencies and identify clear sectoral priorities. These will then be incorporated in the revised *Sectoral Research and Innovation Policy* (PSRI) for 2018–2027 (MESRSI, 2018a).

The *Sectoral Research and Innovation Policy* has introduced what it terms 'federative research programmes' with relevant other ministries to ensure more efficient delivery (MESRSI, 2018b). To date, the Ministries of Health and Agriculture are each leading a programme in partnership with the Ministry of Higher Education, Scientific Research and Innovation. The federative research programme has its limitations, since there is no financial incentive at present and ministerial participation is voluntary. Ideally, the revision of the *National Policy for Scientific and Technological Research* should make ministerial collaboration mandatory and provide a grant incentive scheme. The programme is on the right track, however. This connection between research-intensive sectors has been missing from all research policy documents of the past 30 years.

The National Fund for Research and Innovation for Development (FONRID) has supported 70 projects since its inception in 2011, including about 20 in 2019 for a total value of US$ 1 million. However, more than 95% of research grants go to the National Scientific and Technological Research Centre. Moreover, it was initially intended for the private sector to contribute to FONRID (Article 62 of its statutes) but, in practice, the fund is entirely reliant on government subsidies. FONRID is able to partner with countries like Senegal, however, to obtain joint grants in food and agriculture, under the Science Granting Councils in sub-Saharan Africa Initiative.[6]

The National Fund for Education and Research (FONER) was set up in 1994. Until the election of the present government, it served primarily to provide student loans. Its mandate has since been extended to helping postgraduate students pay laboratory and research fees.

To foster the commercialization of innovation, the Ministry of Higher Education, Scientific Research and Innovation launched the revision of the *National Strategy to Commercialize Technologies, Inventions and Innovation* in October 2019. In parallel, the National Agency for Commercializing Research Results is developing innovation platforms: one is currently developing and testing six varieties of maize and a second innovation platform is planned for papaya.

Science a casualty of growing insecurity

The deteriorating security situation is impeding implementation of the *National Economic and Social Development Plan*. After a spate of terrorist attacks in 2019, government troops were deployed to secure the national territory.

Burkina Faso had augmented its research effort to 0.67% of GDP by 2017, one of the highest ratios in Africa, but research budgets have since been cut to fund the security effort. Consequently, 90% of the National Scientific and Technological Research Centre's budget (*ca* US$ 1.7 million) for 2020 has been amputated.

A new virtual university

Prior to stepping down in October 2014 following a popular revolt, the Campaoré government had initiated a sectoral policy for secondary and higher education and scientific research in 2010. A *National Action Plan for the Development of Higher Education* (PNADES 2014–2023) had sprung from this policy, alongside its operational plan for the period 2014–2017.

However, the reform was inconsistent with the government's economic choices driven by the World Bank's Structural Adjustment framework, so made no notable impact.

The transitional government charged with organizing the presidential election in 2015 included in its *Emergency Plan* the construction of an 'educational technopole' at the country's main tertiary institution, the University of Joseph Ki-Zerbo. This project was completed shortly before the election.

The newly elected Kaba Thiéba government then launched a major Higher Education Support Project with a budget of US$ 70 million, under its *National Economic and Social Development Plan* (2016–2020) [PNADES]. With more than half of the population being under the age of 20 years, one aim is to extend access to a greater number of young hopefuls. The *Revised Action Plan* for PNADES expects demand for university admission (public and private) to double to 30 000 between 2020 and 2023.

The Higher Education Support Project has been inspired by Senegal's own experience and has three main thrusts. A World Bank loan of US$ 23.5 million is co-financing the creation of a virtual university by 2020, at a total cost of US$ 45.7 million. This virtual university will focus on basic science, digital science, engineering and robotics.[7] It is part of a broader effort to create more Internet services for students, including online enrolment. To allay fears that the virtual university will be a less effective pedagogical tool than a physical university, given the country's poor Internet penetration and the need for students to access pedagogical infrastructure, 16 digital open spaces will be dotted around the country's 13 regions to provide students with computers, laboratories and other equipment. By March 2019, three of these open spaces were under construction in Ouagoudougou, Bobo Dioulasso and Koudougou (MESRSI, 2018c).

The second thrust is a scheme co-ordinated by the Ministry of Higher Education, Scientific Research and Innovation since late 2019 to improve teaching and professional training, in partnership with the International Institute for Water and Environmental Engineering, one of the centres of excellence funded by the World Bank (Table 18.1).

The third thrust is the establishment of the Scientific Research Excellence Award to recompense the work of individuals or groups which demonstrates a real or potential socio-economic impact. A ceremony on 14 December 2018 conferred the first 14 awards of about US$ 20 000 each. On this occasion, the government appointed the members of the Higher Council for Scientific Research and Innovation recommended by the *National Policy for Scientific and Technical Research* (2012).

CABO VERDE

Ambitions for a circular economy

Cabo Verde has West Africa's highest GDP per capita (see Figure 18.1) and has attained middle-income status since 2011. The economy is dependent on the services sector, which contributes about 70% of GDP, compared to less than 6% for agriculture (Yingying, 2018). Cabo Verde's economy is reliant on remittances, external monetary transfers and development aid, making it vulnerable to external shocks.

The country is implementing a *Strategic Plan for Sustainable Development* (2017–2021) which has four key objectives:

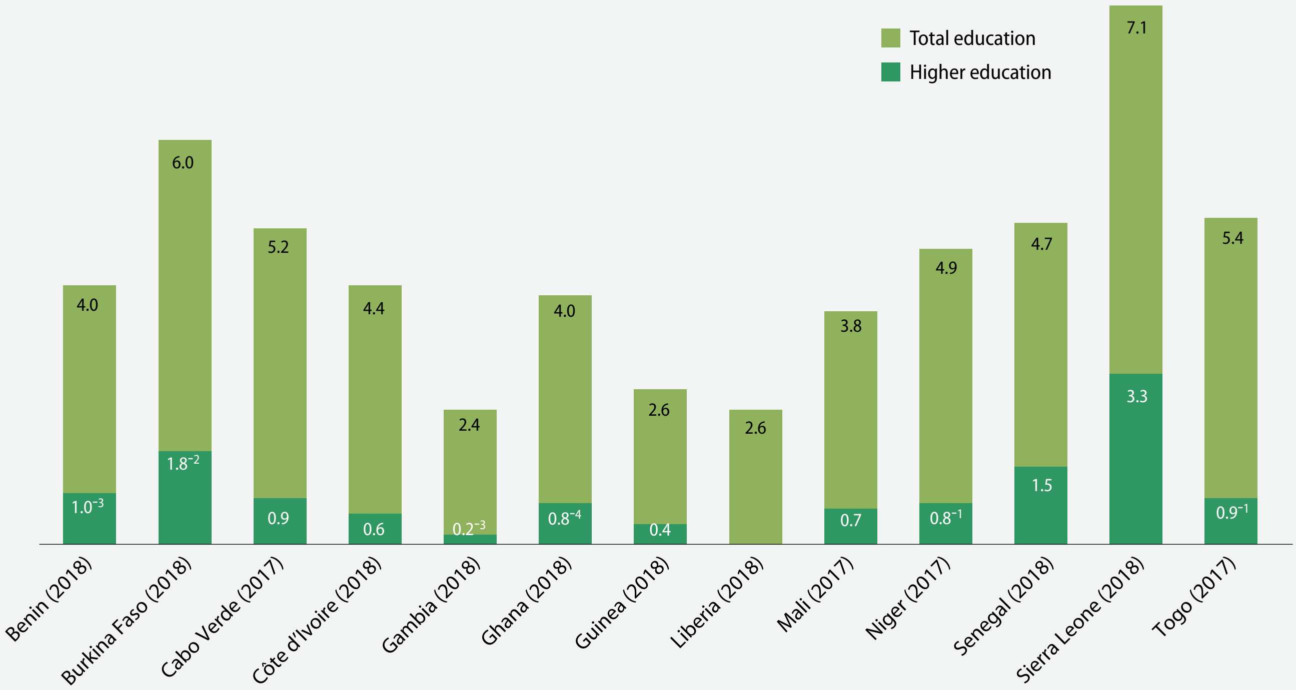
- turn Cabo Verde into a Circular Economy in the Mid-Atlantic, through connectivity and development of the blue economy, green growth, tourism and business, industry and financial services;
- guarantee sustainable tourism, domestic industry and export promotion;
- promote social inclusion and reduce inequalities through education and professional training; health and social security; job creation and youth and gender equality; and
- strengthen democracy, justice and international diplomacy and engage the diaspora.

Considerable capital investment in key transformative sectors will be necessary to achieve these objectives. In the quest for new forms of collaboration with international partners and the private sector, the government organized an investment forum in December 2018 in Paris for international public and private partners, on the theme of Building New Partnerships for the Sustainable Development of Cabo Verde. The forum was supported by the World Bank, the African Development Bank and others.

Cabo Verde is relying mostly on international co-operation to develop its higher education sector. The most important investment in the past five years has been the construction of the Palmarejo campus, with funding from the Chinese government, at the country's only public university, the University of Cabo Verde.

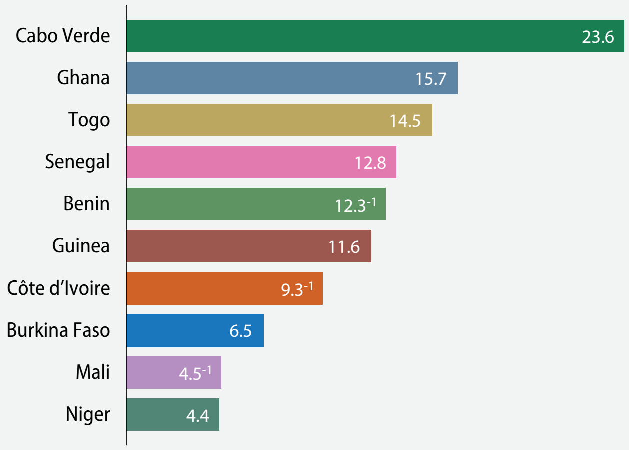
Figure 18.6: **Trends in higher education in West Africa**

Public expenditure on education and higher education in West Africa as a share of GDP, 2018 or closest year (%)

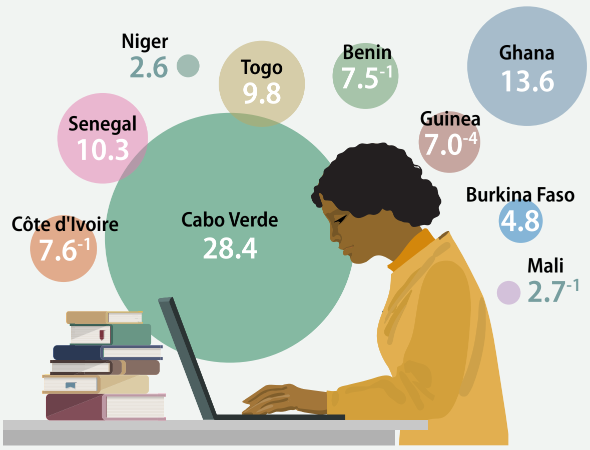


Gross enrolment ratio in West Africa, 2018

Share of 18–25-year cohort (%)



Share of women at West African universities, 2018 (%)



Tertiary enrolment in West Africa by level of study, 2018 or closest year

	Post-secondary diploma	Bachelor's degree or equivalent	Master's degree or equivalent	PhD or equivalent
Benin (2017)	–	–	14 431	2 072
Burkina Faso (2014)	3 511	43 145	33 243	–
Cabo Verde (2017)	239	10 988	370	62
Côte d'Ivoire (2017)	74 984	101 758	33 982	7 190
Ghana	164 796	250 733	25 995	2 169
Guinea (2014)	12 593	92 317	10 699	2 334
Mali (2015)	1 497	63 314	18 001	338
Niger	15 902	41 424	20 605	2 194
Senegal	345	143 621	33 701	7 212
Togo	11 864	84 431	3 975	1 652

Share of women among PhD graduates

26%
in Burkina Faso and Ghana in 2018

21%
in Niger in 2018

18%
in Senegal in 2017

-n: data refer to *n* years before reference year

Note: Recent data are unavailable for some countries.

Source: UNESCO Institute of Statistics (March 2020)

Cabo Verde stands out in West Africa for the quality and inclusiveness of its higher education system. One in four young people attend university and one-third of students opt for STEM fields (Figure 18.6). Women make up one-third of students but two-thirds of graduates.

The application of STI will be central to effective implementation of the *Strategic Plan for Sustainable Development*. The fairly even spread of R&D across scientific fields indicates good potential for enhancing the economic impact of STI. Publication intensity has levelled out since 2015 (Figure 18.5).

Plans to lead by example

As host to the ECOWAS Regional Centre for Renewable Energy and Energy Efficiency, inaugurated in 2010, Cabo Verde plans to lead by example by becoming entirely reliant on renewable energy sources by 2025.

This policy is consistent with the plethora of documents adopted in 2015 paving the way to more sustainable development, including Cabo Verde's *Tranformational Agenda to 2030*, its *National Renewable Energy Plan* and its *Low Carbon and Climate-reslient Development Strategy*. Two years later, these were followed by a *Strategic Plan for Sustainable Development, 2017–2021*.

On track to becoming a 'cyber island'

Cabo Verde is implementing the second phase of the vibrant digitalization project described in the previous *UNESCO Science Report* (Essegbey *et al.,* 2015). The first phase was completed in 2014 with the construction of a national data centre and an upgrade of the telecommunications network, the government systems network platform and the island interconnection platform. By 2018, 57% of the population had access to Internet (see Table 19.2).

According to the 2017 International Telecommunications Union Report, Cabo Verde ranks fourth in Africa in the ICT Development Index.

Under the country's strategy for becoming a regional ICT hub, Cabo Verde's Operational Information Society Nucleus (NOSi) has delivered e-government applications and services to neighbouring countries in West Africa and attracted government delegations from more than 40 countries wishing to study Cabo Verde's model (Yingying, 2018).

The government is hoping that the Praia Technology Park, due to open in 2021, will attract large companies to Cabo Verde. Construction of the park got under way in 2015, through a project co-financed by the government and the African Development Bank.

CÔTE D'IVOIRE

A broad development agenda

Côte d'Ivoire plans to evolve from being an exporter of raw materials to an exporter of knowledge. In the intermediary phase, the intention is for value-added goods to nurture trade and capital exports. Higher education and scientific research will take pride of place in realizing this development strategy.

In the *National Development Plan for 2016–2020* (PNDES), the government intends to achieve this structural transformation by improving the business climate, supporting the commercialization of research results and promoting responsible technological innovation and transfer. It anticipates being able to rely on a sustained economic growth rate of more than 7%, which it achieved following the end of the political crisis in 2011 but which falls shy of the double-digit target for growth outlined in the *National Development Plan for 2012–2015* (Essegbey *et al.*, 2015). In West Africa, Côte d'Ivoire has the fourth-highest GDP per capita after Cabo Verde, Nigeria and Ghana (see Table 19.1).

According to the World Bank's 2015 *Doing Business* report, six factors hamper business development: lack of access to finance, corruption, high taxes, heavy bureaucracy, inadequate infrastructure and an unskilled workforce.

In light of this and with more than half of the population under the age of 20, it has become vital to provide youth with a quality education. Between 2015 and 2018, the country raised its education effort from 4.8% to 5.1% of GDP, one-quarter of which (1.3% of GDP) went to higher education. Between 2015 and 2017, the gross enrolment ratio rose from 8.8% to 9.3% of the 18–25-year cohort.

In 2014, the government carried out an inventory of Côte d'Ivoire's scientific and technological potential (MESRS, 2014a). This revealed that there were 59 public and 245 private institutions offering technical and vocational training. PNDES makes provision for augmenting this number, paying special attention to agricultural sciences, which attracted just 0.1% of students in 2014.

Some 28 private and five public universities were inventoried, as well as 155 *grandes écoles*, two of which were state-owned. In the 2013/2014 academic year, 26% of university students were enrolled in science and technology, health and agricultural sciences (MESRS, 2014a).

PNDES aims to improve the quality of training and broaden access to higher education. Three universities and two *grandes écoles* are being rehabilitated and the two Regional Higher Education Units in Daloa and Korhogo are to be turned into universities. In addition, new universities are being built in Bondoukou, Man (now operational) and San Pedro. In 2016, the Virtual University opened (MESRS, 2018c).

Some 2 036 university teachers are to be recruited for the public sector and the three-tiered degree system (bachelor's, master's and PhD) was adopted in 2012 (Rep. Côte d'Ivoire, 2012). By 2019, only 498 university teachers had been recruited and the three-tiered degree system was still being put in place.

The Support Fund for Research and Innovation (FONARI) was launched in December 2016. It finances the Special Prize of the President of the Republic for Science and Innovation, a Fund for Research and Innovation (FARI) and a Fund for the Promotion of Women University Teachers and Researchers (FAPECI) [MESRS, 2018c].

The *Action Plan for the National Scientific Research and Technological Development Policy* (2014) frames seven research programmes: agriculture; mining and energy; environment; health; natural substances; civilization; and technology

(MESRS, 2014b). However, a 2018 report states that none of these programmes have been implemented, failing adoption of the law that would have provided the national framework for research and innovation (MESRS, 2018c). This law was outlined in the *National Development Plan for 2016–2020.*

The *National Development Plan for 2016–2020* makes provision for expanding and equipping research structures, developing 24 national research programmes, establishing a virtual library for research institutes and laboratories and setting up an office to commercialize the results of research.

Félix Houphouët-Boigny University, which hosts the Centre of Excellence on Climate Change, Biodiversity and Agriculture (Table 18.1), is a good example. It is collaborating with the National Centre for Agronomic Research to develop climate-smart agriculture: quick-growing aubergines and bananas, cotton plants that produce 700 kg/ha, rather than 200 kg/ha for traditional varieties, and tomatoes that can adapt to the dry and wet seasons (MESRS, 2018a).

Félix Houphouët-Boigny University is also developing plant-based biopesticides as an alternative to chemical pesticides, as well as low-cost phytomedicines for the African market.

The Ministry of the Environment and Sustainable Development estimates that 4 000 tonnes of obsolete pesticides enter Côte d'Ivoire each year. In 2015, the government launched a project to inventory these and eliminate them safely within five years, with World Bank support. By late 2018, the share of obsolete pesticides in total sales had halved to 20% (Traoré, 2018).

THE GAMBIA

Agriculture, tourism and energy to kick-start economy

In the wake of a popular revolt, elections carried President Adama Barrow to power in 2016. The government published its *National Development Plan* (2018–2021) in December 2017. The document describes a 'stalled economy' in 'external debt distress' (85.7% of GDP in 2018), with debt servicing consuming much of government revenue. In addition to revitalizing and transforming the economy, the plan prioritizes good governance, social cohesion and national reconciliation. Indicators have been closely matched to those of the SDGs and *Agenda 2063*.

Modernization of agriculture is a key plank of the plan, as this sector's poor performance is blamed for growing rural poverty. The plan sets out to increase productivity through climate-smart agriculture, sustainable land and water management practices, R&D and extension services to farmers.

The government also aims to make tourism a highly competitive and sustainable industry, in part by remediating environmental degradation.

Energy is another priority. The plan focuses on improving the policy and regulatory environment to attract investment in renewables and secure petroleum resources.

The plan identifies seven cross-cutting enablers: an efficient public sector that is responsive to the citizenry; empowering women to realize their full potential; enhancing the role of the diaspora in national development; promoting environmental sustainability, climate-resilient communities and appropriate land use; becoming a digital nation; engaging civil society as a valued partner in national development; and strengthening evidence-based policy- and decision-making, as well as planning.

The *National Development Plan* (2018–2021) also outlines a strategy for establishing a national ICT agency, technology park and national data centre to strengthen e-government capacities. Regional ICT centres are to be rolled out to enhance connectivity to schools and communities.

Research currently a one-horse town

Although 60% of researchers work in agricultural sciences, output in this field is negligible (Figure 18.5). Medical researchers published 91% of total publications between 2016 and 2018.

This is to be expected, since the London School of Hygiene and Tropical Medicine has a Medical Research Council Unit in The Gambia with excellent laboratory facilities and staff. Its large portfolio ranges from basic research to evaluating the control of priorty diseases for public health in sub-Saharan Africa, such as malaria and hepatitis B.

The challenge for The Gambia will be to expand research capacity beyond the Medical Research Council Unit to the agriculture, industrial and energy sectors.

GHANA

Emphasis on sustainability and job creation

Shortly after winning the presidential election in December 2016, Nana Akufo-Addo set about revising the *National Science, Technology and Innovation Policy* (2010). To this end, he established a technical committee chaired by the Minister for the Environment, Science, Technology and Innovation, with the participation of representatives of stakeholder groups, including the Director of the Science and Technology Policy Research Institute in Accra.

The revised policy projects a bold vision of Ghana becoming a developed country by 2027, with STI positioned as the key driver of the transition to a sustainable economic model less dependent on exports of gold (49% of total exports in 2017), crude oil (17%) and unprocessed cocoa products (15%). The policy outlines strategies for developing the primary sectors of agriculture, health, industry, energy, human settlements, communication and the environment. One may question the chances of attaining developed country status by 2027 but the policy's value lies, above all, in its emphasis on sustainability.

The high profile of the SDGs in Ghana is reflected in President Nana Akufo-Addo's appointment to the UN Secretary General's Eminent Group of Sustainable Development Goal Advocates in May 2019. Ghana's *Voluntary National Review* of its early progress towards the SDGs describes a 'whole of government' and 'whole of society' approach based on collaboration with civil society, the private sector and other stakeholder groups. The government is promoting clean cooking stoves, for instance, and educating

Box 18.2: **Google opens Africa's first centre for artificial intelligence**

In April 2019, Google opened Africa's first centre for artificial intelligence (AI), in Accra, Ghana. The centre has a multinational team, with software engineers and research scientists hailing from Ghana, Nigeria, Lesotho, Senegal and Uganda, as well as Canada, Ireland, Israel, the UK, USA and elsewhere.

The CEO is, himself, from Senegal. In 2018, Dr Moustapha Cissé founded the first African Master's of Machine Intelligence degree at the African Institute for Mathematical Sciences, with the sponsorship of Facebook and Google.

The Accra centre is collaborating with local universities to roll out African solutions to prevailing problems. It intends to provide research grants and PhD scholarships to drive research in AI.

In June 2019, the centre organized a symposium with the Department of Computer Science at the University of Ghana on the theme of challenging the status quo: the role of AI in Africa.

In June 2018, Jeff Dean and Moustapha Cissé penned a blog* on Google's AI website announcing the forthcoming AI centre and affirming that, over the ten years Google had been present on the continent, two million Africans had benefited from the company's digital skills training programme. 'We're supporting 100 000 developers and over 60 tech startups through our Launchpad Accelerator Africa', they said. 'We're also adapting our products to make it easy for people to discover the best of the Internet, even on low-Random Access Memory smartphones or unstable network connections'.

The Launchpad Accelerator Africa provides African start-ups with equity-free support, access to Google engineers and intensive mentoring, as well as training in public relations. It accepts applications from top seed-stage African start-ups located in Algeria, Botswana, Cameroon, Côte d'Ivoire, Egypt, Ethiopia, Ghana, Kenya, Morocco, Nigeria, Rwanda, Senegal, South Africa, Tanzania, Tunisia, Uganda and Zimbabwe.

Unlike IBM in South Africa (see Box 20.4), Google has not signed an agreement with the government relating to its corporate social responsibility in Ghana.

Source: compiled by authors
*See: https://www.blog.google/around-the-globe/google-africa/google-ai-ghana/

farmers on how to minimize the use of chemical fertilizers and adopt responsible irrigation practices (Rep. Ghana, 2019).

The government has developed a *National Data for the Sustainable Development Roadmap* which is prioritizing filling data gaps and encouraging data use. A national platform has been launched to make disaggregated data on the SDGs available to the public. In parallel, Ghana is one of five pilot countries developing an *STI for the SDGs Roadmap* with an inter-agency team led by UNESCO in this country.[8]

A presidential council to oversee STI

One provision of the *National Science, Technology and Innovation Policy (2017–2027)* has already been implemented, with the inauguration of the Presidential Advisory Council for Science, Technology and Innovation in January 2019.

National science fund in the pipeline

GERD amounted to 0.45% of GDP in 2017, a slight improvement over 0.38% in 2010 (Rep. Ghana, 2019). The government reports that one-third (35%) of micro-enterprises and SMEs have adopted improved local packaging technologies and that industry adopted 115 research findings in 2017, up from 70 in 2016 (Rep. Ghana, 2019).

The *National Science, Technology and Innovation Policy* commits the government to raising GERD to 1% of GDP 'in the short and medium term' by combining contributions from the public and private sectors and to 2.5% of GDP in the longer term. In 2019, the government began drafting a bill for the creation of a national research fund, in order to guarantee a more sustainable funding base. Until this is done, it is not clear how funding can effectively cater to the needs of all innovators.

The policy has its shortcomings. The manner in which financial resources will be allocated to science agencies is yet to be addressed appropriately and the Minister of Environment, Science, Technology and Innovation is not a core Cabinet member, although he is entitled to attend Cabinet meetings. On the whole, though, there appears to be a lot of goodwill towards STI in Ghana at the highest levels of decision-making.

Plans for a research commercialization centre

There are plans to set up the Ghana Innovation and Research Commercialisation Centre to serve as a bridge between the government, public research institutions and industry. In parallel, the *National Entrepreneurship and Innovation Plan* will assist in the establishment of technology incubators. A Computer Numerical Control Machine Tools Centre is being set up in each of Accra and Kumasi to develop strategic technologies and to provide basic infrastructure for engineering innovation.

Although the revised policy restates some earlier policy objectives, it also introduces some progressive measures. For example, it proposes creating special incentives such as scholarships for university students and graduates studying STEM fields. It also proposes reviving the National Science and Technology Museum Project, which has been on the drawing board, astonishingly, since 1965. The policy revisits the concept of science acculturation, advocating a national network of regional science and technology museums.

Digital Agenda: leaving no-one behind

Ghana was one of the first countries to ratify the *Malabo Convention* (2014). In 2017, the Minister of Communications, Ursula Owusu-Ekuful, announced the *Ghana Digital Agenda* as a pivotal government policy at an ITU Telecom World Conference in the Republic of Korea, assuring participants that 'no-one will be left behind'.[9]

Two years on, some public institutions have already migrated to digital platforms, including the Ghana Ports and Harbours Authority, the Lands Commission, the Ministry of Tourism and the Ghana Passport Office. The government has launched a biometric National Identity Card with tactile elements for the blind and a National Digital Property Addressing System, powered by the locally developed Asaase GPS App, which will provide every Ghanaian with a unique permanent digital address linked to postcodes. Notwithstanding some teething problems, digitalization has already lived up to expectations by considerably augmenting the revenue of the ports.

A major stimulus has come from World Bank support for the eTransform Project for digital platforms and infrastructure enhancement, capacity-building and regulation frameworks. The eTransform Project dates back to 2013 but has been extended to December 2020. In an effort to bridge the digital divide, regional community information centres have been built across the country to bring e-government services directly to communities.

Unconventional ways of promoting innovation in the digital space are being explored. In December 2019, the Ministry of Communications announced the three winners of its first Miss Geek Ghana competition for budding software app developers aged 13 to 25 years.[10] In addition to cash prizes, the young women will receive business training and financial support to develop their socially innovative project.

Ghana's *Digital Agenda* has been championed by Vice-President Mahamudu Bawumia. One objective has been to develop strategic partnerships with leading technology companies in the USA's Silicon Valley, such as General Electric, Google and IBM. This approach seems to be working; some tech innovation centres have recently opened, including Google for AI (Box 18.2, see previous page) and the Accra Digital Centre, an incubator hub financed by the World Bank and Rockefeller Foundation.

A *National Space Policy*

The current government has also formulated sector-specific policies, including the *National Space Policy* of June 2019, which was pending adoption by the Cabinet in 2020. The goal of this policy is to foster sustainable development through education, cutting-edge research and commercialization. In line with this policy, the Ghana Space Science and Technology Institute (est. 2013) is introducing space science into school and university curricula and plans to establish a space science museum and planetarium.

The institute managed the Ghana Astronomical Project, which completed the conversion of an abandoned communication satellite in the town of Kuntunse into a radio astronomical telescope in 2017. This telescope is being used to monitor agriculture, biodiversity, land-use changes and water resources, among other things. The Kuntunse telescope is part of the Square Kilometre Array project led by South Africa (Box 18.3).

In June 2017, the privately owned All Nations University in Koforidua launched Ghana's first satellite, GhanaSat-1. This educational satellite was sent into orbit from the International Space Station.

GUINEA

Infrastructure, research and innovation prioritized

Guinea possesses two-thirds of the world's known reserves of bauxite, as well as abundant agricultural land and water resources, according to the government's *Voluntary National Review* (2018) of its progress towards the SDGs. Despite this, the country is obliged to import food and electricity. Manufacturing and value addition (including mines) accounted for 0.8% of jobs in 2012 (Rep. Guinea, 2018).

Limited electrification is penalizing the domestic mining industry, which hosts major international companies such as Rio Tinto (Australian-British), Alcoa (USA), Vale (Brazilian) and Rusal (Russian). Just 3% of the country's hydropower potential is exploited. The main source of energy is biomass (77%), followed by imported hydrocarbons (22%) and hydropower (1%). Renewables account for about 0.02% of the energy mix, with just 1.5% of kitchens being equipped with butane gas. Solar lamps have been installed in rural and urban areas and the Souaptiti Dam is under construction, among other projects. Despite some progress, only one in three Guineans had access to electricity in 2016: 82% in urban areas and 7% in rural areas (Rep. Guinea, 2018).

Strong economic growth since 2016 offers Guinea an opportunity to accelerate ongoing reforms (Figure 18.1). The *National Plan for Economic and Social Development 2016–2020* (PNDES) is the first five-year implementation plan of *Emerging Guinea: Vision 2040*, drafted by the government in the wake of the devastating Ebola outbreak in 2014.

More than one-third of *Plan*'s budget for SDG9

PNDES has four pillars: the promotion of good governance; a sustainable and inclusive economic transformation; inclusive development of human capital; and sustainable management of natural capital. One priority area is 'economic infrastructure, innovation and research', which corresponds to SDG9. This priority area alone accounts for 39.1% of the PNDES budget. The aim is to promote research and innovation oriented towards developing a green economy.

PNDES' more than 170 flagship projects are being operationalized through several sectoral policies, including: the *Strategy for Recovery and Socio-Economic Resilience Post-Ebola*; the *Accelerated Food and Nutrition Security Programme and Sustainable Agricultural Development 2016–2020*; and the *Private Sector Development Strategy*.

The Ministry of Higher Education and Scientific Research has developed an action plan for its own implementation of PNDES. This action plan focuses on six areas: improving the governance of the system and institutions; greater access and equity; development of quality teaching, learning and research; staff motivation and skills development; greater financing from more diversified sources; and the promotion of academic, scientific and technical co-operation.

The budget of the Ministry of Higher Education and Scientific Research doubled between 2011 and 2019. Reforms are under way, beginning with the implementation of a master's programme to produce 5 000 graduates and the introduction of

Box 18.3: **Space tech taking off in West Africa**

Even before the *Science, Technology and Innovation Strategy for Africa 2024* (STISA-2024) made it a priority,* several West African countries were investing in space science and technology for socio-economic development.

The African space market was estimated to be worth US$ 10 billion in 2014 (Space in Africa, 2019). This figure supports the economic rationale of having a space programme in a region dominated by lower middle-income countries.

Nigeria: the region's trailblazer

Nigeria is West Africa's trailblazer in space, having invested in the subregion's first satellite back in 2003, NigeriaSat-1. This satellite had been built by a British company and launched by a Russian one. NigeriaSat-1was used for environmental monitoring, alerting to impending disasters and tracking desertification, among other things.

Nigeria has since launched other satellites and plans, ultimately, to send Nigerian astronauts into space.

The African Regional Centre for Space Science and Technology Education, based at Obafemi Awolowo University in Nigeria, is recognized across the continent as a centre of excellence.

Ghana: helping to build world's largest telescope

Another West African country exploring the potential of space science is Ghana. It is one of the nine African partners of the South African-led Square Kilometre Array (SKA) project,[19] which is building the world's largest telescope with a collecting area of over 1 million km^2 and receiving stations (radio astronomy telescopes) on the African and Australian continents. The project should be fully operational by 2030, with completion of the first phase expected in 2023 (see Box 20.1).

In 2017, Ghana became the first African country besides South Africa to convert a disused telecommunications antenna into a radio astronomical telescope capable of applying Very Long Baseline Interferometry for global network observations. The Government of Ghana has earmarked about 30 million Ghana cedis – roughly US$ 6 million – for its participation in the SKA project (Asabere, 2017).

Senegal: collecting data for flyby of asteroid

A key indication that other West African countries have woken up to the space challenge is Senegal's participation in the August 2018 mission to collect data in preparation for the flyby of an asteroid called Ultima Thule in January 2019. Scientists from France and the US National Aeronautics and Space Administration brought five tons of astronomical equipment to observe the skies with their counterparts in Senegal.

This progress owes much to the vibrancy of the Senegalese Association for the Promotion of Astronomy (Baratoux, 2018).

Rapid growth in publications

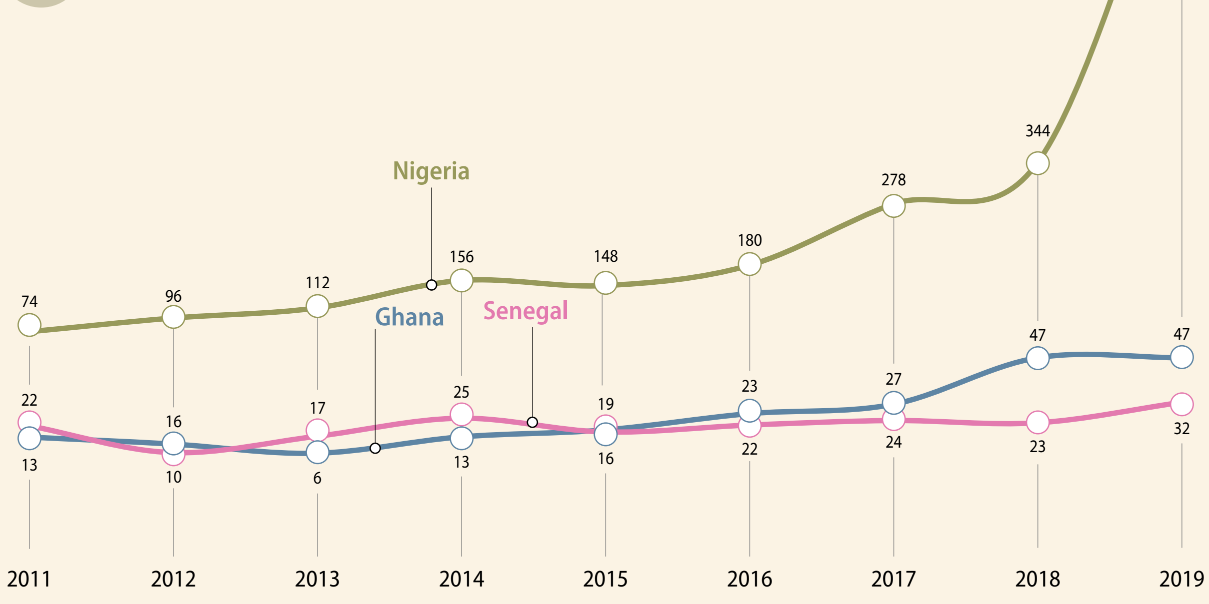
The number of scientific articles in physics and astronomy has grown rapidly in Ghana and Nigeria since 2016 (Figure 18.7).

More countries may soon join. The ECOWAS Commission has formulated a *Strategy on Space Sciences and Geomatics* and is investing in an Earth observation satellite, in collaboration with the Nigerian National Space Research and Development Agency.

* The African Union adopted an *African Space Strategy* in 2017, followed by an African Outer Space Programme in 2019 (see chapter 19).

Source: compiled by author

Figure 18.7: **Publications on physics and astronomy from Ghana, Nigeria and Senegal, 2011–2019**



Source: Scopus; data treatment by Science Metrix

ICTs in the education sector. The government has also launched a progamme to build infrastructure and purchase equipment for universities.

A National Agency for Quality Assurance

In 2017, the National Agency for Quality Assurance (ANAQ) was set up through the Booster Skills for Employability of Young People project (BoCEJ). BoCEJ is a government initiative designed to reduce the unemployment rate among young graduates of public and private universities and technical and vocational training schools, by giving them skills adapted to the labour market.

BoCEJ was launched in 2015, with financial support from the International Development Association of the World Bank Group.

GUINEA-BISSAU

A fresh start overshadowed by crisis

Between 2015 and July 2019, Guinea-Bissau was mired in a political and institutional crisis, deprived of a prime minister and national assembly. Despite the crisis, the economy grew by about 6% until 2017 (Figure 18.1).

The crisis was resolved after legislative elections were held in March 2019 and a prime minister appointed, followed by the formation of a government four months later. One of the 16 ministers (and 15 secretaries of state) is in charge of higher education and scientific research but the Ministry of National Education has also been awarded responsibility for the higher education sector.

Despite the crisis, the government operationalized its vision for *Guinea-Bissau 2025* in its *Terra Ranka Strategic and Operational Plan, 2015–2020*. This plan has sought to put in place a governance system in the service of the citizen; ensure sustainable management of natural capital and preserve biodiversity; build a network of modern, competitive infrastructure; strengthen human capital and improve the quality of life of every citizen; and build a private sector and diversified economy.

It is in this context that the Ministry of Education adopted the Sectoral Programme for Education (2017–2025) in July 2017. It covers all levels of education, as well as scientific research, and focuses on improving access and equity; quality; and governance and stewardship.

Academic and professional training is to be oriented more towards the needs of the labour market and infrastructure is to be built to satisfy growing demand. According to national data, public and private tertiary enrolment more than tripled between 2005 and 2013 from 3 122 to 10 439 students; the government expects the number to rise to just over 15 000 by 2025. This increase would boost the country's gross enrolment ratio in higher education from 6.3 to 7.0 but still place it below the average for West Africa. In 2013, investment in higher education amounted to just 0.1% of GDP (Figure 18.6).

The Sectoral Programme for Education plans to develop research units at Amilcar Cabral University, the country's only public university. Applied research will be promoted and networks created between researchers from partner universities at home and abroad. The programme also plans to develop linkages between the National Institute of Scientific Research and Amilcar Cabral University to strengthen teaching and research capacities. The status of university teachers and researchers is to be enhanced and mechanisms for funding research are to be identified.

Holding the country back is its poor Internet penetration (3.9%), the third-lowest in sub-Saharan Africa after Eritrea and Somalia (see Table 19.2). In 2015, Amilcar Cabral University was one of eight universities in West Africa to receive physical and virtual ICT infrastructure through a UNESCO project (see p. 472).

LIBERIA

A pro-poor agenda

Liberia's *Pro-Poor Agenda for Prosperity and Development* (2013–2018) is the second in a series of five-year national development plans for realizing its *National Vision: Liberia Rising 2030*.

The government is making a concerted effort to rebuild and develop its largely agrarian economy. Between 2012 and 2017, the Smallholder Agricultural Productivity Enhancement and Commercialization (SAPEC) programme sought to improve household income and food security by using sustainable methods to intensify production of vegetable and cassava crops, adding value to produce and refining marketing techniques. To date, 14 climate-smart rice varieties have also been introduced to farmers, in collaboration with AfricaRice.

It is estimated that 135 000 people benefited from SAPEC, 60% of them women. This is close to the target of 150 000. The programme developed the first farmer e-database, with over 321 766 farmers from all 15 counties agreeing to record their phone numbers, identity photos and assigned identity numbers.[11]

SAPEC was implemented with funding from the Global Agriculture and Food Security Programme, the African Development Bank and Ministry of Agriculture. There are signs that the project has been a success but the sustainability of such programmes is a challenge, given that about 95% of funding comes from abroad.

Also of note is the enactment of the Land Rights Law in September 2018. It devolves forest land-use decisions from the national government to community-level self-governance. The law provides for the establishment of community-based land development management committees which may use their 'forest lands and harvest all timber and non-timber products thereon, directly or indirectly in keeping with the provisions of the Community Rights Law of Liberia [2009] and the National Reforms Forestry Law of 2006'. The 2006 law stipulates that local communities are to be 'fully engaged in the sustainable management of the forests of Liberia' (SDI, 2019).

As part of its *Pro-Poor Agenda*, the government plans to introduce free university tuition for all in 2021. In 2019, the National Commission on Higher Education anticipated this move by adopting a policy requiring all new tertiary institutions applying for accreditation to be licensed first, to ensure they offer high standards of access, relevance and quality in their programmes. In 2018, the Commission had to shut down six illegal private universities offering poor-quality academic programmes.

A *National ICT Policy*

The country has enacted the *National ICT Policy* (2018–2023) prepared by the Ministry of Posts and Telecommunications. So far, several steps have been undertaken to digitalize the country, including the reform of the Liberia Telecommunications Authority and a revision of regulations and legislation to promote competitiveness in the telecommunications sector (Lumeh, 2019).

The Liberia Revenue Authority has set up a Mobile Tax System and online courses are being introduced at the University of Liberia, which is deploying a Digital Registration System. Still pending is the development of convergent licensing regimes and the enforcement of standards and regulations for electronic transactions and cybersecurity, in particular (Lumeh, 2019).

A fund for entrepreneurship

The Liberia Innovation Fund for Entrepreneurship (LIFE) became operational in 2015. It is helping to develop the private sector and create jobs for youth by providing seed funds to industries in the key sub-sectors of textiles, rubberwood and made-in-Liberia products. LIFE is funded jointly by the Governments of Japan and Liberia and managed by the Ministry of Commerce and Industry.

A growing interest in innovation led to the enactment of the Liberia Intellectual Property Act in 2016. The act defines the functions, structure and responsibilities of the Liberia Industrial Property Office, which has responsibility for registration and oversight of copyright, trademarks, geographical indications, patents and other forms of intellectual property in Liberia. Between 2015 and 2018, 27 patents were granted to Liberian inventors by the top five patent offices.

In July 2016, the long-standing Monrovia Industrial Park was placed under the Ministry of Commerce and Industry to accelerate its development. A year later, three factories were operating inside the park; other investors have since joined them, setting up factories for steel and wheat flour manufacturing, among other products.

MALI

A first: sustainable funding for R&D

The *National Science, Technology and Innovation Policy* was adopted in 2017, along with an *Action Plan* for 2017–2025. This policy has been developed with technical and financial support from UNESCO, after political instability interrupted the process in 2012.

The policy innovates by guaranteeing sustainable support for research funding, for the first time. The Competitive Fund for Research and Technological Innovation actually dates from 2011 but it became operational in 2017 through the imposition of an annual levy of 0.20% on tax revenue. The fund has since supported 46 research projects for a total investment of 2.3 billion CFA (*ca* US$ 3.9 million).

Many retiring researchers haven't been replaced

The fund comes at a crucial time, as Mali's research effort had dropped back to 0.29% of GDP to R&D by 2017, half of which came from abroad (50.2%) [Figure 18.4].

The number of researchers is down. Many retirees have not been replaced, causing the number of full-time equivalent (FTE) researchers to drop from 39 to 31 per million inhabitants between 2006 and 2015. This may also explain Mali's stagnating scientific productivity (Figure 18.5).

There were 2 091 research personnel in 2017, according to a study by the Institute of Statistics of Mali. One-third (34.5%) were researchers, down from 41.7% in 2015.

Founding of an Academy of Sciences

The *Action Plan* for the new policy has led to the creation of the National Academy of Sciences. This move was recommended initially by the Malian Society of Applied Sciences (MSAS) at the National Education Forum in 2008. MSAS has organized a biennial forum in Mali on applied sciences since 2000.

To ensure a coherent, participatory approach to implementation, the decree approving the *National Science, Technology and Innovation Policy* was signed by all ministerial departments with a relevant portfolio.[12]

Since, there has been a certain instability in piloting the policy. After just a year of implementation, there was an institutional reshuffle in September 2018 which saw the higher education sector detached from the ministry's portfolio to make room for the new Ministry of Innovation and Scientific Research.

This new structure was to be short-lived. In May 2019, higher education and scientific research were once more merged into a single ministry.

Partners for entrepreneurship

In order to expose the young to entrepreneurship and market needs, the *National Science, Technology and Innovation Policy* has opened membership of university councils to representatives of companies and civil society, as in Senegal (Essegbey *et al.,* 2015). Private companies are consulted on the content of university curricula. Some companies have established partnerships with universities to 'incubate' young graduates and, thereby, give them the entrepreneurial skills they need to found their own companies.

The policy has also innovated by institutionalizing the president's Grand Prix for Science and Innovation and creating an annual Science Fair in 2016.

Robotics nurturing a science culture

One strategic priority of the *National Science, Technology and Innovation Policy* has been to develop a science culture. This is in keeping with Mali's *Strategic Framework for Economic and Sustainable Development (2016–2018),* which deems 'it particularly timely to use ICTs to develop the teaching of STEM at secondary level and to encourage girls to opt for scientific careers'.

On 19 March 2018, the government inaugurated the National Centre for Collaborative Education in Robotics (RobotsMali, see photo, p. 466) at the new Cité universitaire of Kabala south of Bamako. UNESCO's Bamako office provided RobotsMali with 40 laptop computers, pedagogical materials and robot and drone kits, with financial support from China.

In addition to teaching children, teenagers and university students about robotics and coding, RobotsMali trains them in AI, electronics and the Internet of Things, as well as in entrepreneurship, marketing, design and project management. Malian teenagers have since won awards at several international competitions on robotics.

Staff at UNESCO's Bamako office have also been touring schools to help teachers introduce robotics into the curriculum. The deteriorating security situation in the north of the country means that children are spending more time indoors and robotics has proved to be an extremely popular after-school activity.

Mali held its first Miss Science competition in 2018, with UNESCO support. All 80 contestants were given computers and mobile phones by the three Ministries of National Education, Higher Education and the Promotion of Women. In an interview, 11-year-old contestant Coulibaly Seydou spoke of her love of mathematics and how the Miss Science quiz had given her the confidence to pursue a career as a mining engineer.[13]

NIGER

Moves to develop manufacturing

Thanks to reforms initiated in 2016 to revitalize the economy and combat the effects of climate change in Niger, GDP progressed by more than 5% in 2019. This level of growth should last until 2024, according to the International Monetary Fund, especially as the country has discovered new oil deposits.

The *Economic and Social Development Plan for 2017–2021* is striving to develop manufacturing and reduce the weight of the informal sector, which accounts for 90% of employment.

In 2018, the government finalized its *National Policy for Science, Technology and Innovation* with the support of the African Development Bank (AfDB) and UNESCO. Inspired by the vision of ECOPOST, the policy intends to help turn Niger into an emerging economy through the development and use of STI in the country's socio-economic and environmental sectors.

There is an urgent need to align policy with the needs of the economy and improve the co-ordination and funding of policy implementation. Research output has stagnated since 2015, judging from the country's publication record (Figure 18.5). Faced with obsolete equipment and insufficient research credits, researchers have little incentive to innovate. Several funds do exist, however, including: the Support Fund for Scientific Research and Technological Innovation (FARSIT, set up in 2010; the Intellectual Property Support Fund (2010); and the Support Fund for Continuing Professional Training and Apprenticeship (2007).

High population growth a headache for education sector

Economic competitiveness is also hamstrung by an adult illiteracy rate of over 70%, one of the highest in ECOWAS. Niger's education sector is struggling to cope with annual population growth of 3.8%, the fastest on the continent.

Gross university enrolment progressed from 1.4% in 2011 to 3.3% in 2015 and 4.4% of the 18–25 year cohort in 2018. Although this ratio remains among the lowest in West Africa, the surge in student numbers has put considerable pressure on infrastructure. This led the government to establish four new public universities in 2014:

- the University of Dosso, specializing in ICTs and hosting Technoden, a technological hub for the development of the digital economy;
- the University of Agadez, situated in a region rich in minerals, with a Higher Institute of Fossil and Renewable Energy;
- the University of Diffa, in the Lake Chad Basin, with a Higher Institute of Environment and Ecology and a Faculty of Agronomy; and
- the University of Tillabéri, which includes a Faculty of Agronomy.

To guarantee the quality of study programmes in both public and private universities, Niger set up a National Agency for Quality Assurance in Higher Education (ANAQ-SUP) by decree in February 2019.

NIGERIA

A fragile economy

Home to a population of 191 million, Nigeria accounts for over half of West Africa's population. Interestingly, Nigeria's working age population and adult literacy rate are both estimated at about 60% (NBS, 2018; World Bank, 2019b).

With the economy being driven mainly by oil revenue, GDP growth and exports of goods and services have slowed since the end of the commodities boom in 2014 (Figure 18). More could have been done during this boom period to diversify the economy. As it is, the drop in oil receipts since 2014 has fuelled greater inequalities in income and access to opportunity. Unemployment hit an all-time high of 23% in the third-quarter of 2018, while GDP declined from an all-time high of US$ 568 billion in 2014 to US$ 397 billion in 2018. Despite this, the Nigerian economy remains the largest in Africa.

In parallel, rising insecurity from armed banditry and terrorism has deprived many farmers of their livelihoods, leading to a spike in food insecurity and an increase in the number of citizens living below the poverty line. National security networks are stretched to the limit, with both kidnapping and killings on the rise in many parts of the country, making the economy unattractive to foreign investors (see Table 19.1). These security issues are further exacerbated by the high levels of unemployment.

Only a handful of multinational companies have local partnerships leading to real technology spillover in Nigeria.

The World Bank's 2013 study on *Local Content Policies in the Oil and Gas Industry* was designed to address that lapse (Tordo *et al.,* 2013). Although the study was endorsed by the government, it has not yielded much impact.

A combination of abundant natural resources and a poor manufacturing base has led the Federal Government to hinge its industrial policies, over the years, largely on import substitution to conserve foreign earnings and generate revenue from the export of raw materials.

Since coming to power in 2015, the government led by President Muhammadu Buhari has devised various strategies to wean the economy off its over-reliance on crude oil, including by fostering Nigeria's competitive advantage in raw materials and product development, broadening the scope of industry and accelerating expansion of the manufacturing sub-sector. These policies were implemented through the *Nigeria Industrial Revolution Plan* (2014) and the newly established Nigeria Industrial Policy and Competitiveness Advisory Council (Industrial Council).[14] In spite of the government's efforts, the year-on-year cyclical growth rate of the manufacturing sector has been slow: 1.58% in 2016, 0.83% in 2017, 2.09% in 2018 and 0.81% in 2019, according to the National Bureau of Statistics and Central Bank of Nigeria.

The current *Economic Recovery and Growth Plan* (2017) faces the same hurdles as its predecessors: overdependence on revenue from crude oil exports; serious infrastructural deficits; weak human capital development; ineffective institutions; mismanagement of public financial systems; and weak governance (World Bank, 2019b). Despite efforts to create a friendlier climate for local and international investors, Nigeria still ranks 146th out of 190 economies for the ease of doing business.

The plan does recognize the need to build a knowledge economy, however, and can be linked to several achievements: positive growth in the agricultural sector, a lower inflation rate, sustained recovery from recession, the launch of an SME empowerment programme, better transportation infrastructure and greater power generation, among others.

Time to expand the national grid

One factor hindering the government's efforts to expand the manufacturing sector has been the inadequate and largely epileptic power supply needed to drive the production of goods and services. This sector, like others, has had to rely essentially on self-generated electricity using stand-alone generators, pushing up the cost of production and, thereby, making goods uncompetitive against imports.

The government seems determined to put the necessary energy infrastructure in place. It has announced plans to remove all non-fiscal barriers to investment in the power sector and ensure a competitive business environment with free entry and exit rights for investors, irrespective of nationality, although these plans had not yet translated into concrete policies as of mid-2020. In the appropriation bill presented to the Ninth Assembly on 7 October 2019, the president highlighted the target of expanding the national grid from just under 5 000 MW at present to 11 000 MW by the end of 2023. Moreover, with the pledged support of the German government and other international development partners, power generation is projected to rise to 25 000 MW by 2030.

In December 2019, the Nigerian Rural Electrification Agency (est. 2015) supported the commissioning of the first solar hybrid mini-grid site in Niger State under the World Bank-assisted Nigeria Electrification Project. The site was constructed by Power-Gen Renewable Energy Nigeria Limited and is expected to provide 350 end-users with affordable electricity. This project contributes to the *National Renewable Energy and Energy Efficiency Plan* (2015).

In 2019, the federal government also commissioned a 7.1 MW solar hybrid power plant at Bayero University in Kano and a 2.8 MW plant at the Alex Ekwueme University in Ebonyi. It has pledged to provide 37 federal universities and 7 federal teaching hospitals across the country with off-grid captive power, according to the National University Commission.[15]

The *Nigerian Renewable Energy Master Plan* (2006) fixed the targets of having renewable energy contribute 13% of total electricity generation by 2015, 23% by 2025 and 36% by 2030. The plan also aims to increase electricity access from 54% in 2017, according to the World Bank, to 75% by 2025.

New research bodies but little funding

Vision 20:2020 was launched in 2010 to make Nigeria one of the top 20 economies in the world by 2020. This target was based on the assumption of a consistent 12.5% annual growth rate in GDP per capita to not less than US$ 4 000 per annum by 2020. After peaking at US$ 3 223 (in current US dollars) in 2014, GDP subsequently slid back to US$ 2 028 in 2018, according to World Bank data. *Vision 20:2020* has aspired to translate rapid economic growth into equitable social development. Prevailing economic indicators suggest that there is little likelihood of reaching this laudable goal by 2020.

Another target was to invest a share of GDP in R&D comparable to that of the 20 leading economies by 2020. The federal government approved a *National Science, Technology and Innovation Policy* in 2012 to underpin *Vision 20:2020*. It has five pillars: leadership; priority-setting; funding; partnership; and the development of a popular science culture. The policy stressed human capital development, intellectual property, technology transfer and the commercialization of research results.

The policy called for the establishment of a National Research and Innovation Council chaired by the president, which was set up in 2016. The council is mandated to set research priorities, co-ordinate STI activities and facilitate fundraising to support innovation in areas of national need.

The policy stressed the need for the federal government to commit at least 1% of GDP to a National Research and Innovation Fund. In 2019, President Buhari was cited as saying that this requirement was practically unworkable[16] (Udegbunam, 2019).

As of 2020, neither the National Research and Innovation Council, nor the National Research and Innovation Fund had been activated.

By and large, the implementation of STI policy has been hampered by the same weaknesses that bedevil the economy, together with inadequate technological infrastructure to develop and commercialize R&D products, limited interaction among government research institutes, industry and academia, inadequate research personnel, recurrent policy inconsistencies and, of course, paltry research funding. Nigeria's comparatively low research output (Figure 18.5) reflects this state of affairs.

The Federal Ministry of Science and Technology has devised measures to overcome barriers to the commercialization of public R&D. For instance, the National Office for Technology Acquisition and Promotion has established more than 40 intellectual property and technology transfer offices at universities and research institutes across the country. Up to 40 business and technology incubators have also been established.

The ministry has also devised a *Science, Technology and Innovation Roadmap 2030* (2017) and a *National Raw Materials Competitiveness Strategy* (2016). It has signed memoranda of understanding with three Nigerian companies for the commercialization of endogenous research in areas such as dairy, soybean and cassava processing technologies: Tiger Foods Ltd, LenofKonsult and Lashone Links Ltd. Despite these efforts, the commercialization of research results remains insufficient.

Current policies need to acknowledge that global competition is being driven by highly sophisticated technologies such as AI, robotics, nanotechnologies and bioinformatics. These are the areas in which Nigeria needs to develop a critical mass of capabilities. At this stage, there is still little knowledge of AI in Nigeria. Oxford Insight's 2019 AI readiness index shows that Nigeria is ill-prepared for this new development.[17] See also Figure 20.6.

It is, thus, timely that the *National Science, Technology and Innovation Policy* of 2012 is up for review. This will also be an opportunity to align it with *Agenda 2030*, *Agenda 2063* and *STISA-2024*, among other international initiatives.

The review will also be an opportunity to develop linkages with the *National Policy on Climate Change and Response Strategy* (2015), devised by the Department of Climate Change within the Ministry of Environment. This policy prioritizes low-carbon, high-growth economic development and building a climate-resilient society.

The policy follows the *National Adaptation Strategy and Plan of Action on Climate Change for Nigeria* (2011), which enumerates strategies for agriculture, marine resources, fisheries, forestry, biodiversity, health, housing, energy, commerce and other critical areas.

In 2019, the Minister of Science and Technology inaugurated an interministerial committee drawn from 16 ministries to 'midwife' the review process. As always, the committee includes top civil servants, members of the Academies of Science and Engineering, technocrats, public policy experts and development partners, including ECOWAS and UNESCO, non-governmental organizations and captains of industry. The committee is due to present the revised *National Science, Technology and Innovation Policy* in mid-2020.

SENEGAL

More universities and a technopole

The *Senegal Emerging Plan* (2014) provides the national framework for turning Senegal into an upper middle-income country by 2035. The plan has three thrusts: structural transformation of the economy; promotion of human capital; and good governance.

Despite an average real GDP growth rate of 6.2% during the plan's first phase (2014–2018), the economy remains dominated by services, with an insufficient stock of skilled human capital. The desired structural transformation is still in its infancy.

In order to address underemployment and provide businesses with the skills they need, three flagship reforms are being implemented under the plan:

- alignment of graduate skills with the needs of the economy: more than 342 tertiary curricula and skills benchmarks have been revised, a professionalization programme has been developed for universities and a Programme for Youth Entrepreneurship has been launched; it targets both universities and colleges offering technical and vocational training, in addition to young entrepreneurs;[18]
- accelerated development of technical and vocational training: a strategic development plan has been developed for the period 2016–2020; and
- the structuring and promotion of continuing education.

Rapidly growing demand for higher education is putting pressure on the existing university network. Between 2015 and 2018, gross tertiary enrolment rose sharply from 10.8% to 12.8% of the 18–25-year-old cohort. According to the Ministry of Higher Education, Research and Innovation's *Evaluation de la carte universitaire : rapport d'activités 2012–2019*, the number of students almost doubled between 2012 and 2018 from 93 866 to 190 145, with 35% enrolled in private institutions.

In public universities, about 32% of students (nearly 35 000) were enrolled in STEM disciplines in 2017. This may partly explain why the number of FTE researchers climbed steeply from 362 to 564 per million inhabitants between 2010 and 2015 (Figure 18.4).

To operationalize the *Senegal Emerging Plan*, a sectoral plan for higher education and scientific research was implemented from 2013 to 2017. This has since been revised and published as a *Sectoral Policy Paper for the Development of Higher Education, Research and Innovation* covering the period 2018–2022. Both plans have invested massively in infrastructure development to expand the physical capacity of universities and link education, science and industry (MESRI du Sénégal, 2018):

- six universities have been extended and rehabilitated;
- two universities have been built with a capacity each of 30 000 students: Sine Saloum El Hadji Ibrahima Niass University and Amadou Mahtar Mbow University, the latter specializing in scientific disciplines and having welcomed its first student intake in October 2019;

- a network of 14 Higher Institutes of Professional Training (ISEP) is being created, beginning with those of Thiès, Diamniadio, Matam, Bignona and Richard Toll;
- the Virtual University of Senegal was created in 2013 with 20 open digital spaces initially – a further 30 are being built across the country and it has served as a model for Burkina Faso's own virtual university; and
- the City of Knowledge opened in October 2019 in the new city of Diamniadio near Dakar (Diallo, 2018). This 'ecosystem' for the incubation of start-ups groups a House of Science, the local ISEP, the headquarters of the Virtual University, a media centre and administrative offices.

The City of Knowledge offers training in robotics, AI, big data, molecular genetics, computer simulations and cybersecurity, the aim being to involve a cross-section of tertiary institutions from Senegal and beyond in giving budding entrepreneurs the skills they need (Diallo, 2018). Diamniadio's role as a budding technopole led to it being chosen as the site of the country's first data centre in 2016, established by the country's second-biggest telecoms operator, Tigo, at a cost of more than 3 billion FCFA (*ca* US$ 5 million) [Diallo, 2016].

Data holes in policy plans

The Ministry of Higher Education, Research and Innovation has drafted Senegal's first explicit science and technology policy, with the technical and financial assistance of UNESCO. The lack of sufficient national data to inform the process has, however, impeded finalization of the document in the past couple of years.

This policy would be the logical expression of the political will to commit more resources to R&D. Between 2010 and 2015, Senegal raised its research effort from 0.40% to 0.58% of GDP. Moreover, the proportion of funds coming from abroad shrank over the same period from 41% to 8%.

The higher education and private sectors contribute little research funding and there is no financial mechanism in place at present to incite the industrial sector to do more.

Improving funding for innovative projects

In 2015, a study by the National Agency for Statistics and Demographics found that only 8.7% of companies maintained relations with research centres but that more than half (52.3%) of companies with ties to research centres used their products (Cissé *et al.,* 2019). Between 2012 and 2016, the ministry created 14 research and testing centres, bringing the total to 23 (MESRI du Sénégal, 2018).

Since 2015, the ministry has invested heavily in the acquisition of heavy laboratory equipment and in a super-intensive parallel computer; it has also given researchers free access to online scientific databases.

In order to improve access to project funding for women researchers, the ministry has introduced a Project for Supporting Female University Researchers in Senegal (PAPES) which had financed more than 100 projects by mid-2018 (MESRI du Sénégal, 2018). In November 2019, two women students from Gaston Berger University won Nestlé's Africa Innovation Challenge in the university category for their food technology project.

In order to make research and innovation drivers of socio-economic development, the government has strengthened co-ordination within the Ministry of Higher Education, Research and Innovation since 2018 by creating a Directorate for Research and Innovation.

Box 18.4: **The sovereign fund prioritizing Senegal's sustainable development agenda**

In 2012, the government created, by law, the Sovereign Fund for Strategic Investments (FONSIS).

This fund uses state revenue from oil and gas to invest in capital funds targeting SMEs in sectors prioritized by the *Senegal Emerging Plan*, such as solar energy, agriculture and health. The long-term goal is to reduce dependence on this form of revenue through a diversified investment portfolio.

In 2015, FONSIS created a subsidiary, the Medical Infrastructure Hub (POLIMED), which designs and manages clinics and hospitals. POMIMED is currently rehabilitating the Matlaboul Fawzaïni Hospital and putting in place an e-information system for patient files.

In February 2020, FONSIS signed an agreement with General Electric to equip public and private clinics and hospitals with scanners and other modern medical equipment.

In January 2019, the pharmaceutical company Parenterus, a subsidiary of FONSIS, opened its first factory in Senegal.

Another subsidiary is Sogenas, a company specializing in the production and commercialization of dairy cows genetically modified to resist hot, dry conditions.

In November 2019, FONSIS raised 31 billion francs CFA to build solar plants in Kaél and Kahone with a total capacity of 50 MW. Approximately 25 billion francs CFA are being provided by a consortium consisting of Proparco, part of the Agence française de développement, the World Bank and European Investment Bank.

These new solar plants bring the total to four. They will help Senegal to reach its objective of raising the share of renewable sources to at least 21% of the country's energy mix by 2018. Moreover, the Senegalese electricity company, Senelec, will be able to buy each kilowatt hour for just 25 francs CFA, reportedly the lowest price in sub-Saharan Africa.

In 2019, FONSIS created a generational fund for long-term investments, which pay smaller dividends but involve a lesser degree of risk.

Up until now, investments have focused on SMEs in Senegal but the fund has begun investing abroad, as well, as authorized by its statutes.

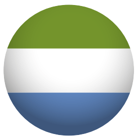
Source: www.fonsis.org

In addition, a National Council for Higher Education, Research, Innovation, Science and Technology is being set up to serve as a think tank on national research policy.

The government is also transforming its Investment Fund for Scientific Research, which offers competitive research grants, into a National Fund for Research and Innovation (MESRI du Sénégal, 2018).

In 2012 and 2013, the government established two investment funds dedicated to supporting innovative SMEs: the Guarantee Fund for Priority Investments (FONGIP) and the Sovereign Fund for Strategic Investments (FONSIS, Box 18.4 on previous page).

SIERRA LEONE



Free education for schools

Sierra Leone is a country marked by tragedy. Barely a decade after the end of the civil war in 2002, the country confronted the deadly Ebola outbreak in 2014, estimated to have amputated 20% of GDP. The economy still subsists on primary commodity exports, especially diamonds, iron ore, titanium ore, cocoa, coffee and wood.

Sierra Leone's *Medium-Term National Development Plan: Education for Development* (2019–2023) prioritizes education (SDG4) and peace, justice and strong institutions (SDG16).

In August 2018, the government allocated 21% of the national budget to the Free Quality School Education Programme, to accelerate progress towards universal primary and secondary education – the government estimated secondary-level enrolment at 68% in 2018 – and provide free textbooks and learning materials, according to the country's *Voluntary National Review* (MPED, 2019).

Sierre Leone is striving to achieve other SDGs. For example, its comprehensive Decent Work Country Programme has led to the development of a Labour Market Information System and *National HIV/AIDS Workplace Policy*.

For SDG13 on climate change, Sierra Leone is enforcing compliance on environmental protection, through monitoring and other strategies, such as the integration of messages on climate change into school and university curricula (MPED, 2019).

Agro-business incubator for women

In May 2019, a year after being elected president, Julius Maada Bio informed parliament that the government had put in place a Business Incubator for African Women Entrepreneurship (SDG5), with emphasis on agro-business. In parallel, the government has established a Women's Development Fund to provide female traders and entrepreneurs with seed capital.

A draft Gender Equality and Women's Empowerment Policy was awaiting Cabinet approval in 2019. It fixes the target of achieving at least 30% female representation in governance structures (MPED, 2019).

A focus on innovation hubs

The government created the Directorate of Science, Technology and Innovation in 2018 to pilot its Digitization Initiative for introducing e-government.

The Directorate has since developed a prototype for an integrated geographical information system to map government services and infrastructure, in collaboration with other ministries.

The Directorate has also spearheaded the creation of Sierra Leone's first school for computer coding, hosted by an innovation hub founded in 2019 at the University of Sierra Leone's Institute of Public Administration and Management (MPED, 2019).

Meanwhile, the Sensi Tech Hub in Freetown has been building a community of young entrepreneurs and technologists over the past couple of years. It also proposes a digital literacy plan for students in rural areas, using solar-powered boxes to connect laptops in a country with just 13% Internet access in 2017 (see Table 19.2).

TOGO

A vision of an emergent country

Togo's development policies for the past 30 years have typically reflected the economic orthodoxy of international financial institutions, ever since the country adopted its first Structural Adjustment Programme back in 1988. This changed in 2018, when Togo aligned its development policy with that of other African countries. Its *National Development Plan 2018–2022* espouses the vision of an emergent Togo by 2030, with emphasis on the structural transformation of the economy.

Value addition and electrification

The country's new policy vision is to restructure the economy through the development of processing centres for agricultural, manufacturing and extractive products. To this end, the government is upgrading vocational training centres for young men and women working in industry, agriculture, tourism, finance and crafts.

In order to encourage international trade, the highway linking Lomé to Ougagdougou will be enlarged and airport infrastructure modernized. There are plans to develop an industrial park and agro-hubs through public–private partnerships and to support women entrepreneurs and young entrepreneurs (Manciaux, 2019).

Under the *National Development Plan,* the Cizo project intends to distribute affordable solar kits to 300 000 rural households and 800 health centres by 2022. In addition, about 3 000 farms will be equipped with solar pumps. Users will be able to make their payments from a distance, thanks to a technology integrated in the kits. Funded through donations from the African Development Bank and European Union, the project is expected to raise the rural electrification rate to 40% (ARERE, 2019).

The third objective of the *National Development Plan* is 'the promotion of technological universities and R&D centres'. This follows the setting up of a Presidential Council for higher education and research in 2013, the year the Ministry of Industry, Free Zones and Technological Innovations drew up a national policy on technological innovation. It also follows a sectoral policy, the *Strategy for the Promotion of Information and Communication Technologies* 2011–2015.

Togo's first *National Policy for Science, Technology and Innovation* was approved in 2014 but it would take another three years for the law providing the relevant framework to be adopted. The challenges facing science in Togo are similar to those of most French-speaking African countries. In the face of competing priorities, a favourable policy rhetoric has not translated into significant financial support for R&D.

CONCLUSION

A race against the clock

With the African Continental Free Trade Area on the horizon, West African countries are racing against the clock to restructure their economies and modernize infrastructure. Electrification is a key element of this strategy. It underpins not only the economy and R&D but also countries' digital agenda.

Governments are also investing heavily in vocational and higher education to absorb demand – more than 60% of the population is under the age of 20 in some countries – combat underemployment and give graduates marketable skills, another prerequisite for a modern economy. At the same time, countries are having to deal with increasingly capricious weather patterns that are playing havoc with food security.

Among all these competing priorities, R&D is taking a back seat, even though West African governments now recognize that STI will be indispensable to restructure their economies and reduce poverty. Centres of excellence participating in the WASCAL project (Box 18.1), for instance, are developing climate-smart agriculture.

The rhetoric has changed but…

The rhetoric has changed – all but six West African countries now have an explicit STI policy – but the litmus test resides not in the formulation of such a policy but in its implementation. Without adequate instruments, primary among which are adequate funding and a supportive legal framework, a policy cannot be implemented effectively. When the bulk of research funding comes from abroad, it cannot be sustainable. Senegal is now more than halfway towards the AU's 1% target for R&D expenditure – all the more impressive given that the contribution coming from abroad has been slashed.

Paradoxically, Senegal is still without an explicit STI policy. A draft policy exists but its finalization has been languishing for want of adequate statistics. Lack of data is impeding not only evidence-informed policy formulation but also effective monitoring and evaluation. It is discouraging to see fewer countries publishing data on R&D than before the SDGs were adopted in 2015.

Is West Africa ready to embrace the Fourth Industrial Revolution? Can current policies accommodate the development and deployment of state-of-the-art technologies such as AI, nanotechnology and robotics? Given the vital role that big data play in Industry 4.0, more countries need to follow Cabo Verde, The Gambia and Senegal's lead by supporting the creation of a locally led data centre.

The current expansion of technology hubs is good news for West African governments, for it is start-ups that offer the best chance of narrowing the technological divide, as long as they are able to access venture capital and seed funds to keep themselves afloat in the trying early years. The regulatory framework must be reformed to create optimum conditions for business incubation. For instance, tax rebates should be envisaged for tech start-ups to draw investors and cities wishing to attract innovation hubs should be able to offer broadbrand infrastructure, as in the case of Lagos.

Governments should also support frequent monitoring, information-sharing and collaborative research across the region to anticipate the future needs of the tech-hub ecosystem. The network of 22 centres of excellence created with World Bank support is turning out master's and PhD graduates who can lead this collaborative endeavour.

Governments in the subregion have a unique opportunity to reap the 'demographic dividend' offered by their young populations. The shining talents of RobotsMali, Miss Geek Ghana or Senegal's City of Knowledge are the entrepreneurs of tomorrow. West Africa's innovation ecosystem must be ready for them.

KEY TARGETS FOR WEST AFRICAN COUNTRIES

- The presidents of the national parliaments of ECOWAS members invite member states to lower fertility rates to three children per woman by 2030.
- The African Union's *Abuja Declaration* (2001) sets the target of devoting at least 15% of the national budget to health care by 2025.
- Cabo Verde plans to become entirely reliant on renewable energy sources by 2025.
- Ghana, alongside its partners on the Square Kilometre Array project, expects the world's largest telescope to be operational by 2030.
- Guinea-Bissau is seeking to cross the 15 000 threshold for public and private tertiary enrolment by 2025.
- Nigeria aims to expand the national grid from just under 5 000 MW to 11 000 MW by the end of 2023.
- Nigeria intends to raise the share of renewable energy in total electricity generation to 36% by 2030 and to give 75% of the population access to electricity by 2025.
- In Togo, the Cizo project plans to distribute affordable solar kits to 300 000 rural households and 800 health centres by 2022.

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ENDNOTES

1 In June 2019, representatives of the African Union visited the European Food Safety Authority in Italy, to study how to set up an equivalent body in Africa (Herszehnorn and Marks, 2020).

2 The signatories are Benin, Chad, Comoros, Republic of Congo, Guinea-Bissau, Mauritania, São Tome & Principe, Sierra Leone, Togo, Tunisia and Zambia.

3 The World Bank has pledged to support the initiative to the tune of US$ 25 billion by 2030.

4 These were: the University of Abomey Calavi (Benin), Abdou Moumouni University (Niger), Amilcar Cabral University (Guinea-Bissau), Cheikh Anta Diop University (Senegal), Félix Houphouët-Boigny University (Côte d'Ivoire), University of Ouagadougou (Burkina Faso), the University of Lomé (Togo) and the University of Science, Techniques and Technology (Mali).

5 In Nigeria, the National Biosafety Management Agency Act was approved by the National Assembly in April 2015 and amended in 2019. This has enabled the National Biotechnology Development Agency to focus its research on the use of biotechnology and genetic engineering to improve crops and animal production. In the past five years, the agency has developed and produced two *Bt* cotton varieties, for instance. This research was supported by the Bill and Melinda Gates Foundation as part of efforts to revive the hitherto moribund textile industry in Nigeria. The agency has also unveiled prototype biodigesters for use by households and small businesses like restaurants. For research output trends, see Figure 20.6.

6 This initiative is supported jointly by Canada's International Development Centre, the UK's Department for International Development and South Africa's National Research Foundation.

7 See: https://uv.bf/presentation/

8 The other four pilot countries are Ethiopia, India, Kenya and Serbia. The inter-agency team brings together UNESCO, the World Bank, United Nations Department of Economic and Social Affairs, United Nations Conference on Trade and Development and the EU's Joint Research Centre.

9 See: https://www.moc.gov.gh/government-embarks-digital-inclusion-agenda

10 See: https://msgeek.org.gh/

11 See: https://tinyurl.com/rjjr87j

12 Lead among them were the Malian Ministry of Scientific Research and Higher Education; Ministry of Foreign Affairs and International Co-operation; Ministry of the Economy and Finance; Ministry of Promotion, Investment and the Private Sector; Ministry of Agriculture; Ministry of Livestock; Ministry of National Education; Ministry of Industrial Development; and the Ministry of Health and Public Hygiene.

13 See (in French): https://fr.unesco.org/news/premier-concours-miss-science-du-mali

14 One of the Industrial Council's five priority areas is to ensure that industry's needs in terms of skills are being met by academia. The other priority areas are: policy and regulation; trade and markets; critical infrastructure; and finance.

15 See http://nuc.edu.ng

16 The president was reported to have described the provision in the National Research and Innovation Council Bill for 5% of the annual allocation to 14 entities listed in Section 17 of the bill to be paid into the National Research and Innovation Fund as being as practically difficult to implement; it was on these grounds that he rejected this bill in April 2019, shortly after it had been approved by the National Assembly (Udegbunam, 2019).

17 Some private and civil society groups like Data Science Nigeria are promoting AI and an AI-focused innovation hub has been established at the University of Lagos. Private entities, such as banks like UBA and telecommunications companies like Glo, now use AI-powered digital assistants.

18 See: https://psej.net

19 The others are Botswana, Kenya, Madagasar, Mauritius, Mozambique, Namibia, South Africa and Zambia.

AT A GLANCE

A bit of heaven at Hell's Gate: children enjoy the Olkaria Geothermal Spa in Hell's Gate National Park in Naivasha, Kenya. KenGen built this public spa as part of a broader project to develop geothermal energy in the Rift Valley. Today, more than than one-third of Kenyan households are powered by geothermal energy (Box 19.1). © KenGen Foundation

- Regional integration is recording noticeable milestones, especially on the economic and infrastructural fronts, with investment prioritizing railways, as well as digital and energy infrastructure.
- The development of digital infrastructure has seeded a digital economy, with a growing number of innovation and tech hubs.
- Despite the skills shortage for the digital revolution, the higher education sector, including technical and vocational education, has not received enough attention in Central Africa, in particular.
- Five countries now have an explicit science, technology and innovation (STI) policy. These tend to focus on economic growth and competitiveness.
- Countries are investing in renewables but projects tend to be reliant on foreign expertise. Scientific output on renewable energy is still negligible in most countries.
- Environmental impact assessments are not being conducted systematically for planned mega-infrastructure projects.

19 · Central and East Africa

Burundi, Cameroon, Central African Republic, Chad, Republic of Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Kenya, Rwanda, Somalia, South Sudan, Uganda

Ann Njoki Kingiri and Charles Awono Onana

INTRODUCTION

Glimpse of hope in economic recovery

Economic growth in Central and East Africa averaged 2.8% in 2018–2019, less than the continental average of 3.2%. GDP per capita has risen, or remained stable, in all but Equatorial Guinea and the Republic of Congo (Figure 19.1; Table 19.1). The former is still recovering from the economic recession caused by the 2014 slump in global oil prices. The Republic of Congo's economy slowed to 4.4% in 2019, following the slump in global prices for cobalt and copper, which account for over 80% of exports.

In 2018, economic growth in Central Africa was driven primarily by the recovery of oil prices. Oil exploration remains the leading source of revenue for Chad, Equatorial Guinea and South Sudan and is being pursued in Ethiopia and Somalia (Figure 19.1). The laying of the proposed East African Crude Oil Pipeline System should unlock the oil and gas potential of Kenya and Uganda, in particular. South Sudan (10th), Kenya (17th) and Ethiopia (19th) made it into the top 20 oil-producing countries in Africa in 2018.

Poor governance and corruption continue to undermine economic growth and prospects for attracting foreign direct investment (FDI). Burundi, Eritrea, Somalia and South Sudan all score poorly on the Ibrahim Index of African governance (Table 19.1).

Several countries have been experiencing a debt crisis. In 2018, external debt in Central Africa stood at 27% but was as high as 67% in the Republic of Congo. In the wider region, all but Djibouti, Equatorial Guinea, Gabon, Kenya and South Sudan have Highly Indebted Poor Country (HIPC) status and are eligible for HIPC Initiative Assistance.

Some countries may be raising their debt exposure. Djibouti's central government debt rose from 72% to 87% of GDP between 2015 and 2016. As of 2018, Ethiopia was devoting 60% of GDP to servicing its foreign debt (Hurley *et al.*, 2018). There is a risk that the economic fallout from the Covid-19 pandemic in 2020 will force highly indebted countries to make a choice between investing in health care and servicing their debt burden.

The manufacturing and services sectors are playing a greater role in some of the region's fastest-growing economies, including Djibouti, Ethiopia, Kenya, Rwanda and Uganda (Figure 19.1). The services sector remains largely informal, however, resulting in low productivity and precarious employment (Medina *et al*., 2017). Workers in the informal economy have been particularly exposed to job insecurity during the Covid-19 pandemic.

Towards digital economies

A number of countries have adopted digital strategies in recent years. Uganda, for instance, is developing a strategy to attract investment in the technologies of the Fourth Industrial Revolution (also known as Industry 4.0). Cameroon is prioritizing the digital economy. Kenya hosts one of two IBM research centres in Africa, the other being in South Africa (see Box 20.4).

Rwanda is using robots and drones to curb the Covid-19 pandemic. Like Ghana, it is using drone technology provided by the US firm Zipline to deliver blood samples from remote areas (see cover photo). Rwanda is also using drones to police citizens and enforce lockdown measures while at the same time informing them how to stay safe from the virus. The UNDP Accelerator Lab partnered with the Ministry of Information and Communication Technology and Innovation to acquire and deploy five smart anti-epidemic robots for use in two Covid-19 treatment centres and at Kigali International Airport. These robots are helping hospitals to monitor patients' needs, such as by taking their temperature, to limit interaction between medical personal and patients.

The African digital revolution is being buoyed by consistent growth in mobile phones (Table 19.2) and digital payment systems with advanced functionalities that draw on the confluence of mobile money and the Internet of Things. One example is the solar-powered M-Kopa app launched in Kenya in 2012, which employs a pay-as-you-go retail model; it is estimated to have benefited 150 000 households in East Africa by 2015.[1]

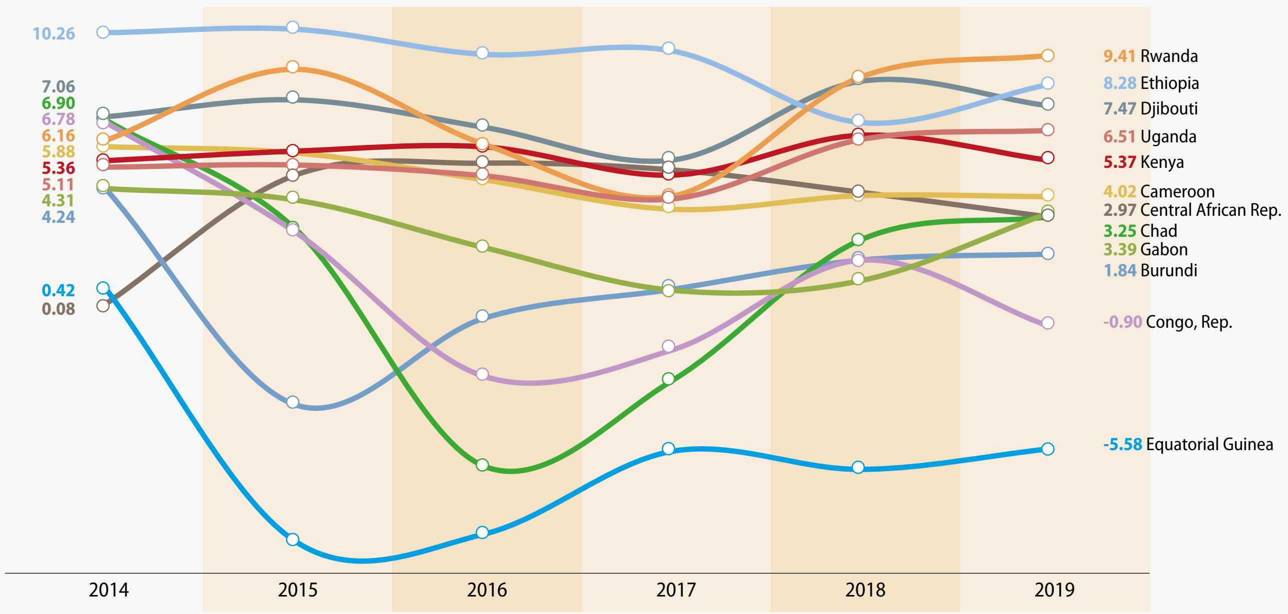
Use of big data by mobile service providers can help to address some of the challenges of the digital world such as fraud management and customers' analytics in accessing different financial services (Gatune and Brown, 2018). This would partly propel achievement of the *African Union Convention on Cyber Security and Personal Data Protection* (the *Malabo Convention*) adopted in 2014. This agreement was prompted by the spread of Internet penetration in Africa (Table 19.2) raising concerns over the need to promote cybersecurity governance and cyberstability across the continent (see also Chapter 18).

Internet, nevertheless, still reaches less than 10% of the population in several Central African countries, namely, Burundi, Chad, the Central African Republic, Republic of Congo and Eritrea (Table 19.2).

In 2017, the African Union endorsed the Programme for Infrastructure Development in Africa (PIDA). One focus is the Internet Exchange Point (IXP) programme, which is based on the ongoing project funded by the European Union for an African Internet Exchange System (AXIS). The aim is to

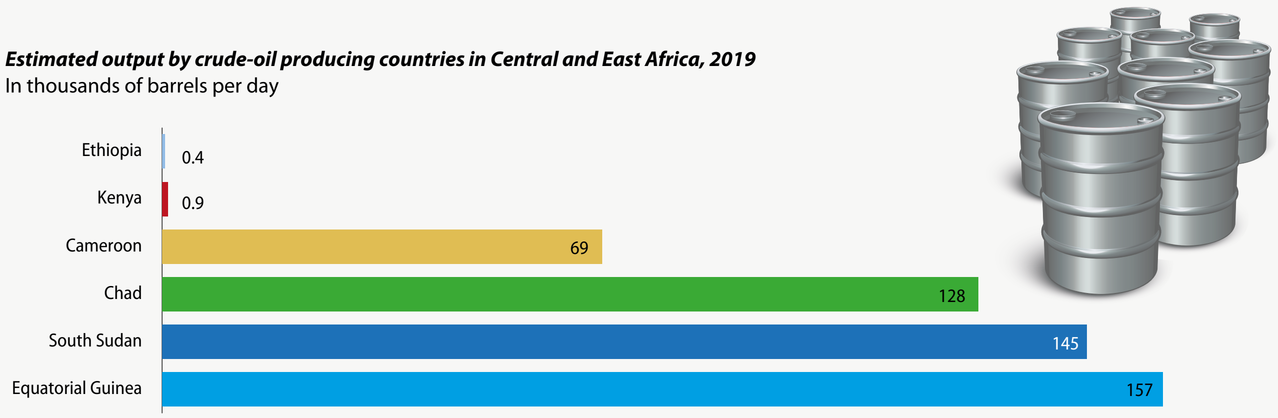
Figure 19.1: **Socio-economic trends in Central and East Africa**

Rate of economic growth in Central and East Africa, 2014–2019 (%)

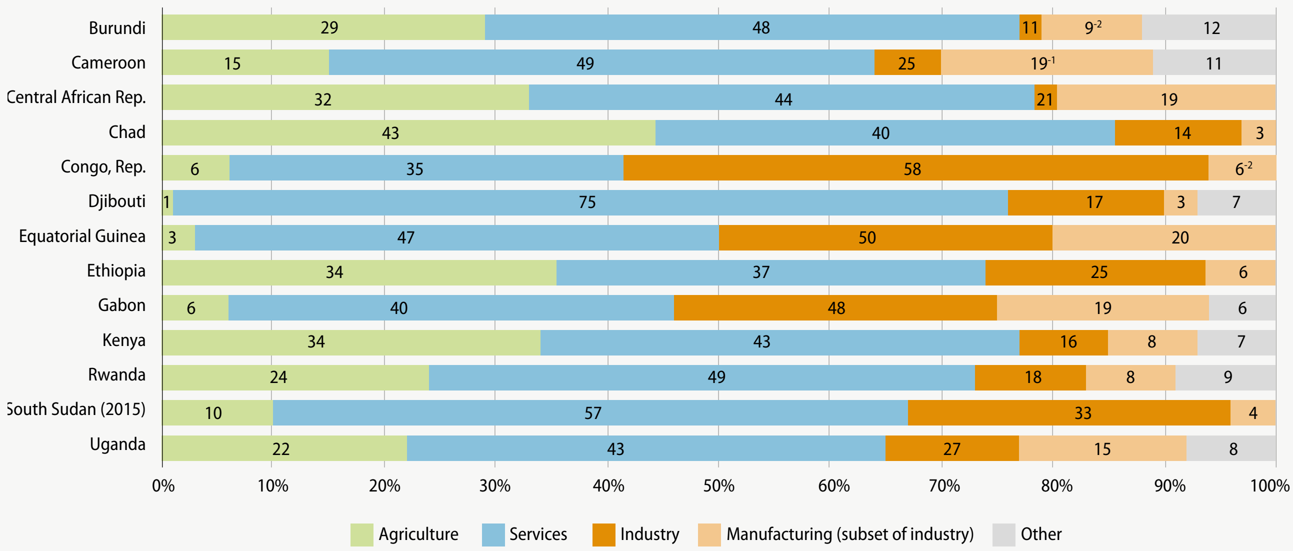


Note: Recent data are unavailable for Eritrea, Somalia and South Sudan.

Estimated output by crude-oil producing countries in Central and East Africa, 2019
In thousands of barrels per day



GDP per economic sector in Central and East Africa, 2019 or closest year (%)



Note: Data are unavailable for Eritrea and Somalia.

Source: World Bank's World Development Indicators, October 2020; for crude oil production: US Energy Information Administration increase inter-African traffic by raising the proportion of countries hosting IXPs. By late 2017, the IXP had been set up in 35 countries (AU, 2019). In Central and East Africa, all but Uganda are participating in the programme.[2]

Renewable energy a high priority

The African Union's *Agenda 2063* places high priority on investment in renewable energy to foster economic growth and eradicate energy poverty. However, the bid to ensure access to energy for all has spawned investment in both fossil fuels and renewable energy resources. The number of people gaining access to electricity each year has doubled from 9 million (2000–2013) to 20 million (2014–2018), with Kenya, Ethiopia and Tanzania now accounting for half of those with access to electricity (IEA, 2019; Table 19.2).

Ethiopia and Kenya are each investing in massive infrastructure projects: the Grand Renaissance Dam for Ethiopia and geothermal power for Kenya (Box 19.1).

In 2017, the Central African Economic and Monetary Community (CEMAC) established a *Central African Energy Policy* to 2035 to ensure reliable, efficient energy infrastructure for the region's physical integration. The Central African Energy Pool co-ordinates a range of activities by the Economic Community of Central African States (ECCAS) that include establishing a regional energy market, interconnecting electricity grids and raising member states' energy capacity. In 2015, ECCAS adopted a development fund for Central Africa's electricity sector and a code for the procurement of electricity in Central Africa which sets out the principles governing production, transport, distribution, transit and cross-border

Box 19.1: **Kenya now eighth in the world for geothermal power**

When the Olkaria V geothermal power plant (172 MW came online in November 2019, it pushed Kenya's geothermal production capacity up to about 860 MW, enabling Kenya to overtake Iceland (755 MW) to rank eighth worldwide.

Today, more than 35% of Kenyan households rely on geothermal power. The Olkaria geothermal fields are the second-most productive in the world after The Geysers field in the USA.

Necessity is the mother of invention

The first exploration wells were drilled in the Kenyan Rift Valley in the 1970s. This led to construction of Kenya's first geothermal power plant, Olkaria I (45 MW), over 1981–1985.

Things accelerated in 2008 with the launch of *Kenya Vision 2030* and its emphasis on renewable energy to reduce dependence on imported fossil fuels and broaden access to electricity. By 2030, the aim is to achieve a geothermal production capacity of at least 3 000 MW.

Olkaria IV (150 MW) came on line in October 2014 and Olkaria IAU (150 MW) four months later. Olkaria VI (150 MW) should follow by 2022.

In the past five years, Kenya has become a world leader for development of the so-called *Wellhead Technology*, whereby single wells are used to supply steam to small turbines (~5 MW each) for power production, thereby ensuring a rapid return on investment.

These turbines are now producing about 84 MW in Olkaria. To this can be added two small turbines in Olkaria and the Eburru geothermal field. The former turbine is operated by the locally run Oserian Greenhouse Farm.

Two Kenyan companies leading exploration

The country's two main geothermal companies are the Kenya Electricity Generating Company (KenGen), partly (30%) privatized in 2006, and the Geothermal Development Company (GDC), a fully government-owned undertaking founded in 2009.

KenGen has been responsible for developing the Olkaria field, together with OrPower, owned by Ormat International.

GDC, meanwhile, has been developing the Menengai geothermal field about 100 km north of Olkaria. In 2019, GDC began drilling exploration wells in the Paka geothermal field farther north, with promising results.

A prototype geothermal spa and farm

Several countries along the East African Rift System have recently shown interest in the potential of geothermal energy for drying, heating, bathing, fish farming and other purposes.

Both Kenyan companies have seized upon this commercial potential. KenGen has built a geothermal spa in Olkaria that is proving popular with the public (see photo, p. 496) and Oserian has become the largest geothermally heated greenhouse farm in the world. It uses steam to grow roses under plastic over 50 ha.

In Menengai, meanwhile, GDC has developed a resource park which showcases different types of steam use, including milk pasteurization, laundry and dryer units, heated fish ponds and a greenhouse.

A geothermal training programme

Between 2010 and 2019, 89 Kenyan geoscientists and engineers attended the six-month course run by Iceland's Geothermal Training Programme, double the number over the entire period from 1982 to 2009. Most participants are employed by KenGen and GDC. Twenty-four have since returned to Iceland to complete an MSc degree and a further three have received a fellowship to complete a PhD in Iceland.

Originally part of the United Nations University (UNU), the Geothermal Training Programme is now part of GRÓ, a (category 2) centre operating under the auspices of UNESCO.

In 2019, Japan provided Kenyan geologists with research grants within a new project entitled Comprehensive Solutions for Optimum Development of Geothermal Systems in the East African Rift Valley (see Table 24.1).

Source: Lúdvík S. Georgsson, former director of UNU Geothermal Training Programme

Table 19.1: **Socio-economic indicators for sub-Saharan Africa, 2019 or closest year**

	Population trends			Economic growth		Trade and foreign investment				Governance	
	Population (thousands)	Population growth (%)	Life expectancy at birth, 2018 (years)	GDP per capita (constant 2017 PPP$)	GDP growth (%)	FDI inflows as a share of GDP, 2018 (%)	High-tech exports as a share of manufactured exports (%)	Manufactured exports as a share of merchandise exports (%)	Exports of goods and services as a share of GDP (%)	Ibrahim African Governance Index score	Ibrahim African Governance Index change over 2010
Angola	31 825	3.2	60.8	6 654	-0.9	-4.3^{+1}	5.3^{-1}	4.4^{-1}	40.8	40.0	+5.4
Benin	11 801	2.7	61.5	3 287	6.9	1.0	2.8^{-1}	6.1^{-1}	29.6	58.6	+1.1
Botswana	2 304	2.2	69.3	17 766	3.0	1.2	0.7^{-1}	97.0	33.6	66.9	+0.8
Burkina Faso	20 321	2.8	61.2	2 190	5.7	1.7	6.0^{-1}	9.7^{-1}	27.7	54.0	+1.0
Burundi	11 531	3.1	61.2	752	1.8	0.0	17.0^{-1}	10.3^{-1}	9.1	36.9	-3.6
Cabo Verde	550	1.1	72.8	7 172	5.7	5.3^{+1}	0.0^{-1}	16.5^{-1}	50.9	73.1	+0.2
Cameroon	25 876	2.6	58.9	3 653	4.0	2.0	4.9^{-2}	9.4^{-2}	16.6	43.5	-0.6
Central African Rep.	4 745	1.7	52.8	945	3.0	0.8	27.9^{-2}	65.1^{-2}	19	30.7	-0.9
Chad	15 947	3.0	54.0	1 580	3.2	5.9	–	–	36.7	33.9	+3.7
Comoros	851	2.2	64.1	3 081	2.7	0.6	3.0	56.1	13.2^{-1}	43.2	-2.6
Congo, Dem. Rep.	86 791	3.2	60.4	1 098	4.4	37.0	–	–	32.1	31.7	-2.8
Congo, Rep.	5 381	2.6	64.3	3 298	-0.9	2.7	2.2^{-2}	8.3	77.4	36.1	-0.2
Côte d'Ivoire	25 717	2.5	57.4	5 238	6.9	1.1	6.8^{-1}	10.4	23.5	53.9	+9.0
Djibouti	974	1.5	66.6	5 519	7.5	5.6	–	–	154.7	41.3	+2.0
Equatorial Guinea	1 356	3.5	58.4	18 558	-5.6	3.0	–	–	55.1	28.7	-0.3
Eritrea	3 214	1.4	65.9	–	–	–	–	–	–	25.8	-0.8
Eswatini	1 148	1.0	59.4	8 688	2.0	2.9^{+1}	0.3	65.2	40.5^{-1}	43.8	+2.5
Ethiopia	112 078	2.6	66.2	2 220	8.3	4.0	51.8^{-2}	5.9^{-1}	7.9	46.6	+6.7
Gabon	2 173	2.5	66.2	14 870	3.4	5.0	–	–	51.4	47.7	+1.0
The Gambia	3 348	2.9	61.7	2 207	6.0	2.0	0.2^{-1}	44.2^{-1}	21	55.9	+9.2
Ghana	30 418	2.2	63.8	5 413	6.5	4.6	8.3^{-1}	5.5^{-1}	36.0	64.3	+0.1
Guinea	12 771	2.8	61.2	2 564	5.6	2.9	1.0^{-4}	27.2^{-4}	42.3	42.5	+1.3
Guinea-Bissau	1 921	2.5	58.0	1 989	4.6	1.4	–	–	23.5	41.4	+2.8
Kenya	52 574	2.3	66.3	4 330	5.4	1.9	3.6^{-1}	28.4^{-1}	12.0	58.5	+3.7
Lesotho	2 125	0.8	53.7	2 768	1.5	4.8^{+1}	0.2^{-2}	89.3^{-2}	43.6	52.3	-0.5
Liberia	4 937	2.4	63.7	1 428	-2.3	4.0	–	–	28.7	47.9	+1.2
Madagascar	26 969	2.7	66.7	1 646	4.8	4.4	0.3^{-1}	32.4	26.5	44.4	+1.7
Malawi	18 628	2.6	63.8	1 060	4.4	1.5	11.5^{-2}	8.3^{-2}	31	51.5	-1.3
Mali	19 659	3.0	58.9	2 327	5.0	2.7	1.2^{-2}	37.4^{-2}	23.0	46.6	-2.5
Mauritius	1 266	0.0	74.4	22 989	3.6	2.6	2.1	60.5	39.2	77.2	-0.5
Mozambique	30 366	2.9	60.2	1 280	2.2	18.2	5.6^{-1}	9.4^{-1}	38.0	49.0	-0.2
Namibia	2 495	1.9	63.4	9 637	-1.1	-0.1^{+1}	0.2^{-1}	34.5^{-1}	35.8	65.1	+3.4
Niger	23 310	3.5	62.0	1 219	5.8	3.6	3.0^{-3}	9.4^{-3}	11.7	47.8	+0.4
Nigeria	200 964	2.6	54.3	5 135	2.2	0.5	1.9^{-1}	3.6^{-1}	15.5	45.5	-1.6
Rwanda	12 627	2.6	68.7	2 226	9.4	3.1	12.5^{-3}	12.2^{-3}	19.0	60.5	+3.7
Sao Tome & Principe	215	1.9	70.2	3 964	2.4	5.6	46.0^{-1}	24.0^{-1}	–	60.4	+2.8
Senegal	16 296	2.7	67.7	3 395	5.3	3.6	0.9	28.7	22.8	63.2	+3.3
Seychelles	98	0.9	72.8	29 056	4.7	13.9^{+1}	2.2	20.8	68.9	72.3	+7.8
Sierra Leone	7 813	2.1	54.3	1 718	5.5	5.3	0.1^{-2}	3.3^{-2}	17.5^{-1}	51.0	+4.8
Somalia	15 442	2.9	57.1	–	–	–		–	–	19.2	+5.7
South Africa	58 558	1.3	63.9	12 482	0.2	1.3^{+1}	5.3^{-1}	47.9^{-1}	29.9	65.8	-0.9
South Sudan	11 062	0.8	57.6	–	-10.8^{-4}	0.0^{-3}	–	–	36.6^{-4}	20.7	–
Tanzania	58 005	3.0	65.0	2 660.4	5.8	1.8	6.9^{-1}	74.4^{-1}	15.1^{-2}	53.0	+0.2
Togo	8 082	2.4	60.8	1 596	5.3	-3.4	0.2^{-2}	51.3^{-2}	29.6	50.1	+4.8
Uganda	44 270	3.6	63.0	2 181	6.5	3.7^{+1}	3.5^{-1}	22.5^{-1}	19.4	51.8	+0.7
Zambia	17 861	2.9	63.5	3 479	1.7	2.1^{+1}	2.3	14.4	35.0	52.0	-0.8
Zimbabwe	14 645	1.4	61.2	2 836	-8.1	3.1	4.8	17.6	19.0^{-1}	46.1	+7.4

+n/-n: data refer to *n* years before or after reference year

Note: The Ibrahim African Governance Index is composed of four categories: safety and rule of law, participation and human rights, sustainable economic opportunity and human development.

Source: World Bank's World Development Indicators, October 2020; for African Governance Index: Ibrahim Index of African Governance 2020 trade in the ECCAS zone. This code also encourages private enterprise and the establishment of a regime permitting competition in the energy sector.

In 2016, ECCAS acceded to the *International Energy Charter*, which provides a sound legal basis for sustained investment in the energy sector; the *Tokyo Declaration* issued by the parties to the charter at their 27th meeting in 2016 underscored the charter's potential for promoting sustainable energy and global energy security more actively.

In order to overcome electricity shortages, the East African Community's (EAC's) *Vision 2050* (2015) envisages a range of partnerships, including a power-sharing arrangement between Rwanda and Kenya, the importation of cheap electricity into the region from Ethiopia and heightened investment in biogas and solar energy. This strategy is in line with the EAC's *East African Power Master Plan* (2013–2038).

The EAC's *Vision 2050* announced Kenyan plans to establish an oil refinery in Lamu to ensure greater price stability and a more secure energy supply, as well as opportunities for technological development (EAC, 2015). However, the government shelved the plan in 2019, meaning that oil will continue to be exported as crude at a lower sales price (Tubei, 2019).

In October 2020, the African Union Development Agency[3] and African Development Bank (AfDB) released a baseline study containing recommendations for a master plan to develop a continental energy grid and market. Supported by the European Union, the study recommends aligning the master plan for energy with the PIDA. The next step will be to define the terms of reference and identify funding for the master plan.[4]

Future of agriculture as economic driver uncertain

The agriculture sector remains the largest source of employment in Central Africa, in particular. The prospects for agriculture to remain an economic driver in the region remain uncertain, owing to overreliance on rainfed agriculture and agricultural commodity exports.

Greater investment in STI to enhance agricultural development figures among the recommendations for fast-track implementation of the commitments under the *Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods* (2014). According to the first *Biennial Review Report and Scorecard* measuring 43 indicators, 20 out of 47 countries are on track to reach their goals under the *Malabo Declaration* (AU, 2018). Four of these indicators are given in Table 19.2.

Climate change is exacerbating natural disasters like drought and locust swarms which devastate agriculture. In 2020, East Africa was overwhelmed by exceptional swarms of desert locusts. In January, the United Nations' Food and Agriculture Organization (FAO) warned that these swarms 'pose an unprecedented threat to food security and livelihoods in the Horn of Africa.' In October, it cautioned that 'winter breeding by swarms started several months earlier than normal along the Red Sea coast, which could allow an extra generation of breeding this season.'[5]

The countries with the highest risk of being invaded by desert locust swarms are Djibouti, Eritrea, Ethiopia, Kenya, Somalia, South Sudan, Uganda and Tanzania, according to the Climate Prediction and Applications Centre run by the Intergovernmental Authority on Development (IGAD). During a meeting held on 22 May 2020, IGAD deliberated on establishing a Joint Inter-Regional Contingency and Response Action Plan to guide the upscaling of cross-border and cross-regional control operations, improve co-ordination and link efforts to contain the desert locust invasion in the IGAD region.[6] By the time of writing in December 2020, this action plan had not yet been adopted.

Agriculture is a key focus of efforts to boost regional integration. CEMAC has adopted the *Central Africa Regional Strategy for Risk Prevention, Disaster Management and Adaptation to Climate Change* (2016). The strategy lays out plans to fund a satellite and meteorological information centre in Douala for disaster resilience, with AfDB support.

ECCAS, meanwhile, has adopted the *Central African Common Agricultural Policy* (2014), with financial support from the World Bank and technical assistance from the Rural Hub supporting development and food security in West and Central Africa.

The EAC, meanwhile, is prioritizing better agricultural practices such as mechanization, irrigation, improved seeds and fertilizer use (EAC, 2015).

The Central and East African economies have overlapping membership of no fewer than eight regional economic communities. The four mentioned above are those that have made a notable contribution to regional integration, namely: IGAD, CEMAC, ECCAS and EAC.[7]

The new Central African Health Organization

In 2015, ECCAS governments and heads of state approved the creation of the Central African Health Organization with a watermark Community Health Fund for Central Africa. This initiative complements the common pharmaceutical policy adopted in 2014 with the aim of improving access to health services by making safe, effective and low-cost pharmaceutical products available to the entire population.

A programme established in 2014 to control human African trypanosomiasis (or sleeping sickness) has since trained health workers to diagnose the disease in all six CEMAC countries, plus Angola and the Democratic Republic of the Congo.

At the continental level, one significant achievement has been the establishment of the Africa Centres for Disease Control and Prevention in Addis Ababa in 2016 (Box 19.2).

Regional integration enhancing development prospects

The agreement establishing an African Continental Free Trade Area for the free circulation of goods, services, capital and people was endorsed by member states in 2019. Should the desired single market be fully realized, it would boost tourism and exports to the rest of the continent, with processed food and manufactured products being the main beneficiaries (UNECA, 2019).

In 2016, the share of intraregional trade in Central Africa was the lowest of any of the eight regional economic communities recognized by the African Union. By contrast,

Table 19.2: **Investment in public services, research and agriculture in sub-Saharan Africa, 2018 or closest year**

	Access to services					Health	Education		Research	Agriculture			
	Share of population with electricity access, 2018 (%)	Share of population with access to basic drinking water services, 2017 (%)	Share of population with access to at least basic sanitation, 2017 (%)	Internet access per 100 inhabitants, 2017	Mobile cellular subscriptions per 100 inhabitants, 2018	Public health expenditure as a share of GDP, 2017 (%)	Public expenditure on education as a share of GDP, 2018 (%)	Public expenditure on higher education as a share of GDP, 2018 (%)	GERD as a share of GDP, 2018 (%)	Public expenditure on agriculture as a share of total public expenditure, 2017 (%)	Total agricultural research spending as a share of Agricultural GDP, 2017 (%)	Growth rate of value-added agriculture, 2017 (%)	Agricultural land sustainably managed as a share of all agricultural land, 2017 (%)
Angola	43.3	55.8	49.9	14.3	46.6	2.8	–	–	0.03^{-2}	14.8	0.1	9.4	–
Benin	41.5	66.4	16.5	14.1	87.7	3.7	2.9*	0.7^{-3}	–	9.3	0.4	29.9	0.2
Botswana	64.9	90.3	77.3	41.4	173.8	6.1	–	–	0.54^{-5}	3.0	2.7	-1.0	15.3
Burkina Faso	14.4	47.9	19.4	15.9	100.2	6.9	5.4*	1.5^{-1}	0.61^{-1}	10.5	0.8	4.7	7.7
Burundi	11.0	60.8	45.8	2.7	57.6	7.5	5.1	–	0.21	–	2.7	-0.2	18.7
Cabo Verde	93.6	87.1	73.9	57.2	108.3	5.2	5.2^{-1}	0.9^{-1}	–	7.3	0.9	-79.1	20.0
Cameroon	62.7	60.4	39.1	23.2	81.8	4.7	3.1*	–	–	4.3	0.3	6.8	–
Central African Rep.	32.4	–	–	4.3	32.3	5.8	–	–	–	3.2	0.2	12.4	–
Chad	11.8	38.7	8.3	6.5	48.1	4.5	2.5^{-1}*	0.23	0.30^{-2}	8.3	0.1	-15.3	–
Comoros	81.9	80.2	35.9	8.5	67.6	7.4	2.5^{-3}	0.3^{-3}	–	–	–	–	–
Congo, Rep.	19.0	27.9	20.2	8.6	42.8	2.9	3.5*	–	–	1.6	0.4	10.7	–
Congo, Dem. Rep.	68.5	43.2	20.5	8.7	95.3^{-1}	4.0	1.5^{-1}*	0.5^{-3}	0.41^{-3}	2.4	–	9.1	–
Côte d'Ivoire	67.0	36.3	32.1	36.5^{+2}	145.3	4.5	3.3	0.5	0.10^{-2}	1.9	0.1	14.0	0.6
Djibouti	60.4	75.6	27.2	55.7	41.2^{-1}	3.3	3.6*	–	–	4.9	0.2	10.0	11.6
Equatorial Guinea	67.0	64.7	66.3	26.2	45.2^{-1}	3.1	–	–	–	10.5	–	7.6	43.1
Eritrea	49.6	–	–	1.3	20.4^{-2}	2.9	–	–	–	–	–	–	–
Eswatini	76.5	69.0	58.4	30.3	93.5^{-2}	6.9	7.1^{-4}	0.9^{-4}	0.27^{-3}	–	0.5	-28.4	–
Ethiopia	45.0	29.6	7.3	18.6	37.2^{-2}	3.5	4.7^{-3}	2.3^{-3}	0.27^{-1}	16.8	–	2.3	14.7
Gabon	93.0	85.8	47.4	50.3	138.3^{-1}	2.8	2.7^{-3}	1.0^{-4}	–	0.6	0.2	16.7	51.1
The Gambia	60.3	78.0	39.2	19.8	139.5^{-1}	3.3	2.4*	0.2^{-3}	0.07	5.1	0.6	-4.0	7.0
Ghana	82.4	45.0	18.5	37.9	134.3	3.3	4.0*	0.8^{-4}	–	6.0	11.9	3.6	0.04
Guinea	44.0	61.9	22.7	21.8^{+1}	100.8	4.1	2.3	0.4	–	5.9	0.03	2.9	25.3
Guinea-Bissau	28.7	66.6	20.5	3.9	82.8	7.2	–	–	–	–	–	–	–
Kenya	75.0	58.9	29.1	22.6^{+2}	103.8	4.8	5.3*	0.7^{-3}	–	2.3	2.5	5.9	–
Lesotho	47.0	68.6	42.8	29.8	113.8^{-2}	8.8	7.0	0.5	0.05^{-3}	3.6	0.8	-21.5	–
Liberia	25.9	72.9	17.0	8.0	56.6^{-2}	8.2	2.6*	–	–	–	–	-1.4	–
Madagascar	25.9	54.4	10.5	4.7^{-1}	40.6^{-1}	5.5	2.8*	–	0.01^{-1}	1.9	0.04	-0.1	1.1
Malawi	18.0	68.8	26.2	13.8	47.8	9.7	4.7*	1.1^{-2}	–	17.6	–	-2.3	15.7
Mali	50.9	78.3	20.6	12.7	115.1^{-1}	3.8	3.8^{-1}	0.7^{-1}	0.29^{-1}	12.4	0.1	7.6	21.4
Mauritius	97.5	99.9	95.5	64.0^{+1}	151.4^{-1}	5.7	4.8	0.3	0.35	2.8	3.0	7.3	0.1
Mozambique	31.1	55.7	29.4	20.8	47.7^{-1}	4.9	5.5*	–	0.34^{-3}	6.9	2.9	2.6	–
Namibia	53.9	82.5	34.5	36.8	113.2	8.6	–	1.6^{-4}	0.34^{-4}	4.6	3.2	14.7	8.1
Niger	17.6	50.3	4.0	5.3^{+1}	40.6^{-2}	7.7	3.6*	0.6^{-1}	–	8.0	–	11.6	–
Nigeria	56.5	51.2	12.5	7.5	88.2^{-1}	3.8	–	–	–	2.2	–	-20.7	–
Rwanda	34.7	57.7	66.6	21.8	76.5	6.6	3.1	0.6	0.67^{-2}	7.5	0.6	3.9	61.3
Sao Tome & Principe	71.0	84.3	43.0	29.9	77.1	6.2	5.2*	0.4^{-4}	–	8.5	0.1	15.9	–
Senegal	67.0	80.7	30.0	29.6	109.7	4.1	4.8	1.6	0.58^{-3}	11.0	1.4	6.6	12.2
Seychelles	100.0	96.2	100.0	58.8	198.2	5.0	4.4^{-2}	1.0^{-2}	0.22^{-2}	–	6.3	-10.0	–
Sierra Leone	26.1	50.9	2.3	13.2	86.1	13.4	7.0	3.2	–	4.1	–	3.8	0.3
Somalia	35.3	52.4	38.3	2.0	51.0^{-1}	–	–	–	–	–	–	–	–
South Africa	91.2	92.7	75.7	56.2	165.6	8.1	6.2	0.9	0.83^{-1}	1.2	1.6	12.0	0.2
South Sudan	28.2	40.7	11.3	8.0	33.5^{-1}	9.8	1.5^{-2}	0.8^{-2}	–	–	–	–	–
Tanzania	35.6	56.7	4.5	16.0	82.2	3.7	3.7*	0.7^{-4}	0.51^{-5}	5.9	0.3	-1.0	4.9
Togo	51.3	65.1	16.1	12.4	77.2	6.2	5.4*	0.9^{-1}	0.27^{-4}	6.9	0.3	9.0	21.1
Uganda	42.7	42.0	18.5	23.7	57.3^{-1}	6.2	2.1*	0.3^{-4}	0.17^{-4}	2.9	1.0	3.2	10.7
Zambia	39.8	60.0	26.4	14.3^{+1}	96.4	4.5	4.6*	0.3^{-1}	–	8.2	1.0	-3.4	0.8
Zimbabwe	41.0	64.1	36.2	27.1	90.1	6.6	5.9*	1.0-^{4}	–	6.0	0.7	-2.1	0.3
Malabo target										10.0	1.0	6.0	30.0
Target year										2025	2025	2025	2023

* estimation by UNESCO Institute for Statistics

Note: For drinking water, data represent basic services for the Republic of Congo, Côte d'Ivoire, Ethiopia, Ghana, Nigeria, Sierra Leone and Uganda. Sanitation data represent basic services for Djibouti, Mali, Niger, Nigeria, Senegal, Sierra Leone and Tanzania.

Source: for water and sanitation: World Health Organization and UNICEF (2020) Joint Monitoring Programme database; for health, Internet and mobile subscriptions: World Bank's World Development Indicators, October 2020; for education and GERD: UNESCO Institute for Statistics; for agriculture: AU (2018) *Inaugural Biennial Review Report of the African Union Commission on the Implementation of the Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods* almost one-third (31%) of East African exports went to African markets in 2018. More than half of these originated in Ethiopia (23%) and Kenya (33%) [UNECA, 2020].

Local manufacturers face stiff competition from global competitors, especially China. Other challenges include trade-related disputes and non-tariff barriers that threaten the spirit of regional integration (UNECA, 2020; AfDB, 2020b).

Significant growth in the services sector has potential to support the region's industrialization. In turn, regional integration may boost demand for skilled labour in strategic sectors such as transportation, information and communication technologies (ICTs), energy and manufacturing.

Oil production and mining could also become a strong motivation for subregional integration, as intraregional trade could cushion the shock of volatile global market prices for commodities. Regional integration could also attenuate conflicts over the control of natural resources, a source of insecurity in the region.

Vision 2050 (EAC, 2015) 'focuses on initiatives that will create gainful employment to the economically active population.' It identifies pillars such as the development of a transportation network; energy; information technology; and the structural development of the industrial and manufacturing sector through high value addition and product diversification.

Vision 2050 identifies opportunities in the following manufacturing sectors: textile; extractive; food processing; automotive; machine tools; ship and water vessel building and container manufacturing; and the iron and steel industries.

Vision 2050 also evokes the need to develop research and development (R&D) in the public sector as the starting point for a viable pharmaceutical industry in the region (EAC, 2015).[8] Ethiopia is one country that is planning to develop its own pharmaceutical sector.

Vision 2050 identifies a series of flagship projects for implementation through public–private partnerships, such as the establishment of a regional iron and steel regulatory body and a regional phosphate industrialization framework (EAC, 2015).

The macro-economic policies of the six CEMAC countries are converging to foster financial integration. In 2019, the six countries set up the Financial Market Supervisory Commission to regulate a regional stock exchange and financial markets. This trend towards financial integration is reinforced by the community's decision, in 2018, to close the Douala stock exchange in Cameroon.

Railways driving regional integration in East Africa

A number of factors have converged in East Africa in recent years to boost regional integration, with positive implications for trade. Firstly, the peace and co-operation deal signed by Eritrea and Ethiopia in 2018 has improved the flow of people, cross-border trade, telecommunications and transportation services between the two countries (AfDB, 2019). There is a risk, however, that skirmishes between the Ethiopian army and the rebel Tigray region since late 2020 may set the region back.

Ethiopia is a key security actor in the Horn of Africa. As such, it has the power to act as a catalyst for peace or as a source of instability. By accepting unconditionally the peace deal

Box 19.2: The Africa Centres for Disease Control and Prevention

The Africa Centres for Disease Control and Prevention (CDC) was established by the African Union in Addis Ababa, Ethiopia, in January 2016. Inspired by its namesake in the USA, the Africa CDC serves as an information-sharing platform for member states.

Five regional collaborating centres, one for each of central, eastern northern, southern and western Africa, co-ordinate regional public health initiatives taken by member states. They also serve as hubs for Africa CDC surveillance, preparedness and emergency response.

This infrastructure has been a boon for co-ordinating the response to the Covid-19 pandemic in 2020. The Africa CDC is tracking research and related information through policy briefs and updates, including a caseload dashboard for Africa. It also provides links to partners such as the African Academy of Sciences and World Health Organization.

Africa is experiencing 'frequent outbreaks of diseases and these continue to be magnified as the continent moves towards greater integration', observes Dr John Nkengasong, Director of the Africa CDC. 'The *Africa Health Strategy 2016–2030* […] provides strategic direction to member states in their efforts to create better-performing health systems.'

Tools to sequence pathogens' genes

In October 2020, a public–private consortium led by the African Union Commission through the Africa CDC launched the Africa Pathogen Genomics Initiative. This partnership is investing US$ 100 million over the next four years to expand access to next-generation genomic sequencing tools and expertise.

Partners Illumina and Oxford Nanopore are providing machines and training, the Bill and Melinda Gates Foundation and the US Centers for Disease Control and Prevention are providing funding and technical assistance and Microsoft is providing technical assistance in designing the Africa Pathogen Genomics Initiative's digital architecture.

The Africa Pathogen Genomics Initiative will build a continent-wide disease surveillance and laboratory network to help identify and inform research and public health responses to Covid-19 and other epidemic threats, as well as endemic infectious diseases such as AIDS, tuberculosis, malaria and cholera.

Source: www.africacdc.org

known as the *Algiers Accord* (2000) and the 2002 decision of the Borders Commission of Ethiopia–Eritrea in June 2018, incoming Prime Minister Abiy Ahmed Ali of Ethiopia put an end to 20 years of hostility with its neighbour. The subsequent decision to link Eritrea and Ethiopia by railway line follows this same logic of appeasement.

Meanwhile, Eritrea has re-established relations with neighbouring Djibouti and Somalia, a development which is also expected to boost trade. For instance, access to Eritrea's ports will diversify Ethiopia's access routes to the sea and ease congestion at Djibouti's ports, which handle more than 80% of Ethiopian trade.

The adoption of the Single Customs Territory in 2014 by EAC member states has been another milestone towards regional integration. This has led to the opening of one-stop border posts such those in Namanga and Malaba to facilitate exchanges between Kenya, Tanzania and Uganda.

The Single Customs Territory has been implemented to facilitate customs clearance and the movement of cargo along the new northern and central corridors, as well as along the Standard Gauge Railway line. This infrastructure is the fruit of the Silk Road Economic Belt and 21st Century Maritime Silk Road under the Chinese government's Belt and Road Initiative (Mukwaya *et al*., 2019).

The Standard Gauge Railway is being implemented under the *East African Railway Master Plan*.[9] It will not only greatly improve the existing railway lines in Tanzania, Kenya and Uganda but also extend these initially to Rwanda and Burundi then eventually to South Sudan, Ethiopia and beyond. Ultimately, this central corridor is expected to connect the East African economies with the port of Dar es Salaam over a distance of more than 2 500 km (see also chapter 20). A second northern transport corridor between Lamu Port in South Sudan and Ethiopia is also under construction.

These infrastructure projects are expected to develop the services sector and boost demand for educated and skilled labour. For example, the northern and central corridors have created demand for skills in maritime transport and shipping logistics, as well as information and communication technologies (ICTs).

Since 2015, a range of partners[10] have been reactivating the *Consensual Transport Master Plan in Central Africa* (2004). Achievements include a study of the major multimodal corridor comprising the road between Ouesso (Congo), Bangui (Central African Republic) and N'Djamena (Chad) and navigation on the Congo River and its tributaries, the Ubangui and the Sangha Rivers; a feasibility study for a bridge over the Ntem River to link Cameroon and the mainland of Equatorial Guinea; and the first phase of work on the road connecting Ketta (Congo) to Djoum (Cameroon), with a view to connecting the cities of Yaoundé and Brazzaville.

There are also plans to develop 14 major ports, several international airports and other waterways and lake systems. The latter process will be informed by the Congo–Oubangui-Sangha International Basin Commission co-ordinated by ECCAS, which houses a geospatial data collection centre to improve monitoring of navigability on the various regional transboundary waterways.

TRENDS IN SCIENCE GOVERNANCE

African STI policies neglecting sustainability

Six Central and East African countries have developed and adopted STI policies, namely, Burundi, Cameroon, Ethiopia, Kenya, Rwanda and Uganda (Figure 19.2). However, according to the African Academy of Sciences, STI policies on the continent are predicated primarily on 'economic growth and competitiveness rationales', rather than on sustainable development. It recommends an interface between STI and other policy areas, such as education, industry, agriculture and trade, and a broader interface with social and environmental development policies. The Academy also pinpoints a lack of monitoring and evaluation mechanisms for most STI policies and observes that targets for research intensity tend to be fixed without clear investment plans for R&D (AAS, 2018; AU, 2019).

The *Science, Technology and Innovation Strategy for Africa 2024* (*STISA-2024*) is one of a series of ten-year strategies planned to help realize the African Union's *Agenda 2063 for The Africa we Want*. To ensure effective implementation of *STISA-2024*, African countries agreed to establish an African Science, Technology and Innovation Fund (AAS, 2018) but this had not yet become a reality by late 2020.

The African Academy of Sciences announced the establishment of the Coalition for African Research and Innovation at the World Economic Forum in January 2017. This pan-African mechanism seeks to consolidate and reduce fragmentation of funding, while spurring greater African ownership of research and innovation targeting the Sustainable Development Goals (SDGs) through heightened African investment (AAS, 2018).

Flagship projects for science and technology

The African Scientific Research and Innovation Council (est. 2016) endorsed the following six priority areas at its second congress in November 2019:[11]

- eradication of hunger and food and nutrition security;
- prevention and control of diseases and well-being;
- communication;
- protecting our space;
- creating wealth; and
- cross-cutting actions for infrastructural and research development.

The 14 flagship projects under these six areas are being developed either through an intra-African call for research proposals or the development of projects by the Council's Scientific and Innovation Committee. The creation of an African passport to facilitate the free movement of persons on the continent would facilitate scientific mobility (Table 19.3).

The *African Space Strategy* (AU, 2017) has four components: Earth observation, navigation and positioning systems, satellite communications and space science and technology. The strategy will contribute to several of the aforementioned flagship projects, with the ultimate aim of creating an African

Table 19.3: **The African Union's 14 flagship projects**

African Continental Free Trade Area
African Commodity Strategy
Single Africa Air Transport Market
Continental High-Speed Train Network
Pan-African e-Network
Cybersecurity
Pan-African Virtual and E-University
African Outer Space Programme
Great Museum of Africa
Silence the Guns and End Wars in Africa by 2020
Free Movement of all Persons and African Passport
The Continental Financial Institutions
African Economic Platform
The Grand Inga Hydropower Project

Source: https://www.nepad.org/agenda-2063/flagship-projects

Space Agency, to be hosted by Egypt. The African Union signed a co-operation agreement with the European Union's Copernicus programme in 2018 as a precursor to the African Outer Space Programme launched in 2019 (Table 19.3).

The six priority areas are interconnected. For example, 'protecting our space' covers environmental protection, climate change, biodiversity, atmospheric physics, space technologies, maritime and submaritime exploration and the water cycle, river systems and river basin management (AU, 2019).

'Protecting our space' has implications for the priority area on eradicating hunger, which is, itself, reliant on the sustainability of agriculture; it also pertains to wealth creation, since much of the continent's wealth is derived from mining natural resources (AU, 2019).

One key achievement has been the launch of the Africa Adaptation Initiative in 2015. Countries in Central and East Africa have benefited from the United Nations' Adaptation Fund launched the same year to support implementation of the *Paris Agreemen*t on climate action. Most recently, a US$ 13 million project approved in November 2019 by the Adaptation Fund has been strengthening resilience to drought among smallholder farmers in Djibouti, Kenya, Sudan and Uganda and a second project approved in September 2020 has been using US$ 10 million to promote entrepreneurship and integrated natural resource management in Cameroon.[12]

The African Ministers' Council on Water (AMCOW) has released a new *Strategic Plan 2018–2030* (2018) aligned with the sixth Sustainable Development Goal, in particular. AMCOW's African Water Facility, which is managed by the AfDB, had mobilized over € 1 billion by 2016 for investment projects in water supply, sanitation, irrigation and hydropower (AU, 2019).

More science would accelerate knowledge transition

Vision 2050 acknowledges that weak STI has delayed the transition of member countries to knowledge economies (EAC, 2015, p. 101). To address this gap, the East African Science and Technology Commission (EASTECO, est. 2007) has spearheaded the development and implementation of common STI policies and programmes under its ambitious *Strategic Plan (2017–2022)*.[13] This led to the approval of the *East African Regional Policy for Science, Technology and Innovation (2019–2029)*, *EAC Regional Intellectual Property Policy* and *EAC Regional Bioeconomy Strategy* by the EASTECO Governing Board on 31 March 2021. Approval is now pending from the EAC Sectoral Council of Ministers.

In an effort to implement the *East African Community Market Protocol* adopted in 2010 (Urama *et al*., 2015), partner states have collaborated with EASTECO to establish a Research and Technological Development Fund to promote market-led research, industrial research and technology transfer, as well as technology acquisition, adaptation and development. Operational since 2018, the fund is financed by member states. Its legal statutes were under development in 2021.[14] UNESCO is working with African countries to help strengthen their national innovation systems, including through its Global Observatory of Science, Technology and Innovation Policy Instruments (GO-SPIN). Other initiatives include a pilot programme to align STI policies of African countries with the Sustainable Development Goals, involving the World Bank, the United Nations Department of Economic and Social Affairs, the United Nations Conference on Trade and Development and UNESCO. Ghana, Kenya and Ethiopia are participating in the pilot phase.

TRENDS IN EDUCATION AND RESEARCH

Pressure to raise research and education funding

In January 2016, the African Union Development Agency[15] adopted a *Continental Education Strategy for Africa, 2016–2025* as a step on the path to meeting the goals of *Agenda 2063*. The strategy endorses the principle of quality education, training and research to support innovation, creativity and entrepreneurship.

Progress within Africa in implementing the provisions of this strategy has attracted a mixed reaction. Overall, national governments' commitment to R&D and human capacity-building is found to be wanting, with support coming primarily from external sources (AAS, 2018). According to this report, and drawing on the Global Innovation Index of 2015, about 73% of Uganda's gross domestic expenditure on R&D (GERD), 60% of Kenya's, and 50% of Tanzania's and Burundi's GERD was financed by external sources.

Although there has been a marginal rise in GERD as a share of GDP over the past decade, countries remain far from the continental-level aspirations for a research effort equivalent to 1% of GDP. Moreover, recent data are unavailable for the majority of countries (Figure 19.3).

In May 2017, 13 countries from East Africa and the Indian Ocean recommended the following,[16] at a conference organized jointly by UNESCO and the Government of Djibouti on Policy and Research in Higher Education:

- create a regional centre of excellence to foster innovative research and teaching on climate change mitigation and adaptation;
- persuade countries to devote 1% of GDP to R&D;

Figure 19.2: **Status of STI policy development in Central and East Africa, 2020**

CAMEROON

STI policy
(No explicit STI policy)

Related policies and policy instruments
- *National Development Strategy 2020–2030*
- *Digital Cameroon 2020 Strategic Plan* (2017), implemented by Ministry of Posts and Telecommunications
- *National Strategic Plan for Information and Communication Technologies 2020* (2016)

Ministry responsible for STI
- Ministry of Scientific Research and Innovation

CHAD

STI policy
(No explicit STI policy)

Related policies and policy instruments
- *Vision 2030* (2017), implemented through three successive National Development Programmes
- *National Development Plan 2017–2021*
- *Energy Policy* (2019)

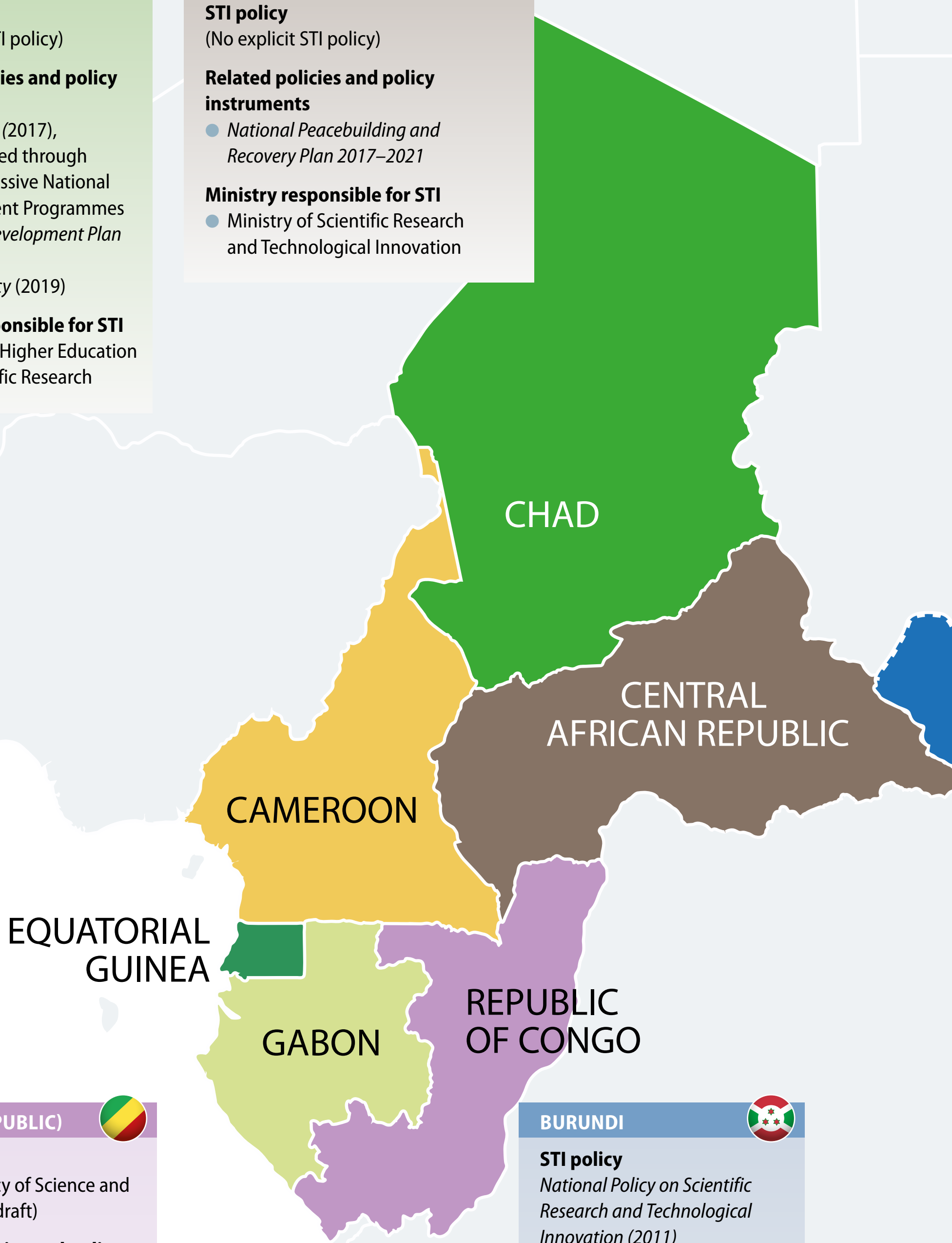
Ministry responsible for STI
- Ministry of Higher Education and Scientific Research

CENTRAL AFRICAN REPUBLIC

STI policy
(No explicit STI policy)

Related policies and policy instruments
- *National Peacebuilding and Recovery Plan 2017–2021*

Ministry responsible for STI
- Ministry of Scientific Research and Technological Innovation



EQUATORIAL GUINEA

STI policy
(No explicit STI policy)

Related policies and policy instruments
- No explicit policy or policy instruments

Ministry responsible for STI
- Ministry of Education, Higher Education and Sports

GABON

STI policy
(No explicit STI policy)

Related policies and policy instruments
- *States General of Education, Research and aligning Training with Jobs* (2010)
- *Emerging Gabon: Strategic Plan to 2025* (2012)

Ministry responsible for STI
- Ministry of Higher Education, Scientific Research and Technology Transfer

CONGO (REPUBLIC)

STI policy
National Policy of Science and Technology (draft)

Related policies and policy instruments
- *National Development Plan 2018–2022*
- *Education Sector Strategy 2015–2025*
- National Development Programme 2018–2028 (with sectoral research policy)

Ministry responsible for STI and other relevant institutions
- Ministry of Scientific Research and Technological Innovation
- Science and Technology Commission

BURUNDI

STI policy
National Policy on Scientific Research and Technological Innovation (2011)

Related policies and policy instruments
- *Strategic Plan for Science, Technology, Research and Innovation* (2013)
- *National Agricultural Strategy* (2018–2027)
- *National Agricultural Investment Plan* (2018–2022)

Ministry responsible for STI and other relevant institutions
- The Ministry of Higher Education and Scientific Research
- National Commission for Science, Technology and Innovation

UN Disclaimer

SOUTH SUDAN

STI policy
(No explicit STI policy)

Related policies and policy instruments
- *Higher Education, Science and Technology Policy Framework* (2011)
- *General Education Strategic Plan* (2017–2022)

Ministry responsible for STI
- Ministry of Higher Education, Science and Technology

ERITREA

STI policy
(No explicit STI policy)

Related policies and policy instruments
- *National Indicative Development Plan 2014–2018*

Ministry responsible for STI and other relevant institutions
- Ministry of Education
- Ministry of Health

DJIBOUTI

STI policy
(No explicit STI policy)

Related policies and policy instruments
- *National Strategy: Vision Djibouti 2035* (2014)
- *Higher Education and Research Strategy Document* (2015–2019)

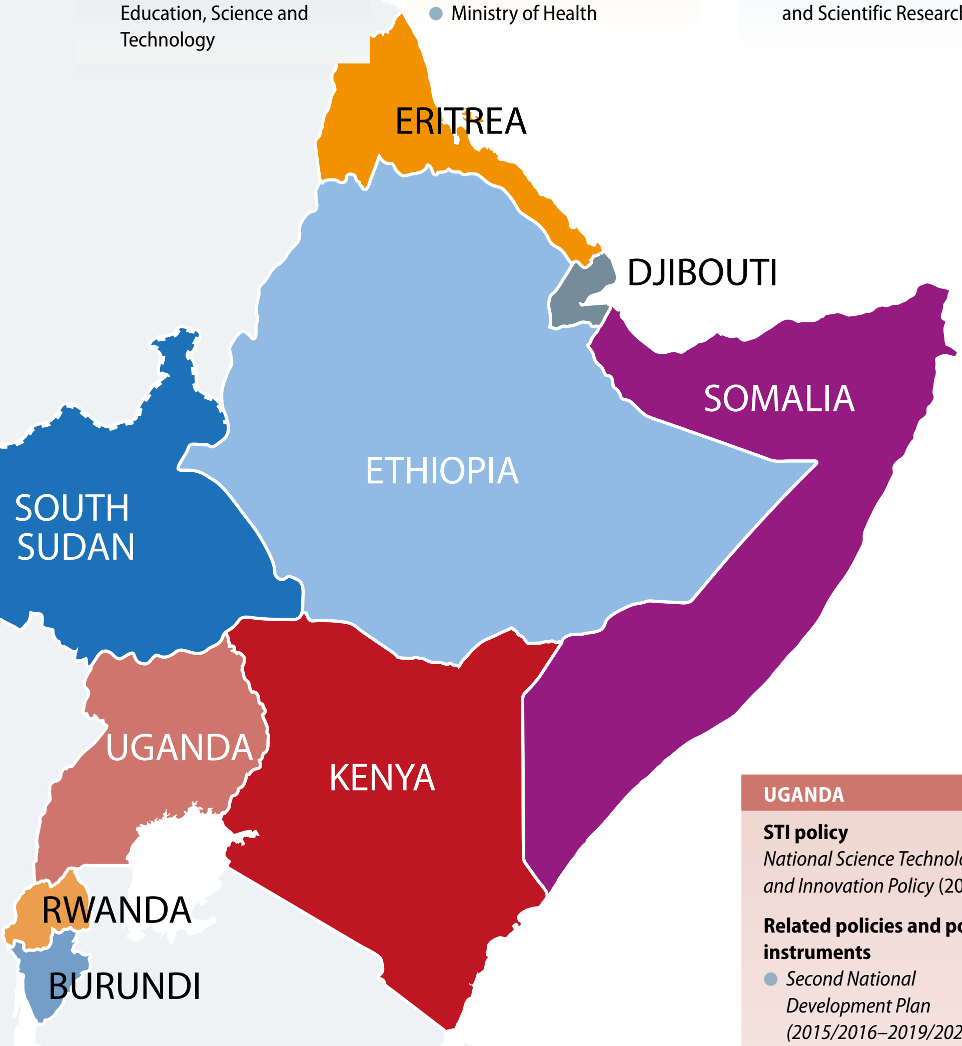
Ministry responsible for STI
- Ministry of Higher Education and Scientific Research

ETHIOPIA

STI policy
National Science, Technology and Innovation Policy (2012)

Related policies and policy instruments
- *Growth and Transformation Plan II* (2015/2016–2019/2020)
- *Start-up Strategy* (2018)

Ministry responsible for STI
- Ministry of Innovation and Technology



SOMALIA

STI policy
(No explicit STI policy)

Related policies and policy instruments
- *National Development Plan* (2017–2019)
- National Information and Communication Technology Policy and Strategy (draft)

Ministry responsible for STI
- Ministry of Education, Culture and Higher Education

UGANDA

STI policy
National Science Technology and Innovation Policy (2009)

Related policies and policy instruments
- *Second National Development Plan (2015/2016–2019/2020)*
- *National Science, Technology and Innovation Plan 2012/2013–2017/2018*
- Science, Technology and Innovation Sector Development Plan 2019/2020 –2024/2025 (draft)
- *Digital Uganda Vision*

Ministry responsible for STI and other relevant institutions
- Ministry of Science, Technology and Innovation
- National Council for Science and Technology
- Uganda Industrial Research Institute

KENYA

STI policy
Science, Technology and Innovation Policy (revised in 2018 and 2020)

Related policies and policy instruments
- *National Research Priorities 2018–2022*
- Science, Technology and Innovation Act (2013)
- *Third Medium-term Plan* (2018–2022) of *Vision 2030* (2008)
- National Research Fund (est. 2013)
- Energy Act (2019)

Ministry responsible for STI and other relevant institutions
- Ministry of Higher Education, Science and Technology
- National Commission for Science, Technology and Innovation (est. 2013)
- National Innovation Agency (est. 2013)

RWANDA

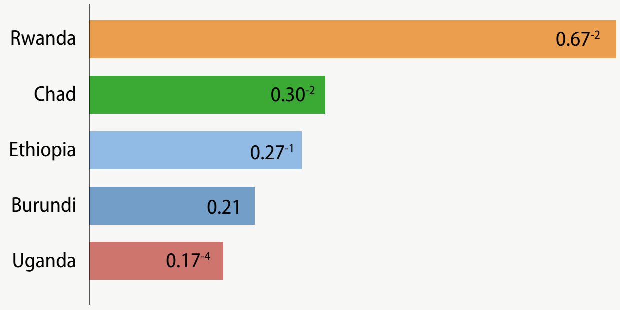
STI policy
National Science Technology and Innovation Policy (2006), revised in October 2014, not yet approved by Cabinet

Related policies and policy instruments
- *National Strategy for Transformation* (2017–2024)
- National Research and Innovation Fund (2017)
- Rwanda Research and Innovation Endowment Fund (operational since 2013)
- *National Risk Atlas of Rwanda* (2015)
- *ICTs in Education Policy* (2016)
- *Education Sector Strategic Plan* (2018–2024)

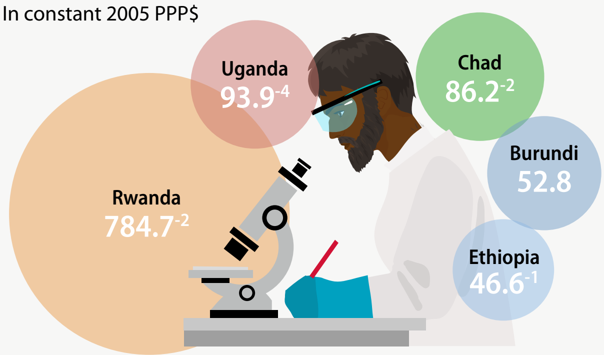
Ministry responsible for STI
- Ministry of Education

Figure 19.3: **Trends in GERD and researchers in Central and East Africa**

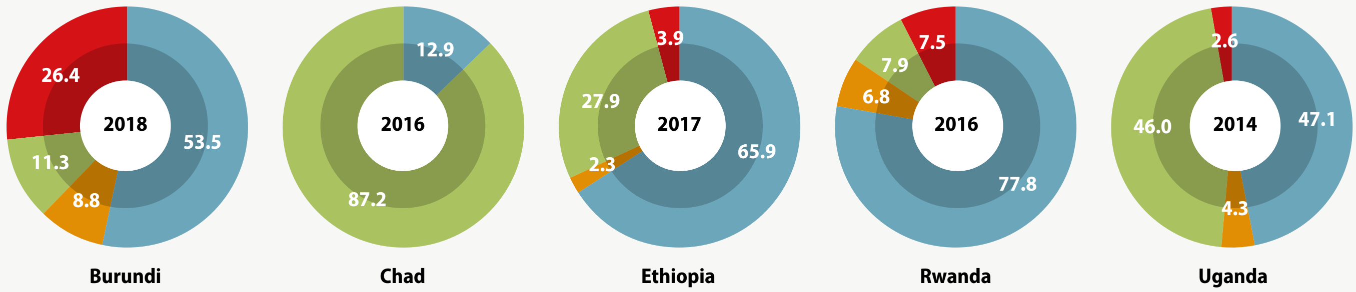
GERD as a share of GDP in Central and East Africa, 2018 (%)



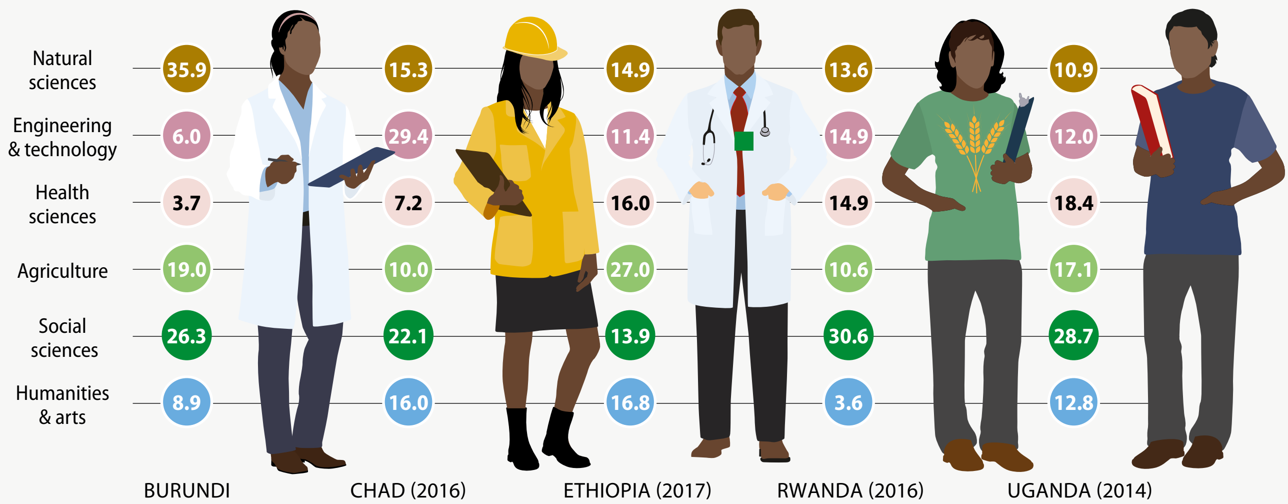
GERD per researcher (FTE) in Central and East Africa, 2018
In constant 2005 PPP$



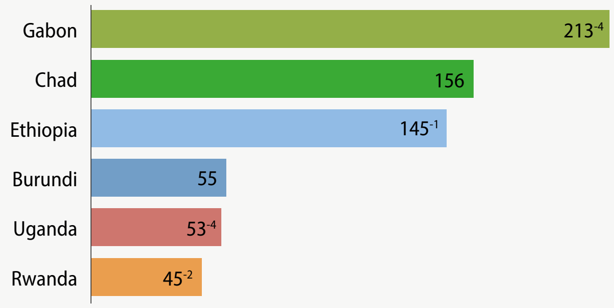
GERD by sector of performance in Central and East Africa, 2018 or closest year (%)



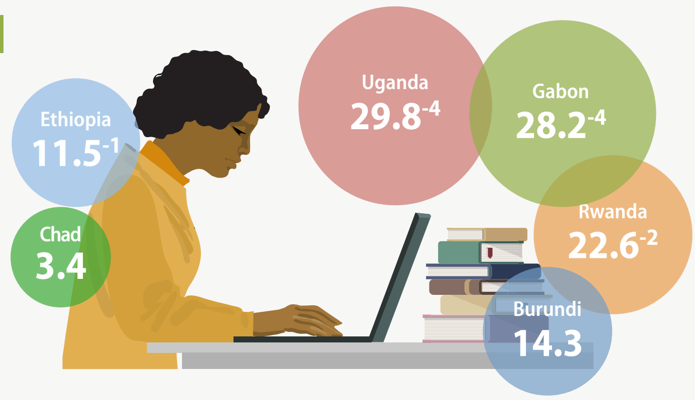
Researchers (HC) by field of science in Central and East Africa, 2018 or closest year (%)



Researchers (HC) per million inhabitants in Central and East Africa, 2018



Share of female researchers (HC) in Central and East Africa, 2018



-n: data refer to *n* years before the reference year

Note: Recent data are unavailable for most countries in Central and East Africa.

Source: UNESCO Institute for Statistics

- develop interdisciplinary teaching programmes grouping natural and social sciences to integrate issues such as peace, security and gender equality in the university system, in collaboration with regional research networks like the Greater Horn Horizon Forum; and
- develop a joint research programme for East Africa on the use of ICTs in education.

Governments in East Africa have responded positively to growing pressure from the African scientific community to improve science funding and acknowledge the role of scientific advice in policy-making (AAS, 2018). Djibouti, Kenya and Rwanda have been particularly reactive. For instance, Djibouti is due to inaugurate a regional centre on climate change mitigation and adaptation in 2021.

Public expenditure on education is above the global average (4.6% of GDP in 2014) in Kenya and Ethiopia and equivalent to this benchmark in the Republic of Congo (Figure 19.4). The share of public expenditure allocated to higher education amounts to less than 1% of GDP in most countries. The notable exception is Ethiopia, where it accounts for half of public expenditure on education overall.

Insufficient numbers of science and engineering students

The low absorption rate of researchers in industry may imply not only that available skills are unsuited to market needs but also that there is little demand from domestic firms for innovation. This dampens the prospects for technological upscaling and heightened productivity to serve as an engine of regional integration (UNECA, 2019). African countries aspire to catch up by taking advantage of promising Industry 4.0 technologies such as the Internet of Things and artificial intelligence but seizing this opportunity will require a critical mass of technicians and innovators able to think outside the box (Gatune and Brown, 2018).

One way to address this skills gap may be to pay greater attention to technical and vocational training and to align university teaching and research activities on the needs of the labour market (UNECA, 2020). It may be desirable to update the *Continental Strategy for Technical and Vocational Education and Training* adopted by the African Union in 2007 to reflect the rapid technological advances of the past decade.

The current low level of student enrolment in science and engineering disciplines is also dampening prospects for industrializing the region (Figure 19.4).

In order to strengthen training in strategic fields for industrialization, ECCAS countries have been working with UNESCO and the AfDB since 2010 to develop university of technology poles of excellence. UNESCO submitted a feasibility study to the Executive Secretariat of ECCAS which triggered the release of AfDB funds in 2016 to take the project forward. However, these funds have not been spent since ECCAS entrusted implementation to private-sector partners. In 2020, the AfDB and ECCAS were involved in talks on resuscitating the project.

In August 2020, UNESCO teamed up with the Huawei ICT Academy (Kenya) to produce a week-long training programme for early-career university faculty members from Comoros, Ethiopia, Kenya, Madagascar, Mauritius, Rwanda, the Seychelles and Uganda who were keen to integrate artificial intelligence (AI) into their regular teaching curriculum.[16] The programme taught transdisciplinary skills and creative thinking. Successful trainees were awarded Huawei certification as certified professionals in AI. It is planned to organize more courses in 2021.

At the institutional level, one success story has been the gradual but effective operationalization since October 2018 of the Cameroon–Congo interstate university based in Ouesso (Congo) and Sangmelima (Cameroon).

Several centres of excellence have also been established in East Africa within a World Bank project (Table 19.4). When the World Bank launched the project in 2013, Cameroon was the only Central African country to participate in the call for projects. The World Bank selected the project for a centre at the University of Yaoundé specializing in ICTs, which foresaw facilities such as a supercomputer, laboratories and an incubator for start-ups specializing in intensive computing. However, the World Bank eliminated Cameroon from the programme in 2019. This means that science and engineering in Central Africa is evolving on the margins of this transformative programme.

More intra-African collaboration in science

The volume of scientific publications has progressed in all countries, albeit to varying degrees, with particularly impressive growth observed in Cameroon, Ethiopia, Kenya and Rwanda, which have all raised their publication intensity considerably since 2011 (Figure 19.5).

Health sciences still dominate output across the region, followed by agricultural and environmental sciences, but the most prolific countries are diversifying their research focus. Some 11% of publications from Cameroon between 2017 and 2019 concerned physics and astronomy and a further 10% cross-cutting technologies.

Cameroon has sub-Saharan Africa's highest publication intensity for energy research, as well as for AI and robotics, and the second-highest intensity for materials science. It does not figure in the top 15 for biotechnology (see Figure 20.6).

Cameroon's high output in energy research may be explained by the fact that oil companies are funding university research laboratories to help improve training in the field of petroleum geology.

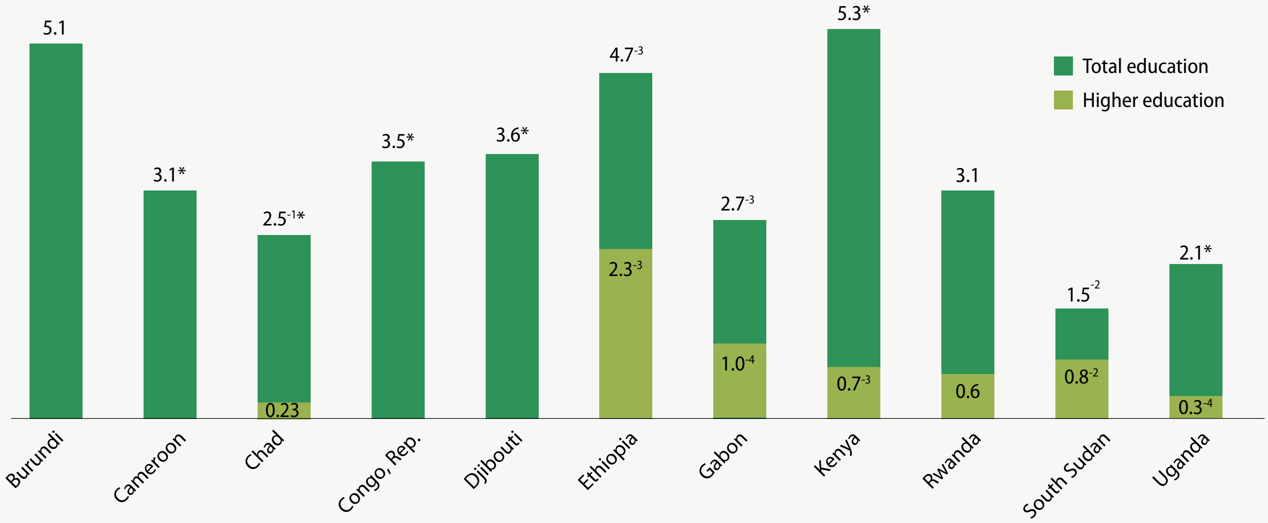
Although Cameroon's output on renewable sources of energy is growing, it remains modest: over the dual periods 2012–2015 and 2016–2019, publications doubled on hydropower (from 10 to 24 articles), wind-turbine technology (from 7 to 20) and on biofuels and biomass (from 13 to 29), and rose on photovoltaics (from 14 to 24) [Figure 19.6].

In Ethiopia, 13% of output concerned cross-cutting technologies. Ethiopia, Kenya and Rwanda have attained a similar publication intensity for AI and robotics (0.5–0.6 articles per million inhabitants), placing them in the top 15 for this field in sub-Saharan Africa (see Figure 20.6).

Of the four, Kenya has the highest proportion of output on animal and plant biology (10%). Despite the importance of

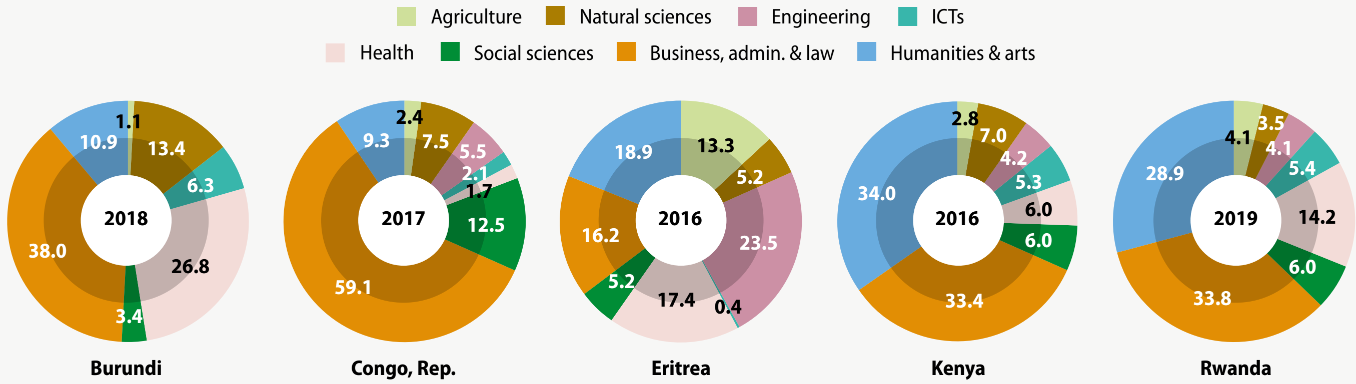
Figure 19.4: **Trends in higher education in Central and East Africa**

Public expenditure on education and higher education in Central and East Africa as a share of GDP, 2018 (%)



* estimation by UNESCO Institute for Statistics

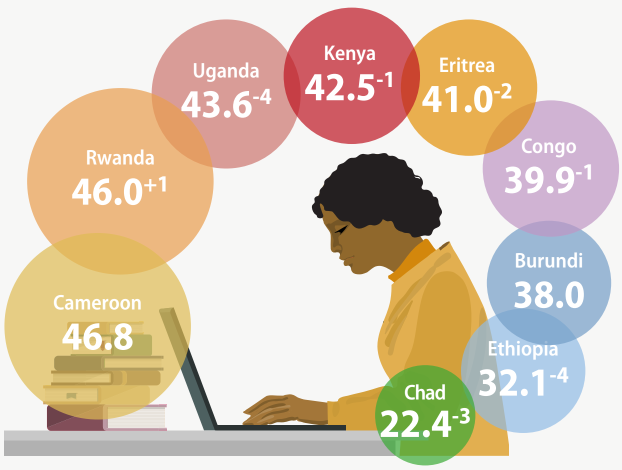
Distribution of tertiary graduates in Central and East Africa by programme, 2018 or closest year (%)



Tertiary enrolment in Central and East Africa by level of study, 2018 or closest year

	Post-secondary diploma	Bachelor's degree or equivalent	Master's degree or equivalent	PhD or equivalent
Burundi	–	40 300	1 262	307
Cameroon	36 624	224 903	62 008	7 258
Chad (2015)	993	38 285	2 438	195
Congo, Rep. (2017)	12 792	34 716	7 032	821
Eritrea (2016)	3 295	6 891	45	–
Ethiopia (2014)	–	555 335	29 697	1 983
Kenya (2019)	26 225-2	439 768	51 079	10 215
Rwanda (2019)	4 306	63 557	4 214	51

Share of female students enrolled at Central and East African universities, 2018 or closest year (%)



+n/-n: data refer to *n* years before or after reference year

Note: Recent data are unavailable for many countries in Central and East Africa. The field of study was not specified for 1.5% of Kenyan graduates.

Source: UNESCO Institute for Statistics

Table 19.4: **Centres of excellence established in East Africa in 2017**

Country	Lead institution	Centre of excellence (focus)
Ethiopia	Addis Ababa University	Water management
	Addis Ababa University	Railway education and research
	Addis Ababa University	Innovative drug development and therapeutic trials for Africa
	Haramaya University	Climate smart agriculture and biodiversity conservation
Kenya	Egerton University	Sustainable agriculture and agribusiness management
	Jaramogi Oginga Odinga University of Science and Technology	Sustainable use of insects as food and feed
	Moi University	Phytochemicals, textiles and renewable energy
Rwanda	University of Rwanda, College of Business and Economics	Data science
	University of Rwanda, College of Science and Technology	Energy for sustainable development
	University of Rwanda, College of Science and Technology	Internet of Things
	University of Rwanda – College of Education	Innovative teaching and learning of mathematics and science
Uganda	Makerere University	Materials, product development and nanotechnology
	Makerere University	Crop improvement
	Mbarara University of Science and Technology	Pharm-biotechnology and traditional medicine
	Uganda Martyrs University	Agro-ecology and livelihood systems

Note: A centre of excellence in ICTs was established in 2014 at the University of Yaoundé as part of the first wave of centres within the ongoing World Bank project. It was followed by a centre of excellence in health at the University of Buea in 2017. However, the World Bank subsequently eliminated Cameroon from the project. In 2019, the World Bank designated the University of Djibouti as a centre of excellence, along with other new centres in West Africa. For background, see Essegbey *et al.* (2015).

Source: World Bank (2016) A regional solution to transform science and technology education in Africa. Eastern & Southern Africa Higher Education Centers of Excellence Project. World Bank: Washington, DC. See: https://tinyurl.com/yxfhmmss

mining and Kenyan investment in geothermal power, the share of geosciences in publications remains low (Figure 19.5).

The high share of co-publications (+80% in most countries), coupled with the fact that all but Djibouti count at least one other African country among their five closest scientific partners, supposes that other African countries are contributing to national totals to a varying degree. Rwanda, for instance, counts Kenya, South Africa and Uganda among its top five scientific partners (Figure 19.5).

More tech hubs but patent registration costly

Kenya, Cameroon and Ethiopia dominate the table for the volume of patents granted by the world's top five patent offices (Figure 19.7). Kenya has, by far, the most tech hubs in Central and East Africa (70), followed by Cameroon (28), Uganda (19) and Rwanda (12) [see Figure 20.2].

A growing number of entrepreneurs are designing environmentally friendly products. One example is the Kenyan ecopreneur Lorna Rutto, who founded her social enterprise, Ecopost Ltd, in 2009. It recycles plastic waste to make fences, flooring and other products, thereby also reducing timber use.[17]

The high cost of registering intellectual property and lack of a common system is hindering patenting in Africa. This problem is unlikely to be resolved in the near future, since the Pan-African Intellectual Property Organization is taking longer than expected to become operational (Box 19.3).

COUNTRY PROFILES

BURUNDI

A focus on reducing food insecurity

Burundi has one of the highest population densities on the continent, with a demographic growth rate of 3.1% in 2019. GDP per capita is the lowest in sub-Saharan Africa. In 2019, Burundi was the only country in sub-Saharan Africa to receive no FDI at all (Table 19.1).

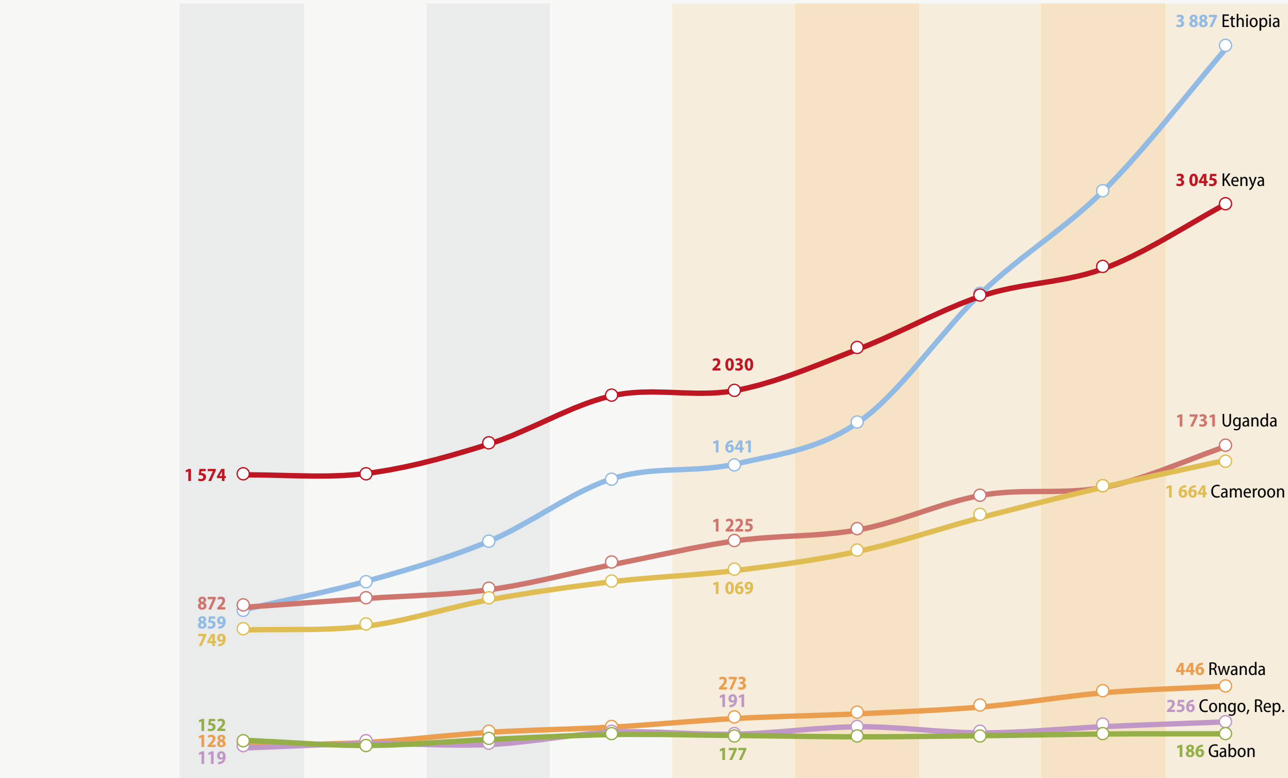
Vision Burundi 2025 (2011) remains the main blueprint for the country's development. It framed the second *Poverty Reduction Strategy* (2012–2018), for instance.

Agriculture (mainly rain-fed) employs 90% of the population, yet only 36% of land is arable (MoFA, 2018). According to the 2018 World Hunger Index, around 15% of the population is living in acute food insecurity. This vulnerability worsens during the long dry season, which is getting drier and hotter. To meet its objectives for food security, the country will need to boost its agricultural productivity, the lowest in the region (MoFA, 2018).

This is what the *National Agricultural Strategy* (2018–2027) and *National Agricultural Investment Plan* (2018–2022) set out to do. The aim is to facilitate equitable access to arable land and develop and implement policies and programmes to support crop diversification and greater productivity for livestock and fisheries. Between 2011 and 2019, Burundi scientists produced seven articles on ways to help smallholder food producers increase their income and six on the sustainable use of terrestrial ecosystems. There was no observed output – at least

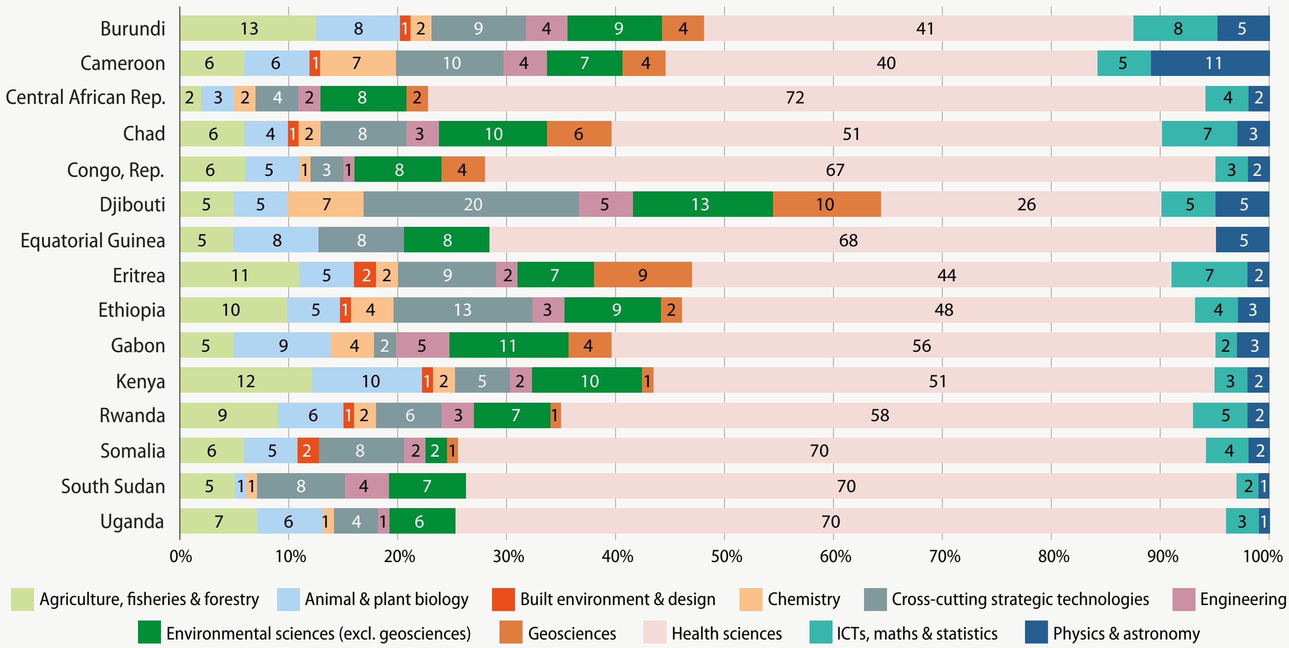
Figure 19.5: **Trends in scientific publishing in Central and East Africa**

Volume of scientific publications in Central and East Africa, 2011–2019



	2011	2012	2013	2014	2015	2016	2017	2018	2019
Burundi	26	31	33	39	47	45	56	73	70
Chad	24	21	24	30	30	42	56	54	60
Somalia	5	6	7	12	15	10	44	24	59
Central African Rep.	33	37	34	44	37	65	46	62	47
Eritrea	24	10	23	25	26	21	34	47	46
South Sudan	5	11	17	16	12	10	27	29	27
Djibouti	16	19	18	23	16	18	20	21	20
Equatorial Guinea	7	7	8	12	16	16	12	14	14

Scientific publications in Central and East Africa by broad field of science, 2017–2019 (%)



1.32

Average citation rate for Ethiopia, the country with the highest output in Central and East Africa, 2014–2016; the G20 average was 1.02

88%

Average share of publications with foreign co-authors in Central and East Africa, 2017–2019

58%

Share of Ethiopian publications with a foreign co-author, 2017–2019, the lowest proportion in the region

How has output on SDG-related topics evolved since 2012?

Countries are publishing more on the following topics than would be expected, relative to global averages: help for smallholder food producers; traditional knowledge; tropical communicable diseases; HIV research; medicines and vaccines for tuberculosis; and climate-ready crops. Output from Rwanda and Uganda on climate-ready crops has even quadrupled since 2011.

Kenya published at least three times the global average intensity on sustainable management of fisheries and aquaculture between 2011 and 2019. It hosted the first global Sustainable Blue Economy Conference in 2018 and co-hosted the second United Nations Ocean Conference in 2019.

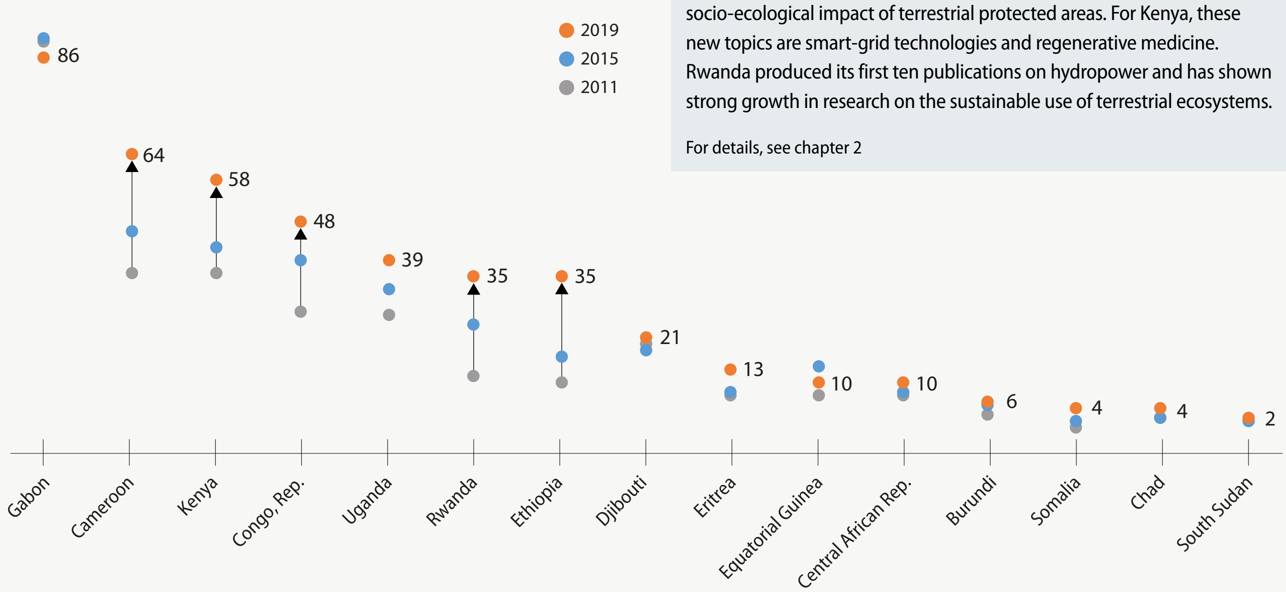
The reservoirs of the new Great Ethiopian Renaissance Dam began to fill in July 2020. Despite the negotiations over water rights with other users of the Blue Nile River, Ethiopia produced only three publications on transboundary water management from 2011 to 2019.

Growth is observed in the following new research topics for Ethiopia: sustainable transportation, eco-industrial waste management, wind-turbine technology, hydrogen energy, better battery efficiency and the socio-ecological impact of terrestrial protected areas. For Kenya, these new topics are smart-grid technologies and regenerative medicine. Rwanda produced its first ten publications on hydropower and has shown strong growth in research on the sustainable use of terrestrial ecosystems.

For details, see chapter 2

Scientific publications per million inhabitants in Central and East Africa, 2011, 2015 and 2019

Data labels are for 2019



Fourteen countries count at least one other African country among their top five collaborators.

Top five partners for Central and East Africa for scientific co-authorship, 2017–2019 (number of papers)

	1st collaborator(s)	2nd collaborator(s)	3rd collaborator(s)	4th collaborator(s)	5th collaborator(s)
Burundi	Belgium (45)	USA (37)	China (34)	Uganda (29)	UK (28)
Cameroon	France (879)	USA (728)	UK (513)	South Africa (506)	Germany (436)
Central African Rep.	France (67)	UK (30)	Cameroon (28)	USA (23)	Belgium/Gabon (18)
Chad	France (61)	USA (42)	Switzerland (38)	UK (34)	Cameroon (33)
Congo, Rep.	USA (236)	UK (137)	France (134)	Congo, Dem. Rep. (123)	Switzerland (105)
Djibouti	France (37)	Italy/USA (9)		Germany (7)	China (6)
Equatorial Guinea	Spain/USA (16)		UK (10)	China/Tanzania (5)	
Eritrea	China (24)	India (18)	USA (17)	South Africa (11)	Switzerland (10)
Ethiopia	USA (1 419)	India (897)	UK (854)	Germany (525)	South Africa (522)
Gabon	France (228)	Germany (135)	USA (129)	UK (87)	Cameroon (73)
Kenya	USA (2 900)	UK (1 871)	South Africa (1 024)	Germany (750)	Uganda (591)
Rwanda	USA (481)	UK (171)	South Africa (161)	Kenya (153)	Uganda (123)
Somalia	USA (40)	Italy (28)	Sweden (15)	UK (13)	Kenya/Malaysia (12)
South Sudan	USA (32)	Uganda (24)	Kenya (15)	UK (13)	Sudan/Switzerland (11)
Uganda	USA (2 039)	UK (1 184)	South Africa (625)	Kenya (591)	Canada (381)

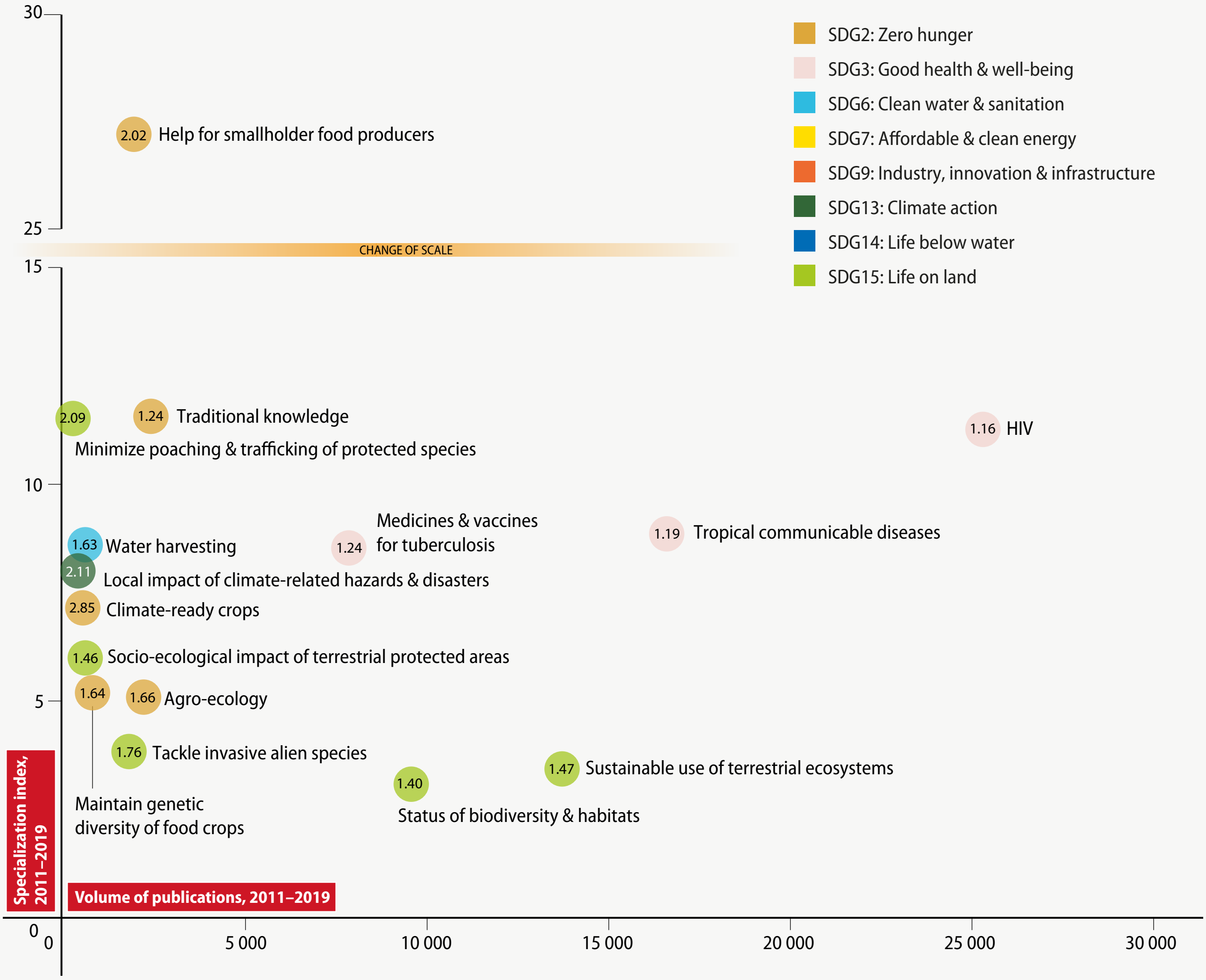
Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

Figure 19.6 **Trends in scientific publishing on SDG-related topics in sub-Saharan Africa**

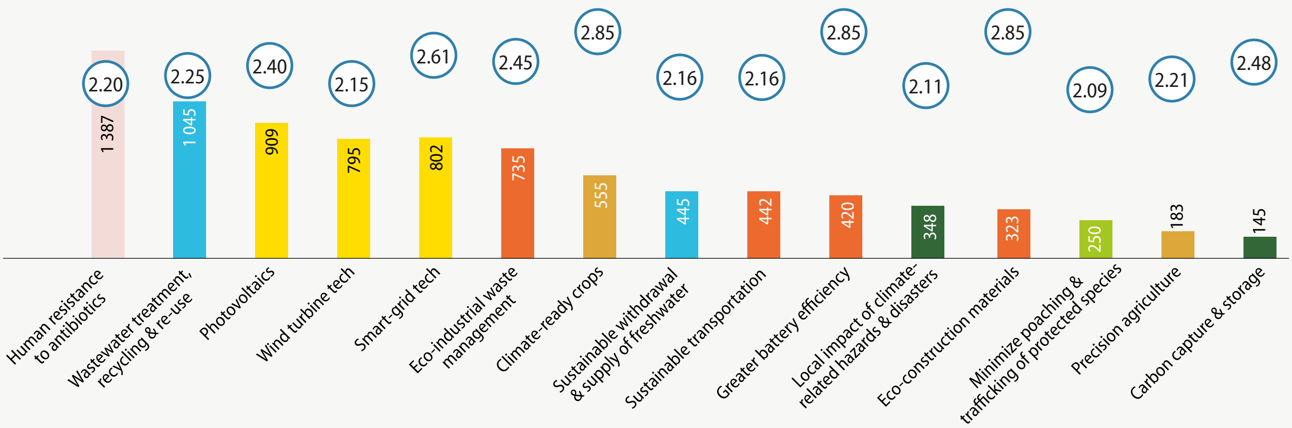
For topics with more than 100 publications over the period under study

Top fifteen topics in sub-Saharan Africa by specialization, 2011–2019

Values in the circles represent the growth rate



Top fifteen topics in sub-Saharan Africa by growth rate, in order by volume, 2012–2019



Note: The growth rate is calculated as the number of publications from 2016–2019 divided by the number of publications from 2012–2015. The specialization index reflects the intensity of focus on a research topic relative to the global average share of publications (set at 1.00). The following topics (in order by volume) were excluded because sub-Saharan African authors produced fewer than 100 publications during the period under study: radioactive waste management; new technologies to protect from climate-related hazards; sustainably manage marine tourism; local disaster risk reduction strategies; eco-alternatives to plastics; ecosystem-based approaches in protected areas on land; ecosystem-based approaches in marine environments; transboundary water resource management; floating plastic debris in the ocean; national and urban greenhouse gas emissions; extent of water-related ecosystems; nuclear fusion; and ocean acidification. See chapter 2 for details.

Source: Scopus (including Arts, Humanities and Social Sciences); data treatment by Science-Metrix

Box 19.3: **Towards a single Pan African intellectual property system**

As part of its *Science, Technology and Innovation Strategy for Africa* to 2024 (*STISA-2024*), the African Union adopted the statutes of the Pan-African Intellectual Property Organization (PAIPO) in 2016.

PAIPO has a mandate to harmonize and align the national intellectual property systems in Africa, as well as those of the two regional jurisdictions.

The first of these regional jurisdictions is the African Regional Intellectual Property Organization (ARIPO, est. 1976). Originally covering only English-speaking countries, ARIPO has since extended membership to other countries, including Mozambique, São Tomé and Príncipe and Somalia.

Similarly, the Organisation africaine de la propriété intellectuelle (OAPI, est. 1977) initially only covered French-speaking countries. It now counts Guinea-Bissau and Mauritania among its 17 member states.

Conspicuous by their absence are Nigeria and South Africa. Respectively the continent's largest economy and Africa's most developed patent office, they are members of neither ARIPO nor OAPI.

Moreover, as of October 2020, PAIPO has yet to become operational. It had been scheduled to reach this stage by 2018 and to be fully functional by 2023.

Registration of intellectual property a costly process

In most cases, the process for registering intellectual property remains costly and difficult to navigate for local inventors. For example, it costs over US$ 37 000 at ARIPO and US$ 30 000 at OAPI to register and maintain a 30-page patent for the first ten years (de Andrade and Viswanath, 2017). This compares with US$ 5 216 in South Africa, US$ 4 330 in Malaysia and just US$ 2 500 in the UK.

Table 19.5: **Estimated patenting costs at ARIPO, OAPI and in South Africa, 2017**
In US$

Stage of patent process	ARIPO	OAPI	South Africa
Filing	1 797	5 150	1 589
Examination	1 165	–	–
Prosecution	1 060	2 879	120
Grant	1 830	162	180
Cumulative annuities	31 990	21 941	3 327
Total	**37 842**	**30 132**	**5 216**

Source: de Andrade and Viswanath (2017)

To compound matters, the rules governing page limits before an extra fee applies differ widely across jurisdictions and the renewal fees (annuities) can be high (Table 19.5).

As a result, only 17 000 patent applications were registered in Africa in 2018, equivalent to 0.5% of the global total. Of these patent applications, only 18.4% originated from local residents, according to the World Intellectual Property Organization's statistics database. In the same year, the UK alone registered more applications for patent registration than Africa as a whole: 20 941, of which 61.4% originated from local residents.

ARIPO and OAPI should join forces to simplify online procedures for patent applications and significantly reduce the cost of pre-examination fees and services for young African innovators, university students and early-stage start-ups. Doing so would be a particularly powerful means of nurturing Africa's creative forces and helping the most promising ideas to translate into financial assets and gain visibility with potential investors.

In addition, all 54 African countries should more actively pursue mutual recognition of intellectual property as a way to support implementation of Africa's continental free trade area.

Source: compiled by Bakary Traoré, OECD

in international journals tracked by Elsevier – on topics related to climate-ready crops or agro-ecology.

The *National Agricultural Strategy* (2018–2027) and its investment plan are part of implementation of the country's ambitious *Strategic Plan for Science, Technology, Research and Innovation* (2013), which aims to place science in society. The strategy covers the following areas: food technology; medical sciences; energy, mining and transportation; water; desertification; environmental biotechnology and indigenous knowledge; materials science; engineering and industry; ICTs; space sciences; mathematical sciences; and social and human sciences.

With regard to material sciences, specifically, it is noteworthy that Burundi's publication intensity has doubled from 0.6 to 1.2 articles per million inhabitants since 2012, placing it in the top 15 for sub-Saharan Africa for this strategic technology (see Figure 20.6).

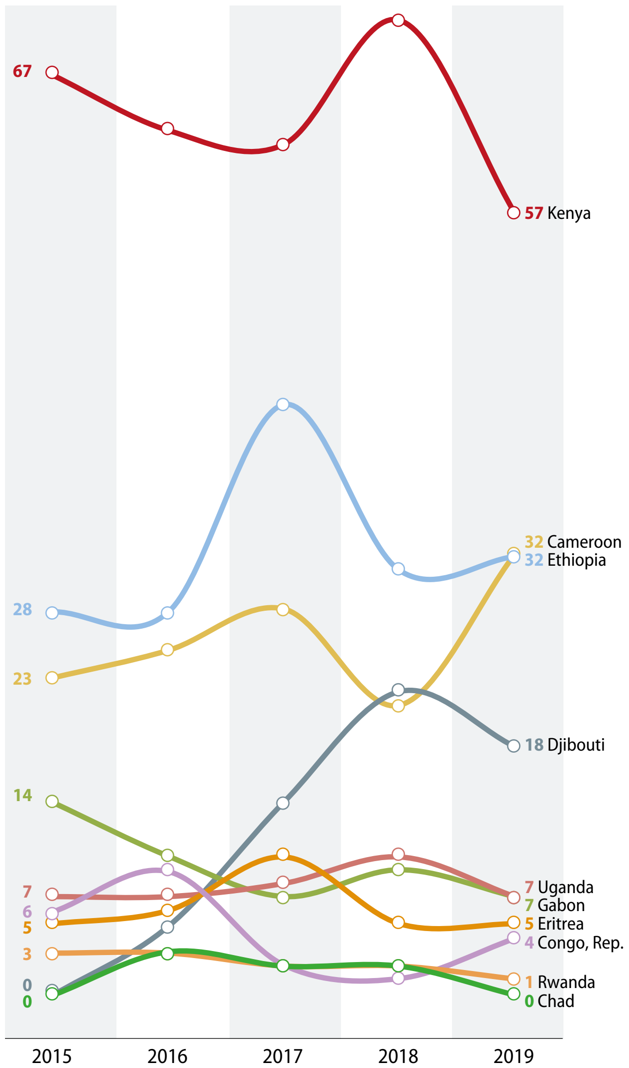
Medical sciences remain the main focus of research: medical researchers accounted for 4% of the country's scientists in 2018 (Figure 19.3) but 41% of scientific publications between 2011 and 2019 (Figure 19.5).

Burundi has almost tripled its scientific output since 2011 but the pace has not picked up since the adoption of the Sustainable Development Goals in 2015. With six scientific publications per million inhabitants, Burundi still has one of the lowest publication intensities in Central and East Africa. Some 97.5% of publications involved foreign co-authorship between 2017 and 2019, with Ugandans figuring among the top five partners (Figure 19.5).

The focus of the *Strategic Plan for Science, Technology, Research and Innovation* (2013) has been on developing an institutional framework and infrastructure, fostering greater regional and international co-operation and placing science in society. In October 2014, the EAC Secretariat designated the National Institute of Public Health a centre of excellence (Urama *et al*., 2015). Data are unavailable on output on nutritional sciences, the institute's area of specialization but, between 2011 and 2019, Burundi scientists produced seven articles on each of HIV and tropical communicable diseases and a further five on tuberculosis, all focus areas for the SDGs.

The *Strategic Plan* has also focused on training researchers. Researcher density (in head counts) has improved from 40 (Urama *et al.,* 2015) to 55 researchers per million inhabitants since 2011 (Figure 19.3). Moreover, the amount available to each researcher has risen from PPP$ 14 310 (constant 2005 values) to PPP$ 22 480 and the domestic research effort has also increased since 2012, from 0.11% (Urama *et al.,* 2015) to 0.21% of GDP (Figure 19.3).

Figure 19.7: **Number of IP5 patents granted to inventors from Central and East Africa, 2015–2019**



Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China. Burundi, Central African Republic, Equatorial Guinea, Somalia and South Sudan received no IP5 patents during the period under study.

Source: PATSTAT; data treatment by Science-Metrix

CAMEROON

Infrastructural projects to leave a heavy footprint

Cameroon's population grew by a rapid 2.6% in 2019 (Table 19.1). Despite stable economic growth of 4% on average between 2016 and 2019, supported primarily on the supply side by the tertiary sector, Cameroon has been plagued by an image problem which makes it less attractive to investors. FDI contributed just 2% of GDP in 2018 (Table 19.1).

The country's image has not been helped by the persistent insecurity in the north and political turmoil in the southwest and northwest (AfDB, 2019).

The economy, nevertheless, remains the most resilient in Central Africa, thanks to its relative diversification,[18] even if it remains highly exposed to fluctuations in global commodity prices. The economy has managed to absorb more than 350 000 refugees and asylum-seekers from neighbouring Central African Republic and Nigeria (HRW, 2019).

Cameroon has invested heavily in infrastructure projects that should leave a heavy footprint on the national economic landscape. These include the development of a deep seaport in Kribi and four hydropower projects in Memvele, Mekin, Nachtigal and Lom Pangar.

In parallel, Cameroon is participating in the Biosphere and Heritage of Lake Chad (Biopalt) project, which is restoring ecosystems around Lake Chad and fostering the adoption of 'green' income-generating activities (Box 19.4; Figure 19.6).

Among the 56 research topics analysed by UNESCO, output was highest on tropical communicable diseases (289 papers in 2019) and HIV (239), followed by the sustainable use of terrestrial ecosystems (174), the status of territorial biodiversity (121) and reproductive health and neonatology (120). Less than 20 articles were published in 2019 on help for smallholder food producers and renewable energy.

Digital economy a priority axis

The development of the digital economy is a priority axis for the government. Since 2018, the Ministry of Posts and Telecommunications (MINPOSTEL) has organized a biennial forum on the digital economy to identify and support the most promising ideas for the creation of start-ups. This is part of MINPOSTEL's *Digital Cameroon 2020 Strategic Plan* (2017), which focuses on the digital economy. This forum complements the National Days of Excellence for Scientific Research and Innovation organized each year since 2007 by the Ministry of Scientific Research and Innovation to identify the ten best ideas for the creation of start-ups in all fields and provide them with financial and technical support.

By 2019, there were 28 active tech hubs in Cameroon (see Figure 20.2). One example of a digital start-up in the health sector is GiftMom Co. (Box 19.5).

The *National Strategic Plan for Information and Communication Technologies 2020* (2016)[19] has contributed to a surge in investment in related infrastructure across the country (Toussi, 2019). By 2017, almost one in five citizens had Internet access and four-fifths had a mobile phone subscription (Table 19.2) This has made it possible for citizens to remit money to their

Box 19.4: **Restoring the Lake Chad Basin with local communities**

The Lake Chad Basin is a key source of freshwater for more than 45 million people. Located at the crossroads of Cameroon, Chad, the Central African Republic, Niger and Nigeria, the basin is also characterized by degraded ecosystems that are imperiling livelihoods.

Between 1960 and 1985, the surface area of Lake Chad shrank by 95% owing to the decrease in rainfall, although its extent has been expanding since the 2000s. Insecurity in the area has been exacerbated by the Boko Haram sect, displacing large swaths of the population.

Since 2017, the Biosphere and Heritage of Lake Chad (Biopalt) project has set about improving the living standards of the riparian communities. Local people have been trained in how to safeguard and sustainably manage the basin. An early warning system for droughts and floods has been put in place. The habitats of emblematic species such as the elephant and Kouri cattle (*Bos taurus longifrons*) have been restored. Communities have received financial assistance to develop 'green' income-generating activities, such as the production of spirulina, a high-protein plant.

The project is being implemented by UNESCO in partnership with the Lake Chad Basin Commission and with funding from the African Development Bank to the tune of US$ 6.5 million. Representatives of civil society, local communities and indigenous peoples all participated in designing the project, which sets out to ensure that 'nothing is done for communities without communities'.

The Lake Chad Basin is rich in biodiversity and cultural heritage. It hosts two world heritage sites (Lakes Ounianga and Manovo-Gounda), a UNESCO biosphere reserve (Waza) and Ramsar sites of wetlands of international importance.

The project is helping countries to prepare their application for the creation of a transboundary biosphere reserve in the basin.

Lake Chad was recently inscribed on the World Heritage Tentative List of Cameroon, Chad, Niger and Nigeria. However, in September 2020, Chad requested the suspension of the application for World Heritage site status after signing agreements with companies for oil exploration inside the nominated property.

Source: UNESCO

bank via the MTN Homeland service app launched in 2019 and to purchase goods and services online. A 2020 survey found that 88% had purchased items via WhatsApp and 68% via Facebook (GSMA, 2020). However, low levels of literacy and infrastructure have deprived many women of Internet access.

In 2017, Cameroon was one of only four African countries to have 4G connectivity (SDG Centre for Africa, 2017). A submarine fiber optic cable connecting Cameroon to Brazil has been laid since 2016.

The first African centre for 3D printing

In order to strengthen national capacities in digital engineering, the government has put in place a number of initiatives. In 2014, the University of Yaoundé became the first in Central and East Africa to host a centre of excellence financed by the World Bank. It specialized in ICTs. A second centre of excellence specializing in health was designated in 2017 at the University of Buea. However, in 2019, the World Bank decided to withdraw Cameroon from the programme.

The government founded the National School of Posts, Telecommunications and Information and Communication Technologies in 2016. It has also set up a high-tech centre specializing in robotics, digital manufacturing and computer-aided vision, as well as a three-dimensional (3D) printing centre that is unique in sub-Saharan Africa. A training centre for various computer-aided design and drawing tools has also been operational since 2017.

By 2019, Cameroon had the highest publication intensity in artificial intelligence and robotics in sub-Saharan Africa (see Figure 20.6).

Box 19.5: **GiftedMom: digitizing health care in Cameroon**

GiftedMom Co. is a start-up created in 2016 by young Cameroonians in order to increase antenatal care attendance and vaccination of babies and reduce the transmission of HIV from mother to child, by informing pregnant women and new mothers in rural areas, especially, about available resources.

Gifted Mom Co. has developed a smartphone application for Android users that can be downloaded from the Google Play store. An automated SMS and voice application sends notifications to pregnant women and nursing mothers reminding them when to go for their next antenatal care session or take their baby for vaccination.

Weekly SMS are sent to subscribers informing them of the available educative medical resources that the Ministry of Public Health and its partners have put in place.

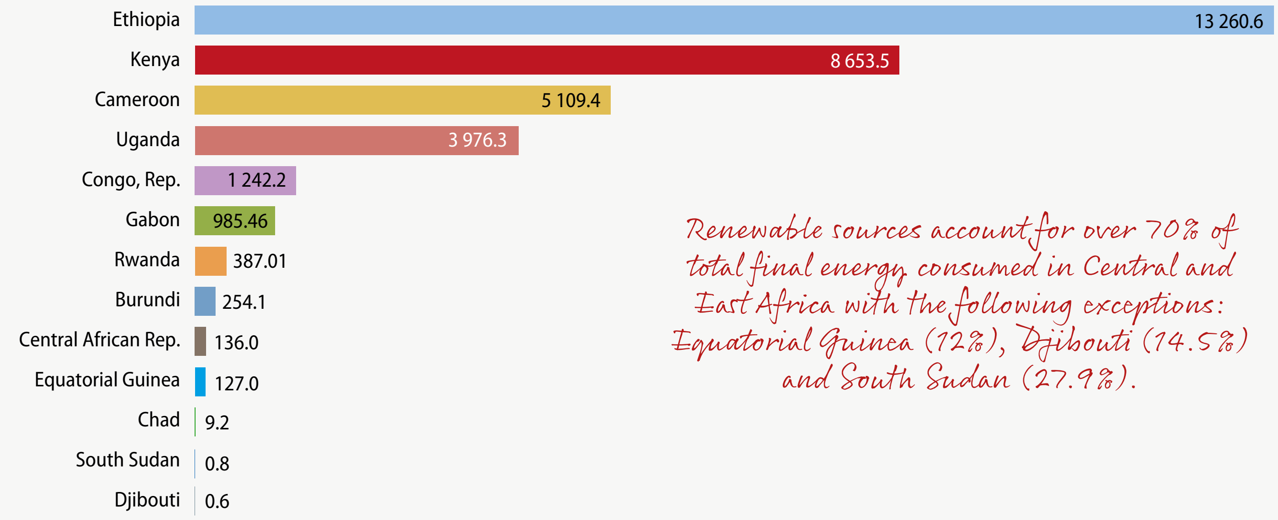
Pregnant women or nursing mothers can subscribe to the GiftedMom SMS and Voice Reminder service at hospitals, or directly by sending the keyword MOM to 8566.

Registered as a non-governmental organization, GiftedMom Co. is currently operating in 34 communities across the country. So far, it has affected the lives of over 10 000 pregnant women and nursing mothers, as well as those of their partners and community health-workers.

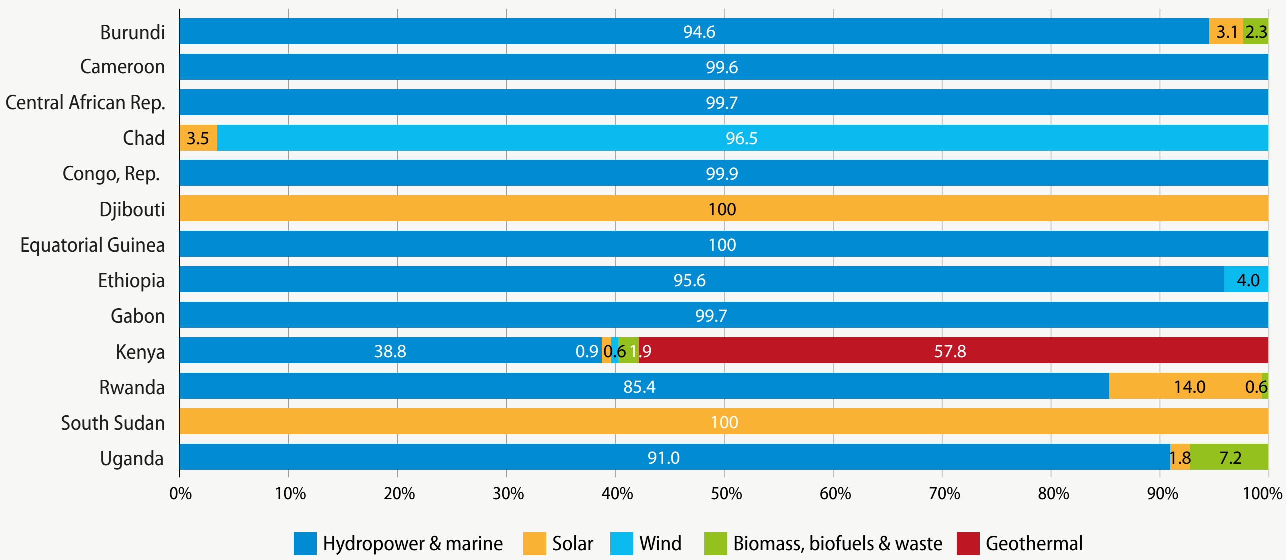
Source: compiled by authors; see also: https://tinyurl.com/giftedmom

Figure 19.8: **Renewable sources of electricity in Central and East Africa**

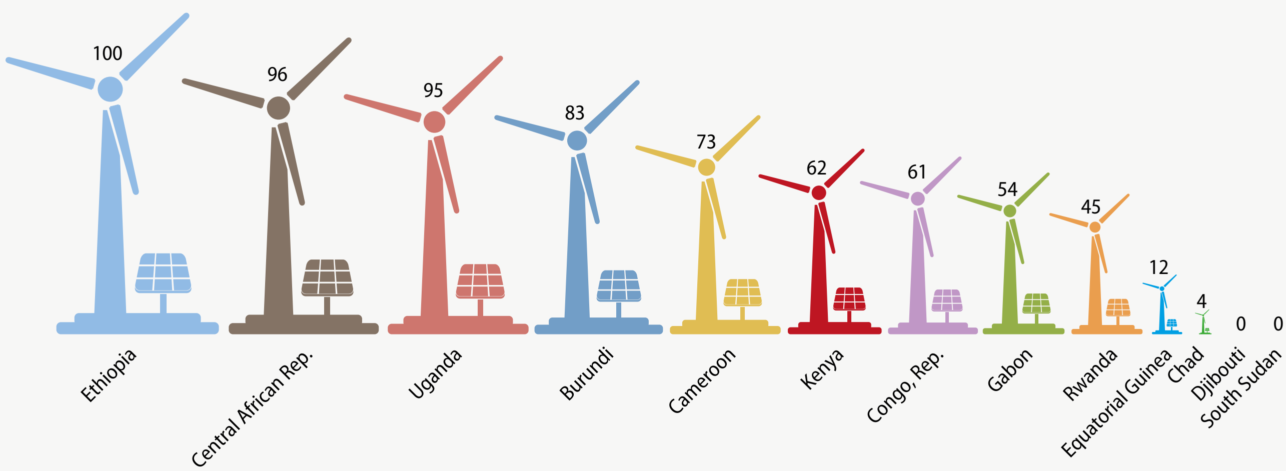
Electricity generated from renewable sources in Central and East Africa, 2018
In GWh



Share of each source of energy in renewable electricity generation in Central and East Africa, 2018 (%)



Share of renewables in total electricity generation in Central and East Africa, 2018 (%)



Note: Biomass, biofuels and waste includes traditional uses of biomass, such as wood and charcoal burning.

Source: International Renewable Energy Agency

CENTRAL AFRICAN REPUBLIC

Emergence from a conflict

The country is emerging from a civil war that has displaced one-third of the population since 2012. This conflict has led to the collapse of the country's main productive sectors, namely agriculture, extractive industries and forestry. Mining sites have been monopolized by armed groups, while the growing scale of trafficking in mineral resources and corruption have financed warlords and fuelled instability, further weakening the state's ability to meet the urgent needs of the population.

The socio-political situation remains fragile but, with support from the international community, the country is gradually returning to stability with the appeasement of intercommunity hostilities.

A focus on peacebuilding and recovery

The government is focusing primarily on ensuring security, national reconciliation, redeployment of the state and economic revival.

The *National Peacebuilding and Recovery Plan 2017–2021* is tackling the consequential underinvestment in economic infrastructure, while striving to improve the business climate and create jobs. The government has three strategic objectives: to relaunch and develop in a sustainable manner the productive sectors, with emphasis on agriculture and livestock, extractive and forestry industries; rehabilitate and build transport, electricity and communication networks; and ensure greater support for businesses and financial services, vocational training and entrepreneurship.

The country has been participating in the Biosphere and Heritage of Lake Chad (Biopalt) project, which has been helping to improve livelihoods around the basin since 2017 (Box 19.4).

CHAD

Lack of infrastructure hampering development agenda

Overreliance on oil, which funds the bulk of the government budget, had plunged Chad into recession in 2016 and 2017 after the drop in global oil prices. By 2019, growth had recovered to 3% (Figure 19.1), driven largely by heightened cotton production (+142%) [AfDB, 2020c].

Economic diversification is being hindered by the underdeveloped state of infrastructure: Chad ranked 51st out of 54 countries on the Africa Infrastructure Development Index in 2018 (AfDB, 2020c). Just 6% of Chadians had access to Internet in 2017, for instance, although almost half had a mobile phone subscription (Table 19.2).

Economic diversification is also being hampered by regional insecurity caused by the Boko Haram insurgency, which has led to Chad taking in refugees from neighbouring countries (MEPD, 2019).

Although the population is growing rapidly at a rate of 3% per year (Table 19.1), Chad remains overreliant on foreign labour from Cameroon and other neighbouring countries, owing to skills shortages in most sectors (AfDB, 2020c).

A vision aligned with sustainable development

The government's *Vision 2030* (2017) is aligned with the Sustainable Development Goals and is being implemented through three successive National Development Programmes, the first covering the years 2017–2021.

The government acknowledges the need to create more synergies between SDGs for greater impact. Domestic resources cover 11% of the cost of implementing the programme and international partnerships a further 22%, leaving a two-thirds funding gap (MEPD, 2019).

Chad is participating in the Biosphere and Heritage of Lake Chad (Biopalt) project (Box 19.4).

Some 12% of the population had access to electricity in 2018 (Table 19.2). Chad adopted an *Energy Policy* in 2019 which stresses the country's potential for renewable energy. This roadmap includes legislative measures to liberalize the energy sector, in the hope that putting an end to the monopoly of the state electricity provider, the Société nationale d'électricité, will attract greater investment (MEPD, 2019).[20]

Scientific output has doubled since 2015

Chad devoted 0.30% of GDP to R&D in 2016 (Figure 19.3). It counted 156 researchers (in head counts) per million inhabitants, who were spread relatively evenly across the broad fields of science and engineering (Figure 19.5). Women accounted for just 3% of the research pool (Figure 19.3).

Of note is that annual output in terms of scientific publications recorded in international journals doubled between 2015 and 2019 (Figure 19.5). Half of these concerned health sciences. The prevalence of malaria and neglected tropical diseases is on the rise and the survival rate for tuberculosis (77%) remains unsatisfactory (MEPD, 2019).

Despite a *Strategic Plan to Combat Tuberculosis* (2018–2021), scientists produced just six articles on medicines for tuberculosis between 2012 and 2019, according to the UNESCO study of 56 research topics (Figure 19.6). On the other hand, the number of articles on malaria and tropical diseases has surged from 10 (2012–2015) to 30 (2016–2019).

Despite the risk of declining rainfall (MEPD, 2019), scientists are not publishing on related topics such as climate-ready crops, agro-ecology, sustainable withdrawal and supply of water, water harvesting or wastewater treatment and recycling. Output is up, however, on the sustainable use of terrestrial ecosystems, from 4 (2012–2015) to 13 (2016–2019) publications.

The government has acknowledged the challenge it faces in integrating climate change into national and sectoral policies and the lack of awareness of climate change among much of the population. In March 2019, the government published a manual on climate change to foster education for sustainable development. In 2018, it adopted a *National Policy for Environmental Protection* (MEPD, 2019).

REPUBLIC OF CONGO

A focus on remedying the skills shortage

The economy grew by 1.6% in 2018, after contracting in 2016 and 2017 (Figure 19.1). This recovery was driven by an increase in national oil production, coupled with higher global market prices.

Growth was insufficient to reduce poverty, which affects about four in ten Congolese, but revenue did increase by 13%. This, coupled with a 24% decrease in public expenditure, as prescribed by the CEMAC regional programme, saw the budget deficit shrink from 12.5% (2017) to 4.8% (2018) of GDP (AfDB, 2019).

In 2017, oil accounted for 55% of GDP, 85% of exports and 80% of budgetary resources. This overreliance on fluctuating global oil prices makes it urgent to diversify the economy. This will require improving both the business climate and economic governance, as well as training.

One aim of the *Education Sector Strategy 2015–2025* is to improve training in priority areas for the future diversified economy, such as mining, petroleum, finance, banking, agro-industry, construction, transportation and ICTs.

The sectoral research policy, defined in the National Development Programme 2018–2028, is articulated around three strategic capacity-building programmes. The first of these focuses on the construction, rehabilitation and equipping of research infrastructure within universities, as well as infrastructure supporting innovation, such as technopoles and incubators.

In line with this programme, the Ministry of Higher Education has developed a strategy for the creation of departmental poles to ensure a better territorial distribution of higher education and give more Congolese the opportunity to attend university. The ministry is funding the construction of accommodation for 64 000 students by 2024 and equipping universities with research equipment. Incentives are being put in place to direct student flows to scientific and professional streams.

The second capacity-building programme focuses on agriculture. It aims to improve seeds and planting material, soil fertility, pest control, farming techniques and food crop productivity.

The third programme focuses on institutional capacity-building. A strategy supported by sectoral policies will be drawn up for research and for the national information and communication system. It will include the restructuring of research centres, which will be given a special status.

The government has requested renewed technical support from UNESCO to finalize the *Science, Technology and Innovation Policy* over the period from 2021 to 2025, with the aim of making the research and innovation sectors a national priority. This is part of a process that began in 2004 (Urama *et al*., 2010) that has been interrupted in recent years by the drop in revenue from oil production.

A programme for the creation and operationalization of four national research institutes has been underway since 2016, namely, the National Institute for Agronomic Research, the National Institute for Forest Research, the National Institute for Research in Extractive Sciences and Natural Resources and the National Research Institute for Health Sciences.

In addition, two research organizations are being restructured to form the National Geographical Institute, from the National Research Institute in Social and Human Sciences and the National Research Institute in Engineering Sciences, Innovation and Technology.

DJIBOUTI

Aspirations of becoming a regional digital hub

Djibouti recorded strong economic growth in 2019 (Figure 19.1; Table 19.1). This trend has been driven by the services sector, which has benefited from the opening of the railway line linking the capital of Ethiopia to the port of Djibouti. Port facilities accounted for 77% of growth in 2018, followed by industry on 19% (AfDB, 2019; AfDB, 2020c).

The railway line is one of Djibouti's Belt and Road projects. Other projects include two new airports, a new port at Ghoubet, an oil terminal and a toll road.

Among the risk factors for economic growth is debt distress, with its adverse implications for the current account balance. Djibouti's debt-to-GDP ratio amounted to 102.9% in 2018, double the 50% target and surpassed in Africa only by that of Sudan (166.6%).

The government intends to position the country as a regional trade, logistics and digital hub (AfDB, 2020c). Djibouti joined the African Continental Free Trade Area in March 2018. The US$ 3.5-billion Djibouti International Free Trade Zone was officially launched four months later. This free trade zone is the largest of its kind on the continent and is jointly operated by Chinese partners and by the Djibouti Ports and Free Zones Authority.

The *National Strategy: Vision Djibouti 2035* (2014) focuses largely on technological innovation. The government is looking to cement Djibouti's place as a hub for information exchange. By 2017, 56% of the population had access to Internet (Table 19.2). Djibouti finds itself in the enviable position of being at the crossroads of broadband submarine cables linking Europe, Asia and Africa.

In 2018, a four-year Public Administration Modernization Project got under way. Supported by the World Bank, it foresees the rollout of digital systems to improve citizens' access to services and boost government revenue by making tax and customs administrations more efficient (ESI Africa, 2018).

During the Forum on China–Africa Cooperation in Beijing in 2018, the Chinese government pledged support for Djibouti's emerging digital economy through a strategic bilateral partnership.

Meanwhile, the education sector has benefited from UNESCO's ICT Competency Framework for Teachers programme. In 2016, UNESCO held a workshop in Djibouti to show online facilitators how to integrate this framework into teaching.

The University of Djibouti has used international and private-sector partnerships to expand its teaching and research portfolios. It has established new masters' programmes and a multidisciplinary graduate school (Group of 77, 2018). In 2019, the World Bank designated the university a centre of excellence within its ongoing programme (Table 19.4).

Plans to become 100% renewable

Djibouti intends to raise the share of renewable sources in its energy mix from 80% to 100% by 2020. The government is building a wind farm in Goubhet which should be able to produce 60 MW of electricity by 2022.

The state company Electricity of Djibouti has also been drilling in the Lake Assal area since mid-2018, with the intention of setting up the country's first geothermal plant. The project is funded by the government, the AfDB, World Bank, Global Environmental Facility and other partners.

In 2018, a project submitted by the Centre for Studies and Research of Djibouti (CERD) to study the recharge system of the Ali-Sabieh aquifer was selected for funding by the International Geosciences Programme run jointly by UNESCO and the International Union of Geological Sciences. The concentration of sulfates and nitrates in the aquifer surpasses the World Health Organization's limit for potability, causing methemoglobinemia, or the 'blue baby' phenomenon.

A regional observatory for climate change

In 2021, the Ministry of Higher Education and Research is planning to inaugurate the Regional Observatory on Global Change, which it has developed together with CERD. The International Atomic Energy Agency has provided sophisticated scientific equipment for the centre, which will be studying the impact of climate change on the vulnerable and fragile ecosystems of East Africa, as well as emergent diseases like chikungunya and Covid-19.

Scientific output evolved little between 2011 and 2019, in terms of volume (Figure 19.5). However, Djibouti's publication intensity in materials science and energy-related research has risen considerably, placing it in the top 15 in sub-Saharan Africa for these fields (see Figure 20.6).

Since 2011, the three top SDG-related research topics have concerned medicines for tuberculosis, tropical communicable diseases and geothermal energy. Output has also grown since 2016 on the sustainable use of terrestrial ecosystems and the status of biodiversity.

EQUATORIAL GUINEA

Empowering the private sector to diversify the economy

In 2017, Equatorial Guinea graduated out of the World Bank's least developed country category. GDP per capita is one of the highest in Africa but life expectancy is lower than the sub-Saharan average (Table 19.1). The inequitable distribution of wealth has led to widespread social inequality. Youth unemployment is high and roughly half the population lacks access to potable water.

Transparency in public resource management is limited by the absence of reliable statistics. This hampers both the monitoring of budget execution and any assessment of the effectiveness of public policies, notably their impact on the poor.

The country's main development challenge lies in diversifying its oil-rent economy. Empowering the private sector has been one of the goals of the *National Economic Development Plan: Horizon 2020 in Equatorial Guinea* (2007), along with developing infrastructure and human capital and improving governance. The plan has targeted strategic new sectors such as fisheries, agriculture, ecotourism, mineral exploitation and finance.

To make it easier to register a business in Equatorial Guinea, the government launched a 'single window' for investors and entrepreneurs, in January 2019.[21]

The government has introduced other incentives to attract investment, such as tax exemptions. In 2014, it launched a co-investment fund called Holding Equatorial Guinea. This led to the signing of a memorandum of understanding in 2018, for instance, with the Gnima Group in the USA and Choco-Revo in Japan to revive Equatorial Guinea's cocoa sector and, thereby, enhance the livelihood of smallholder farmers (Dhami, 2018).

Horizon 2020 has set out to make energy available to all. By 2018, 67% of the population had access to electricity (Table 19.2). In March 2016, the government embarked on a five-year project with the United Nations Development Programme (UNDP) to develop a renewable energy policy, with a focus on creating a domestic market. The project includes a series of demonstration projects in small-scale hydropower and solar energy, as well as related capacity-building.[22]

In 2019, Equatorial Guinea had the lowest volume of scientific publications in the region. The UNESCO study of 56 research topics found a strong focus on tropical communicable diseases, which accounted for 20 publications in 2012–2015 and 30 in 2016–2019. No research papers were produced on the topic of help for smallholder food producers or renewable energy.

ERITREA

A focus on sustainable energy and education

Eritrea has been making some progress towards its development goals. By 2017, one in five citizens had a mobile cellular subscription, although just 1.3% had access to Internet. Nearly half of the population now has access to electricity (Table 19.2).

The government sees regional integration as a means of promoting its economic development agenda. To this end, the government plans to turn Massawa and Assab into vibrant ports to reduce transaction costs and boost trade and regional integration.

The July 2018 bilateral peace agreement with Ethiopia offers new prospects for international partnerships. The Eritrea–European Union Cooperation under the 11^{th} European Development Fund (2016) is prioritizing the creation of sustainable jobs and regional integration,[23] with emphasis on infrastructure and the usage of sustainable and affordable energy. The priority subsectors are geothermal energy, solar photovoltaic and wind power.

The energy sector is considered central to advancing Eritrea's sustainable development agenda, as lack of energy is penalizing all sectors, including health and agriculture. This priority is outlined in the *National Indicative Development Plan 2014–2018*.

The fourth *Strategic Partnership Cooperation Framework 2017–2021* elaborated by United Nations agencies based in Eritrea is also supporting Eritrea's sustainable development agenda, with a focus on basic social services (health, basic education, etc.), environmental resilience and disaster risk reduction, capacity-building and inclusive growth (food security, etc.).

Education is a government priority. Upon joining the Global Partnership for Education in 2013, Eritrea received a grant to support the formulation of a plan to 2017 for the education sector. Thanks to this support, the number of children from nomadic and disadvantaged communities attending school has surged; between 2013 and 2017, the proportion of children completing primary school increased from 40% to 45%. For girls, enrolment levels rose from 37% to 43%.

The number of students enrolling in the Eritrea Institute of Technology (est. 2008) in Mai Nefhi has also been gradually increasing. This institute, the main national source of higher education in science, engineering and education, is funded largely by the Ministry of Education.

ETHIOPIA

Industrialization a major economic driver

From 2005 to 2015, Ethiopia was among the fastest-growing economies in Africa, with GDP progressing by 10.7% each year, on average. This enabled the country to double its per-capita GDP and substantially reduce extreme poverty from 34% (2010) to 24% (2016) of the population (World Bank, 2020a). In 2019, the economy was still growing at 8.3%, driven by the agriculture sector (34% of GDP in 2019), which has been a key focus of public investment, along with infrastructure development.

Under the second *Growth and Transformation Plan* covering the 2016–2020 period, the government has been focusing on modernization and industrialization to realize its ambition of turning Ethiopia into a middle-income economy by 2025. Led by construction and textiles, the industrial sector grew by 12.6% in 2019 and the services sector by 11.0%, reflecting strong growth in information technology services and tourism (Figure 19.1).

In 2018, the government committed 60% of its 2018 budget to poverty-targeted sectors such as education, health, agriculture, water and roads. It has been striving to increase the proportion of paved roads from 13% to 16% between 2014 and 2019.

The trade deficit has widened, with the performance of the manufacturing sub-sector having fallen short of the targets fixed in the *Growth and Transformation Plan*. A flexible system of financing through microfinance institutions, coupled with tax incentives and the relaxation of certain regulations, has boosted the large informal sector (AfDB, 2019).

A toxic combination of drought, flooding, locusts and the Covid-19 crisis culminated in a humanitarian crisis in 2020. The National Disaster Risk Management Commission estimated, in October 2020, that more than 15 million Ethiopians were in need of humanitarian assistance, according to the Ethiopian News Agency (2020).

Industrial parks attracting foreign investment

In an effort to position itself at the epicentre of light manufacturing industries in Africa, the first *Growth and Transformation Plan* envisioned the establishment of five industrial parks. So far, four have been completed: Bole Lemi in Addis Ababa and another three in the cities of Hawassa, Kombolcha and Mekelle.

Another two in Dire Dawa and Adama are under construction, out of the 14 foreseen under the second *Growth and Transformation Plan*. Three private industrial parks are also now in operation.

These industrial parks have proven a magnet for investment in export-oriented light manufacturing industries, particularly apparel and leather products. FDI flows to Ethiopia have grown by almost 50% per year, on average, and amounted to US$ 3.4 billion in 2018, making Ethiopia one of the top five recipients of FDI in Africa.

Training under way of railway engineers

The prospect of being able to transport merchandise to the coast via the Addis Ababa–Djibouti Railway has been another drawcard for foreign manufacturers. In 2011, the rehabilitation of a railway line originally built by the French over a century ago got under way. Funded largely through Chinese loans and built by Chinese engineers, the line was inaugurated in January 2018.

The Ethio-Djibouti Standard Gauge Railway Share Company was established in 2017 to operate the railway, with Ethiopia holding a 75% majority share.

The Ethiopian Railway Corporation has established the African Railway Academy in Bishoftu to train engineers to take over operation of the railway line once the China Railway Group Ltd and the China Civil Engineering Construction Corporation withdraw in 2023 (Kassa, 2017).

Roads still need to be built to ensure that passengers and freight can access train stations situated on the outskirts of town, as in the case of Dire Dawa, for instance.

Grand Renaissance Dam: ongoing negotiations with partners

Meanwhile, the construction of the Ethiopian Grand Renaissance Dam on the Nile River, with Chinese investment, offers the prospect of exporting hydropower to neighbouring countries and improving the productivity of the agriculture sector.

One of the largest hydropower projects in Africa, the Ethiopian Grand Renaissance Dam is also one of the most controversial, as it modifies the water distribution agreement adopted in 1959 by Ethiopia and the two downstream riparian states, Egypt and Sudan. The three countries agreed to co-operate in the *Principles of Declaration* (2015) but, as of late 2020, they were still negotiating the pace at which the dam should initially be filled, as well as a range of technical and legal issues.[24]

The '2222 plan' for tech-based start-ups

As the country pursues its industrialization strategy, it will need to build its technical and innovative capabilities to enhance productivity and add value to manufactured and agricultural goods. In 2018, the incoming government of Abiy Ahmed Ali introduced several reforms to accelerate the uptake of technologies and innovation-driven development. For instance, the Ministry of Science and Technology was renamed the Ministry of Innovation and Technology and the science portfolio was transferred to the Ministry of Education.

In late 2018, the Ministry of Science and Technology announced its *Start-up Strategy* centred around the '2222 plan', namely that of providing 2 000 new tech-based start-ups with seed funds for two years to help them generate 20 000 jobs and US$ 2 billion in revenue. This strategy foresees the creation of incubators (called incubation centres) for new tech-based firms. In 2020, the ministry began building an innovation hub on the outskirts of Addis Ababa to house incubation centres. It also plans to establish an incubation centre in each of the country's nine regional science and technology bureaux.

In 2019, the government invited the United Nations Conference on Trade and Development (UNCTAD, 2019) to review the *National Science, Technology and Innovation Policy* (2010) with a view to modernizing it and aligning it on the country's new development programme. The new programme lays emphasis on developing the textile and pharmaceutical sectors to promote exports and import substitution.

Mainstreaming the Kaizen method in higher education

During the first *Growth and Transformation Plan*, public resources were poured into higher education, resulting in a surge in enrolment at all levels. At postgraduate level, for instance, the number of students attending public and private institutions more than doubled from 14 272 (2009/2010) to 33 915 (2014/2015).

In line with the government objective, 30% of undergraduate students were enrolled in science programmes and a further 40% in engineering and technology programmes in 2014, according to the second *Growth and Transformation Plan*. However, the plan considered that the efforts to strengthen the quality of higher education had proved insufficient.

The government has since adopted the Kaizen method, an approach to management that originated in Japan. It posits that, just because something has always been done in a certain way does not mean that there is no room for improvement. The Kaizen method is inclusive, considering that no employee is too modest to contribute to what should be a perpetual process of small, frequent adjustments to work processes.

The Kaizen method is being applied to industry, with the aim of improving productivity among 20–30% of the companies trained. In total, by the end of the second *Growth and Transformation Plan*, 750 000 micro- and small businesses will have been familiarized with the Kaizen philosophy.

The Kaizen philosophy is being introduced into the education sector in two phases between 2016 and 2020, in order to improve the quality of teaching and, thereby, produce competent scientists, engineers and managers for research and industry. The target is for about 100 institutions offering technical and vocational training to increase their success rate for obtention of the Certificate of Competence from 40% to 100%.

About 40 universities are also participating in the Kaizen programme. To ensure its sustainability as a training system, 5–10 graduates from Addis Ababa University and as many PhD students from Mekelle University will follow doctoral training in the Kaizen philosophy.

GABON

Efforts to combat unsustainable development

The *Emerging Gabon Strategic Plan to 2025* (2014) is built on four pillars: sustainable development, better governance, human capital and infrastructure development. The plan is being implemented through a Co-ordination Office set up in 2016.

The AfDB is contributing around € 300 million to the plan to support infrastructure projects, boost the economy and improve the business climate. Since the launch of the *Economic Recovery Plan* in June 2017, the National Agency for the Promotion of Investment has introduced a 'single window' to make it easier for entrepreneurs to register their business. A new institutional framework has also been established to foster public–private partnerships and a national arbitration tribunal has been set up.

The AfDB contribution is also helping to combat desertification. Although most of the country is covered in forest, desertification is becoming a threat, owing to uncontrolled mining, intensive logging without reforestation and a boom in intensive agriculture and cocoa and oil palm plantations. The government has adopted legislation to regulate the extraction of hydrocarbons and minerals. It has also been encouraging the local processing of wood, palm oil and manganese. As a consequence, the manufacturing sector contributed 19% of GDP in 2019 (Figure 19.1), three times the share in 2012.

According to the UNESCO study of 56 research topics, the number of scientific publications on the sustainable use of terrestrial ecosystems and the status of biodiversity has grown steadily since 2012. Gabonese scientists also published their first seven articles in international journals on the topic of minimizing poaching and wildlife trafficking between 2016 and 2019 but they are not yet publishing on hydropower.

There has been a visible acceleration in infrastructure development, with more than 30% of GDP being invested in this area, including in hydropower projects.

About FCFA 1 250 billion is being invested over five years to reform the national education system, with five objectives:

- revision of curricula and training programmes, accompanied by a rigorous system for monitoring enrolment trends for a better control of flows;
- development of professional streams adapted to the job market and the establishment of strict controls to restrict enrolment in saturated streams;
- exploration of mechanisms to optimize technical and vocational training, in partnership with the private sector, to guarantee better employability;
- a review of legislative frameworks; and
- a quantitative and qualitative assessment of infrastructure, equipment and human resource needs.

In 2018, Gabon signed a joint programming document with UNESCO to support the production of basic statistics and the preparation of a sectoral plan for education.

KENYA

An emerging green, digital economy

Kenya Vision 2030 (2008), the country's blueprint for developing a knowledge economy, is being implemented through five-year plans. The third of these, covering the 2018–2022 period, is being driven by the president's Big Four Agenda, namely food security, affordable housing, manufacturing and affordable health care for all.

The *National Research Priorities 2018–2022* unveiled by the National Commission for Science, Technology and Innovation (NACOSTI) (est. 2013) align with the Big Four Agenda. These priorities are: food and nutrition security; manufacturing; universal health coverage; academic R&D and affordable housing.

The 2016 *Economic Survey* found that agriculture, forestry and fisheries contributed most (15.2%) to the economy, followed by transportation and storage (9.7%), construction (8.2%), education (7.5%), manufacturing (6.3%) and ICTs and telecommunications (6.1%). By 2019, the manufacturing sector was contributing 8% of GDP (Figure 19.1). The manufacturing sector has benefited from the ongoing development of industrial parks, which were recognized by the Special Economic Zones Act (2015) as being flagship projects.

A mix of renewable and non-renewable energy

The manufacturing sector has also benefited from a more reliable electricity supply. In order to boost access to electricity, Kenya has adopted both fossil and renewable sources of energy. One flagship project has been the development of geothermal energy, which now reaches more than one-third of Kenyan homes (Box 19.1). The construction of Kenya's first coal plant, meanwhile, has been derailed by local environmental and social activism (Box 19.6).

The *Energy Act* (2019) updates its predecessor dating from 2006. The 2019 act makes provision for investment in rural electrification and renewable sources of energy. The act is perceived as a great boost for STI, owing to the mix of both renewable-energy technologies, such as hydropower, wind, solar and geothermal, and non-renewable technologies such as nuclear energy and coal.

In 2019, the president inaugurated the Garissa Solar Power Plant, poised to become the largest in East Africa. The plant can produce enough electricity to light more than 600 000 homes. It is owned and operated by the Kenya Rural

Box 19.6: **Kenyan tribunal halts construction of coal-fired plant**

On 26 July 2019, a ruling by Kenya's National Environmental Tribunal halted construction of the Lamu coal-fired power plant, on the grounds that the environmental and social impact assessment license had been granted without following procedures for stakeholder participation or a rigorous evaluation of alternatives.

The decision followed three years of campaigning by local non-governmental organizations and stakeholder groups, including Save Lamu, a coalition of 30 community organizations.

In 2015, the AMU Power Company Ltd, a Sino-Kenyan consortium, had signed an agreement with the Industrial and Commercial Bank of China for the construction of the country's first coal-fired plant by Chinese enterprises, at an anticipated cost of US$ 2 billion. The plant was initially to use imported coal from South Africa and Zimbabwe before adapting its supply source to the newly discovered coal reserves in Kenya's Kitui county Mui Basin.

One argument put forward in support of the coal-fired plant was the need to anticipate the rising demand for energy in Kenya. However, growth in demand turned out to be slower than expected, leading the Energy Regulatory Commission of Kenya to instruct the AMU Power Company Ltd to halve Lamu's future capacity. This move would have pushed the average cost of a kilowatt hour produced at Lamu ten times higher than the cost at full capacity, raising retail prices for electricity in Kenya.

Environmental groups argued that reductions in the cost of renewable energy were making coal-fired power plants increasingly uncompetitive. According to a study by Lazard (2018), between 2009 and 2018, the annualized levelized cost of energy for solar photovoltaic and wind energy dropped by 88% and 69%, respectively. Conversely, these costs for coal and nuclear energy increased by 9% and 23%, respectively.

Kenya has managed to increase electricity generation by developing the highly productive Olkaria geothermal fields (Box 19.4).

Source: adapted from Wang (2019)

Electrification Authority. It was built by China Jiangxi using a loan from China's Exim Bank. Electricity generated by the plant is expected to be about 30% cheaper for households than diesel-generated power (CRO, 2016).

Absence of a national research agenda being felt

In 2020, NACOSTI[25] co-ordinated consultations with stakeholders on the draft *Science, Technology and Innovation Policy*. The draft observes that, despite some improvement, 'the government has not prioritised budgetary allocation for R&D, leading to the research agenda being influenced by development partners [...] private sector participation in funding of R&D is still very low'. Established by the Science, Technology and Innovation Act (2013), the National Research Fund was to receive 2% of Kenya's GDP each financial year but this is not yet the case (MoE, 2020).

Although the policy aligns with the African Union's seven priority areas, including that of 'protecting our space', Kenyan priority areas for reaching the SDGs remain very general.[26] Moreover, the document acknowledges 'a very strong relationship between the social, economic and political pillars' (MoE, 2020) but omits mention of the third pillar of sustainable development, namely, the environment.

The draft policy observes that the absence of a national research agenda has led to research priorities being set at the subsectoral level, leading to research being fragmented and poorly co-ordinated. This omission has also led to a silo mentality among the actors of the national innovation system that has restricted research that is multidisciplinary, interinstitutional, product-oriented and market-driven. Most of the entities in charge of policy-making operate in isolation from other agencies (MoE, 2020).

The policy observes that, in the public research sector, there is an emerging age-gap between senior and junior scientists, engineers and technologists and, in industry, a shortage of critical technical and research skills (MoE, 2020).

The policy suggests reforming the academic promotion system, which currently prioritizes teaching over research performance. Kenyan scientists, nevertheless, increased their output by 50% between 2015 and 2019 (Figure 19.5).

Just 5% of Kenyan publications concerned strategic technologies such as AI and robotics, materials science, energy and biotechnology between 2017 and 2019 (see Figures 20.6 and 20.7), despite the importance of agriculture for the economy, the size of health research (51% of publications) and the priority accorded to ICTs and energy.

The UNESCO study of 56 research topics found that scientific output on geothermal energy stagnated between 2012 and 2019 at fewer than 80 publications and remained low for wind-turbine technologies (37 publications) and photovoltaics (20).

Conversely, Kenyan output on help for smallholder food producers is 124 times the global average intensity; moreover, output on this topic has almost doubled from 175 (2012–2015) to 333 publications (2016–2019), as has Kenyan output on climate-ready crops: from 39 to 93 publications over the same period.

Lower costs, greater bandwidth spawning digital tech

Kenya's *National ICT Master Plan: towards a Digital Kenya* (2014–2018) was followed by the *National ICT Policy* (2019). The Kenya Information and Communication Technology Authority (est. 2013) is the government agency responsible for implementing these policies.

Osiakwan (2017) credits Kenya for the following milestones:

- an aggressive government programme to develop affordable broadband infrastructure;
- two critical inventions: mobile money through the M-Kopa company, which has since branched out into solar systems (Box 19.7), and a crowdsourcing platform;
- the development of a tech incubator and accelerator model for the continent; and
- political goodwill towards business, as evidenced by the president's dubbing of Kenya as a 'start-up nation'.

By 2019, the penetration rate for mobile phone connectivity was estimated at 104%. By 2017, one in four (23%) Kenyans had access to Internet (Table 19.2). According to the 2019 *Kenya Economic Survey*, two-thirds (66%) of Kenyans had mobile money subscriptions by 2018.[27]

In October 2018, the government launched the first Constituency Innovation Hub in Nairobi's Kamukunji Constituency. The hub is a pillar of the Ajira Digital Programme, which will ultimately give the public free WiFi access in 290 constituencies. Under the programme,

Box 19.7: **Factory turning out solar panels in Kenya**

In January 2018, pay-as-you-go firm M-Kopa announced sales of over 100 000 photovoltaic (PV) solar panels manufactured in Kenya by Solinc, a local firm.

Solinc set up the first solar PV module factory in Central and East Africa in 2011. By 2018, the company had about 30 Kenyan employees.

M-Kopa has been sourcing its 20-W and 15-W solar panels from the Solinc factory in Naivasha since 2016. These panels are used in M-Kopa's larger home systems, which include televisions, lighting, radio and phone-charging. M-Kopa has vowed to source all of its solar panels in Kenya, with plans to invest in 500 000 panels by 2020.

Mugo Kibati, Chairman of M-Kopa, considers Kenya to be a hub for solar innovation. 'The government has created an enabling environment for the solar sector', he says, 'and now we are seeing the impact and benefits flowing into the wider economy.'

Source: M-Kopa press release, 16 January 2018, see: https://tinyurl.com/mkopa-solar-solinc

Box 19.8: **Digital learning being mainstreamed in Kenyan schools**

Since its inception in 2016, the government's Digital Literacy Programme has set out to generalize the use of digital technology and other communication tools in primary and secondary education.

The first phase focused on improving digital infrastructure, developing digital content, training teachers and procuring digital devices.

The second phase commenced in July 2019 with a focus on 'using to learn'. The aim is to use technology to enhance pupils' creativity and capacity to innovate. During this phase, a Shared Digital Learning Resource Centre will be set up in schools.

The theme of the third phase is 'using to produce'. Here, the objective is to start making use of technology to create jobs and mentor learners to prepare them for university. During this phase, advanced laboratories will be set up within schools to enable pupils to design their own prototypes.

Source: compiled by authors; see: https://tinyurl.com/edu-kenya

every constituency will start with one innovation hub and eventually increase these to four. Each hub will introduce young people to online work and provide them with the necessary tools, training and mentorship to enable them to work and earn a decent income. The hubs will each be equipped with 40 tablets, for use by those who do not have their own devices. The National Government Constituency Development Fund Board will finance each hub (Mukara, 2018).

The lower cost of broadband and faster connectivity speeds have spawned a competitive public–private partnership involving the state-owned National Optic Fibre Backbone Infrastructure and privately owned terrestrial fibre network operators (Ndemo and Weiss, 2017). This has resulted in a growing number of new ventures applying high-tech solutions to real problems across a wide range of sectors, including digital finance (fintech), agriculture, energy (Boxes 19.1 and 19.7) and education (Box 19.8).

Digital loans surpass traditional loans

The revolution in digital finance, including the advent of mobile money, has been unprecedented. Kenya is one of the most mature digital credit markets in developing economies, where the volume of digital loans surpassed traditional loans in 2015 (MicroSave Consulting, 2019).

Market-enabling digital platforms are emerging in Kenya, as evidenced by the growing number of successful tech-based start-ups. With 70, Kenya has, by far, the most tech hubs in Central and East Africa (see Figure 20.2). These start-ups have made it easier for buyers and sellers to do business (Drouillard, 2017).

Kenya's first graduate school in information technology

Kenya's first graduate school in information technology, the Kenya Advanced Institute of Science and Technology, will be accommodated by Konza Technology City (Urama *et al.,* 2015), which is still under development.

The graduate school has been modelled on the Korean Advanced Institute of Science and Technology. The Korean government is expected to contribute KES 10 billion (*ca* US$ 90 million) towards establishing the graduate school, which is set to admit its first intake of masters and PhD students in 2021. They will be enrolled in three faculties: Mechanical, Electrical and ICT Engineering; Chemical, Civil and Agriculture Engineering and Biotechnology; and Basic Science.

RWANDA

A roadmap for sustainable development

In 2018, Rwanda began implementing its fourth medium-term strategy, the *National Strategy for Transformation* (2017–2024), which bridges the last stages of *Vision 2020* (2000) and the start of *Vision 2050*, Rwanda's roadmap for becoming a high-income knowledge economy. All five areas outlined in *Vison 2050* embrace ICTs and advanced technological innovation.

Vision 2050 accommodates global commitments such as the SDGs, the EAC's own *Vision 2050* and the African Union's *Agenda 2063*.

The government approved a roadmap for implementing the SDGs in December 2015. The National Institute of Statistics has since launched an online portal grouping the latest data available for relevant indicators.[28]

Rwanda is applying natural capital accounting to inform the planning process by considering the important contribution made by natural resources to the economy, in keeping with its endorsement of the *Gaborone Declaration* in 2012 (Rep. Rwanda, 2019; Urama *et al*., 2015).

The *National Risk Atlas of Rwanda* (2015) has assessed the five hazards to which Rwanda is most exposed, namely droughts, floods, landslides, earthquakes and windstorms, to inform disaster risk reduction strategies (Rep. Rwanda, 2019).

The National Climate and Environment Fund (FONERWA, est. 2012) was formally established by law in August 2017. It has financed projects that include zero-carbon, affordable housing, power generation using rice husks and the establishment of a modern e-waste recycling facility (see photo, p. 78), implemented in partnership with the Ministry of Trade and Industry (Rep. Rwanda, 2019).

When it comes to scientific publishing, it is health sciences that dominate output (58%). Just 7% of publications focus on environmental sciences. Of the 56 SDG-related research topics analysed by UNESCO, Rwandan scientists produced the greatest number of publications (92) on HIV research between 2012 and 2019.

Box 19.9: A subregional centre of excellence in theoretical physics

The East African Institute for Fundamental Research was established in 2018. Located on the University of Rwanda campus in the capital city, it is poised to become one of the most important institutes of physics in Africa. It is a short walk away from the university's departments of physics and mathematics, with which it enjoys close collaboration.

The East African Institute for Fundamental Research is a partner of UNESCO's Abdus Salam International Centre for Theoretical Physics (ICTP), based in Italy, on which it is closely modelled. It is the fruit of negotiations between the ICTP and the Rwandan Ministry of Education, which has always been extremely supportive of the centre.

Like the ICTP, the East African Institute for Fundamental Research provides advanced training and research in condensed matter physics, geophysics and high energy physics, cosmology and astroparticle physics. It offers MSc and PhD programmes, as well as postdoctoral fellowships. It also has a visiting scientists programme.

For the 2019/2020 academic year, 20 students were enrolled in an MSc degree, including three women. A further three were enrolled in a PhD programme. Most students receive scholarships from the ICTP, the Rwandan government or the Organization for Women in Science for the Developing World, a programme unit of UNESCO (see also Chapter 3).

In addition to research, the East African Institute for Fundamental Research has hosted activities on topics of relevance to artificial intelligence, such as short courses on machine learning and data science that have attracted 72 participants, including 14 women.

Source: Mary Ann Williams, ICTP

An ambitious digital agenda

The government is pursuing an ambitious digital strategy to transform the country into a knowledge economy. One priority is to develop e-governance through the Irembo platform, in order to improve public service delivery and bolster citizen participation in governance. These are the two main objectives of the *Smart Rwanda 2020 Master Plan* (2015).

In 2018, Rwanda began implementing its fourth medium-term strategy, the *National Strategy for Transformation* (2017–2024), which primarily assures the transition from *Vision 2020* to *Vision 2050*, Rwanda's roadmap for becoming a high-income country. Under the *National Strategy for Transformation* the government has adopted a programme to develop ICT infrastructure. One objective of *Vision 2020* was to achieve 60% mobile subscriptions by 2020. By 2019, this target had been surpassed (77%) but less than one in four Rwandans had access to Internet (Table 19.2), half the 50% target (Uwizeyimana, 2019).

According to Rwanda's *Voluntary National Review* (Rep. Rwanda, 2019), the government is committed to ensuring quality education. To this end, the *Education Sector Strategic Plan* (2018–2024) centres on, *inter alia*, using ICTs in education and introducing a science culture into all levels of education.

This plan aligns with the *ICT in Education Policy* (2016), which has focused on developing digital content that is consistent with the curriculum being introduced through 'smart' classrooms connected to the Internet. ICTs will be used to train teachers and other education leaders and to enhance research.

The centres of excellence established under the World Bank programme will be a key element of this strategy, given their focus on data science and the Internet of Things (Table 19.4). Another subregional centre of excellence in theoretical physics was established in 2018 at the University of Rwanda (Box 19.9). Rwanda has also hosted one of the African Institutes for Mathematical Sciences since 2016.

The government is also driving national digital skilling campaigns by championing digital ambassador programmes and platforms such as Smart Africa, which has organized the annual Transform Africa summit since 2013.

Kigali Innovation City developing fast

Kigali Innovation City is a key realization of *Vision 2020*. A milestone was reached in late 2018, when the pan-African investment firm for infrastructure Africa50 pledged to contribute equity of US$ 400 million to the project. The AfDB is also a stakeholder in Africa50 (Bizimingu, 2018).

Kigali Innovation City is under construction in Kigali's Special Economic Zone. The hub has been designed as a mixed-use development where people can both live and work. It will blend world-class universities, tech companies, commercial real estate and shops, hotels and apartments. Tech companies and their employees will be grouped in the Digital Innovation Precinct (Bizimingu, 2018). Carnegie Mellon University in the USA has already established its Africa campus on the site.

SOMALIA

ICT and natural resource sectors targeted for growth and inclusive economy

Since 2017, President Mohamed Abdullahi Farmajo has reviewed the country's foreign policy, including its regional integration. This led to Somalia securing Common Market for Eastern and Southern Africa (COMESA) membership in July 2018, a development that may have brought the country a step closer to its parallel goal of gaining membership of the EAC.

The government is endeavouring to develop the ICT sector. The draft National Information and Communication Technology Policy and Strategy covers the period to 2024.[29] It prioritizes network coverage and the development of domestic digital infrastructure, among other areas. The policy also takes cognizance of cross-cutting strategic technologies such as the Internet of Things, artificial intelligence, robotics, big data and blockchain.

In 2018, the National Communications Law established the National Communications Authority to regulate the ICT sector. In the budget for fiscal year 2018, the government allocated US$ 3.4 million – equivalent to 1.2% of the total government budget – to facilitating more equitable and efficient Internet access.[30] Half of Somalis now have a mobile phone subscription,[31] although Internet penetration remains low (Table 19.2).

In 2018, the government launched a campaign to persuade the business community, academia and policy-makers to tackle the challenges that women face in the ICT sector, in order to foster gender equality.

In late 2017, the Ministry of Youth and Sports unveiled the *National Youth Policy* (2017–2021),[32] which prioritizes expanding access to technical and vocational education and training, as well as self-employment. Unfortunately, this ambitious policy lacks a tangible monetary commitment to ensure its implementation. It sets out to:

- develop high-quality curriculum for the non-formal education sector, including through facilities such as the One Stop Youth Resource Centres;
- establish boarding schools and mobile schools to enhance access to basic education by youth in rural areas; and
- launch a youth loan fund to help the young start up their own businesses.

Regulating oil and gas exploration

The federal government has been devoting more attention to regulating oil and gas exploration. It has established a legal framework for this industry, with support from the World Bank and the AfDB that has resulted in the introduction of a downstream law and the completion of a petroleum registry for legacy right-holders (SNDP, 2017).

SOUTH SUDAN

Reviving the education sector

South Sudan is the latest country to have joined the East African Community, in April 2016. The country is endowed with crude oil and other natural resources. Although most of the population lives off subsistence agriculture, this sector only contributes 10% of GDP (Table 19.2).

South Sudan's economic prospects are closely tied to its oil and gas exports. However, the instability caused by the civil war, along with the high volatility of oil prices, has affected the market. Revenue from this industry should be used to invest in modernizing infrastructure as overall output is projected to drop to well below 100 000 barrels per day by 2030 (OIES, 2019).

In May 2017, the Ministry of General Education and Instruction unveiled the *General Education Strategic Plan* for 2017–2022.[33] It targets four national priorities: to increase equitable access to general education and improve the quality of education, to enhance management capacities at all levels of education and promote technical and vocational education and training to develop skills and foster self-employment.

On 26 March 2019, the European Union launched the Education in Emergency programme for South Sudan with implementing partners the United Nations Children's Fund and World Food Programme. The € 24.4 million project is providing 75 000 schoolchildren with hot daily meals, helping to train 1 600 teachers, equipping learners with books and stationery and providing 40 000 children in and out of school with psychosocial support services.[34]

Half of education spending going to universities

The budget allocation for the education sector experienced a nearly four-fold increase in the year from 2017 to 2018 (MoGEI and UNICEF, 2019). As of 2016, the government was spending 1.5% of GDP on education, a greater proportion than the average for East and Southern Africa (MoGEI and UNICEF, 2019). Half of this expenditure went to higher education (Table 19.2).

Strong demand for higher education has turned universities into primarily teaching centres. Scientists nevertheless increased their output from 10 to 27 articles between 2016 and 2019, 97% of which had foreign co-authors. Sudanese researchers count among the top five partners for scientific collaboration (Figure 19.5).

UGANDA

A decision to prioritize STI

The first concrete sign of the government's decision to prioritize STI was the creation of the Ministry of Science, Technology and Innovation in June 2016. This ministry is complemented by the National Council for Science and Technology (NCST) and Uganda Industrial Research Institute.

The decision to prioritize STI is encapsulated in both *Vision 2040* (2013)[35] and the *Second National Development Plan* (2016–2019). The latter recognizes the strategic role of scientific innovation in uplifting other economic sectors and enhancing technological development. It provides a roadmap for integrating STI into the national development process, boosting technology transfer and adaptation, enhancing endogenous R&D and improving the legal framework for STI (NPA, 2015).

In March 2017, the Minister of Science, Technology and Innovation delivered the first-ever Ministerial Policy Statement for the Science, Technology and Innovation Sector to parliament as a contribution to the debate on the budget (RoU, 2020). The statement outlines a number of achievements, including the revamping of the National Innovation Fund from 2017 onwards, the development of software products that can analyse soil fertility and offer patients alternative online service delivery, as well as a locally fabricated neonatal incubator for premature babies that was undergoing testing at the time.

In 2014, government expenditure on higher education represented only about 0.3% of GDP (Table 19.1). The NCST's

Millennium Science Initiative (2007–2013) had set out to help universities and research institutes become more productive and turn out better-qualified graduates in science and engineering. This project appears to have produced results, judging from the average citation rate for scientific publications over 2016–2018 and growth in research output (Figure 19.5). Firms are also using the results of public research more than previously.

Seven out of ten articles produced by Ugandan scientists concern health. Among the 56 research topics related to the SDGs analysed by UNESCO, more than 3 000 articles from Ugandan researchers concerned HIV research and almost 1 300 tropical communicable diseases between 2011 and 2019. Growth was notable for Type 2 diabetes (from 27 to 81 papers) and climate-ready crops (from 9 to 39). There were 259 publications on the sustainable use of terrestrial ecosystems between 2016 and 2019 but fewer than 10 on various sources of renewable energy, with the exception of biofuels and biomass (26 papers).

Addressing infrastructure bottlenecks

In line with *Vision 2040*, government spending is addressing infrastructure bottlenecks by building hydropower plants, a modern road network and railways. In parallel, Uganda is developing oil fields with an international consortium of companies. The crude oil extracted will be transported to international markets via a pipeline through Tanzania and to a planned domestic refinery.

The government's rural electrification programme has reportedly increased connection to the national grid by over 60% since 2009. Support for renewable energy is picking up, in line with the *Electricity Connections Policy 2018–2027*, although this is not yet reflected in the research record. As of 2019, hydropower accounted for 79% of electricity generation, thermal plants for a further 9%, co-generation for 8% and solar energy for 0.1% of the total (Rep. Uganda, 2020).

The government has been striving to improve water quality by reducing pollution, eliminating dumping and minimizing the release of hazardous chemicals and materials by continuous monitoring of industrial facilities that discharge wastewater (Rep. Uganda, 2020).

In 2020, the government was preparing a national irrigation master plan which will take into account the impact of climate change on agriculture and build on public–private partnerships. Just 0.5% of cultivated area in Uganda is currently irrigated, according to the government, compared to 3.6% in Tanzania, 2.0% in Kenya and 1.6% in Burundi (Rep. Uganda, 2020).

A national strategy for Industry 4.0

In 2018, the government set up a national taskforce on the Fourth Industrial Revolution to develop a strategy[36] for creating a smart society by 2040. The strategy recognizes the need to build capacity in this emerging field where the digital, physical and biological worlds converge.

Currently, Uganda does not figure among the top 15 countries in sub-Saharan Africa for scientific research in any of the following fields: AI and robotics; energy-related research; materials science; biotechnology; bioinformatics, or nanotechnology (see Figure 20.6).

Steady growth in the ICT sector

Digital Uganda Vision[37] is a national policy and strategic framework outlining how the government can leverage digital technologies across sectors as diverse as education, health, agriculture, social security, banking, justice and communications through investment to deliver *Vision 2040's* goal of building a smart society. The document has been developed by the Ministry of ICT and National Guidance.

Research ICT Africa has published a report that identifies opportunities and challenges for the implementation of the *Digital Uganda Vision* (Gillwald *et al*., 2019). The government has since launched a digital transformation programme in a bid to improve digital literacy, skills and knowledge. The expected results include greater Internet penetration (Table 19.2), less costly digital devices and services that will, in turn, create more direct jobs in the digital economy and foster e-government services. The government also plans to build more digital incubation hubs and specialized parks.

In 2017, the government launched the National ICT Initiatives Programme. It awards grants to selected digital start-ups in the form of seed capital, provides training and makes working space available to entrepreneurs at its innovation hub in Nakawa (Turyasingura and Gongo, 2019).

In 2020, the government was planning to introduce a local start-ups bill which would require all accounting officers to exhaust the local market prior to procuring digital solutions from abroad (Turyasingura and Gongo, 2019).

In October 2020, the government unveiled its *National 4IR Strategy*. It targets four areas: enhancing smallholder productivity; improving the delivery of health care and education; e-government and alleviation of pressures on urban areas; and an enabling environment for the digital economy.

Partnering to develop space tech

Since 2019, the government has ramped up plans to launch its first satellite in 2022 (Space in Africa, 2019). It is not yet clear what type of satellite will be prioritized but the government is pursuing collaboration with Egypt, Israel, Japan and the Russian Federation to realize this project.

The government plans to send three engineers to Japan to study space sciences, for instance. Skills development is a priority. Over 2017–2019, just 1% of Ugandan scientific publications concerned physics and astronomy (Figure 19.5).

On 22 February 2019, the Ugandan and Russian governments formed an Intergovernmental Commission on Economic, Scientific and Technological Cooperation, through the signing of a Memorandum of Understanding on Scientific, Technical and Innovation Cooperation in Moscow. Bilateral collaboration will target technologies for space exploration, mineral resources, ecology, agriculture, biotechnology and chemistry. The two partners will also explore the idea of establishing a national space technology research centre in Uganda with Russian support.

CONCLUSION

Technology to improve public services and the business climate

The desire to build strong, prosperous societies in Central and East Africa is being undermined by two widespread problems: a wave of insecurity in many countries and poor governance. These twin factors have exacerbated poverty and created an unfavourable climate for business that could compromise the region's goal of a diversified economy underpinned by modern infrastructure and industrialization. This goal is, itself, part of a bigger mosaic: the project for an African Continental Free Trade Area.

Several countries are taking advantage of more widespread telecommunications infrastructure to improve public services and transparency by introducing e-governance. In parallel, they are seeking to improve the business climate by making it easier for new businesses to register, reducing the cost of telecommunications and developing a more reliable electricity supply and faster bandwidth. The development of roads, railways, airports and ports should also make it easier for companies to do business in the region.

Meaningful growth will stem from technological innovation

Many economies in Central and East Africa have come to realize that meaningful economic growth can only be achieved through investment in technological innovation. There are now a total of 166 active technology hubs in 12 Central and East African countries. Four out of ten (42%) of these are located in Kenya alone. Governments must do more, however, to support this vibrant start-up ecosystem by making it easier and less costly for inventors to register their intellectual property in Africa.

Rwanda and Uganda, in particular, are embracing the Fourth Industrial Revolution in both policy and practice. New challenges such as Covid-19 and chronic ones like natural disasters may become opportunities for countries to tap into the potential benefits of technologies such as artificial intelligence, bioinformatics, the Internet of Things and data science.

This calls for a review, or the development, of science, technology and innovation policies, in order to provide much-needed direction for the innovation ecosystem. There is a need to develop the requisite skills and capabilities for the new digital economy, as Cameroon, in particular, has realized.

Centres of excellence: a key component of regional integration

Generally speaking, the higher education sector has not received much support in recent years, in terms of funding for training and research. This goes for both degree training and technical and vocational education. Djibouti, Gabon, Kenya, Rwanda and Uganda have all aligned this ambition with their national development plans. The next five years will be critical to ensure that these policies deliver on their promises.

One highly positive development has been the opening of centres of excellence in several East African countries in 2017, as part of a wider project supported by the World Bank.

Central Africa is conspicuous by its absence from this dynamic. It must not remain on the sidelines of this growing network of quality research and training, if regional integration is to extend beyond embracing the political and economic dimensions.

Will the price of rapid development be too high?

Ethiopia and Kenya have become models in the region for the development of industrial parks. These business incubators are gaining a foothold in all subregions but Central Africa. The economies of Central Africa remain overdependent on raw materials, especially oil, weakening their resilience to external shocks from fluctuating global commodity prices and delaying the necessary diversification of the economy to create jobs, reduce inequality and stimulate trade.

Ambitious infrastructure projects are under way to create transnational railway lines and modernize roads, ports and airports. Pipelines are being laid to transport oil to the coast and plans are afoot to develop oil refineries. Strenuous efforts are being made to overcome the chronic energy deficit by developing infrastructure such as small and large hydropower projects, solar and wind parks and geothermal plants.

There is a notable overreliance on FDI to fund some of these projects. This poses a risk that countries engaging in megaprojects in East Africa, in particular, may find themselves in a state of debt distress. Governments must exercise greater caution, in order to ensure their ability to bounce back to a sustainable level of debt in the long run.

This has become an even greater imperative with the Covid-19 epidemic in 2020. Governments must not find themselves faced with the terrible choice between whether to service their debt or provide their population with health care.

Indeed, the rush to industrialize must not blind governments to the imperative of sustainable development. Short-term gains can cause long-term pain. Gabon, for instance, a largely forested tropical country, has found itself confronted with the problem of desertification, following the adoption of intensive agriculture and the expansion of cocoa and oil palm plantations.

It is encouraging that many countries are developing renewable sources of energy but these projects often rely on foreign expertise. Scientific output on renewable energy is negligible in most countries. There is a need to revise academic curricula to ensure an endogenous capacity in fields that will be central to countries' sustainable development: energy, transportation, construction, agriculture, health, manufacturing, etc. The centres of excellence can play a key role in developing this endogenous capacity.

The Ethiopian Railway Corporation provides another interesting model. It has founded the African Railway Academy to train engineers to take over operation of the railway line built by Chinese partners once the latter withdraw in 2023.

KEY TARGETS FOR CENTRAL AND EAST AFRICA

- Ethiopia plans to establish a tech incubation centre within the country's nine regional science and technology bureaux;
- The national strategy *Vision Djibouti 2035* aspires to create a vibrant digital economy by 2035;
- Cameroon, as part of its *Vision 2035*, has set itself the objective of developing a local digital industry by encouraging research and innovation;
- The *Gabon Emergent 2025* strategic plan aims to establish a new development model that integrates human well-being, social equity, sustainable growth and environmental conservation;
- Uganda's *National 4IR Strategy* commits to creating a continental hub for Industry 4.0 and a smart, connected Ugandan society by 2040.

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ENDNOTES

1 See: https://tinyurl.com/mkopa-solar-makes-top-10
2 See: www.au-pida.org/view-programme/51/
3 The African Union Development Agency was formerly known as the New Partnership for Africa's Development.
4 See the African Union's press release: https://tinyurl.com/AU-energy-masterplan
5 Information here on the 2020 swarms of desert locusts in the Horn of Africa is taken from the FAO's Desert Locust Watch: www.fao.org/ag/locusts/en/archives/briefs/2515/2516/index.html
6 See: https://igad.int/2429-igad-calls-for-increased-regional-collaboration-to-fight-desert-locust
7 See Annex 1 for the list of member states for each of these regional economic communities.
8 The Southern African Development Community launched a P*harmaceutical Business Plan* in 2017, as part of the S*ADC Industrialization Strategy and Roadmap* (2015–2063). See chapter 20.
9 The East African Railway Master Plan is a proposal for rejuvenating existing railways serving countries in East Africa. The preparation of the Master Plan followed a Summit directive issued in 2004 following the near collapse of the railway system in the region.
10 These partners are the Development Bank of Central African States, United Nations Economic Commission for Africa, the General Secretariat of ECCAS and the CEMAC Commission.
11 For an evaluation of implementation of these flagship projects, see AU (2019).
12 For details of projects implemented through the Adaptation Fund, see: https://www.adaptation-fund.org/projects-programmes/
13 See: https://tinyurl.com/y6bcenbn
14 The Research and Technological Development Fund receives financial support from partner states through their national science bodies. These include Uganda's National Council for Science and Technology, Tanzania's Commission for Science and Technology, Rwanda's National Council for Science and Technology, Kenya's National Research Fund and the African Centre for Technology Studies. The fund has received additional support from the UK's Department for International Development, South Africa's National Research Foundation and Canada's International Development Research Centre. The level of funding support currently varies from year to year, based on the expressed need and availability of funds in partner states. The legal statutes under development will define the manner and level of financial contribution from each partner state. The fund management infrastructure, including as regards co-ordination and priority areas for support, have already been finalized and approved by the EASTECO Governing Board and EAC Sectoral Council of Ministers. Source: personal communication by Fortunate Muyambi, Acting Executive Secretary/ Principal Officer, Innovation, Technology Development and Acquisition, EASTECO, in May 2021.
15 In 2019, the New Partnership for Africa's Development was rebranded the African Union Development Agency.
16 These are Comoros, Djibouti, Eritrea, Kenya, Madagascar, Mauritius, Uganda, Rwanda, Seychelles, Somalia, South Sudan and Tanzania.
17 Trainees were introduced to python programming; the propaedeutics of deep learning; image and speech recognition programming; and human–machine dialogue programming.
18 See: www.ecopost.co.ke/
19 According to the National Institute of Statistics, in 2019, 86% of Cameroon's export earnings came from crude petroleum oils (41.8%); cocoa and its derivatives (15.4%); liquefied natural gas (11.0%); sawn timber (7.0%), raw cotton (5.4%), logs (3.6%); and raw aluminum (2.4%). See (in French): https://tinyurl.com/Cameroon-exports-2019
20 Cameroon's *National Strategic Plan for Information and Communication Technologies 2020* envisions supporting young women who are drawn to scientific and technical careers and developing women's skills in engineering.
21 Chad is participating in the Regional Programme for the Promotion of Domestic and Alternative Energy in the Sahel (PREDAS) [MPED, 2019].
22 This followed the adoption by the government of Decree No. 67/2017, published in September 2017.
23 This project is entitled Sustainable Energy for All: Promoting small-scale hydropower in Bioko and other clean energy solutions for remote islands. See: https://tinyurl.com/y42ky3y5
24 These priorities are outlined in the Eritrea–EU National Indicative Programme 2014–2020 (2015). See: https://tinyurl.com/EU-Eritrea-agreement
25 Ethiopia is a state party to the Agreement on the Nile Basin Cooperative Framework (2010) which established the Nile River Basin Commission.
26 The Kenyan National Commission for Science, Technology and Innovation falls under the Ministry of Education.
27 As of 2020, Kenya's draft revised Science, Technology and Innovation Policy states that 'the strategy is responding to the demand for STI to impact across critical sectors such as agriculture, energy, environment, health, infrastructure development, mining, security and water among others.' See: https://tinyurl.com/draft-STI-policy-Kenya-2020.
28 See: https://africaopendata.org/dataset/kenya-economic-survey-2019
29 See: https://sustainabledevelopment-rwanda.github.io/sdg-indicators/2-2-1/
30 See: http://mptt.gov.so/wp-content/uploads/2019/04/Draft-National-ICT-Policy-Strategy-Somalia-V0.6.pdf
31 See: www.mof.gov.so
32 According to the Cable UK 2020 study, Somalia is the seventh-cheapest country globally for the price of data: 1 GB of data costs, on average, just US$ 0.5, lower than Kenya (US$ 1.05), Djibouti (US$ 1.12) and Ethiopia (US$ 2.44). This is attributed to the strong competition among 11 different local companies providing telecommunications services in Somalia.
33 See: https://tinyurl.com/y6djdrxm
34 See: https://tinyurl.com/yyqm2j2s
35 See: https://tinyurl.com/emergency-education-south-suda
36 See: https://www.gou.go.ug/content/uganda-vision-2040
37 It is entitled *Uganda's National 4IR Strategy* (2020). See: https://ict.go.ug/2020/10/26/executive-summary-ugandas-national-4ir-strategy/
38 For details of Digital Uganda Vision, see: https://ict.go.ug/initiatives/digital-uganda-vision/

AT A GLANCE

The Khi Solar One plant in South Africa was the first on the continent to use solar thermal tower technology. Commissioned in February 2016, it can supply 45 000 households with clean energy. South Africa is one of three Southern African countries with an electrification rate above 90%, along with Mauritius and Seychelles. The Southern African Development Community opened a Centre for Renewable Energy and Energy Efficiency in Namibia in 2015, to broaden regional access to electricity. © Christy Strever

- Governments are making it easier to do business, in order to modernize their economies and ready themselves for the African Continental Free Trade Area. Some are striving to provide businesses with greater intellectual property protection.
- Despite widespread progress in digital infrastructure development, cost has limited the uptake of e-services by the public and local businesses, in the absence of sufficient market competition.
- To ensure universal access to energy and mitigate climate change, countries are expanding the grid and investing in renewables, as the region confronts more severe storms and longer periods of drought.
- All but Comoros now count at least one active tech hub. Some of these hubs are employing Industry 4.0 technologies, such as 3D printers and drones, but financial sustainability remains a challenge.
- Scientists are developing closer ties, including in agricultural research and through the Square Kilometre Array hosted by South Africa.

20 · Southern Africa

Angola, Botswana, Comoros, Democratic Republic of Congo, Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Tanzania, Zambia, Zimbabwe

Erika Kraemer-Mbula, Gussai Sheikheldin and Rungano Karimanzira

INTRODUCTION

An economy dominated by services

Since the previous *UNESCO Science Report* (Kraemer-Mbula and Scerri, 2015), the Southern African Development Community (SADC) has become the largest regional group within the African Union, with the addition of Comoros in August 2018.[1]

The population of Southern Africa has grown by 11% to 354 million since 2015 (see Table 19.1). Two-thirds are younger than 35 years.

Health and education remain top priorities (see Table 19.2). In six countries, these sectors benefited from a reduction in military expenditure as a share of overall public expenditure between 2015 and 2018. However, in four countries, expenditure on health actually decreased between 2015 and 2017 (Figure 20.1). In 2018, Angola, the Democratic Republic of Congo and Mauritius presented exceptionally high levels of out-of-pocket expenditure – borne directly by the patient – for health services.

The region contributes about one-quarter of the continent's GDP. Within Southern Africa, Angola, South Africa and Tanzania alone contribute about 73% of GDP. However, countries are still battling inequality and extreme poverty. This is especially true for Malawi, Madagascar and the Democratic Republic of Congo, where more than 70% of the population lives on less than US$ 1.90 per day. Unemployment, underpinned by weak economic growth, remains a major challenge, particularly for South Africa, Eswatini, Namibia, Botswana and Lesotho. The unemployment rate for youth is even higher than 33% in these countries.

The SADC economy is dominated by the services sector, which contributes half of GDP or more in 12 countries (Figure 20.1).[2] Mining and agriculture continue to make large contributions to many SADC economies. However, it is the manufacturing sector that has been identified as a key growth engine for the region, with the potential to drive industrialization and promote structural transformation, value addition and job creation. This sector grew by 4.3% in 2018 (AfDB, 2019a). In the Democratic Republic of Congo, the manufacturing sector now contributes one-fifth of GDP (Figure 20.1), up from 16% in 2013 (Kraemer-Mbula and Scerri, 2015).

Covid-19 exacerbating food insecurity

The region's economic powerhouse, South Africa, has recorded growth of just 0.79% of GDP, on average, since 2015, well below the SADC average of around 2% of GDP (Figure 20.1). In 2020, all SADC member states introduced social protection measures to cushion the impact of the Covid-19 epidemic.

SADC (2020) reported in July 2020 that at least 60 million jobs in Southern Africa had been affected by Covid-19. The report estimates that, over 2019–2020, there was an almost 10% increase in the number of food-insecure people, a likely impact of the pandemic. Malawi, Eswatini and Zimbabwe saw the largest increases.

In July 2020, SADC adopted harmonized guidelines with the Common Market for East and Southern Africa (COMESA) and the East African Community (EAC) for safely and efficiently moving goods and services during the Covid-19 pandemic. According to these guidelines, trade is to be facilitated by, among other things, providing frontline personnel with adequate personal protective equipment and testing all drivers before departure at accredited testing facilities.

The SADC Secretariat has hosted meetings with COMESA and EAC to share information. One such meeting in June 2020 focused on ensuring the safety of workers while opening up the economy.

African innovation contributing to pandemic response

In October 2020, the World Health Organization (WHO, 2020a) found that Africa accounted for 12.8% of 1 000 new or modified existing technologies developed worldwide to support the Covid-19 response. Most African inventions involved digital technologies (57.8%). About 25% made use of three-dimensional (3D) printing and 11% of robotics.

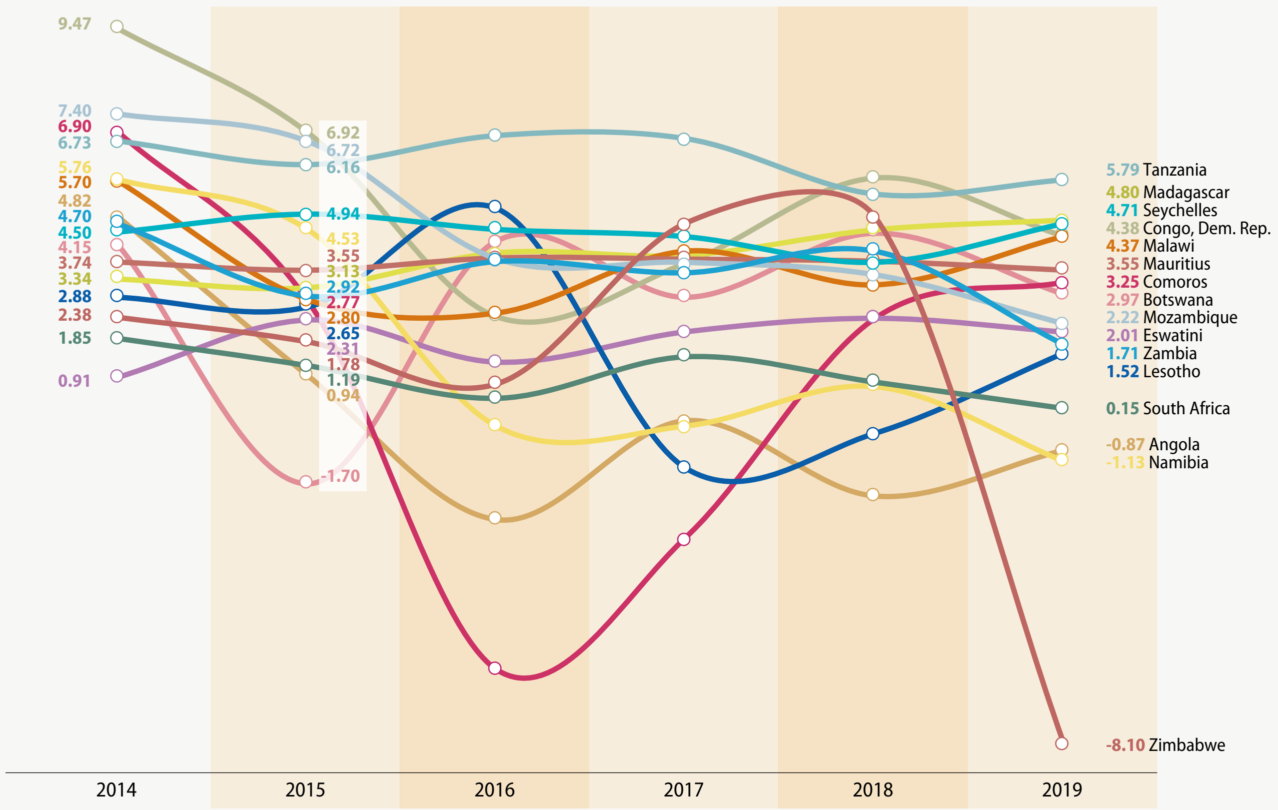
South Africa accounted for the highest domestic share of African inventions. For instance, in April 2020, the South African start-up CapeBio developed a Covid-19 test kit based on a real-time polymerase chain reaction which provides results in 65 minutes.

In April 2020, the South African government tasked the South African Radio Astronomy Observatory (SARAO) with managing the national effort to design, produce and procure 20 000 lung ventilators through the National Ventilator Programme. The observatory was chosen for its experience of designing sophisticated systems for the MeerKAT radio telescope in the Northern Cape (Box 20.1). By December 2020, 18 000 units had been produced and 7 000 distributed. The ventilators were paid for out of the Solidarity Fund, which contributed about ZAR 250 million (*ca* US$ 16.7 million) towards the initiative.

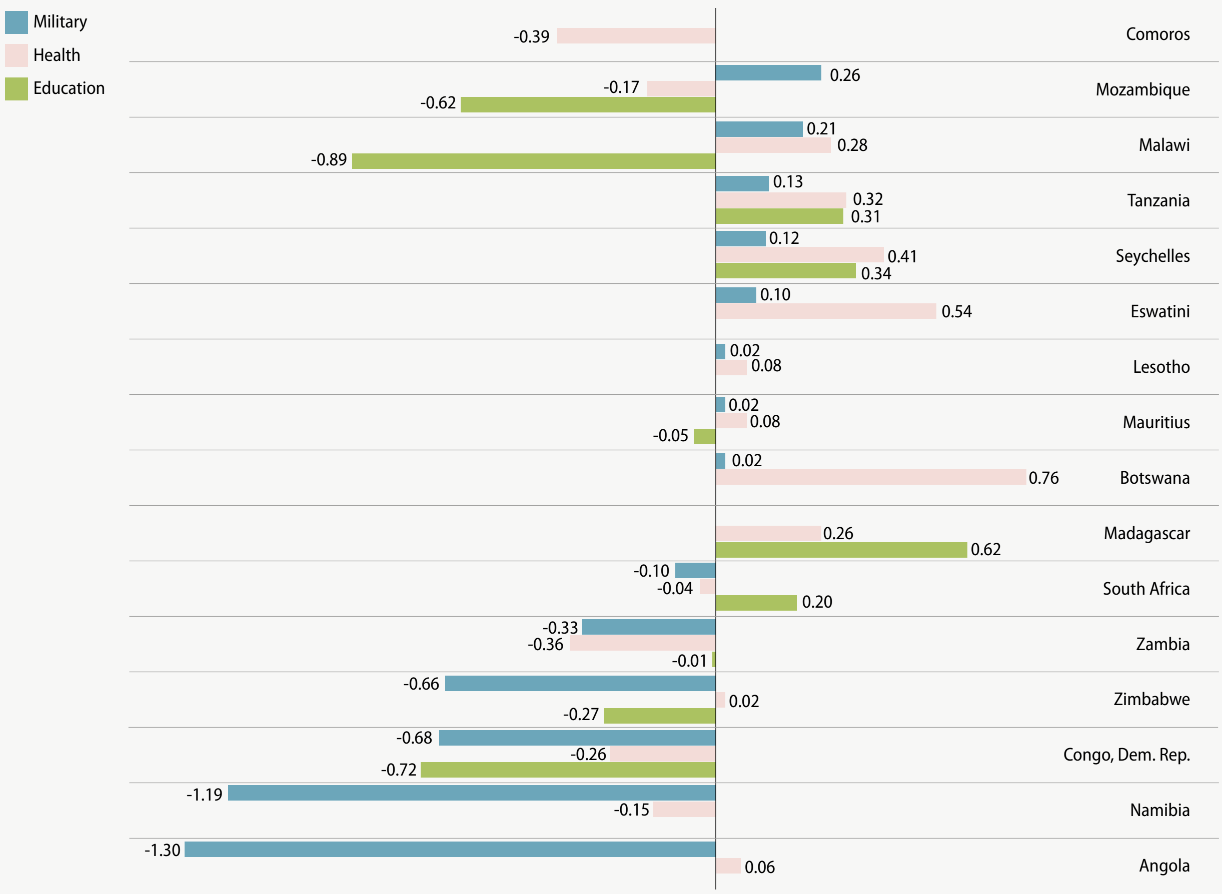
The *Africa Innovates* report highlights several success stories (UNDP, 2020). For instance, in Zimbabwe, the Sis Joy chatbot, powered by artificial intelligence (AI), offers health advice to those with limited access to health care. A Covid-19 module has been integrated into Sis Joy to advise on when to see a doctor or self-quarantine. Users can also make appointments through volunteer doctors and nurses.

Figure 20.1: **Socio-economic trends in Southern Africa**

Rate of economic growth in Southern Africa, 2014–2019 (%)

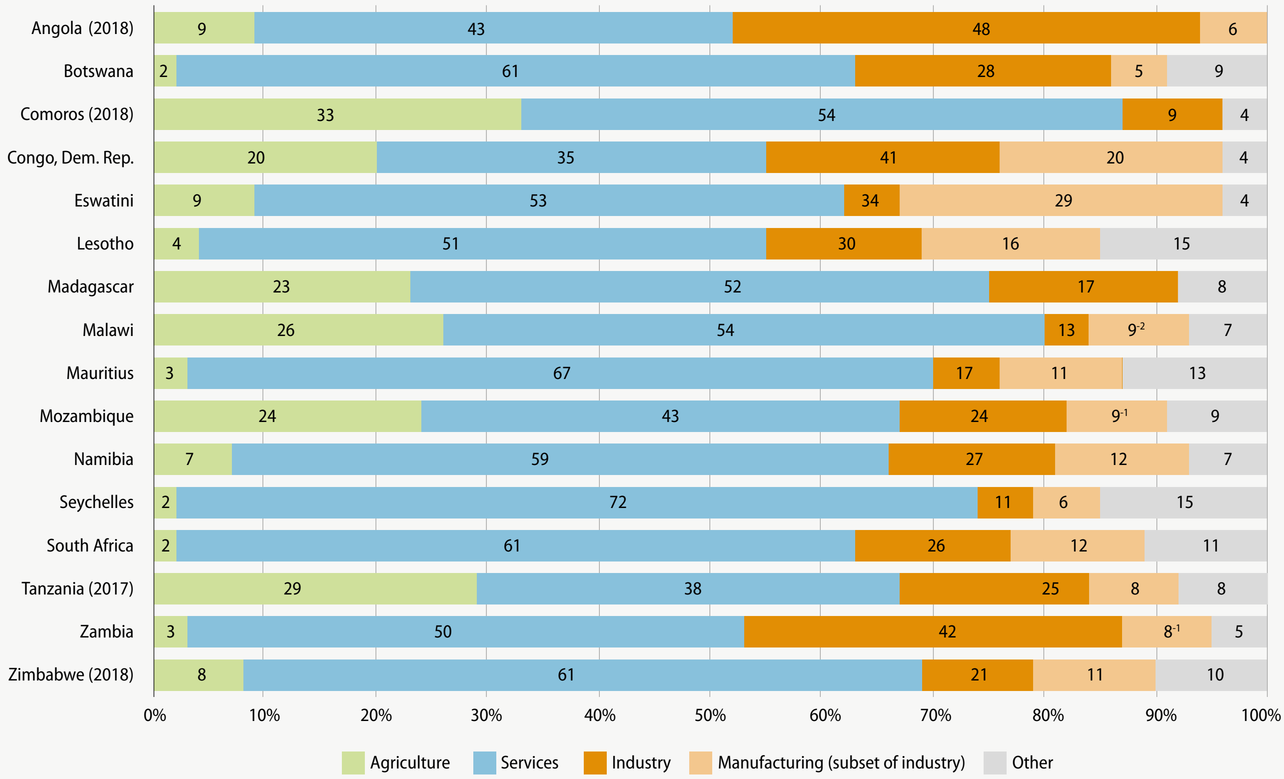


Change in government expenditure on education, health and the military as a share of GDP, 2015–2018 (%)

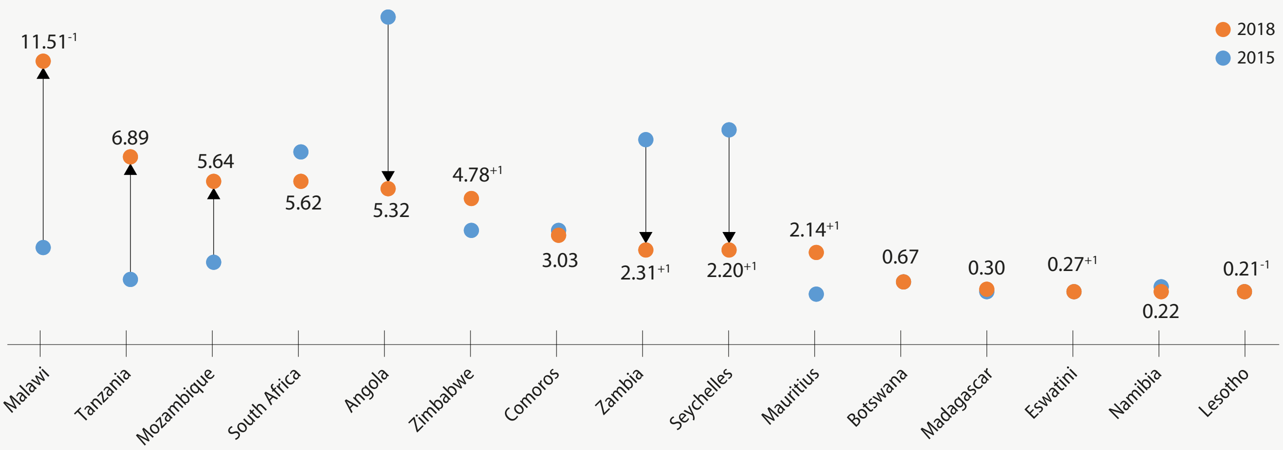


Note: Data are unavailable for the change in education expenditure for Angola, Botswana, Comoros, Eswatini, Lesotho and Namibia. The health data cover the 2015–2017 period.

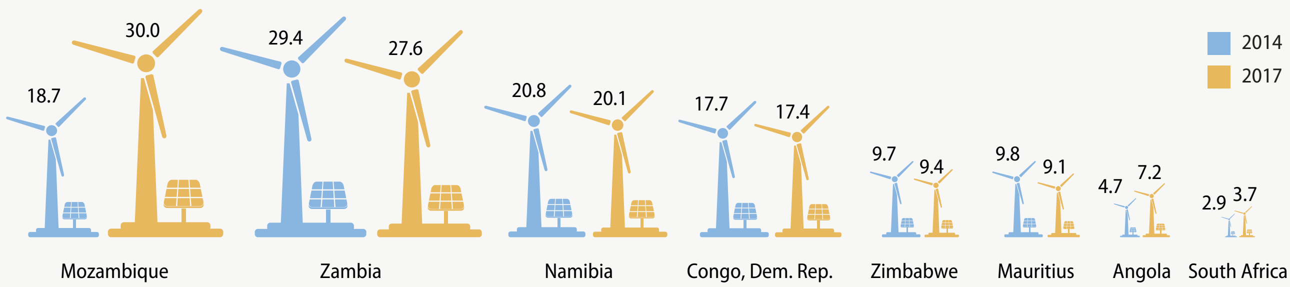
GDP per economic sector in Southern Africa, 2019 or closest year (%)



High-tech exports from Southern Africa as a share of manufactured exports, 2015 and 2018 (%)
Data labels are for 2018



Share of modern renewables in Southern Africa's final energy consumption, 2014 and 2017 (%)



-n/+n: data refer to *n* years before or after reference year

Note: Modern renewables exclude traditional uses of bio-energy, such as wood burning. Botswana is excluded, as the value for this indicator is close to nil. Data are unavailable for some countries.

Source: World Bank's World Development Indicators, November 2020; for energy: International Energy Agency

Trade liberalization at core of regional integration

March 2018 saw the passing of a milestone, with the launch of the African Continental Free Trade Area. It entered its operational phase in July 2019, by which time 54 countries had signed the agreement and 29 had ratified it.

Once fully operational, it will be the world's largest free trade area. By committing countries to removing tariffs on 90% of goods, liberalizing tariffs on services and addressing other non-tariff barriers, the free trade area should considerably boost the value of intra-Africa trade and investment.

Trade liberalization is a core element of the SADC regional economic integration strategy. In 2018, SADC exports of goods to countries beyond the region (US$ 154 billion) stood at about the same level as imports (US$ 149 billion). Intra-African trade accounts for 14.4% of total African trade, with a decline observed in low-income countries from 22.6% in 2015 to 20.4% in 2018 (AfDB, 2019a).

The SADC Trade-related Facility, an innovative programme financed to the tune of € 32 million by the SADC Secretariat and European Union (EU) since 2014, has provided 12 participating countries with financial and technical support to underpin regional integration, enhance trade with the EU and strengthen these countries' competitiveness in global trade.[3] Projects under this programme were due to be completed in September 2019 but some deadlines have been extended.

SUSTAINABLE DEVELOPMENT AGENDA

Industrialization a regional focus

One impediment to regional economic integration has been the dispersed order in which countries are progressing towards this common goal. The SADC's original *Regional Indicative Strategic Development Plan* (2003) envisaged establishing

Box 20.1: **The radio telescope at the heart of the Fourth Industrial Revolution**

South Africa signed the convention establishing the Square Kilometre Array (SKA) observatory in March 2019, concluding four years of negotiations. The treaty establishes the SKA Observatory as the second intergovernmental organization dedicated to astronomy after the European Southern Observatory; it will come into force once it has been ratified by the legislatures of at least five signatory countries, which must include the three SKA hosts, South Africa, Australia and the UK. As of September 2020, only the UK's signature is pending.

The core stations of the SKA are already under construction, however, in South Africa. Remote outer stations are spread across eight African countries: Botswana, Ghana (see Box 18.3), Kenya, Namibia, Madagascar, Mozambique, Mauritius and Zambia.

Meanwhile, the MeerKAT will retain the title of the world's most powerful radio telescope until the SKA is completed. The MeerKAT's first 64 dishes were inaugurated in July 2018. An additional 133 dishes are being added to the MeerKAT from 2020 onwards. Scientific papers using data from the MeerKAT have already been published and cited in well-known publications.

Although the South African Radio Astronomy Observatory is responsible for building the MeerKAT, the radio telescope is managed by the National Research Foundation, itself co-ordinated by the Department of Science and Innovation.

An investment boom for the African space industry

About 75% of the components used in the construction of the MeerKAT have been sourced locally. Several inventions are being commercialized and more than ZAR 110 million (*ca* US$ 6.5 million) has been awarded to 16 domestic small and medium-sized enterprises through a financial assistance programme.

The Centre for High Performance Computing has been extensively upgraded to meet the data demands of the MeerKAT and its staff have been trained in data science, in partnership with universities.

Some 7 284 employment opportunities have been created by the construction of the MeerKat and the KAT-7, a radio telescope in the Northern Cape commissioned in 2012, counting related projects.

About 300 people are employed full-time on the SKA at three sites: Cape Town, Johannesburg and Carnarvon. Employees have helped schools in Carnarvon to enhance their teaching of maths and science; 14 pupils have also been awarded university bursaries and another 72 have been granted scholarships to study at further education and training colleges from 2020 onwards.

In addition, a training centre has been built to give youth the artisanal skills that will be in heavy demand for the SKA and other industries in the Northern Cape.

At the national level, more than 1 160 SKA bursaries have been granted, as of 2020, at undergraduate, PhD and postdoctoral levels; the target is to double this number by 2030. This should include awarding 133 bursaries to recipients from other SKA partner countries in Africa.

The number of South African astronomers with a PhD has already tripled from 60 in 2015 to over 200.

The long game

The African Very Long Baseline Interferometry Network project aims to build a network of radio telescopes on the African continent (see Box 18.3). The SKA is assisting with this project by providing training and institutional support.

The Centre for High Performance Computing is also rolling out a Big Data Africa Programme to build capabilities at universities in partner countries.

The SKA project has attracted foreign direct investment of over ZAR 500 million (*ca* US$ 30 million) by hosting guest telescopes and instruments. It has also attracted leading astronomers from around the globe, who have relocated to South Africa and are assisting in skills transfer and technology exchange.

Source: compiled by authors

a free trade area in Southern Africa by 2008, followed by a customs union by 2010, a common market by 2015, a monetary union by 2016 and a common regional currency by 2018. The free trade area went ahead as planned but, as of December 2020, not all SADC member states are participating in this arrangement. Neither the customs union, nor the common market, nor the monetary union has yet been established.

The SADC's revised *Regional Indicative Strategic Development Plan* (2015–2020) focuses on industrialization as a way to accelerate market integration and a more equitable distribution of opportunities among member states.

The *SADC Industrialization Strategy and Roadmap 2015–2063* (2015) complements this plan by prioritizing the development of three sectors with potential to integrate global value chains: agro-processing, mineral beneficiation and pharmaceuticals (Table 20.1).

The region is developing a Protocol on Industry which is expected to be ready by the end of 2020. It will provide the legal mandate for the SADC Secretariat to co-ordinate the implementation of regional industrial programmes and projects, including the *SADC Industrialisation Strategy and Roadmap* and its *Costed Action Plan* (2017).

The *Regional Qualifications Framework for Schooling, Technical and Vocational Education and Training and Higher Education* (SADCQF) was revised in 2016 to align it with the SADC *Industrialisation Strategy and Roadmap*. In parallel, a model implementation plan was developed for countries to follow.

Eight countries are currently piloting an alignment of their national frameworks with SADCQF.[4] This process will create an equivalence for qualifications obtained within SADC countries and should, thereby, boost mobility and regional integration.

In parallel, SADC adopted a Vision 2050 framework in August 2020. In 2018, the Council of Ministers had directed the SADC Secretariat to align this future-oriented strategy with the African Union's *Agenda 2063*: *the Africa we Want* (Box 20.2). This resulted in an updated *Regional Indicative Strategic Development Plan* for 2020–2030, adopted in August 2020.

A 2019 review highlighted the progress made in implementing the aforementioned strategies for greater market integration. It also identified a range of challenges, including the lack of tangible projects being implemented by member states to realize strategic objectives, inadequate infrastructure and low funding levels for regional development projects (Ngwawi, 2019).

A new regional fund for infrastructure

One of the main funding mechanisms in the region is the *European Development Fund*, currently focusing on trade facilitation, finance and investment. In 2019, the SADC Secretariat signed three development co-operation programmes for a total of € 47 million over five years to foster inclusive, sustainable industrial development, greater intraregional trade and job creation.[5]

There have been internal discussions ever since the SADC Treaty was signed in 1992 about establishing a SADC Regional Development Fund to provide seed funding for the region's ambitious infrastructure plans. In 2017, the decision was taken to operationalize this long-anticipated fund.

The second phase of the Southern African Innovation Support Programme (SAIS II) was launched in 2017,[6] to enhance regional co-operation and help national innovation systems contribute to inclusive businesses and development. It is funded by Finland's Ministry for Foreign Affairs and hosted by Namibia's National Commission for Research, Science and Technology but also operates in Botswana, South Africa, Tanzania and Zambia. The programme is developing a training curriculum for innovation-supporting organizations, mentoring innovation accelerators and holding hackathons and start-up weekends.

Prepping for Industry 4.0

The technological advances brought about by the Fourth Industrial Revolution (also known as Industry 4.0) are set to transform global value chains. The SADC region needs to be more receptive to these opportunities, especially since it has placed industrial development at the heart of its regional integration agenda.

All technologies related to Industry 4.0 require reliable, secure and affordable digital connectivity, at a minimum. Mobile connectivity is widespread in Southern Africa; over 90% of the population is covered by at least a 3G mobile network in Lesotho, Mauritius, Seychelles and South Africa. However, only the three latter countries have a level of Internet penetration (see Table 19.2) above the world average of 51% (2018).

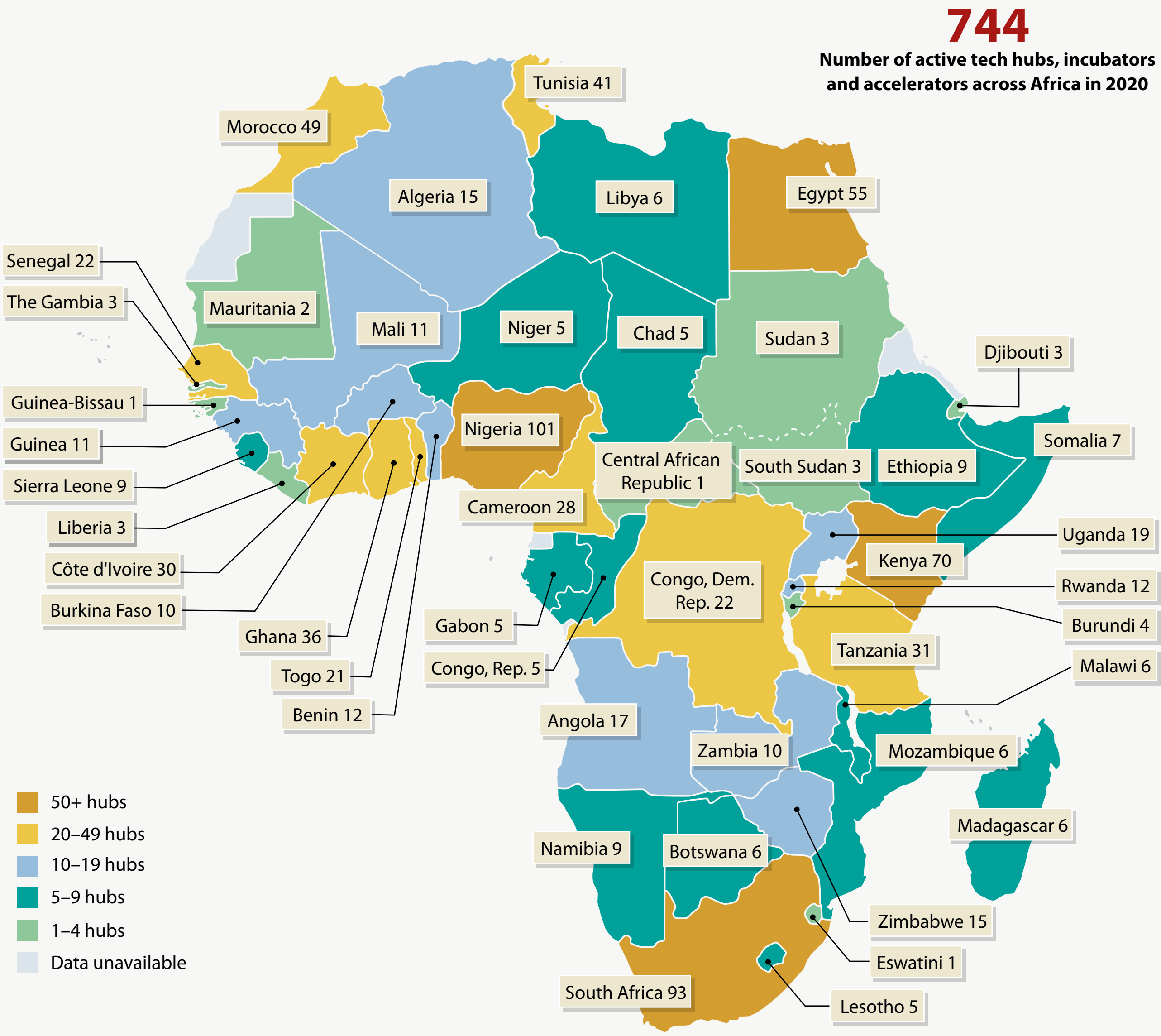
Chapter 20

Table 20.1: **Selected programmes adopted by the SADC Secretariat since 2015**

Title	Function
SADC Industrialization Strategy and Roadmap (2015)	promotes beneficiation and value addition to progress from a factor-driven development phase to an investment and efficiency-driven phase
SADC Research and Innovation Management Capacity Programme (2016)	aims to develop management capacities for research and innovation at research institutions
SADC Regional Climate Change Programme (2016)	provides a high-level framework for co-ordinated implementation in priority areas identified by member states
SADC Cyberinfrastructure Framework (2016)	fosters development of cyberinfrastructure to enable cutting-edge R&D within universities, research institutions and industry
SADC Water Programme for Building Resilience to Floods and Droughts (2017)	launched with UNESCO, has four thrusts: strengthening planning, policies and strategies; early warning, hazard mapping and disaster risk management; research, innovation and learning; and institutional and human capacity-building
SADC Charter on Women in Science, Engineering and Technology (WiSET) Organization (2017)	provides a legal and institutional framework for the establishment of SADC Women in Science, Engineering and Technology Organization
SADC Intellectual Property Framework (2018)	fosters mutual co-operation through policy and legislation, human and administrative infrastructure and respect for intellectual property rights

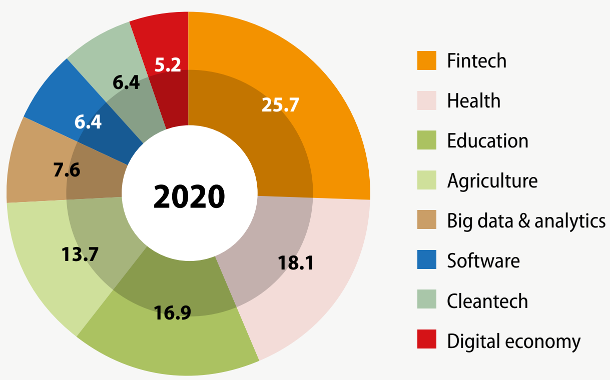
Source: Anneline Morgan, SADC Secretariat

Figure 20.2: **Active tech hubs in Africa, 2020**

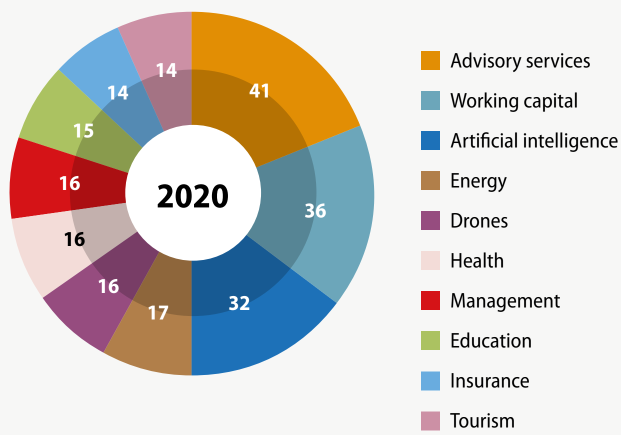


UN Disclaimer

African tech hubs by sectors of activity, 2020 (%)



Number of products developed by African tech hubs in top ten product categories, 2020



Note: The total number may differ from the sum of hubs in all countries because some hubs are active in multiple countries. An entity is considered active if it had a digital presence over the past two quarters. A tech hub is an organization with a physical address, offering facilities, financial or in-kind support to tech entrepreneurs. An incubator provides facilities and/or in-kind support at an early stage. An accelerator provides facilities, short-term funding and support.

Source: Briter Intelligence data, Briter Bridges, November 2020

In 2017, ministers responsible for information and communication technologies (ICTs) released the *SADC Declaration on the Fourth Industrial Revolution*. It highlighted the importance of creating an enabling environment for ICT development and for implementation of the SADC *Digital 2027* strategy. There were also discussions on whether to establish a regional think tank on the Fourth Industrial Revolution.

During a policy dialogue in July 2018 to establish SADC's position on Industry 4.0, ministers responsible for education, training, science and technology called for digitalization, technology and innovation to be prioritized. The same year, the ICT Subcommittee recommended drafting a SADC cybersecurity action plan, a SADC strategic position paper on big data and a SADC resolution.

Several countries are exploring e-governance to improve the delivery of public services. This is the case of Madagascar, for instance, where nearly all public services are carried out in person. A law passed in 2018 (#027) called for the establishment of a national civil registry and identification centre. The same year, the government created a Digital Governance Unit to implement Madagascar's *Digital Governance Strategy* (2019). Within this framework, a project is being implemented to establish an interoperable civil registry and introduce streamlined digital services for both citizens and businesses that adhere to the 'once-only' principle, within the Digital Governance and Identification Management System Project financed by the World Bank.[7]

In some countries, the development of infrastructure supporting the digital revolution has been held back by a lack of competition in the business sector, resulting in high costs and low uptake by businesses and consumers. This is the case in Lesotho and Mozambique, for instance.

Efforts to improve the business environment

Several countries are striving to improve the business environment. For instance, Namibia's Business and Intellectual Property Bill (2016) provides a framework for online business registration through the one-stop Integrated Customer Service Facility. This facility launched a portal called NamBizOne in 2017, to guide investors' administrative and legal requirements for starting a business.

The Seychellois government established the High-level Ease of Doing Business Committee in 2018. A number of reforms are being considered, such as that of creating a single window for business registration and making all relevant records and procedures digitally accessible, such as through online tax payments (Rep. Seychelles, 2020).

In 2016, Seychelles launched its Seed Capital Grant Scheme, which provides seed capital of up to SCR 50 000 (*ca* US$ 2 500) for early-stage start-ups.

To boost business confidence, the Democratic Republic of Congo adopted a law in July 2018 defining rules for public–private partnerships. In March 2020, Decree No 20/004 granted benefits to investors operating in the country's special economic zones, including an exemption from import duties and taxes on machinery, tools and equipment for ten years.

Most SADC countries have active tech hubs

Research carried out by Groupe Spécial Mobile (GSMA) shows that, between 2016 and 2020, the number of active technology hubs across Africa surged from 314 to 744. In Southern Africa, the majority are located in South Africa (93), Tanzania (31), the Democratic Republic of Congo (22), Angola (17) and Zimbabwe (15) but most countries count several hubs. Increasingly, incubators and accelerators are targeting tech and digital entrepreneurs (Figure 20.2).

About one-quarter of these hubs are classified as co-working spaces, or 'makerspaces', where the use of 3D printers, drones and other Industry 4.0 technologies is commonplace (AfDB, 2019a). Financial sustainability is a challenge for many of these hubs, which often rely on grants from development partners and international donors to survive (AfDB, 2019a).

A stronger legal regime for intellectual property

South Africa is the only country with a strong patenting record (Figure 20.3). It has not joined the African Regional Intellectual Property Organization, however (see Box 19.3), as membership was initially incompatible with certain requirements of the World Trade Organization's Agreement on Trade-Related Aspects of Intellectual Property Rights, to which South Africa was a signatory.

Patenting in Namibia and Tanzania has actually subsided since 2015 (Figure 20.3). Namibia has recently strengthened its legal and regulatory regime for intellectual property to boost innovation. Malawi, which registered no patents at the top five patent offices between 2015 and 2019, has done the same (see **Country profiles**).

It is important for laws to be followed by a decree of application, if they are to have any effect. As of September 2019, legislation passed in Eswatini in 2018 concerning patenting, copyright and the establishment of an intellectual property tribunal had not been followed by a decree of application (Motsa and Magagula, 2019).

In 2018, ministers adopted the *SADC Intellectual Property Framework* to foster mutual co-operation on reforming national intellectual property regimes.

A Centre for Renewable Energy and Energy Efficiency

With only Seychelles, Mauritius and South Africa having achieved an electrification rate above 90% (see Table 19.2), improving access to electricity is a common policy objective.

In 2015, the SADC Centre for Renewable Energy and Energy Efficiency opened in Namibia, an initiative led by SADC ministers with a portfolio for energy.[9]

The overall share of renewables in the region's power capacity increased from 23.5% in 2015 to approximately 38.7% in mid-2018 (REN21, 2018).

Off-grid solutions being explored

Countries are still underexploiting their potential for biomass, solar, wind and hydropower. Despite Namibia's 300 days of sunshine a year, 82% of the primary energy supply was still being imported as of 2017, according to the International Renewable Energy Agency (IRENA).[10]

Box 20.2: **A pan-African vision for science**

In 2014, the African Union adopted its *Science, Technology and Innovation Strategy for Africa to 2024* (STISA-2024), which calls on member states to 'accelerate Africa's transition to an innovation-led [and] knowledge-based economy'. This is one of the long-term goals of the African Union's *Agenda 2063: the Africa We Want*, adopted in 2013. However, there is currently no official implementation plan for *STISA-2024*, nor any official set of indicators.

In February 2020, the first continental report on the implementation of *Agenda 2063* was released, based on reports received from 31 member states. Assessed against the seven aspirations of *Agenda 2063*,[15] Southern Africa is one of the worst-performing regions, along with Central Africa, as it has achieved only 25% of the relevant targets. East Africa, by contrast, has achieved 39% of its own targets.

The report also highlights the notable progress made by the continent in implementing its African Union Flagship Projects (see Table 19.3). For instance, the Single African Air Transport Market was launched in January 2018 and formally established by the *Solemn Commitment*, signed by 29 member states accounting for almost 80% of intra-African air traffic. By 2020, 32 member states had signed the 2018 *Protocol to the Treaty Establishing the African Economic Community on the Free Movement of Persons, Right of Residence and Right of Establishment*, which falls under the African Union's Free Movement of People and the African Passport project (see Table 19.3).

Limited progress in education, health and cybersecurity

There has been limited progress in areas relating to education, health and cybersecurity. For instance, a flagship project focused on imparting quality education and medical tele-expertise to African Union member states, in collaboration with top Indian academic and medical institutions, was discontinued in 2017. By this point, it had seen 22 000 students graduate in various undergraduate and graduate disciplines, conducted 770 annual telemedicine consultations and held 6 700 medical education sessions for nurses and doctors.

In cybersecurity, only four of the required 15 member states have ratified the *Convention on Cybersecurity and Personal Data Protection* (2014, see also Chapter 18). Although data protection guidelines were developed and launched in 2018, many African countries are still in the early stages of developing domestic cyberstrategies.

Plans for an African Medicines Agency

The African Union has established several institutions which should help to realize the objectives of STISA-2024 (Table 20.2). Other continental strategies complement these institutions, such as the *Continental Education Strategy for Africa* (2016) to 2025, the *African Space Strategy* (2017) and the revised *African Health Strategy 2016–2030* (2016).

One focus of the *African Health Strategy* is to mobilize research and innovation to address Africa's health challenges. WHO's *Research for Health Strategy for the African Region 2016–2025* supplements this strategy (WHO-AFRO, 2015). The adoption of a treaty by ministers of health in May 2018 for the establishment of the African Medicines Agency represents a giant step towards harmonizing the continent's regulatory framework for drugs.

Support for evidence-based policy-making

The year 2016 saw the launch of the Science Granting Councils Initiative, a continental, multi-funder initiative to strengthen the capacities of science granting councils in sub-Saharan Africa. It focuses on strengthening councils' capacities to support evidence-based policy-making. A cross-cutting theme is to promote women's participation in science, technology and innovation (STI).

Through this initiative, the science granting councils engage in capacity building activities; designing and monitoring research programmes, utilizing robust STI indicators; supporting knowledge exchange with the private sector; and establishing partnerships between the councils and other actors (Chataway *et al.*, 2019).

Table 20.2: **Institutions established to support the *Science, Technology and Innovation Strategy for Africa to 2024***

Institutions linked directly to *STISA-2024*	
African Scientific, Research and Innovation Council (est. 2016)	has a mandate to implement *STISA-2024*
African Observatory of Science, Technology and Innovation (est. 2016)	a continental repository for statistics and a source of analysis for evidence-based policy-making; produces the *African Innovation Outlook*
Pan-African Intellectual Property Organization (est. 2016)	yet to be ratified by any country (at least 15 required, see Box 19.3)
Institutions linked indirectly to *STISA-2024*	
Pan-African Private Sector Trade and Investment Committee (est. 2015)	expected to be the precursor to an African Business Council, envisaged under the African Continental Free Trade Area architecture
Africa Virtual and E-learning University (est. 2015)	advancing slowly due to inadequate staffing and equipment for the delivery of online courses
Africa Centres for Disease Control and Prevention (est. 2015)	expected to play a key role in developing public health institutes (see Box 19.2)
Committee of Ten Heads of State and Government championing Education, Science and Technology (est. 2015)	directly supporting implementation of *STISA-2024* in each of Africa's geographical regions; first meeting held in Malawi in 2018
Pan-African Quality Assurance and Accreditation Framework (est. 2014)	developed in partnership with the Association of African Universities

Source: AU (2019); Table 20.2: Anneline Morgan, SADC Secretariat

Namibia's *Fifth National Development Plan* aims to expand electricity access to 67.5% of the population by 2023. The N$ 4.7 billion plan (*ca* US$ 340 million) announced by the public utilities company, NamPower, plans to add 220 MW to the electricity grid by 2023, through four plants powered by solar and wind energy, as well as biomass. Namibia's largest solar plant, the Mariental Photovoltaic Solar Park (45.5 MW), became operational in September 2019.

In the Democratic Republic of Congo, the African Development Bank (AfDB) has approved a US$ 20 million loan to implement the Green Mini-Grid Programme. This pilot project is installing three hybrid solar mini-grid systems in three towns between 2019 and 2023.[11]

Lesotho's *Scaling-Up Renewable Energy in Low Income Countries Investment Plan* (2017), prepared with support from the World Bank, the AfDB and other donors, calculates the total potential capacity for domestic renewable resources at 2 300 MW. Lesotho currently relies on imports to meet about half of its total electricity demand (160 MW) [LEWA, 2018].

Under Lesotho's *Electrification Master Plan 2018–2028* (2018), prepared with support from the EU, one-fifth of the public budget for electrification has been earmarked for off-grid electrification. Solar photovoltaic energy is considered to be most suited to the purpose. The remainder of the budget will go towards expanding the grid.

Climate-smart agriculture being explored

Several countries have experienced severe episodes of drought and flooding since 2015. In 2019, Cyclone Idai caused severe flooding in Madagascar, Malawi, Mozambique and Zimbabwe, for instance. In Mozambique, the government has been investing in climate-resilient infrastructure (Box 20.3).

In 2017, UNESCO and the SADC launched the SADC Water Programme for Building Resilience to Floods and Droughts (Table 20.1).

Climate-smart agricultural practices are being explored to mitigate the impact of extreme weather events. In Madagascar, where an estimated nine-tenths of the population works in agriculture, the Manitatra 2 project has been promoting organic warm compost, which offers higher yields and improves crops' resistance to drought and disease. Funded by the EU and implemented by the Groupement Semis Direct Madagascar over the period 2018–2021, the project estimates that it had reached 18 000 Malagasy farmers by August 2020 (GCCA+, 2020).

Zambia has developed a *Climate-Smart Agriculture Investment Plan*[12] (2019) to improve its chances of achieving its goals for crop production and food availability by 2050. The plan predicts that climate change could diminish the yields of key crops by 25% but, crucially, that climate-smart agriculture could increase crop yields by 23%.

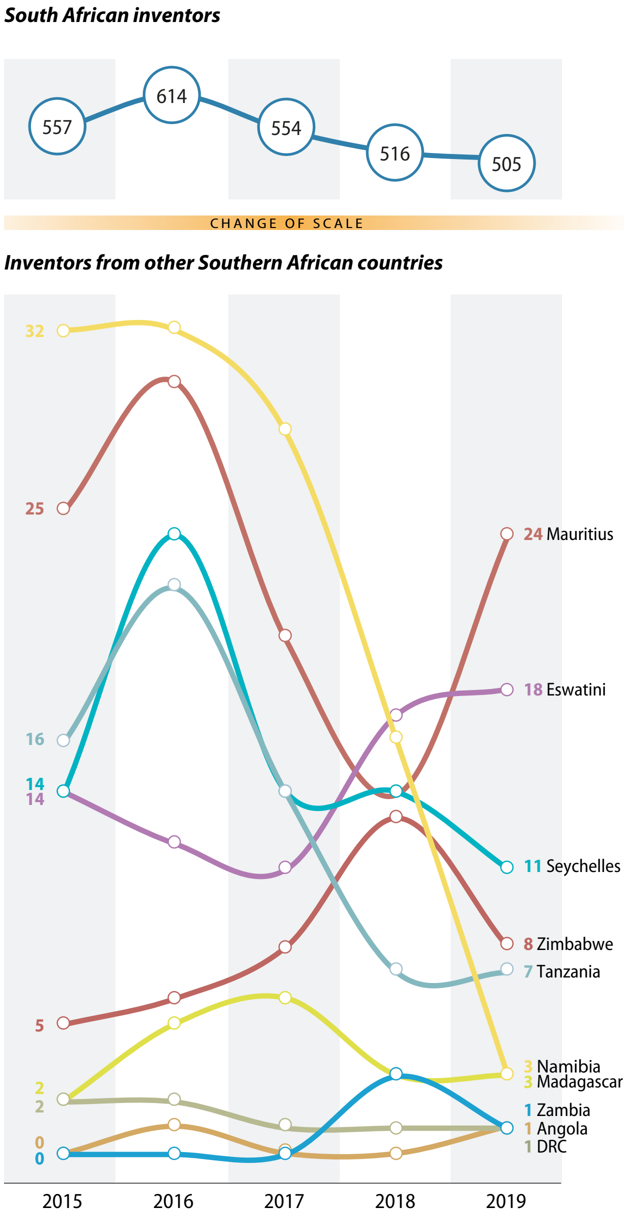
Climate-smart agricultural practices would have the added advantage of mitigating greenhouse gas emissions. Land-use, land-use changes and forestry account for about 93% of Zambia's emissions, most of which come from burning biomass (World Bank, 2019). More than eight-tenths of the population relies on wood-burning to cook (Nzobadila, 2017).

Agriculture is a focus of national planning, especially in countries where food security presents a serious challenge. For instance, the combination of drought and flooding in Malawi over the 2015/2016 agricultural season led to the declaration of a State of Disaster. Malawi's *National Agricultural Policy* (2016) and *National Irrigation Policy* (2016) together provide a strategic framework for improving productivity, economic diversification and value addition.

Several countries have increased their scientific output on climate-ready crops since 2016 (see Figure 19.6).

Some SADC countries are collaborating on agricultural research. In 2019, Malawi's National Commission for Science and Technology developed collaborative calls for agricultural

Figure 20.3: Number of IP5 patents granted to inventors from Southern Africa, 2015–2019



Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China. Botswana, Comoros, Lesotho, Malawi and Mozambique received no IP5 patents during the period under study.

Source: PATSTAT, data treatment by Science-Metrix research with Mozambique and Zimbabwe, to address common knowledge gaps. Collaborative ventures were conducted through the Science Granting Councils Initiative, which Malawi joined at its inception in 2016.[13]

More countries monitoring STI

SADC countries are strengthening their capacity to measure their national innovation systems. In the third *African Innovation Outlook* (2019), ten out of 16 countries reported data from national surveys, five of which were new additions to this report.[14] Southern Africa is presently the best-covered region in Africa for data on science, technology and innovation (STI, see chapters 18 and 19).

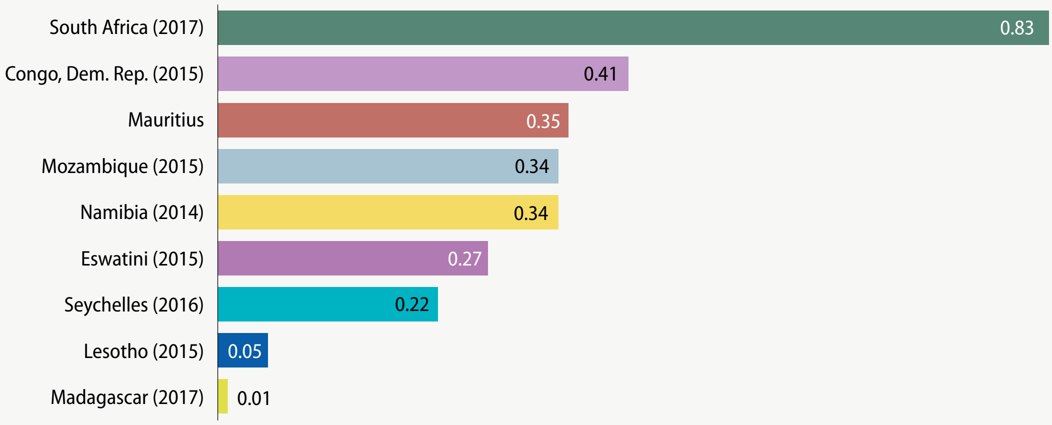
Improvements in this area could be a sign of the impact of the *Science, Technology and Innovation Strategy for Africa 2024* (*STISA-2024*), approved in 2014 (Box 20.2). This pan-African strategy stressed the need to monitor and evaluate the implementation of policies. However, survey coverage remains fragmented; only nine SADC countries have reliable data on gross domestic expenditure on research and development (GERD) for the years since 2014.

No SADC country has reached the 1% target for research intensity that has been reaffirmed in both the African Union's *Agenda 2063* (2015) and *STISA-2024* (Figure 20.4).

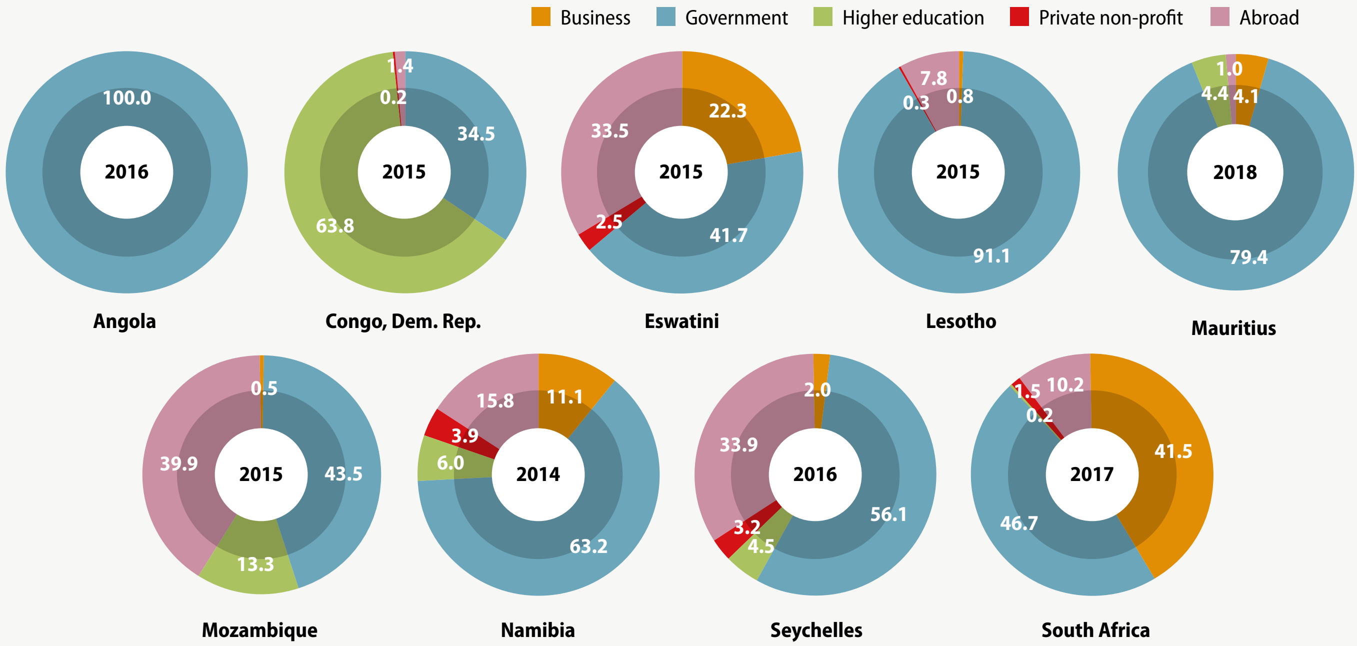
According to the *African Innovation Outlook* (2019), the percentage of innovative firms is quite high in all countries: 52% in Namibia, 59% in Eswatini, 73% in Seychelles, 75% in Lesotho and 85% in Angola. This comes with a caveat; most countries are still developing their capacity to gather accurate innovation data and some have fairly small sample sizes.[15]

Figure 20.4: **Trends in research expenditure in Southern Africa**

GERD as a share of GDP in Southern Africa, 2018 or closest year (%)



GERD by source of funds in Southern Africa, 2018 or closest year (%)



Note: Data are unavailable for some countries.

Source: UNESCO Institute for Statistics

Box 20.3: **Climate-resilient infrastructure for Mozambique**

The rising frequency and intensity of extreme weather events in Mozambique have placed a focus on climate-resilient infrastructure (Rep. Mozambique, 2020).

Under the Safer Schools Project, more than 1 000 resilient classrooms have been built since 2017. Guidelines include building schools on firm subsoil, above ground level; ensuring that they are symmetrical in shape; and reinforcing the roofs (UEM and UN-Habitat, 2015).

Drainage channels installed in the Mozambican city of Beria in 2018 reduced the damage inflicted by storm water flooding discharged by Cyclone Idai in 2019.

However, the *Municipal Recovery and Resilience Plan* (2019) released subsequently acknowledged that the drainage channels were in need of rehabilitation and expansion, for a total estimated cost of US$ 193 million over five years.

Source: compiled by Jake Lewis

This makes international comparisons and benchmarking of innovation indicators difficult.

A study analysing the number of engineers, technologists and technicians in the region, as well as member states' capacity for industrialization, was endorsed by the SADC Ministers of Science and Technology in 2017 (Figure 20.5). The study by Lawless (2019) informs implementation of key SADC policies such as the *Protocol on Education and Training* (1997) and the *Protocol on Science, Technology and Innovation* (2008), the latter having outlined the legal framework for co-operation in this area. The study, thereby, provides a basis for planning and implementing programmes to develop infrastructure.

Highly variable researcher density

Researcher density varies considerably in the SADC region (Figure 20.5). Eswatini is the only country to have achieved gender equality, with a 47% share of women researchers, although South Africa (44%) is on the cusp (see chapter 3). Few researchers work in the business sector, with the exception of South Africa (Figure 20.5).

Eswatini, Namibia and South Africa are the only countries where more than 10% of researchers work in the business enterprise sector, although most countries do not publish this type of data (Figure 20.5).

Eswatini became one of the first countries to draft a constitution for the members of its SADC Women in Science, Engineering and Technology Chapter after the SADC Secretariat adopted a *Charter on Women in Science, Engineering and Technology* in 2017 to foster gender equality.

In 2015, the Southern Africa Network for Biosciences, a programme run by the New Partnership for Africa's Development (NEPAD), launched FemBioBiz to empower women entrepreneurs in the agri-food, health and nutrition sectors. It is billed as the largest programme of its type in Southern Africa. Its objectives are to heighten the visibility of women in biosciences and contribute to the investment-readiness of women-led businesses, as well as to the entrepreneurship ecosystem as a whole. To this end, it is currently developing peer-to-peer networks, conducting training and providing mentorship in eight Southern African countries.[16]

Strong growth in materials science

South Africa accounted for half of sub-Saharan Africa's publication output on cross-cutting strategic technologies between 2011 and 2019 (Figure 20.6). However, many of these publications may have co-authors from other African countries, since intra-African co-authorship is growing (Figure 20.7; see also Figures 18.5 and 19.5).

Botswana, Mauritius, Namibia and South Africa figure in the top 15 for sub-Saharan Africa for publication intensity on AI and robotics; energy-related research; and biotechnology. Angola scores highly for publication intensity in materials science and South Africa for the volume of output on this technology (Figure 20.6). In 2019, South Africa published most in Africa on energy-related topics (959 publications), followed by AI and robotics (701). Growth between 2012 and 2019 was fastest in materials science (from 123 to 441 publications) and nanotechnology (from 40 to 84 publications) [Figure 20.6].

South Africa is set to host what will be the world's largest telescope, the Square Kilometre Array, which offers Southern African countries an opportunity to lead in the application of Industry 4.0 technologies. Since pre-construction began in 2013, the project has trained scientists and engineers at MSc and PhD level and developed both physical and soft infrastructure, including software (Box 20.1).

COUNTRY PROFILES

ANGOLA

Efforts to improve the business environment

In 2019, Angola was the second-largest Southern African economy but one of the lowest-ranking countries in the *Doing Business* index. The incumbent president, João Lourenço, was elected in 2017 on a platform to fight corruption, diversify the economy and attract foreign investment (World Bank, 2020a).

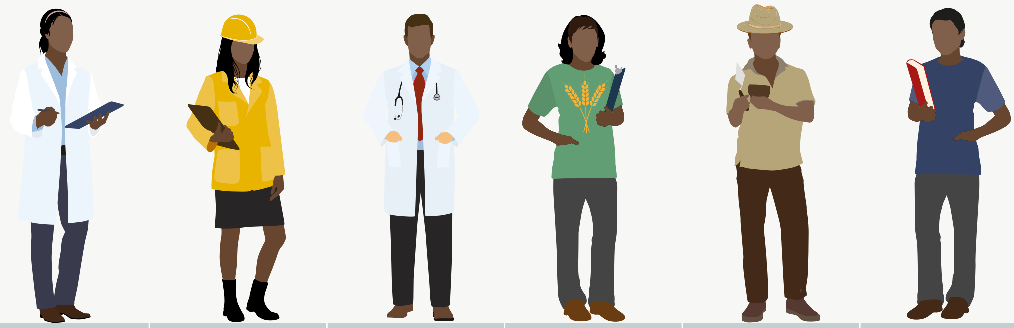
The Private Investment Law (2018) and Competition Law (2018) set out to streamline and simplify processes for foreign investors. The former established a special regime for investment in priority sectors, among which figure education, research and innovation, telecommunications and information technology, agriculture and the production and distribution of electricity.

The government has also set up the Electronic Private Transaction Processing System, a one-stop platform for submitting an investment proposal.

Figure 20.5: **Trends in researchers in Southern Africa**

Researchers (FTE) in Southern Africa by field, 2017 or closest year (%)

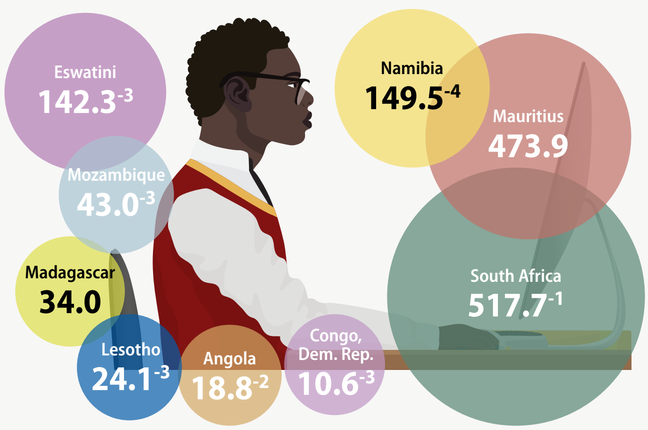
In 2017, engineering graduates accounted for 9% of the workforce in SADC countries.



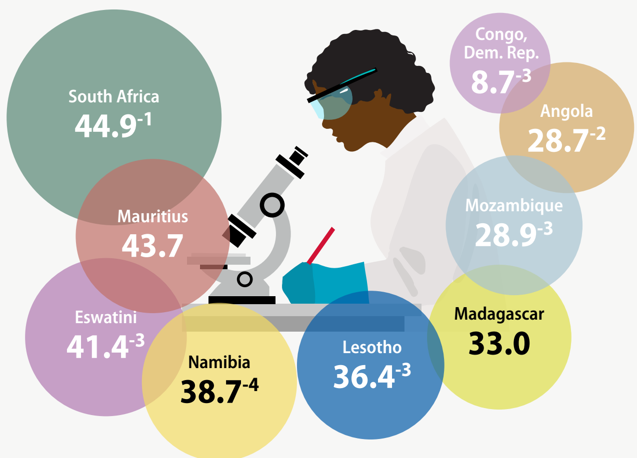
	Natural sciences	Engineering	Medical sciences	Agriculture & veterinary	Social sciences	Humanities & arts
Angola (2016)	28.7	7.1	8.7	28.5	22.0	5.0
Congo, Dem. Rep. (2015)	37.6	5.2	7.9	26.0	15.1	4.5
Eswatini (2015)	13.6	3.7	33.9	16.8	25.5	4.5
Lesotho (2015)	38.4	26.0	–	33.5	2.0	–
Madagascar	34.5	24.9	8.7	9.5	14.1	8.3
Mauritius	17.8	7.3	3.4	21.3	8.7	1.8
Mozambique (2015)	22.1	8.3	11.6	22.2	35.8	–
Namibia (2014)	31.0	2.9	3.5	18.7	37.2	0.6

In 2017, the number of practicing engineers ranged from 18 to 531 per 100 000 inhabitants in SADC countries; the average was 68 per 100 000 inhabitants.

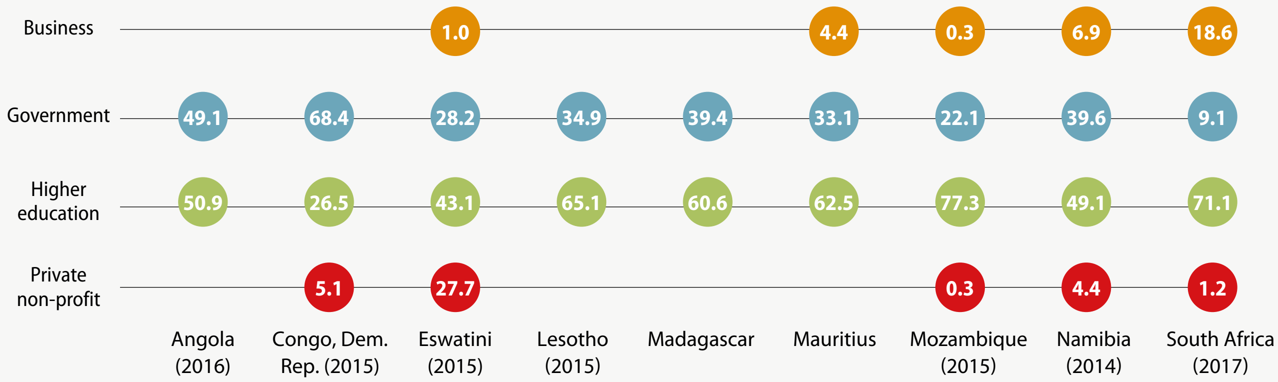
Researchers (FTE) in Southern Africa per million inhabitants, 2018



Share of female researchers (HC) in Southern Africa, 2018 (%)



Researchers (FTE) in Southern Africa by sector of employment, 2018 or closest year (%)



-n: data refer to *n* years before reference year

Note: Data are unavailable for some countries.

Source: UNESCO Institute for Statistics; for engineering workforce: Lawless (2019)

Slow but steady electrification

The mid-term *National Development Plan 2018–2022* (2018) has six strategic thrusts: human development and well-being; sustainable development and an inclusive economy; building infrastructure; promoting peace, good governance, democracy, the rule of law and decentralization; 'harmonious development'; and guaranteeing territorial integrity as well as strengthening the country's activity at the regional and international level. It anticipates creating a network of development zones or hubs to address stability, growth and jobs.

In August 2020, the government announced that about one-quarter of the projects planned under the strategy had been cut, owing to falling global prices for oil and other effects of the Covid-19 pandemic.

The government notes that electrical infrastructure is inadequate and unreliable, with energy tariffs failing to reflect costs (AmCham and Aipex, 2019). Nevertheless, there have been some gains in access to electricity (see Table 19.2). The *Angola 2025 Long Term Strategy* (2008) set a target of 60% for this indicator. In February 2020, the Ministry of Energy and Water announced plans for five solar power plants for a total of 300 MW, to be developed by 2022 at a cost of about US$ 500 million (Goodrich, 2020a).

Doctoral training in strategic areas

Researcher density is insufficient to meet development needs (Figure 20.5). To address this shortage, UNESCO and the Ministry of Higher Education, Science, Technology and Innovation launched a national doctoral training programme in STI in 2019 with a budget of US$ 50 million.

Its objective is to train 160 candidates, with a focus on environment, water, energy, digital technologies, life sciences, natural resources management and marine resources management.

The project has a focus on women, with the aim of raising their share of doctoral enrolment to 30% from an undisclosed baseline.

Plans for a new science park

Although many of the provisions of the *National Policy for Science, Technology and Innovation* (2011) have not been implemented, there has been progress in some areas. In 2019, plans were announced to build a Science and Technology Park in Luanda, with the AfDB providing 90% of the US$ 100 million required for its construction.

The AfDB is also financing the Science and Technology Development Project, running over 2016–2022, which is equipping the Mabubas Science and Technology Park, financing scholarships and research projects and providing support to improve intellectual property management, among other things.

Angola and Brazil linked through deepwater cable system

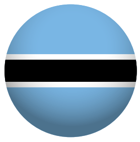
There is evidence of entrepreneurship. Local apps that support informal businesses have been developed, such as in transport services and e-finance. For instance, the ride-hailing start-up Kubinga was reaching about 20 000 users each month in 2019, after two years of operating. The Roque-Online start-up, which allows customers to order goods hand-picked at local markets, accrued 36 000 members in two years (Burns, 2019).

In 2017, Angola Cables became a Microsoft ExpressRoute partner. A year later, it completed its South Atlantic Cable System deepwater installation connecting Angola and Brazil with the first low latency communications cable to be established between South America and Africa.[17]

In 2019, the same company launched its Cloud as a Service platform in Africa to meet demand for cloud-based business applications. Meanwhile, Internet Technologies Angola launched two data centres in 2016 and 2019, equipped with modern data security and potential cloud computing services.

Angola's first digital bank, DUbank Angola, was awaiting approval from the banking sector regulator, as of early 2020 (Macauhub, 2020).

BOTSWANA



Diversifying to meet twin challenges

In 2017, Botswana was facing the 'twin challenges of declining economic growth and a high unemployment rate', according to the *National Development Plan 2017–2023*. The unemployment rate was 18.7% in 2020.

According to the World Bank (2020j), these phenomena are indicative of the limitations of Botswana's diamond-led development model, an analysis shared by the government.

Diversifying the economy is one of the priorities of the *National Development Plan,* along with developing human capital, promoting social development and the sustainable use of natural resources, good governance and national security. This plan has been guided by *Vision 2036* (2016), Botswana's blueprint for achieving high-income status by 2036.

To diversify the economy, Botswana is focusing on areas of comparative advantage, among which feature financial services, education and health, alongside diamonds, beef, tourism and mining. Special economic zones are to be developed around Sir Seretse Khama International Airport and in the Padamatenga area, to attract investment.

Business reforms yet to make their mark

Over 2013–2017, Botswana slipped 12 places in the World Bank's *Doing Business* index. To reverse this trend, the *National Development Plan* recommits to implementing the *Doing Business Reform Roadmap* (2015), a framework for reform to introduce deadlines for business registration, offer cadastral maps online and streamline bureaucratic procedures.

The Industrial Development Act (2019) and Trade Act (2019) came into effect in June 2020. These acts make license and registration certificates issuable over the counter by local authorities.

Reforms to the business environment are yet to make their mark; by 2020 Botswana had slipped a further 16 places to 87th position in the World Bank's *Doing Business* index.

An Academy of Sciences

The Botswana Academy of Sciences was launched in November 2015. Pending an updated version of the *National*

Policy on Research, Science, Technology and Innovation (2011), the *National Development Plan* commits to raising investment in research, which is to be oriented towards economic and industrial needs in the following priority sectors: health; services; ecotourism; software development; agriculture; and manufacturing.

In 2016, the government drafted a *Botswana Climate Change Response Policy,* with support from the United Nations Development Programme (UNDP). It proposes developing a climate-focused research agenda, to guide academic curricula. A National Climate Change Unit is to be established to implement and monitor measures. A national climate change adaptation plan framework was awaiting formal endorsement in June 2020.

According to a UNESCO study of 56 research topics related to the SDGs, Botswanan output on invasive species has surged from 1 (2012–2015) to 15 (2016–2019) publications. Researchers have been tackling the problem of the invasive water fern, *Salvinia molesta*, which has been threatening the Okavango Delta, a UNESCO World Heritage site and Africa's largest wetland, for the past three decades. Thanks to the introduction of a *Salvinia*-munching weevil in 2002 as an alternative to chemical pesticides, the invasion was brought under control in 2016.

A plan to match training to industrial needs

In the *National Development Plan 11*, the government recommits to implementing the *Education and Training Sector Strategic Plan* for 2015–2020. This plan sets out a transformational agenda to revise curricula at all levels of education, augment the use of ICTs and match training to industrial needs. It is proposed to introduce multiple pathways at the upper secondary level, to allow students to choose between vocational skills, social sciences, basic sciences and business studies.

The Botswana International University of Science and Technology (est. 2012) was fully operational by the 2014/2015 academic year. According to the university's annual report, there were 1 881 students enrolled in 2018/2019, 33% of whom were women. In the same year, the university's research focus areas included (BIUST, 2019):

- remote sensing of natural resources and the environment;
- sustainable energy and resource beneficiation;
- solar energy materials;
- applied nuclear sciences and technology;
- transformation enabled by information technology;
- bioinformatics, data science and high performance computing; and
- artificial intelligence and smart systems.

Under the EU-funded Pan-African Planetary and Space Science Network, the university has received a grant of € 1.4 million to ready young scientists for projects like the Square Kilometre Array (Box 20.1).[18]

Developing e-services

In the *National Development Plan*, there has been a policy shift from expanding infrastructure to developing effective e-services and ensuring broadband connectivity.

Since 2009, the Mascom company has established a network of rural community centres (Masco Kitsong Centres) which provide access to Internet and other digital services like mobile money, as well as computer training. By May 2018, there were 110 such centres in as many villages.

Mascom considers itself a public interest entity. In 2016, it launched the e-Schools Project which, by July 2019, had connected 623 government schools to Internet.[19]

In 2020, Mascom provided Botswanans with free Internet access to the government's Covid-19 tracker system. This government system was developed in collaboration with the United Nations Children's Fund, the University of Oslo and other partners. The system was operational by 27 March 2020. It comprises a case-based surveillance programme, a contact-registration and follow-up programme, as well as a ports of entry screening and follow-up programme (UNICEF, 2020).

Legislation to improve cybersecurity was foreseen in the *National Development Plan*. In 2018, parliament passed the Data Protection Act establishing the Information and Data Protection Commission. The act enshrines the right of citizens to access their personal data and to object to the processing of their personal data. However, as of March 2020, the commission had not yet been established, nor the law enforced (Alt Advisory, 2020).

Launch of the Botswana Innovation Fund

The Botswana Innovation Hub (est. 2012) is Botswana's flagship hub. Its Information and Technology Division hosts the Technology Entrepreneurship Programme, which offers support through pre-incubation, incubation and acceleration stages. The hub's five priority focal areas are mining technology, biotechnology, cleantech, ICTs and indigenous knowledge. Over 2017–2018, the hub supported more than 100 start-ups.

In 2018, the hub launched the Botswana Innovation Fund. Its first call for proposals led to the allocation of BWP 5.6 million (*ca* US$ 500 000) in funding to seven projects. Among these was the Intelligent Traffic Management System, a smart system that adjusts traffic light periods based on live traffic flow.

Bridge linking Botswana with Zambia completed

The *National Development Plan* notes that a lack of strategic planning in infrastructural development has led to poor waste management, environmentally unfriendly construction and a loss of biodiversity. Measures foreseen in the strategy include developing legislation to regulate the use of domestic and industrial chemicals and boost the capacity to treat and dispose of hazardous waste.

The plan foresees expanding investment in infrastructure in areas that include wastewater treatment and re-use, railway construction, education and health. In October 2020, construction of the US$ 260 million Kazungula bridge linking Botswana with Zambia was completed. It is expected to serve as a vital transport corridor.

COMOROS

Economy recovering from a cyclone

In April 2019, Cyclone Kenneth devastated infrastructure, causing economic growth to dip from 2.8% in 2018 to 1.5%. Ever since, there has been an influx of development aid to support the productive sector and private sector-driven infrastructure projects (AfDB, 2020a).

Poverty affects 44.1% of the population. Human and institutional capabilities are weak and almost half the active population lacks qualifications (AfDB, 2020a).

One positive trend is the increase in publication intensity from 10 to 22 publications per million inhabitants between 2015 and 2019 (see Figure 19.5). Scientists doubled their output on tropical communicable diseases from 6 to 14 publications between 2012–2015 and 2016–2019 and quadrupled their output to 8 publications on the sustainable use of terrestrial ecosystems.

Comoros is characterized by poor links to the mainland, vulnerability to climate change and a small domestic market. Comoros' intraregional trade within East Africa in 2017 accounted for only 0.1 % of the country's total exports (AfDB, 2019b). There is little diversification of national production and exports consist mainly of ylang ylang, vanilla and cloves.

These factors contributed to Comoros ranking higher than the average for least developed countries on the economic vulnerability index in 2018 (UNECA, 2019).

Plans to stabilize the energy sector

The government aims to stabilize the energy sector by implementing decrees to separate water and electricity, create a new electricity company and review the electricity tariff structure. Between 2016 and 2018, the real electricity access rate rose from 75.4% to 77.8% of the population and available capacity increased by 32% (from 19 MW to 25 MW) [AfDB, 2020a].

According to the AfDB (2020a), key national strategies have not been fully implemented. These include the *Industrialization Strategy* (2017), the *Education Sector Transition Policy* (2017) and the *National Strategy for the Blue Economy* (2013).

DEMOCRATIC REPUBLIC OF CONGO

A record year for deforestation

The Democratic Republic of Congo is presently characterized by weak governance and great fragility, a consequence of ongoing conflict and guerrilla activity in several provinces (World Bank 2020b).

The Congo Basin is home to the world's second-largest rainforest, most of which is in the Democratic Republic of Congo. The year 2017 set a record for tree-cover loss. About 10% of this loss can be attributed to industrial concessions, suggesting that logging is the greater issue (Ikala *et al*., 2018).

Off-grid solar could improve electricity access

The rate of access to electricity is the second-lowest in Southern Africa, despite well-distributed hydropower and solar potential (see Table 19.2). The World Bank notes (2020b) that access to electricity will not improve if future efforts match those seen over the last decade.

The government has focused on a select few hydropower projects and failed to invest in rehabilitation; 29 hydropower plants, representing 49% of total installed capacity, have not been rehabilitated since they were commissioned.

Electricity could reach about one-third of the population by connecting all households in the 26 provincial capitals to the grid. This could be achieved through an estimated US$ 11 billion investment, about 30% of which could come from public investment (World Bank, 2020b). The government will, therefore, need to attract investment which, in turn, will require improving the transparency and stability of the regulatory environment.[20]

Ambivalence over hydropower megaproject

First proposed in 2013, the Grand Inga Dam would constitute the world's largest hydropower scheme and transform the country into an energy exporter.

The project has stalled several times, however. The World Bank withdrew from the project in 2016, citing a lack of transparency and failure to observe international good practices (Warner *et al*. 2018). It was followed by the South African state-owned company, Eskom, which would purchase much of the electricity produced. The Spanish company Actividades de Construcción y Servicios exited the project in early 2020. Local communities have also raised concerns about the dam's social and environmental impact, including in relation to biodiversity loss, deforestation and population displacement. As of 2020, no environmental impact assessment had been conducted (Banktrack, 2020).

There is presently renewed interest in the project, which is one of the African Union's flagships (see Table 19.3). A new consortium has been formed, composed of six Chinese companies around the China Three Gorges Corporation, which hold a 75% stake, and the Spanish firm AEE Power Holdings (Takouleu, 2020).

First science policy to double research intensity

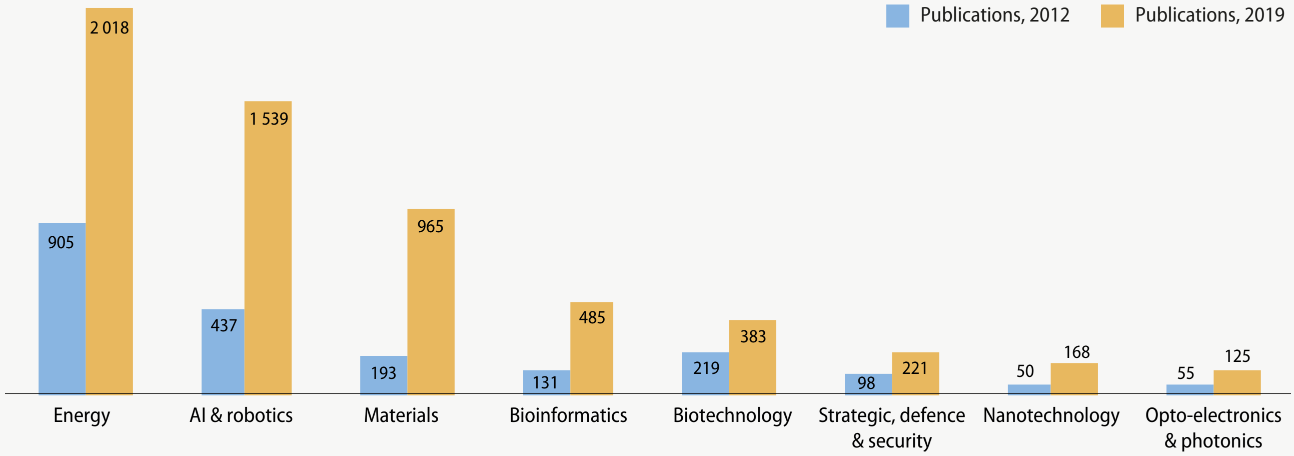
The country's first science policy, presently in draft form, counts five priority areas: reproductive, child and adolescent health; food security and demographics; improving business productivity and promoting 'green industries'; sustainable management of natural resources; and building a knowledge society through education and training. It fixes targets of achieving a research intensity of 0.80% of GDP by 2022 and 1% by 2030.

In health, the goal is to improve nutrition and reduce HIV infection rates among teenagers and women, as well as to provide universal health care coverage by 2030. Developing agricultural capacity, including through agro-ecology, is expected to reduce dependence on food imports, which presently account for about 80% of consumption. Just 2% of land is dedicated to agriculture.

Research infrastructure is outdated and dysfunctional. Nonetheless, Congolese researchers increased their annual scientific output by about 14% on average between 2011 and 2019 (Figure 20.7).[21] Between 2016 and 2019, scientists produced just 15 articles on agro-ecology.

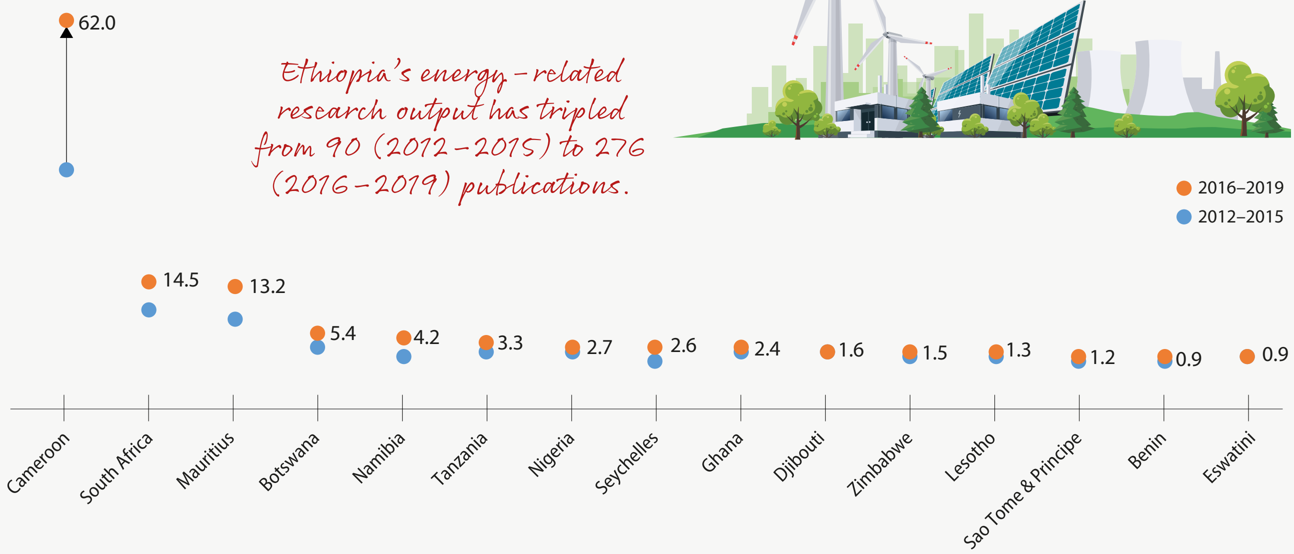
Figure 20.6: **Scientific publishing on cross-cutting strategic technologies in sub-Saharan Africa**

Volume of scientific publications on cross-cutting technologies in sub-Saharan Africa, 2012 and 2019



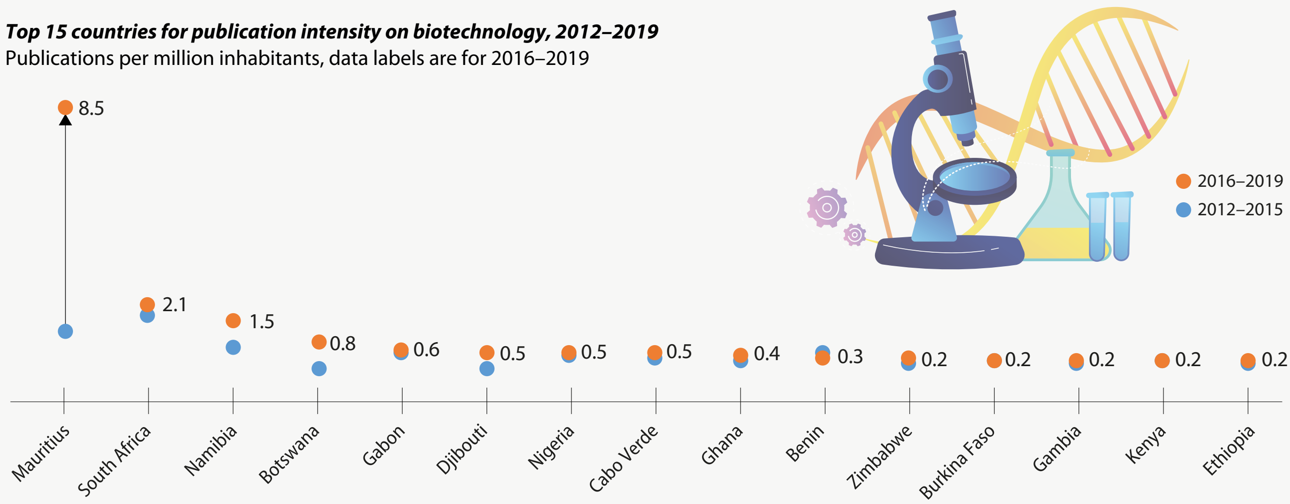
From 2011 to 2019, Nigeria (27%) and South Africa (50%) accounted for the largest shares of publications on cross-cutting strategic technologies in sub-Saharan Africa.

Top 15 countries for publication intensity on energy, 2012–2019
Publications per million inhabitants, data labels are for 2016–2019

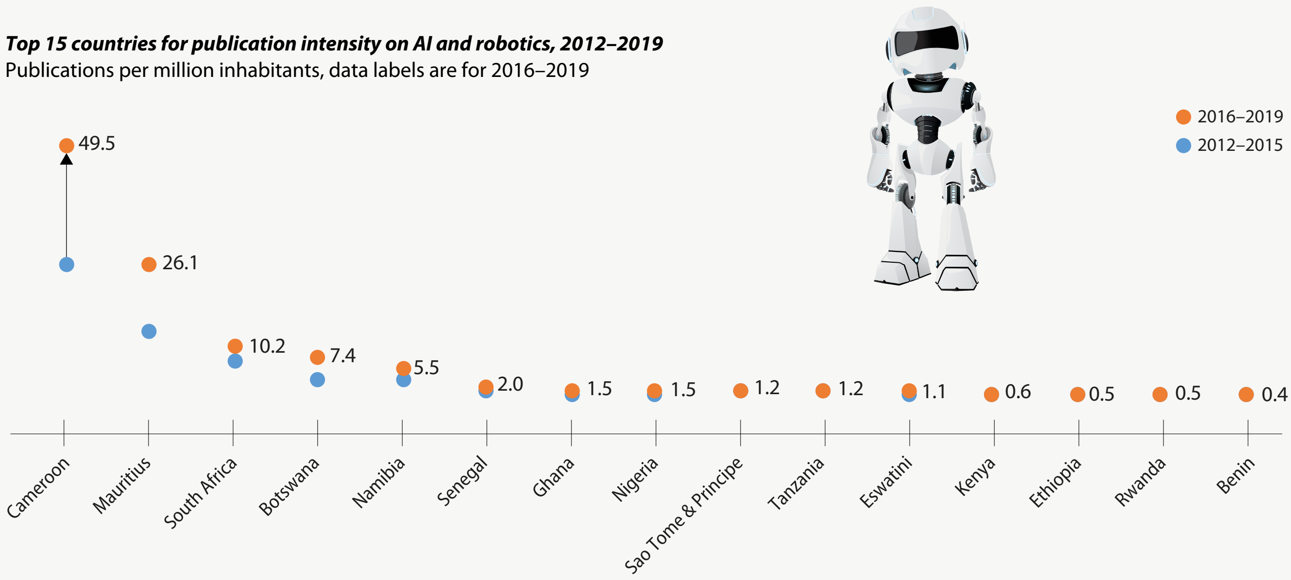


Ethiopia's energy-related research output has tripled from 90 (2012–2015) to 276 (2016–2019) publications.

Top 15 countries for publication intensity on biotechnology, 2012–2019
Publications per million inhabitants, data labels are for 2016–2019



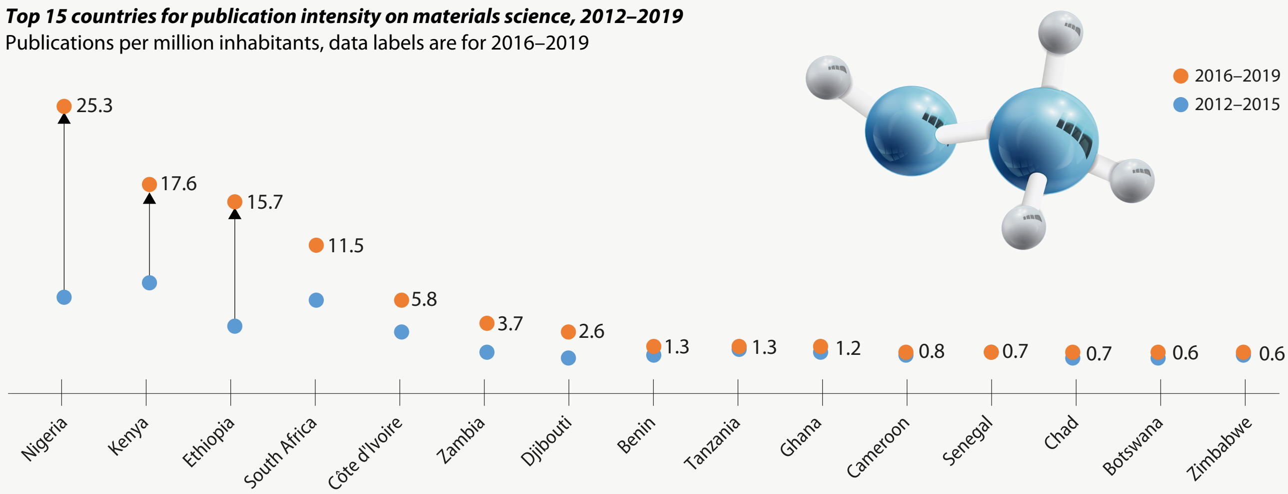
Top 15 countries for publication intensity on AI and robotics, 2012–2019
Publications per million inhabitants, data labels are for 2016–2019



Four countries collectively contributed over half of sub-Saharan Africa's total output on AI and robotics over 2012–2019: South Africa (3 774), Nigeria (1 600), Ethiopia (305) and Ghana (231).

Ghana showed the highest growth rate in sub-Saharan Africa on AI and robotics, with output tripling from 51 publications over 2012–2015 to 180 over 2016–2019.

Top 15 countries for publication intensity on materials science, 2012–2019
Publications per million inhabitants, data labels are for 2016–2019



Nigerian and South African researchers contributed 50% and 47%, respectively, of sub-Saharan African publications on materials science in 2019. Ethiopians contributed a further 5% and Botswanans 3%.

Output on materials science doubled between 2012–2015 and 2016–2019 in 14 sub-Saharan African countries, led in terms of volume by South Africa with 618 and 1 399 publications over these twin periods.

Note: This breakdown takes into account intra-African co-authorship, meaning that some publications may have been counted more than once whenever South African and/or Nigerian scientists partnered with their peers from other African countries. The growth rate was calculated as the number of publications from 2016–2019 divided by the number of publications from 2012–2015.

Note: The four cross-cutting strategic technologies here are part of a wider category that also includes blockchain technology (with only 2 publications from the region in the period under study, both from Kenya) and the Internet of Things (not shown here due to low output). The growth rate was calculated as the number of publications during 2016–2019 divided by the number of publications during 2012–2015 to buffer the variability among individual years. Complete data for all countries can be found in the statistical annex, freely available from the *UNESCO Science Report* web portal.

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

A digital health agency

A combination of mistrust in the health system, limited refrigerated storage capacity for transporting vaccines and restricted access to rural populations resulted in a measles outbreak in 2019. WHO trained more than 60 health professionals from the Ministry of Public Health to strengthen its response on the ground, including in community engagement, health education and epidemiological surveillance (WHO, 2020b).

In August 2018, an outbreak of Ebola was declared, infecting about 3 500 people. The virus proved fatal in about two-thirds of cases, making it the second-largest outbreak of the disease. A vaccine was rolled out to more than 300 000 people, 80% of whom did not contract the disease. The director of Kinshasa's National Institute for Biomedical Research praised local leadership, which mobilized resources to respond. In June 2020, the government and WHO declared the virus eliminated (Maxmen, 2020).

In March 2019, the government launched the National Agency of Clinical Information and Health Informatics Engineering, billed as the country's first digital health agency. Through social media accounts, this agency has provided regular updates on the status of Covid-19 in the country. The agency is also responsible for accelerating the use of telemedicine.

To mark the launch of this agency, a hackathon was held to explore digital solutions to the Ebola epidemic. A team of seven students won the competition with their Lokole app, designed to support the Ebola Response Coordination Team and community workers through real-time data exchange. The app did not require a smartphone or stable Internet connection. Their prize included three months of mentoring and coaching at the tech incubator Ingenious City in Kinshasa.

ESWATINI

A strategy to end AIDS

Eswatini, known as Swaziland prior to April 2018, has abundant mineral resources. It also records one of the highest annual rates of rainfall in the SADC region.

Eswatini depends on South Africa for the lion's share of its intra-Africa trade: 95% of its imports and 74% of exports in 2018 (Tralac, 2019).

Eswatini has the world's highest HIV prevalence rate, estimated by UNAIDS at around 27% of the population in 2018. The incidence of tuberculosis is also high, putting severe pressure on the country's public health budget. The *National Strategic Plan for Ending AIDS and Syphilis in Children 2018–2023* (2018) aims to eliminate the mother-to-child transmission of HIV and congenital syphilis by 2023.

Scientists have doubled their output on HIV from 50 (2012–2015) to 110 (2016–2019) publications, according to the UNESCO study. This corresponds to 39 times the average global intensity on this research topic.

A risk of overrreliance on energy imports

Access to electricity rose by nearly 10% over 2015–2018, up to 76.5% of the population (see Table 19.2). The *National Development Strategy 2022* (1999) had set the target of achieving full access by 2022.

Nearly all of Eswatini's installed electricity capacity was classed as renewable in 2019 (94%), most of which came from bio-energy (59%), according to IRENA. The majority of households rely on fuelwood for cooking and heating (Govt of Eswatini, 2018).

In 2016, the government launched the Energy Planning Capacity-Building Programme with IRENA. This culminated in the release of the *Energy Masterplan 2034* (2018), which strives for a diversified energy mix to support industrialization.

The plan forecasts that, due to a slow injection of funds in rural electrification, the target for electrification will not be reached by 2030. It projects that total national electricity demand will rise by 113% over 2014–2034 but that, under a business-as-usual scenario, dependency on fuel and electricity imports will remain high and domestic renewable resources underutilized.[22]

Greater protection of consumer data

With three in ten citizens now having access to Internet (see Table 19.2), parliament has adopted legislation to criminalize cyberoffences, the Computer Crime and Cybercrime Bill (2017).

It is accompanied by a Data Protection Bill (2017) governing the collection, use, disclosure and care of personal data and an Electronic Communications and Transactions Bill (2017) to regulate and facilitate the use of e-government services and ensure consumer protection.

National Research Council to be revived

Challenges faced by the national innovation system include a lack of incentives to innovate, relatively poor data accessibility and dissemination, an uncertain policy regime and weak linkages between public R&D, the higher education sector and the economy.

In 2015, the Department of Research, Science, Technology and Innovation (est. 2014) launched a review of the *National Science, Technology and Innovation Policy* dating from 2012. The department has since commissioned a new policy which will prioritize innovation and research in agriculture, manufacturing, energy and health.

In 2020, the Ministry of Information, Communication and Technology developed the National Research Bill to resuscitate the now defunct National Research Council, first created in 1972. This council will have a mandate to co-ordinate and fund research and innovation.

In 2018, legislation was passed to establish an intellectual property tribunal. However, as of September 2019, the act had not been followed by a decree of application (Motsa and Magagula, 2019).

Launch of Academy of Science

The Eswatini Academy of Science was launched in 2018, a year after the government drafted the academy's constitution with the assistance of the Academy of Science of South Africa.

In 2019, the academy signed memoranda of understanding with Kenya, Mozambique and South Africa to boost scientific co-operation.

Science park stimulating innovation

The Royal Science and Technology Park Act (2012) creating the eponymous park was revised in 2019.

In addition to promoting research and innovation, the Royal Science and Technology Park serves as a special economic zone; enterprises operating in the park must adhere to a quota by employing a minimum of two-thirds Eswatini citizens.

The complex hosts a Biotechnology Park consisting of a research centre and incubation facility. Focus areas include: agriculture, plant and animal biotechnology; environment and biodiversity; medical biotechnology; and biofuels and biochemicals.

The complex also hosts an Innovation Park comprising a non-profit business incubation centre, the National Data Centre and the Advanced School of Information Technology, affiliated with an international training provider. The business incubator launched a call for proposals in September 2020 relating to ICTs, electronics and value-added agriculture, among other areas.[23]

LESOTHO

Rethinking its development model

Lesotho's *National Strategic Development Plan 2019–2023* (2019) is the main policy framework and the final mid-term strategy for *Vision 2020* (2000). The central objective of creating employment opportunities and making economic growth more inclusive reflects Lesotho's chronic high unemployment (32.8% in 2017) and poverty rates; about 28% of the population lived beneath the bread line in 2017, according to government estimates.

These challenges persist, despite a growth rate of 3–5% over 2011–2016 (Figure 20.1). The government notes in the plan that the situation 'calls for a rethinking of the country's growth and development model to increase its inclusiveness.'

The government considers that implementation of the *National Strategic Development Plan 2013–2017* was impeded by political uncertainty, institutional fragmentation and weak links with the actual spending pattern. Implementation of the present plan is intended to take these barriers into account.

A key objective is to shift from a consumer-driven to a production- and export-driven economy, by focusing on four sectors: manufacturing; tourism and creative industries; agriculture; and technology and innovation.

The manufacturing sector is presently dominated by textiles, garments and footwear exports. The *National Strategic Development Plan 2019–2023* foresees developing an incubation framework to support start-ups through financial support and R&D. The strategy also anticipates establishing sector-specific incubation centres targeting small and medium-sized enterprises (SMEs), such as in banking, manufacturing and agriculture.

In 2018, the National University of Lesotho established an innovation hub to promote innovation and incubate innovative firms, with a view to stimulating job creation. The innovation hub has received M 1 million (*ca* US$ 1 300) from Metropolitan Lesotho to secure space and purchase equipment.

Inclusive education a priority

One aim of the *National Strategic Development Plan* is to offer scientists and engineers greater support, especially women. In 2015, one-third (36%) of researchers were women. They dominated agricultural research (70%) but were contributing little to engineering (10%). Among tertiary graduates, women have achieved parity in natural sciences and agriculture but remain a minority in engineering (18%) and ICTs (31%) [see chapter 3].

The National Strategic Development Plan also prioritizes digital skills training in schools. There are synergies with the *Lesotho Inclusive Education Policy* (2019), which foresees adapting the curriculum to cater to diverse needs and foster skills development, while expanding technical and vocational education and training.

Another aim of the *National Strategic Development Plan* is to promote research into drought-tolerant crops. This is not a topic on which scientists from Lesotho published in international journals between 2011 and 2019, according to a UNESCO study of climate-ready crops and 55 other research topics (Figure 20.7). GERD amounted to just 0.05% of GDP in 2015 (Figure 20.4).

There now seems to be the political will to update the languishing *Lesotho Science and Technology Policy* covering 2006–2011, which has not been implemented for lack of enactment of the proposed Science and Technology Bill; this bill had envisioned creating a Science and Technology Commission to oversee policy implementation and an Innovation Fund. In 2020, the Department of Science and Technology was in the process of drafting a standalone Research and Innovation Policy.

Renewables to advance electricity access

According to the government's *Electrification Master Plan 2018–2028* (2018), eight-tenths of the annual public budget for electrification (M 150 million, *ca* US$ 11 million) is to be allocated to expanding the grid and the remainder to off-grid electrification using renewable energy. The draft *Off-Grid Master Plan 2017–2036* found solar photovoltaic to be the most suitable option for off-grid electrification (Fernandez, 2018). By 2018, 47% of the population had access to electricity (Table 19.2), up from 39% the previous year (MEM *et al.*, 2019).

Building capacity in renewable energy production is recognized by the *National Strategic Development Plan 2019–2023* and *Energy Policy 2015–2025* (2015) as having the potential to support job creation and catalyse private-sector investment. However, as of December 2019, the draft Regulatory Framework for Renewable Energy had not yet been approved at cabinet level. A mid-term review concluded that 'in the absence of clear policy guidelines and a regulatory framework to promote private-sector participation in energy service delivery for both grid- and off-grid services, the private sector has been reluctant to invest' (MEM *et al.*, 2019).

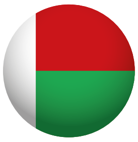
Access to digital services falling behind infrastructure

The World Bank's *Lesotho Digital Economy Diagnostic* (2019) found 'significant potential' but observed that only about one-third of the population was using Internet regularly, despite almost the entire territory being covered by a 3G network in 2018. Demand for digital financial services, however, has been strong, with consumers reportedly eager to benefit from services such as e-payments. Legislation is needed to strengthen the regulatory environment for cybersecurity and e-transactions (World Bank, 2020c).

Another obstacle is the lack of competition in the broadband market, which has pushed up costs and slowed uptake by both businesses and consumers. Information and communication technologies (ICTs) are also being underutilized by the public sector, with inadequate interoperability between systems (World Bank, 2020c).

Since 2013, the e-Government Infrastructure Project funded by the AfDB has been strengthening data centres and portals and improving access to online services like procurement. Service centres connected to Internet have been established in several communities.

MADAGASCAR



Covid-19 threatening development agenda

The primary objective of the *National Development Plan* for 2015–2019 was to reduce poverty through inclusive growth. This programme was replaced by *Madagascar's Emergency Initiative* for 2019–2021, which has three pillars: to improve basic social services, strengthen governance and democracy and foster economic growth.

Madagascar managed to maintain annual growth of at least 4% over 2016–2019 and reduce poverty levels, thanks to an ambitious economic reform programme, coupled with a peaceful transfer of power in 2019 which helped restore investor confidence (Figure 20.1; World Bank, 2020d).

These gains have been jeopardized by the Covid-19 pandemic (World Bank, 2020d). For instance, smallholder Madagascan farmers grow about 80% of the world's vanilla. Global prices for vanilla had risen tenfold over 2015–2019, driven by strong global demand and a shrinking supply linked to climate change, before falling in 2020 (Steavenson, 2019).

By May 2020, Madagascar had lost about US$ 500 million in tourism revenue, as a consequence of travel restrictions linked to the Covid-19 pandemic. Revenue from tourism contributes to conservation efforts. For instance, this has translated into a loss of at least € 20 000 in revenue for the at-risk Menabe Antimena protected area, home to unique dry forest and baobab trees. One of the founders of Ranomafana National Park has warned that, without the US$ 4 million that usually flows into the region from tourism and research, the community 'will be forced to return to cutting the forest and farming' (Vyawaare, 2020a).

The country's rich ecosystems are still under threat from rapid deforestation and other forms of land degradation. In recognition of its efforts to restore Lake Andranobe, the community-led organization Tatamo Miray an'Andranobe won the UNDP's 2020 Equator Prize in the 'nature for water' category. This organization formed in 2004 when the lake's fish stocks were dropping and the watershed shrinking. After enforcing fishery closures and regulating water uptake, fish catches more than doubled over 2014–2019. Villagers planted 200 000 saplings in 2020, in an effort to reduce silting (Vyawaare, 2020b).

E-governance to improve public services

E-governance is being explored as a means of improving the poor delivery of public services. Accessing public services is currently a long, arduous process conducted in person. The lack of interoperability between government systems and datasets adds to inefficiencies, according to the World Bank's Digital Governance and Identification Management System Project document (see endnote 7) .

As of October 2020, Madagascar has the second-fastest fixed broadband Internet service in Africa after Ghana. This has been achieved by connecting to the East African Submarine Cable System in 2010. Few can afford to access Internet, however (see Table 19.2).

A National Fund for Sustainable Energy

Poor access to an unreliable power supply continues to impede the provision of basic services and development of the private sector.[24] In its *New Energy Policy 2015–2030* (2015), the government has set the target of 70% of the population having access to electricity by 2030, compared to 26% in 2018 and 20% in 2015. The private sector will be encouraged to develop renewable energy sources.

A reform to the electricity code in 2017 created the independent National Fund for Sustainable Energy to support projects in rural and peri-urban areas.

An effort has been under way since 2016 to improve the operational performance of JIRAMA, the public water and electricity utility. Funded by the World Bank to the tune of US$ 65 million, the six-year project has, thus far, reduced electricity losses in targeted areas and installed a Management Information System to conduct monitoring and reporting.

MALAWI

National planning prioritizing agriculture

Poverty and food insecurity remain acute challenges in Malawi (Figure 20.1; see Table 19.1). Episodes of drought and flooding in the 2015/2016 agricultural season led to the declaration of a State of Disaster. Malawi has, thus, given priority to developing its agricultural sector, which accounts for about 26% of GDP (Figure 20.1).

The *National Science and Technology Policy* (1991; revised 2002) has not been fully implemented (Mbula-Kraemer and Scerri, 2015). An updated version was expected in 2020 but its release may have been delayed by the Covid-19 pandemic.

The *Malawi Growth and Development Strategy (2017–2022)* identifies five key priority areas: agriculture, water and climate change management; education and skills development; energy, industry and tourism development; transport and ICT infrastructure; and health and population. According to the strategy, the agricultural sector accounts for more than 80% of national export earnings and employs 64% of the workforce.

To address challenges related to climate change, land degradation and insufficient irrigation, the strategy identifies climate-smart agriculture and integrated soil fertility management as potential solutions.

The impact of climate change on agriculture is a particular concern. Between 2013 and 2018, the Governments of

Norway and Malawi implemented an initiative entitled Capacity Building for Managing Climate Change in Malawi, which sought to boost national research capacity and outreach, especially in the agricultural sector; the scheme provided research grants and scholarships, as well as subsidized farm inputs and livestock.

According to a UNESCO study, scientific output on climate-ready crops has risen from 5 (2012–2015) to 18 (2016–2019) publications and, on agro-ecology, from 22 to 46 publications.

Seventeen years after the government approved the creation of a National Science and Technology Fund to sponsor high-quality research, in the National Science and Technology Act (2003), the fund is not yet operational.

According to the National Commission for Science and Technology (NCST), a US$ 22 million investment plan covering the 2018–2023 period is directing resources towards research management, skills and infrastructure development and climate change management.

Skills development in science and engineering is a focus of the *Malawi Growth and Development Strategy*, along with entrepreneurship. The government also intends to link training institutions with enterprises to ensure that skills development matches needs. Other strategies include reducing class sizes and providing students with targeted scholarships and loans.

Malawi invests less per capita in the health sector than any other SADC country, at about US$ 39 in 2017, compared to the regional average of US$ 229. Measures set out in the *Malawi Growth and Development Strategy* include expanding primary and reproductive health care programmes, raising the national budget allocations for health and building upon partnerships with donor agencies (Govt of Malawi, 2017). Output on reproductive health and neonatology surged from 107 (2012–2015) to 253 (2016–2019) publications, according to a UNESCO study.

Hydropower to boost energy production

Biomass accounts for about nine-tenths of energy production. With domestic electricity production (351 MW) satisfying only about half of energy needs, the *Malawi Growth and Development Strategy* advocates public–private partnerships to boost private-sector investment in energy (Govt of Malawi, 2017).

In August 2020, the NCST launched a trilateral call for collaborative research proposals in renewable energy with Zambia and Mozambique, with a focus on renewable energy efficiency, feed-in tariffs and the sustainability and management of renewable energy systems. Successful proposals will receive a maximum of K 22.6 million (*ca* US$ 30 000).

The *National Intellectual Property Policy* (2019) has established an autonomous agency for administration and management and conducted a review of patent, copyright and design legislation. Another aim is to raise awareness of intellectual property at the secondary and tertiary levels of education. The policy also recognizes the need to build the national innovation system, through innovation centres and support structures for SMEs, as well as incentives and funding for innovative activity (Suliman, 2019).

Hydropower is expected to contribute an additional 200 MW to the electricity grid by 2024, through the planned Kholombidzo Hydropower Generation Project, which could be commissioned as early as 2021. Feasibility studies have also been conducted for the proposed Mpatamanga Power Station, which would add an additional 350 MW installed capacity from hydropower. The total cost is estimated at US$ 1.07 billion, of which the World Bank's International Development Association is expected to allocate US$ 350 million.

Foundations for a digitally enabled economy

The *Malawi Growth and Development Strategy* acknowledges that network availability remains intermittent and costly for the population. It prioritizes the development of public online services and a network of community information centres connected to the Internet, as well as the integration of ICTs into core sectoral policies.

Under the National Fibre Backbone project, optical fibre was laid across the country's 28 districts over 2017–2018, to improve connectivity and integrate government operating systems such as the Integrated Financial Management and Information System and the Human Resource Management Information System. Implemented by the Electricity Supply Corporation of Malawi together with the Chinese multinational Huawei, the project was financed via a soft loan of about US$ 23 million from the China Exim Bank (Malakata, 2018).

In 2017, the government launched the Digital Malawi project. Funded by the World Bank to the tune of US$ 72 million, it is striving to improve access to affordable Internet services (digital connectivity) and roll out e-government services (digital platform for services). There will also be an institutional review (digital ecosystems).

By June 2019, the Digital Malawi project had supported the development of telecommunications regulations, to implement the Communications Act (2016) and e-Transactions Act (2016). As of June 2020, the project has provided grants worth US$ 2 million, enabling tech and innovation hubs to enlarge their activities and train youth in digital skills. The project has also received approval to finance a national data centre.[25]

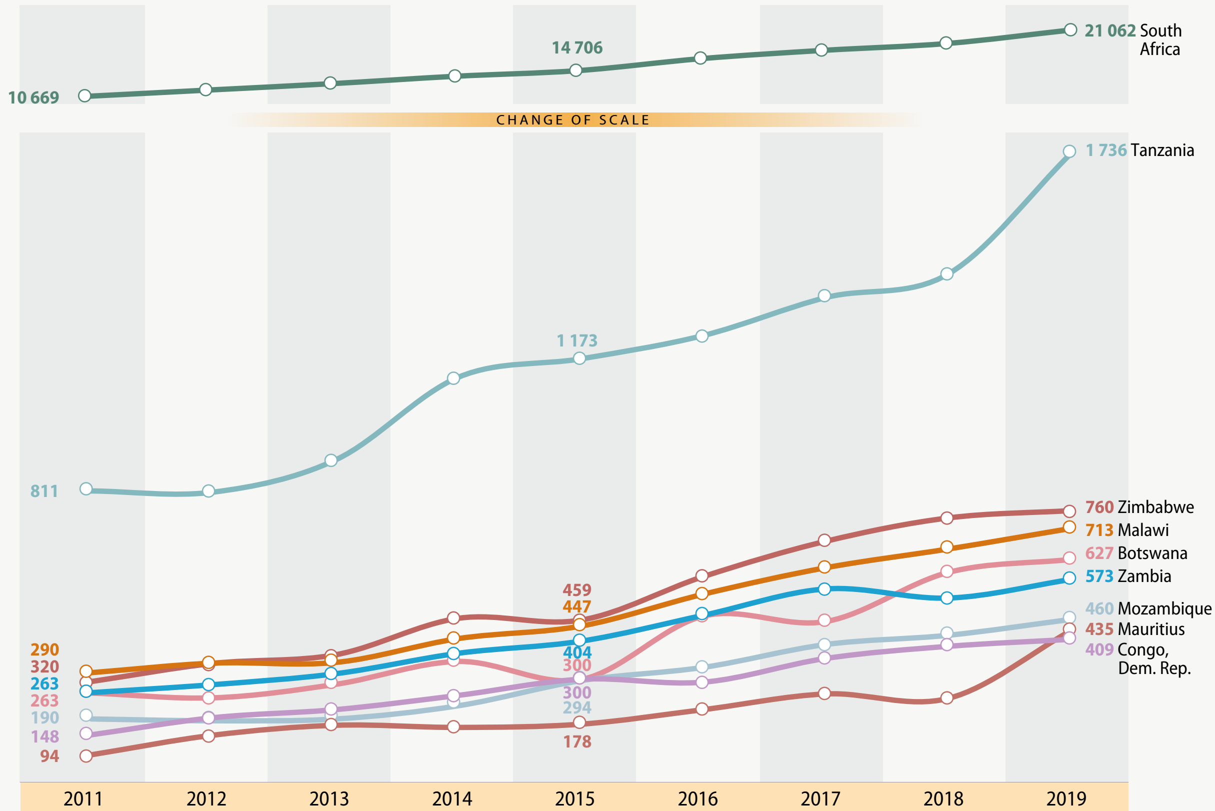
The Digital Malawi project has informed the *Digital Government Strategy* (2018), which recommends establishing innovation hubs, as well as a centre dedicated to research and innovation in ICTs within the National College of Information Technology. As of 2020, there are an estimated six active innovation hubs in Malawi (Figure 20.2). One example is MHub, which has incubated more than 40 start-ups and organized business clinics and coaching for about 20 000 budding entrepreneurs, with a focus on women and youth.

In November 2019, Malawi began phasing out machine-readable passports in favour of biometric ones that meet the standards of the International Civil Aviation Organization (MBC, 2019).

In 2019, the Minister of Foreign Affairs and International Cooperation launched Malawi's first Diaspora Portal. Hosted by the NCST, the portal provides an online platform to support engagement with highly skilled Malawians abroad, including scientists and entrepreneurs.

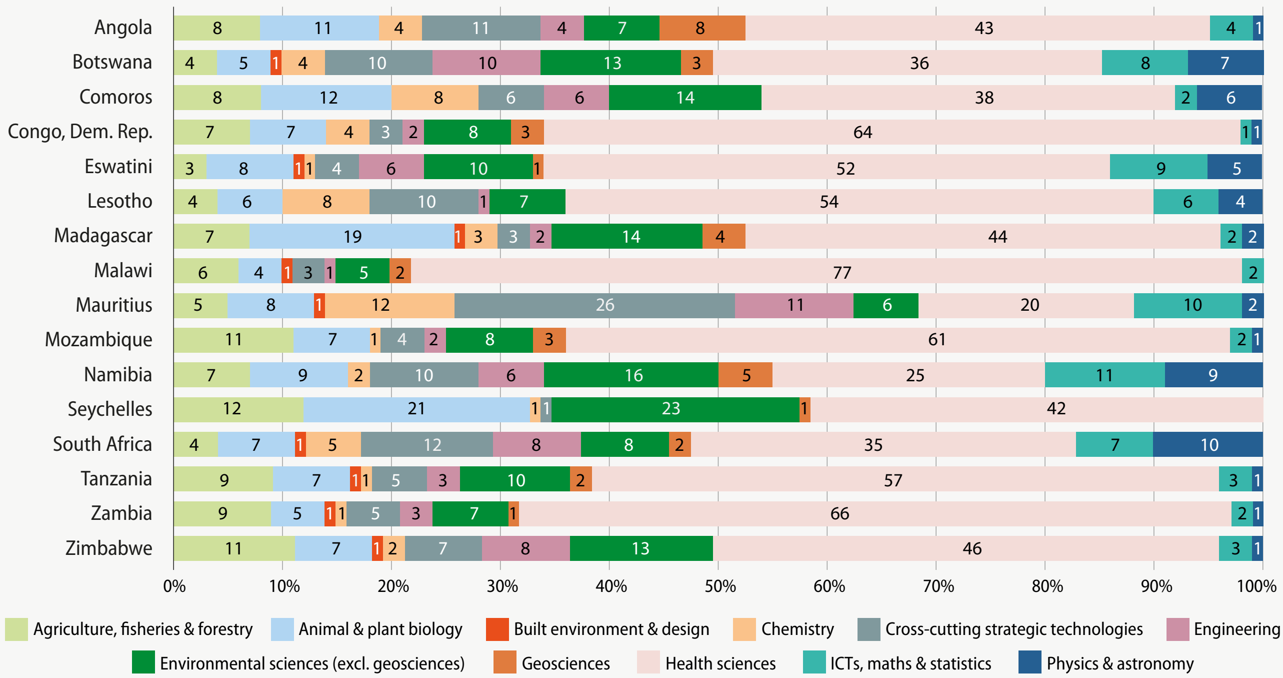
Figure 20.7: **Trends in scientific publishing in Southern Africa**

Volume of scientific publications in Southern Africa, 2011–2019



	2011	2012	2013	2014	2015	2016	2017	2018	2019
Namibia	129	152	193	226	259	279	292	346	381
Madagascar	231	238	265	262	292	276	326	323	341
Eswatini	47	43	48	42	55	64	81	99	116
Angola	50	65	62	87	84	100	134	94	114
Lesotho	27	31	28	26	34	29	35	43	60
Seychelles	35	34	46	41	59	43	54	48	52
Comoros	11	5	18	5	8	18	12	19	19

Scientific publications in Southern Africa by broad field of science, 2017–2019 (%)



1.25

Average citation rate for South Africa, the most prolific publisher in Southern Africa, over 2014–2016; the G20 average was 1.02.

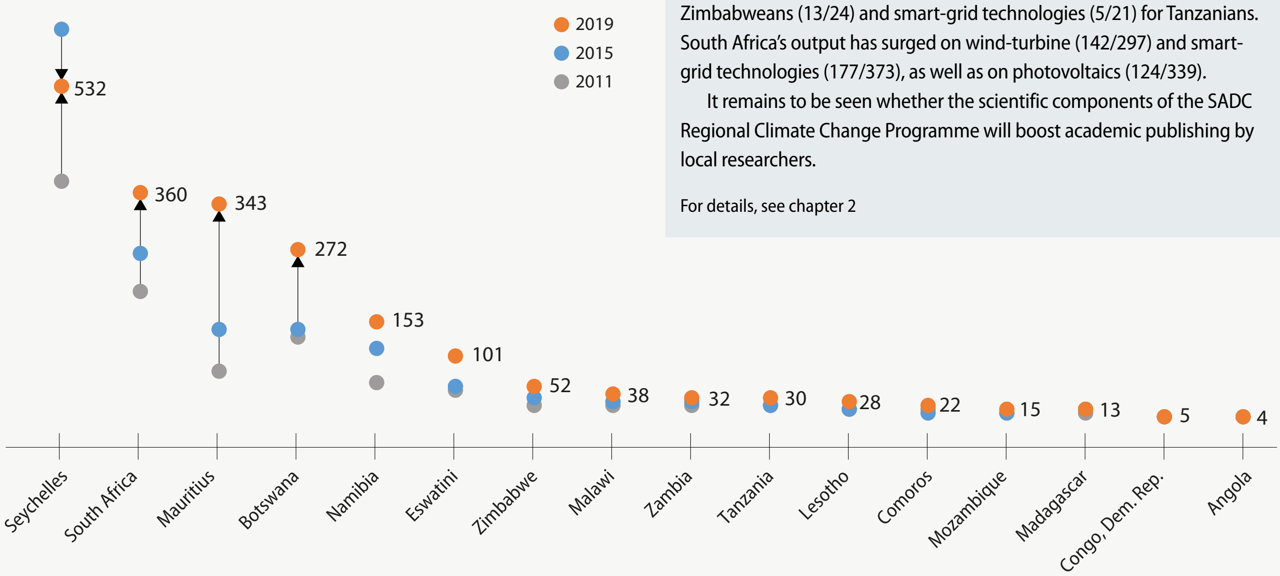
85%

Average share of publications with foreign co-authors in Southern Africa, 2017–2019 (%)

Mauritius (63%) and South Africa (56%) have a much lower share of foreign co-authorship than their Southern African neighbours.

Scientific publications per million inhabitants in Southern Africa, 2011, 2015 and 2019

Data labels are for 2019



How has output on SDG-related topics evolved since 2012?

Southern African countries are publishing more on the following topics than would be expected, relative to global averages: help for smallholder food producers (Zimbabwe's output was 217 times the global average intensity), HIV research, medicines and vaccines for tuberculosis, tropical communicable diseases and traditional knowledge.

One growth area for South Africa has concerned the local impact of climate-related hazards: from 20 (2012–2105) to 95 (2016–2019) publications. On the topic of climate-ready crops, rapid growth has been observed in Malawi (5/18 publications), Mozambique (2/9), South Africa (26/109), Tanzania (5/24), Zambia (12/27) and Zimbabwe (11/42).

All 16 countries in the region published at least three times the average intensity on the sustainable use of terrestrial ecosystems, with output at least doubling in five countries, namely Angola (12/23), Botswana (78/180), Eritrea (4/12), Lesotho (2/7) and Mozambique (35/105).

With regard to renewable sources of energy, Mauritian scientists have boosted output on biofuels and biomass (12/31), as well as hydrogen energy (2/15). Hydropower has been the focus for Zambians (6/15) and Zimbabweans (13/24) and smart-grid technologies (5/21) for Tanzanians. South Africa's output has surged on wind-turbine (142/297) and smart-grid technologies (177/373), as well as on photovoltaics (124/339).

It remains to be seen whether the scientific components of the SADC Regional Climate Change Programme will boost academic publishing by local researchers.

For details, see chapter 2

All but Angola, Madagascar and South Africa count at least one other African country among their closest partners.

Top five partners for Southern Africa for scientific co-authorship, 2017–2019 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator(s)	5th collaborator(s)
Angola	Portugal (123)	USA (64)	Brazil (57)	Spain (40)	Germany (35)
Botswana	South Africa (510)	USA (488)	UK (254)	India (129)	Zimbabwe (111)
Comoros	France (21)	Madagascar (10)	China (9)	Italy/Morocco (6)	
Congo, Dem. Rep.	USA (390)	Belgium (375)	France (193)	UK (173)	South Africa (135)
Eswatini	South Africa (155)	USA (107)	UK (36)	Switzerland (35)	Germany (25)
Lesotho	South Africa (55)	USA (47)	Switzerland (13)	Malawi (10)	Botswana/Uganda (8)
Madagascar	USA (337)	France (326)	UK (192)	Germany (159)	Italy (76)
Malawi	USA (892)	UK (743)	South Africa (369)	Kenya (193)	Uganda (167)
Mauritius	Turkey (135)	South Africa (129)	UK (113)	India (109)	Italy (101)
Mozambique	USA (372)	Spain (235)	South Africa (233)	UK (226)	Brazil (221)
Namibia	South Africa (451)	USA (229)	UK (190)	Germany (182)	Australia (118)
Seychelles	UK (68)	USA (64)	France (40)	Australia/South Africa (35)	
South Africa	USA (10 110)	UK (7 474)	Australia (4 173)	Germany (4 155)	France (3 262)
Tanzania	USA (1 439)	UK (913)	South Africa (508)	Kenya (487)	Germany (437)
Zambia	USA (752)	UK (424)	South Africa (390)	Kenya (183)	Uganda (147)
Zimbabwe	South Africa (865)	USA (513)	UK (438)	Uganda (156)	Kenya (141)

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

MAURITIUS

A high-tech industry in electrical equipment

The Mauritian economy has been expanding at a consistent rate of 3–4% since 2009, driven mainly by the construction and ICT sectors, as well as financial services (Figure 20.1) [AfDB, 2019a, p. 164].

One policy goal is to transform Mauritius into a regional transshipment hub and financial gateway into Africa. Thanks to growing logistics and distribution networks, Mauritius already hosts a number of multinational companies seeking to expand their presence in Africa. It is the only country in the SADC region besides South Africa to have developed a high-tech industry in electrical equipment. High-tech industries do exist in other SADC countries but largely in the chemicals sector (SADC, 2019; Lawless, 2019).

Support for tech-based SMEs

SMEs accounted for about one-half of employment and one-third of GDP in 2018. In 2017, two schemes involving a public–private partnership were introduced, an SME Innovation Award and a National SME Incubator Scheme for start-ups (Rep. Mauritius, 2019).

To address the mismatch between skills and market needs, the government introduced a Graduate Training for Employment Scheme in 2015, which provides unemployed graduates with practical training, a monthly stipend and a work placement. By February 2020, 86 employers had participated in the programme and 469 young people had been trained (Peryagh, 2020).

A Research and Innovation Council and fund

In May 2019, an act of parliament established the Mauritius Research and Innovation Council and the National Research and Innovation Fund.[26]

In January 2020, the council signed a collaboration agreement with the Technology Innovation Agency of South Africa. The partners then released a call for research proposals focusing on 'real-world solutions' in the following broad areas: the green and blue economies; smart agriculture and life sciences; manufacturing; social innovation; and emerging sectors.

Advances in electric transportation

As in other African countries, infrastructure development is a priority. Designed to alleviate traffic congestion, the electric Metro Express Light Rail system will, ultimately, stretch for 26 km and connect five major towns. The first phase got underway in December 2020 (Rep. Mauritius, 2019). A fleet of 30 electric buses is also planned, in order to connect the rail system to residential neighbourhoods (GEF, 2019).

The government has been encouraging the private sector to gear investment towards green projects. For instance, construction of Plaisance Eco-City got underway in 2019, for a total estimated cost of MUR 4 billion (*ca* US$ 100 million). This eco-city sporting apartments, a business park and hotel, will, reportedly, be self-sufficient in wind and solar energy.

By 2018, 33 electric cars and 3 587 hybrid cars were navigating Mauritian roads, a near three-fold increase on both counts since 2016. The number of registered hybrid cars has doubled since the removal of excise duties on electric cars of up to 180 kW.

Efforts to ensure ocean sustainability

The government maintains that around 2.15% of the country's GDP is invested annually in climate adaptation and mitigation measures. Mauritius has pledged to reduce greenhouse gas emissions to 30% by 2030, compared to the business-as-usual scenario, invoking multiple schemes that promote renewable energy and low-carbon consumption practices, such as re-use and recycling. One target is to increase the share of renewables in total energy consumption to 35% by 2025 (Rep. Mauritius, 2019). However, this indicator has actually declined from 11.5% in 2015 to 9.7% in 2017, according to the International Energy Agency.

Meanwhile, the Oceanic Carbonate Chemistry Observatory (est. 2017) has been monitoring marine pollution, ocean acidification and marine debris. Mauritius participates in the Global Ocean Acidification Observing Network alongside over 90 countries (Rep. Mauritius, 2019).

In July 2020, the oil carrier Wakashio ran aground in the Indian Ocean near Esny, in southeast Mauritius, causing an ecological emergency. As of November 2020, 1 000 tons of oil had spilled into the ocean, threatening endangered corals and other marine life. Following a clean-up operation, media outlets have reported that all the oil floating on the ocean has been recovered and that all traces of it along the coastline should have been removed by January 2021 (Reuters, 2020).

Advances in AI and data protection

The *Artificial Intelligence Strategy* released in November 2018 formally recognizes the potential of AI, the Internet of Things and blockchain for development. The strategy identifies uses for AI in health care, to support the diagnosis of disease and care for the elderly; in fintech, to support mobile applications, e-banking and other digital platforms; and in agriculture, as a tool for crop and pest management, as well as precision farming.

The government has since set up the Mauritius Artificial Intelligence Council, which has been mandated to establish an AI roadmap, facilitate project implementation and monitor the socio-economic impact of AI. In 2018, the Financial Services Commission of Mauritius issued guidance with regard to investing in digital assets like cryptocurrencies (FSC, 2019).

Mauritius' Data Protection Act came into force in January 2017. Designed to improve individuals' control over their personal data, it is in line with the European Union's General Data Protection Regulation. For instance, data can only be collected and processed whenever there is a defined purpose and individuals have a right to access their data, rectify or restrict its processing and to object to its collection (Deloitte, 2019).

E-governance a priority

In 2018, the government introduced the Info-Highway project, which makes secure data-sharing possible among government agencies and provides robust e-services.

Mauritius' *Digital Government Transformation Strategy 2018–2022* (2018) sets out the government's approach to e-governance and cybersecurity (Rep. Mauritius, 2019). It outlines a 'once-only principle', according to which data from citizens are to be collected only once, rather than through multiple state agencies. Digital paper services are to be delivered through an end-to-end, paperless, one-stop process.

Infrastructure to support the digital economy is also advancing. In February 2019, a submarine cable linking the island of Rodrigues with the mainland was inaugurated, thereby connecting Rodrigues with the rest of the world (Rep. Mauritius, 2019).

Coding for kids

In education, the government is promoting introductory courses on coding at the primary level. The Digital Youth Engagement Programme provides fourth-year primary school pupils with 15 hours of classes on coding; in 2018, two mobile caravans toured Mauritius to teach coding to about 2 000 pupils from 20 primary schools (Rep. Mauritius, 2019).

MOZAMBIQUE

A 'period of change' on the horizon

Mozambique is set to become a top-ten global supplier of liquefied natural gas, following the discovery of vast gas reserves in the ultra-deepwater Rovuma Basin in 2010 and 2011. Two plants are being constructed at two offshore blocks known as Area 1 and Area 4, where production is expected to begin in 2024 and 2022, respectively (Goodrich, 2020b). These projects have the potential to create a value chain for fertilisers as well as gas-to-liquid and gas-to-power industries in Mozambique.

According to the Mozambique Liquid Natural Gas project's own estimates, 557 households will be displaced to make way for the Area 1 plant. There are also concerns about the impact on biodiversity in the nearby Quirimbas Archipelago, a UNESCO biosphere reserve home to 3 000 floral species and 447 bird species (Rawoot, 2020).

There is a high inflow of foreign direct investment (FDI) into Mozambique (see Table 19.1), although the level has dipped since 2015 when it contributed as much as 24% of GDP. The impact of mega-investment from abroad on the country's power, gas and mining sectors has, nevertheless, 'fallen short of expectations', with the extractive industry creating no more than 1.1% of jobs in 2018. In addition, local communities and industry have not benefited from the high level of FDI, a trend explained by companies' lack of competitiveness, the poor infrastructural network, the small size of the formal economy and the predominance of micro-enterprises and SMEs (Rep. Mozambique, 2020).

The government forecasts 'a period of change' ahead for Mozambique, led predominantly by revenue from extractive industries. For the government, this 'can contribute to transforming the economy by allowing diversification of investment [...] and substantial social investments in health and education.' Agro-processing, fruit- and vegetable-growing and other tradable industries are considered to have the potential to boost the country's international competitiveness (Rep. Mozambique, 2020).

Mozambique's National Research Foundation was one of the first to join the Science Granting Councils Initiative in 2016. Within this initiative, Mozambique has participated in collaborative projects with Zimbabwe, Malawi and Namibia. For instance, in co-ordination with Namibia's National Commission on Research, Science and Technology, the National Research Foundation has launched a bilateral call for collaborative research in agriculture, with a focus on agro-processing.

National electrification

In 2018, 31% of the population had access to electricity (see Table 19.2), some way from the 55% target set by the *Five-Year Plan* for 2015–2019.

Launched in November 2018, Mozambique's National Energy for All Programme targets full access to electricity by 2030. Presently, the electricity grid reaches all 154 districts but many households and businesses are not connected. The project is extending distribution lines and networks to harness existing infrastructure and economies of scale. A geospatial planning tool will be employed to expand the network optimally.[27]

The share of modern renewables (excluding traditional wood-burning) in Mozambique's energy mix rose by 11.3% over 2014–2017 (Figure 20.1), even though wood remains the major source of domestic energy: biofuels and waste accounted for 66.4% of Mozambique's total energy supply in 2018, according to the International Energy Agency.

Mobile services more competitive

In 2014, Mozambique became the first SADC country to join the Alliance for Affordable Internet (A4AI) and the third developing country, after Nigeria and Ghana, to sign a memorandum of understanding with the Alliance. The price of mobile Internet is declining[28] and mobile services have also become more affordable since the arrival of a third operator in 2012 created a more competitive environment (RICTA, 2019). Internet penetration is low but has more than doubled since 2014 (9.2%) [see Table 19.2].

In June 2016, the Telecommunications Act established rules to ensure fair competition, in order to promote the sharing of infrastructure among telecom operators, reduce duplication of investment and increase coverage of rural areas (MoTC, 2017).

R&D surveys provide valuable insights

Mozambique has conducted seven R&D surveys[29] since 2008, plus two innovation surveys, the second of which covered the period 2013–2015 (UNESCO, forthcoming). Research intensity has remained stable at about 0.34% of GDP (Figure 20.4), with 40% coming from foreign sources (UNESCO, forthcoming).

Investment in health and biomedical sciences is more than four times that in natural sciences and engineering.

As of 2016, the social sciences, arts and humanities accounted for the largest share of researchers (1 145 by head count), compared to just 96 researchers in engineering and technology (UNESCO, forthcoming).

Although the requisite public institutions, intermediaries and actors for a functioning national innovation system are present in Mozambique, linkages between these actors remain weak and the private sector is engaging mainly in incremental innovation, rather than in R&D (UNESCO, forthcoming).

The *Strategic and Human Resources Development Plan for Science and Technology* (2006), which is yet to be updated, discussed the need to close the gender gap. By 2018, women accounted for 45.2% of students enrolled in tertiary programmes, up from 41.8% in 2014.

NAMIBIA

A water crisis prioritizes better practices

With the economy dependent on mining, the fall in commodity prices plunged Namibia into recession in 2016 (Figure 20.1).

Drought has since compounded the economic slowdown (World Bank, 2020e). The 2018/2019 rainy season was one of the driest since 1981, leading to a national water crisis.

Namibia's Water Sector Support Programme has been one response to the crisis. It aims to provide the population with access to sustainable water and sanitation services. A central objective has been to market sanitation and bring about behavioural change. The programme is also building and rehabilitating bulk water infrastructure and climate-resilient sanitation facilities. In March 2020, the AfDB provided a US$ 122 million loan to support the programme, which is due to wind up in 2024.

Industrialization slow despite policy focus

Namibia's *Vision 2030* (2004) has steered policy towards the goal of a prosperous and industrialized Namibia. However, as of 2019, manufacturing and wider industry accounted for roughly the same share of the economy as they did in 2004 (Figure 20.1). Economic diversification has been constrained by the small size of the skilled labour force and domestic market, as well as the lack of innovation.

The AfDB (2020b), nevertheless, notes the potential for industrialization, given the country's wealth of natural resources and expected revenue from oil and gas exploration.

The new container terminal and cruise facility at Walvis Bay has doubled the port's handling capacity and brought the government a step closer towards its ambition of turning Namibia into a logistics hub. Funded by the AfDB for US$ 268 million and built by the China Harbour Engineering Company, the new terminal was inaugurated in 2019.

The *Fifth National Development Plan* (2017) translates *Vision 2030* into concrete strategies and plans for the period 2017–2022. The plan has four strategic goals: inclusive, sustainable and equitable growth; healthy and capable human resources; a sustainable environment and enhanced resilience; and good governance through effective institutions. It sets a target of devoting 1% of GDP to R&D by 2022.

Only about half of the population has access to electricity (see Table 19.2) and, as of 2017, 82% of the primary energy supply was imported, according to IRENA. By 2023, the *Fifth National Development Plan* aims to ensure that two-thirds of the population (67.5%) has access to electricity.

A centre for incubation and innovation

Namibia faces a growing skills mismatch and uncompetitive business environment (World Bank, 2020e). The number of patents granted to Namibian inventors has fallen since 2017 (Figure 20.3).

The *National Policy on Micro-, Small and Medium Enterprises in Namibia* covering 2016–2021 aims to institute an enabling business environment for Namibian micro-enterprises and SMEs.

The Start-up Namibia programme is being funded by the German Federal Ministry for Economic Cooperation and Development (BMZ) over 2019–2022.

The project is building an Incubation and Innovation Centre in Windhoek which will serve as a one-stop-shop for start-ups through their ideation, establishment and growth phases. The centre will also help start-ups to access finance, host training courses and publicize Namibian success stories. It will host mobile outreach units to bring its services to start-ups across the country.

The Start-up Namibia programme is also providing initial capital and growth financing to the winners of the National Innovation Challenge for Women, which has accelerated more than 100 female entrepreneurs since its inception in 2017.

Streamlining intellectual property management

The Business and Intellectual Property Authority (est. 2016) has helped to improve the business climate by streamlining processes such as business registration and the administration of commercial and industrial property rights, which had previously been fragmented. It also provides advisory services in these areas.

Moreover, after an *Intellectual Property Assessment Study* (2016) found that intellectual property was insufficiently integrated into national planning, that the policy and management framework was inadequate and that intellectual assets were not being adequately protected, the Business and Intellectual Property Authority sought to remedy this through the *National Intellectual Property Policy and Strategy 2019–2024*.

This strategy proposes establishing a co-ordination committee to link the Business and Intellectual Property Authority with other bodies; enacting a law on ownership and exploitation of research results generated using public resources; amending existing laws to meet international requirements; and generating greater intellectual property with a focus on needs-oriented research.

The Business and Intellectual Property Authority has pledged to oversee implementation of the strategy, monitor and evaluate its impact and ensure policy coherence with national and sectoral policies.

An updated STI policy

The National Commission on Research, Science and Technology released the *National Programme on Research, Science, Technology and Innovation* for 2014–2017, which prioritized areas such as health, agriculture and fisheries, water, manufacturing technologies, ICTs, biotechnology and space science. The document described the national innovation system as being fragmented and scattered, with institutions functioning in isolation.

The government subsequently launched a consultative process to update the *National Policy on Research, Science and Technology* (1999). This led to the formulation of the *Science, Technology and Innovation Policy 2020–2030,* which is accompanied by two five-year implementation plans. The policy sets out to strengthen linkages between the public sector and industry. Strategies include engaging with the private sector and enhancing the use of scientific data for evidence-based policy-making. To improve the policy, legislative and regulatory environment, sectoral policies will be developed for indigenous knowledge systems, space science and technology and public-sector innovation, along with a strategy for the bio-economy.

In space science and technology, Namibia is already participating in the Square Kilometre Array and African Very Long Baseline Interferometry Network hosted by South Africa. For this purpose, the University of Namibia's Department of Physics received a first High Performance Computing rack from South Africa's Centre of High-Performance Computing in 2016 and a second in 2019. The rack also serves other purposes, such as monitoring of land degradation.

The development of national research facilities is about to become a reality, following the approval of the *Science, Technology and Innovation Infrastructure Strategy* by the National Planning Commission in November 2020. The Commission had already launched the National Biotechnology, Testing, Training and Research Laboratory for genetically modified organisms in 2018, once a biosafety regulatory framework was in place to ensure full implementation of the Biosafety Act (2006).

A boost for tech entrepreneurship

Over 2017–2019, UNESCO and the Ministry of Higher Education, Training and Innovation co-implemented a project Supporting the Development of Innovation Acceleration Platforms in Namibia.[30] The project was funded by the Korean International Cooperation Agency.

This led to the formulation of a Namibian Strategy on Innovation: Accelerating Innovation, Realising the Vision for Namibia. The draft strategy was presented at the first Namibian Annual Innovation Conference in February 2019, which drew 350 national stakeholders.[31] The draft strategy sets out a plan to boost innovation through entrepreneurship programmes and support centres, co-ordinated by the proposed Innovation and Entrepreneurship Development Agency.

The project has assessed Namibia's technology business incubators. It found that, as of early 2019, four existed at an embryonic stage.[32] The project has since created an umbrella Business Incubation Hub with the government.

SEYCHELLES

Structural weaknesses

In 2019, Seychelles was the only African country to graduate to the 'very high' bracket of the Human Development Index.

However, the archipelago faces structural issues tied to its geography and small population (see Table 19.1): diseconomies of scale; overreliance upon tourism, fisheries and imported goods; and a relatively uncompetitive private sector. Tourism accounts for about 17% of direct employment and fisheries for 95% of domestic exports (Rep. Seychelles, 2020).

The world's first sovereign fund for oceans?

At the heart of Seychelles' development agenda is the sustainable expansion of its blue economy, based on the responsible use of ocean resources. This priority is reflected in *Vision 2033* (2019), which is to be realized through two consecutive *National Development Strategies* for 2019–2023 and 2023–2033. Another goal is to reduce the vulnerability of key economic sectors to the impact of climate change.

The *Seychelles Blue Economy Strategic Policy Framework and Roadmap* (2018) orientates the blue economy towards high-value jobs, while ensuring the integrity of habitats and ecosystem services. One focus is to strengthen the circular economy, such as by transforming fish waste into products like fertilizer.

Seychelles launched the Sovereign Blue Bond in October 2018 to help local communities and businesses transition to sustainable fisheries and preservation of the ocean. Reportedly the first of its kind in the world, the fund had raised US$ 15 million by June 2020 from foreign investors; this is being put towards expanding protected marine areas and strengthening the governance of fisheries. Loans and grants are provided through the Blue Grants Fund and Blue Investment Fund (Rep. Seychelles, 2020).

Efforts to protect the marine environment are also reflected in international agreements. For example, under the Sustainable Fisheries Partnership Agreement renewed with the EU in October 2019, a limit is imposed on the number of EU vessels that may fish in local waters, as well as the tonnage of fish they may recover. Vessels must also respect conditions of employment for Seychellois seamen (Rep. Seychelles, 2020).

In 2017, the government banned the import and use of plastic bags, single-use plastic kitchenware and Styrofoam takeaway boxes, in line with regulations under the Environmental Protection Act.

Silo mentality to overcome

The National Institute for Science, Technology and Innovation (est. 2014) produced its first *Science, Technology and Innovation Policy and Strategy (2016–2025)* in 2016. It has been condensed and translated into local languages to raise awareness of its provisions.

Under this strategy, a National Research Foundation is to be established, which will be responsible for hoisting research funding to the targeted 2% share of GDP by 2025.

This foundation will also be responsible for building local and international partnerships. In 2020, a *Long-Term National Research Plan* was under development; it is expected to prioritize the establishment of a National Science Centre and a Regional Centre of Excellence in Blue Economy Research.

The first phase of an exercise mapping the national innovation system was completed in August 2019, with support from the United Nations Industrial Development Organization. It identified the following weaknesses: budgetary constraints; poor 'critical STI skills' being cultivated by the education system from the primary to tertiary levels; and a 'silo' mentality among research communities that hindered inter- and transdisciplinary work.

The world's first floating solar farm in a lagoon

The Department of Energy and Climate Change (est. 2015) has developed the *National Climate Change Policy*. Adopted in May 2020, it commits to facilitating research and monitoring of the long-term impact of climate change and supporting related education and training, along with promoting sustainable forms of public and private transportation. The policy foresees establishing a National Climate Change Council to ensure that public planning mainstreams issues related to climate change.

As of 2019, renewables account for 8% of Seychelles' 126-MW total installed capacity, according to IRENA. An additional 9 MW is being added to the electricity grid through two solar photovoltaic plants presently under construction, one of which, the Floating PV Plant in the Providence lagoon, will be the world's first floating solar farm on a saltwater lagoon. In the president's 2020 address on the state of the nation, the target to 2030 for renewables in the share of energy production was raised from 15% to 30%.

In 2017, the UK-based Institute for Environmental Analytics launched the Renewable Energy Space Analytics Tool in Seychelles, which makes it possible to analyse the grid impact of different deployments of renewables, to support policy-makers maximising the impact of their investment.

SOUTH AFRICA

Persistent exclusion hinders development

Since 2014, the economy has suffered from contractions in the agricultural and mining sectors, exacerbated by an ongoing electricity crisis and prolonged strikes. Lethargic economic growth since 2014 (Figure 20.1) has edged South Africa into third place behind Nigeria and Egypt for the size of its economy.

South Africa remains a dual economy with one of the highest and most persistent inequality rates in the world. This duality has been maintained by limited advances in social inclusion and the incapacity to create sufficient jobs (World Bank, 2020f). As a result, youth unemployment in South Africa is the highest in the SADC region, at 55% in 2019.

In spite of these challenges, South Africa counts the region's most sophisticated innovation system. Its strengths include dynamic institutional structures, effective policy frameworks and the region's highest research intensity (Figure 20.4).

The *Medium-term Strategic Framework* for 2019–2024 is the second implementation strategy for the *National Development Plan* (2012–2030). According to this strategic framework, insufficient progress has been made towards eliminating poverty and reducing inequality. It has seven focus areas: a capable, ethical developmental state; economic transformation and job creation; education, skills and health; reliable and quality basic services; human settlements and local government; social cohesion; and a better Africa and world.

Innovation on the agenda

In 2018, the government approved the *White Paper on Science, Technology and Innovation*, which updates its predecessor from 1996. Some shifts in emphasis are notable. There is a focus on innovation, as reflected in the new name and mandate of the Department of Science and Innovation in 2019, previously the Department of Science and Technology (DST). Whereas the 1996 *White Paper* prioritized institutional development, the updated document addresses socio-economic and environmental challenges to improve people's lives. It sets a target of raising GERD to 1.5% of GDP by 2030.

The *White Paper* identifies the main barriers to the national innovation system as being: an inadequate and non-collaborative STI agenda-setting; a lack of policy coherence and co-ordination; weak linkages between the various actors; inadequate monitoring and evaluation; and a poor environment for innovation, among others.

The *White Paper* proposes an 'innovation compact' across government, to ensure STI policy coherence across areas such as the economy, social development, education and the environment.[33]

The *White Paper* will be implemented through consecutive decadal plans from 2020 onwards. These will set out specific measures and be reviewed and updated every five years.

A panel of experts appointed by the minister in 2015 recommended, in 2017, developing an overarching policy and evaluation framework, as well as a national regulatory policy framework.

Circular economy 'a powerful opportunity'

Led by the National Advisory Council on Innovation, the South Africa Foresight Exercise for Science, Technology and Innovation 2030 published its findings in a *Synthesis Report* released in November 2019. The upcoming first decadal plan for the *White Paper* is expected to draw on this exercise.

The foresight exercise identifies nine areas with a high growth potential: the circular economy; education for the future; sustainable energy; the future of society; health innovation; high-tech industrialization, ICTs and smart systems; nutrition security; and water security.

Although the exercise found the circular economy to be poorly understood, it was seen as a 'powerful opportunity' for South Africa to advance its sustainable development agenda. The exercise recommended four thrusts: reducing, reusing and recycling waste; ensuring sustainable water, energy and food security; a low-carbon and climate-resilient economy; and smart connectivity and mobility in communities.

Expanding research infrastructure

The *National Research Foundation Strategy 2020* (2016) fixed the target of raising the global share of publications by South African scientists to 1% by 2020. By 2019, South Africa's global share was 0.8% (see chapter 1).

This strategy set out a new Science Engagement Framework, with four strategic aims: to popularize science; actively engage in discourse on science and technology; promote science communication; and profile South African scientific achievements. It singles out the three national research facilities for nuclear sciences, biodiversity and environmental sciences, in particular, for an injection of capital and expansion.

These priorities are reflected in the *South African Research Infrastructure Roadmap* (2016) published by the Department of Science and Technology. By the time of the roadmap's launch, seven new types of research infrastructure had already been approved (Table 20.3). A further six are foreseen.[34]

In 2016, the DST announced a ZAR 60 million (*ca* US$ 4 million) investment over three years to help meet demand in research and business for big data facilities. There are plans to extend the National Integrated Cyber Infrastructure System by establishing a regional data centre which could eventually form part of a national network of centres to support data-intensive activities. As of December 2020, this initiative appears to be ongoing.

The National Integrated Cyber Infrastructure System integrates the Centre for High Performance Computing,[35] the South African National Research network and the Data Intensive Research Initiative of South Africa. One of its strategic objectives is to enable large-scale global research and science projects, including the Square Kilometre Array telescope (Box 20.1).

The DST also directed funds towards establishing the National e-Science Postgraduate Teaching and Training Platform, which was launched in 2017. Its mission is to cultivate advanced skills in the area of e-science. Six universities offer master's degrees in this field through the platform, which welcomed its first 30 students in 2018. The number of students enrolled in an e-science degree programme doubled to 60 in 2019.

Experiments in co-funding R&D

Since 2013, several new funding instruments have been launched:

- The government has been experimenting with co-funding R&D in strategic sectors with industry, through the Industry Innovation Partnership (2013) fund.
- The Grassroots Innovation Programme (2019) provides social entrepreneurs and innovators in townships and rural areas with technical and financial support. Some 100 innovators were enrolled in the programme in 2019 to help them develop their concept and commercialize their ideas.
- The SME Fund (2016) is backed by ZAR 1.4 billion (*ca* US$ 93 million) in capital. By October 2019, the fund had approved ZAR 1 billion for investment, placing it among South Africa's largest institutional investors. In March 2019, it launched CEO Circle, an initiative with a mandate to invest in emerging businesses run by Black CEOs.
- The Sector Innovation Fund (2013) targets eight industrial sectors and is co-funded by the public and private sectors. A 2019 evaluation of the programme found a need for reform.

A 2019 impact evaluation suggested that the 2006 incentive providing a 150% tax deduction on a firm's research expenditure has had a positive impact on business R&D. However, the evaluation could not demonstrate a significant impact on the productivity, growth or profitability of the firms surveyed.

A broad evaluation of government incentive programmes (DPME/DSBD, 2018) has revealed a lack of co-ordination and learning in government around the design of these programmes; in many cases, monitoring and evaluation have not been incorporated.

Innovation Bridge Portal ready for Covid-19

In 2017, the DST launched the Innovation Bridge Portal, an online platform to foster linkages between national and international innovators, industry and funding partners. The portal enables entrepreneurs to showcase their innovation, access support services and discover funding opportunities.

Table 20.3: **Research infrastructure approved by the *South African Research Infrastructure Roadmap***

Research infrastructure	Year established	Main function
Expanded Freshwater and Terrestrial Environmental Observation Network	2017	operates a network of instrumented landscape-level platforms for environmental research
The Nuclear Medicine Research Infrastructure (NuMeRI)	2017	medical imaging facility focusing on drug development and clinical research
South African Population Research Infrastructure Network (SAPRIN)	2017	consolidates existing health and demographic surveillance sites and leads the development of new ones; collects data to help tackle poverty, inequality, unemployment, lack of access to health care
South African Centre for Digital Language Resources	2019	supports the creation, management and distribution of digital language resources
Natural Science Collections Facility	2017	organizes more than 40 museums, science councils and universities hosting plant, animal and fossil specimens; houses collections in a virtual facility
Shallow Marine and Coastal Research Infrastructure (SMCRI)	2016	provides instruments and physical research platforms along the coast of South Africa to collect data to support environmental policy-making
DIPLOMICS	2017	a network of academic, commercial and industrial labs working in biological disciplines with the 'omics' suffix; supports laboratory infrastructure and advanced training for technicians

During the Covid-19 pandemic, the portal created a space for researchers to submit the details of research projects pertaining to the pandemic, with options to request support for expertise, funding or materials. On another page, innovators could submit information about their inventions and request support for distribution, licensing, sales, etc.

In 2016, the Ministry of Telecommunications and Postal Services released the *National Integrated ICT Policy White Paper,*[36] which delivers a strategy for embracing the Fourth Industrial Revolution, including by stimulating domestic and foreign investment in ICT infrastructure, manufacturing, services and R&D.

IBM Research–Africa, the first industrial research facility on the African continent, is developing Industry-4.0 technologies in Kenya and South Africa (Box 20.4).

A multipronged approach to Industry 4.0

A Commission on the Fourth Industrial Revolution was appointed in 2019, consisting of about 30 stakeholders with a background in academia, industry and government. Its mandate is to ensure that the integration of digital processes boosts competitiveness, supports rural development and is inclusive, especially for youth and women across the Industry 4.0 value chain.

Box 20.4: The social responsibility compact between IBM and the Government of South Africa

The South African government has passed legislation to ensure that companies behave as responsible corporate citizens. Codes of Practice require all entities operating in the South African economy to contribute to the objectives of Broad-based Black Economic Empowerment (B-BBEE).

Since multinationals may have global practices preventing them from complying with the ownership element of B-BBEE through the traditional sale of shares to Black South Africans, the Codes of Practice have made provision for the recognition of Equity Equivalent contributions, as an alternative contribution to the economy.

When IBM decided to set up a research lab in South Africa in 2016, it negotiated an agreement with the government under which IBM pledged to set up an Equity Equivalent Investment Programme.

A focus on social priorities in the host country

Dr Tapiwa Chiwewe from IBM Research in South Africa described the ways in which IBM was fulfilling its commitment to social responsibility in South Africa, at a session on capacity-building in basic and applied research organized in Morocco on 13 December 2018 as part of UNESCO's Forum on AI for Africa.

He explained that IBM was focusing its research in South Africa on health care, education, agriculture and financial services. 'For instance, there is a four-year lag in reporting cancer statistics in South Africa', he said. 'AI can correct this by automating the process of studying pathology reports, meaning that this analysis can now be done in near-real time. In the financial sector, access to credit is a problem. An AI application can create a credit score that will reduce the default rate on repaying loans.'

The first industrial research facility on the African continent, IBM Research–Africa is present in both Kenya and South Africa. The lab in Nairobi is helping farmers in Nigeria to predict crop yields better, manage utilization and maintenance of tractors and obtain financing for the tractors. In Sierra Leone, during the Ebola crisis in 2014, IBM partnered with mobile network operators and the Open Government Initiative to develop a system that enabled citizens to report Ebola-related issues and concerns via texts or voice calls.

The IBM research lab in South Africa is located in the Tshimologong Digital Innovation Precinct, an innovation hub close to Wits University of international repute. In parallel, IBM has set up an academic programme offering internships and scholarships to South African students.

In Dr Chiwewe's view, the best place to train people is the university campus. However, Dr Chiwewe has concluded from his tour of computer science departments across South Africa that few are doing research on AI. This suggests a need for curricular reform.

A number of companies and banks have sponsored university chairs in South Africa. This is a two-way street, since businesses can then recruit qualified students.

Mentorship for young inventors

IBM has an enterprise development programme that provides mentorship for young inventors. 'Today's start-ups have the advantage of being able to access equipment via the cloud from companies such as IBM', says Chiwewe, 'where they can even open free accounts. There is a freer flow of information and knowledge nowadays, which gives start-ups an advantage over their forebears'.

Jumo is one example of a South African start-up that has become a viable business. It has launched an AI-powered platform to assess lending risk and tailor financial products to those living in developing countries where credit information is scarce; it has received an investment of US$ 52 million from several investors, including Goldman Sachs.

Chiwewe told the UNESCO workshop that 'IBM believes in the open source movement and donates some of its patents to open source initiatives. Anyone can log onto IBM's Digital Nation Africa platform to learn about technologies such as AI and obtain a certificate. For more advanced technologies like quantum computing, people can access a 16-qubit quantum computer via the cloud through IBM's Q Experience'.

Source: UNESCO (2019)

An Inter-Ministerial Committee on Industry 4.0 was set up in 2019. It co-ordinates government efforts across seven ministries, as well as the work of the Council for Scientific and Industrial Research (CSIR).[37]

In 2019, South Africa and the World Economic Forum (WEF) signed an accord to establish an affiliate centre of the WEF's Fourth Industrial Revolution Centre as a public–private partnership. Based at the CSIR, the centre will focus on emerging and convergent technologies.

The CSIR hosts programmes on 3D printing at its National Laser Centre. It also runs a Data Science for Impact and Decision Enhancement programme, which trains youth in big data and analytics, using real-life case studies. This programme is central to the government's goal to equip one million young people with skills in data science, 3D printing, cybersecurity, digital content creation, drone piloting and software development by 2030.

In line with the *Big Data Implementation Strategy and Action Plan* (2016), there have been efforts to build computing capacities in partner countries. Computer racks have been delivered and training workshops conducted by the Centre for High Performance Computing in several partner countries, including Namibia (see chapter 20).

Laying the groundwork for open science

In addition to leading the development of the African Open Science Platform (Box 20.5), the government has sought to advance an open science agenda at the national level.

Within the framework of the SA–EU Strategic Partnership, the *SA–EU Open Science Dialogue Report* was published in October 2018. It provides an initial policy framework, a precursor to a formal policy.

The document is founded upon the Department of Science and Technology's recognition that open science is a 'game changer' with the potential to ensure that scientific research is 'cumulative', transparent, informed by data, accessible and supported by public trust. The report's main recommendation is to establish an independent Open Science Advisory Board, which would also assume the functions of co-ordination and monitoring. The report also recommends establishing an open e-learning platform and training programme.

UNITED REPUBLIC OF TANZANIA

Transnational railway under construction

Tanzania graduated to lower middle-income status in 2019 (World Bank, 2020g). Since October 2015, the government has clamped down on corruption and sought to improve public administration.

FDI dipped from 5.7% to 1.7% of GDP over 2010–2016 and has not recovered since. Investors face barriers to hiring foreign workers, opaque tax policies and a relatively unstable regulatory environment (USDoS, 2020).

The *National Development Plan 2016–2021* (2016) emphasizes industrialization and human development as twin priorities. The plan uses the phrase 'business unusual' to encapsulate its ambition of graduating to a middle-income,

Box 20.5: The African Open Science Platform

In December 2016, South Africa's Minister of Science and Technology launched a three-year initiative to lay the foundations for the African Open Science Platform. Funded by the South African Department of Science and Technology, the initiative set out to offer guidance on data policy, map the African landscape and begin the process of building a pan-African open science community.

A Draft Strategy for the African Open Science Platform was developed in early 2018. It argued that 'there is no alternative for Africa but to adapt to this new paradigm but in its own, unique way, as a leader and not a follower'.

The draft strategy acknowledged the risk that open science might allow better-funded research systems to reap the benefits of Africa's open data (AOSP, 2018), yet its authors could 'see no other option'. In their view, to counter the trend towards open science would be to limit the resources available to scientists and impede international collaboration and engagement. With open science being pursued elsewhere, there was a risk that the African knowledge divide could deepen.*

This vision formed the basis of the official strategy, which was launched at the Science Forum South Africa in late 2018.

The African Open Science Platform should provide scientists and other actors with the tools to embrace open science, facilitate data-intensive research and provide a digital space for interaction between scientists and other stakeholders. The platform comprises six strands:

- a federated network of computational facilities and services;
- software tools and advice on policies and practices concerning research data management;
- a Data Science and AI Institute in data analytics;
- priority application programmes, such as in relation to cities, disease, the biosphere and agriculture;
- a Network for Education and Skills in data science and information; and
- a Network for Open Science Access and Dialogue.

Membership will comprise pan-African, regional and national institutions, which will participate in financing the platform and in implementing the six strands. Each of the strands is to be operational by 2021.

*See essay on The Time for Open Science is Now, p. 9.

Source: compiled by Jake Lewis; see: http://africanopenscience.org.za/

semi-industrial economy by 2025, a goal first set out in the *Tanzania Development Vision* to 2025 (1999).

Several major infrastructure projects have been launched. In April 2017, construction got under way of the Tanzania Standard Gauge Railway system, which will extend into Rwanda, Uganda, Burundi (see also Chapter 19) and the Democratic Republic of the Congo. This railway replaces an old metre-gauge system and is expected to reduce freight costs by 40%. As of June 2020, the first phase (300 km) was about 80% complete; the remaining four phases are set to add an additional 1 450 km (Ayemba, 2020).[38]

The Ministry of Transport announced plans in October 2019 to double the aircraft fleet of Air Tanzania, to 14 by 2022, following completion of the new Terminal III at Julius Nyerere International Airport in May (CGTN, 2019).

The Tanzania Strategic Cities Project (2010–2020) has received a total investment of US$ 343 million, primarily from the World Bank. The project is rehabilitating, upgrading and constructing urban roads, footpaths and foot bridges in eight rapidly urbanizing cities (World Bank, 2020h).[39]

Three-quarters of rural communities electrified

The *National Energy Policy 2015* plans to achieve 10 GW of total installed capacity by 2025. Resources have been pumped into the country's utility company, TANESCO, to enhance its technical and financial capacities.

In February 2020, the Minister for Energy, Medard Kalemani, announced a rural electrification rate of 74% (9 001 villages). This exceeds the government target of connecting 7 697 villages to the grid between 2016 and 2021 and places Tanzania among the leaders in Africa for this indicator (Tanzania Invest, 2017; TDN, 2020).

University courses on innovation

Tanzania's National Science and Technology Policy (1996) was replaced by the *National Research and Development Policy* (2010). This policy was, itself, due to be updated in 2020 to incorporate innovation, industrialization and technology transfer but this does not seem to have materialized.

After its Innovation and Entrepreneurship Centre opened in 2015, the University of Dar es Salaam incorporated practice-oriented innovation and entrepreneurship courses into its curricula, as undergraduate and postgraduate electives. The centre offers business counselling and incubation services to students, staff and SMEs, including business plan development, advertising and marketing and financial guidance.

Data on industry and innovation are still relatively scarce. To fill this information gap, the government is 'mobilizing resources from internal and external sources' to support sustainable, high-quality data systems. Building metadata for indicators is a priority (United Rep. Tanzania, 2019, p. 105).

Fintech gaining ground

The *National ICT Policy* (2016) updates the government's 2003 strategy. It aims to strengthen leadership and cultivate human capital in this field, while expanding the provision of reliable broadband.

There are plans to establish an accreditation body for ICT professionals and a separate mechanism connecting training institutions to employers. A new programme will empower citizens to use ICTs. Benchmarks include raising expenditure on ICTs to 0.3% of GDP and filling 90% of the National Data Centre's capacity by mid-2021.

The National Data Centre was established in 2016 (USDoS, 2020). In addition to offering public and private entities services such as data storage and back-up and domain registration, the centre has ventured into fintech; in July 2020, it launched the N-Card enabling digital payments.

Mobile financial services are beginning to substitute conventional banking and payment channels. By 2019, 78% of adults in rural Tanzania could reach formal financial services within a radius of 5 km. As these services have expanded, dependence on informal financial services has declined: from 16% to 7% over 2014–2017 (United Rep. Tanzania, 2019).

There are 31 active technology hubs in Tanzania (Figure 20.2), including the Dar Teknohama Business Incubator (Box 20.6).

ZAMBIA

Agricultural yields threatened by climate change

About six in ten livelihoods in Zambia depend on agriculture. This sector is under pressure from the growing frequency and intensity of extreme weather events. In 2017, the combination

Box 20.6: **Dar Teknohama: a business incubator with a digital mission**

The Dar Teknohama Business Incubator (DTBi) operates as a company with a focus on supporting digital ventures.

With the Tanzania Commission for Science and Technology serving as its guarantor, DTBi is working with local governments to establish similar tech hubs at district level. There are presently six ventures supported by DTBi in Mwanza.

Since 2017, DTBi has collaborated with mobile operators like Airtel to train hundreds of active and aspiring entrepreneurs in information technology.

In June 2018, the hub launched the Tanzania Digital Youth Empowerment Programme (TADIYE) with support from the Embassy of Denmark, to equip budding young entrepreneurs with digital skills through a mobile app.

The app also hosts the Business Plan Innovation Challenge for young entrepreneurs aged 15–35, which provides winners with seed funding of TZS 10–20 million (*ca* US$ 4 000–8 000).

The second round of the challenge saw TZS 320 million (*ca* US$ 140 000) awarded to 24 entrepreneurs. One winning idea was to produce bags that naturally decompose in the soil within 180 days.

Source: compiled by Jake Lewis; see: https://tadiye.or.tz/

of persistent drought and power cuts eroded agricultural productivity and commodity prices. It also fuelled the fiscal deficit (Rep. Zambia, 2020). In November 2020, the government announced plans to default on its foreign debt as a consequence of the Covid-19-induced global economic slowdown.

The government's forthcoming *Climate-Smart Agriculture Strategy Framework* is expected to identify targeted climate-smart practices and institutional mechanisms to support their implementation. The investment plan identifies the following climate-smart practices as showing promise in Zambia: commercial horticulture, crop diversification into legumes, agroforestry and strategies to reduce post-harvest losses.

Poverty and hunger remain serious challenges in Zambia but there has been some progress. Multidimensional poverty declined from 69% to 59% in rural areas over 2016–2020, according to government estimates. Between 2014 and 2019, the scope of the Social Cash Transfer programme was extended from 38 to all 116 districts. This programme has been making regular cash payments to poor households since 2003 (Rep. Zambia, 2020).

Drop in rainfall undermining hydropower

Access to electricity has improved only marginally since 2013 (see Table 19.2), when it reached about 28% of the population.[40] Hydropower accounted for about 81% of Zambia's installed generation capacity in 2019 but has become an unreliable resource, owing to insufficient rainfall.

In the third quarter of 2019, there was a 700 MW energy deficit. To help correct this, the government introduced a feed-in-tariff scheme for small-scale (below 20 MW) renewable energy projects, which have, thus far, seen 200 MW of solar and small hydropower projects commissioned (Rep. Zambia, 2020).

Zambia has also adopted a *National Nuclear Policy* (2020). The ultimate goal is to weave nuclear power into the energy mix to help curtail reliance on hydropower but the policy will also support applications in areas such as health, agriculture and mining.

A shift from sector-based to integrated planning

The *Seventh National Development Plan* for 2017–2021 is the government's first attempt to shift from sector-based to an integrated planning process, in order to improve co-ordination. Its five pillars centre on: economic diversification and job creation; reduction in poverty and vulnerability; reduction in development inequalities; improving human development; and strengthening governance.

The *National Malaria Elimination Strategic Plan 2017–2021* also represents a significant policy shift. Whereas the emphasis used to be on alleviating the burden of malaria, the ambition now is to eliminate malaria altogether by 2021, through improved health care and community engagement. The incidence of malaria declined from 346 to 319 cases per 100 000 population over 2015–2018 (Rep. Zambia, 2020).

A new dawn for industrialization?

Industrial policy was formerly covered by the *Commercial, Trade and Industrial Policy* (2009) but, in light of the underperforming industrial sector and policy gaps, the government released the more focused *National Industrial Policy* (2018–2027) in March 2018.

This policy's key objective is to transform Zambia into a net exporter of value-added goods, utilizing local primary resources. The policy identifies the main barriers over the 2010–2015 period as being low levels of investment, little value addition in extractive industries, an unfavourable tax regime and a lack of engineering skills, in particular.

The policy identifies eight priority subsectors: processed food; textiles and garments; engineering products; wood and wood products; leather and leather products; mineral processing and products; pharmaceuticals; and the blue economy.[41]

Measures include raising investment in supportive infrastructure, promoting R&D with a focus on commercialization; and developing a framework to help formalize micro-enterprises and SMEs. These will be accompanied by new legislation to promote investment, incentive regimes, value addition and local content.

The policy identifies an imbalance in access, ownership and control of productive resources as a key contributor to gender inequality. The government is striving to right this imbalance, not least because 'gender is an economic issue,' by allocating 30% of the resources of the Citizen Economic Empowerment Fund to women.

There are signs of a new dawn for industrialization. The Zambia Industrial Park in Lusaka, which focuses on construction materials, had created more than 300 jobs and contributed more than US$ 10 million to government tax revenue by August 2020. Launched two years earlier, the park was developed with investment from the China National Building Materials Group. It, reportedly, features automated production lines (MS, 2020).

In 2018, construction got under way of the major Chibombo Multifacility Economic Zone, which will receive an initial Chinese investment of US$ 300 million. This facility is expected to create 5 000 local jobs and boast annual productive capacity. The zone is expected to support manufacturing plants in areas such as motor vehicle and generator assembly and food processing (Silimina, 2019).

Young entrepreneurs being encouraged to innovate

Zambia's *Science, Technology and Innovation Policy* dates back to 1996 but an updated policy is reportedly ready for release. Existing research infrastructure is still geared towards basic research and the handful of accredited laboratories do not meet the productive sector's quality standards.

The Science and Technology Innovation Youth Fund is managed by the National Science and Technology Council, which receives an annual government allocation of about US$ 600 000 to pay for research proposals. The council's call for proposals for 2020–2021 awards a maximum of ZMK 250 000 (*ca* US$ 14 000) to 18–35-year-old applicants with an innovative proposal that addresses a national priority area.

In November 2020, Zambia's National Technology Business Centre signed an agreement with the UNDP for a National Innovation Initiative. This led to a call for entrepreneurs and early-stage start-ups to propose inventions that support sustainable development. The 20 winners will each receive a ZMK 50 000 award (*ca* US$ 2 800) at an innovation fair to take place in Lukasa.

ZIMBABWE

A focus on value addition

In 2018, Zimbabwe underwent a historic change in leadership. The new government has expressed a commitment to pragmatic economic transformation to attract investment.

The El Niño climate pattern of 2019 brought on a drought which compromised agricultural yields. Cyclone Idai followed in March. Extreme poverty is estimated to have risen from 29% to 34% of the population over 2018–2019, driven by economic contraction and a sharp rise in prices for basic commodities (World Bank, 2020i).

The central ambition of Zimbabwe's *Vision 2030* (2018) is to achieve upper middle-income status by 2030. The focus is on value addition and beneficiation, to produce higher-value exports. This objective is to be realized through the Transitional Stabilization Programme for 2018–2020, followed by two five-year national development strategies. The first of these was launched in November 2020; it targets an annual growth rate of 5%, with emphasis on the agricultural, mining, electricity and manufacturing sectors.

R&D a feature of the industrial plan

The *National Industrial Development Policy 2019–2023* (2019) identifies fertilizers, pharmaceuticals, potato processing, dairy products, soya and packaging as priority industries for export.

To diversify the industrial sector and make it more competitive, the policy proposes mobilizing funds to develop innovation hubs and industrial parks; providing incentives for R&D with a focus on industrial applications; expanding hard and soft infrastructure for ICTs; and establishing a legal framework that ensures a fair ecosystem for SMEs and large-scale entrepreneurs.

Tax rebates and low interest rates are to be offered to firms that invest in R&D and imports of machinery and equipment are to be exempted from import duties. To promote investment, loans for certain projects will be covered by a government guarantee.

Milestones in fibre-optic networks

Since 2018, the government has been establishing information centres to provide urban and rural areas with enhanced last-mile connectivity. As of December 2020, 154 such centres had been established and were operating in all ten of Zimbabwe's administrative provinces. Broadband facilities have been made available to most universities at preferential rates, with support from private–public partnerships like Liquid Telecom.

Zimbabwe has been implementing the National Communication Fibre Optic Backbone project since 2009. Several milestones have reportedly been reached, including the completion of the Beitbridge-Masvingo-Harare and Beitbridge-Bulawayo-Harare links in 2019, implemented by the public telecommunications company TelOne via a US$ 98 million loan from China Exim Bank (Karombo, 2019).

Research in Industry 4.0 fields

In 2018, the Harare Institute of Technology was charged with taking the lead on Industry 4.0, in light of the competencies of its teaching staff in nanotechnology, bioinformatics, AI, big data analytics, biomedical engineering and other relevant fields.

The Zimbabwe High-Performance Computing facility was launched in 2015, with an interest-free loan from the Chinese government of US$ 5.4 million (The Herald, 2015). The facility has since implemented research programmes in areas that include cognitive robotics and architecture, data analysis for weather and climate change modelling, financial analytics, computational chemistry, civil protection, drug discovery and phylogenic analysis of HIV variants.

The year 2018 saw the launch of the National Geospatial and Space Agency. It is conducting research on fertilizer requirements for various soil types and mapping areas with solar potential and others with a prevalence of malaria, among other projects.

Six new science parks on the horizon

The *Second Science, Technology and Innovation Policy* (2012) is Zimbabwe's most recent.[42] As a signatory and Party to the *SADC Protocol on Science, Technology and Innovation* (2008) since 2018, Zimbabwe had committed to raising GERD to at least 1% of GDP by 2020. This was an ambitious target, given that a national *African Science, Technology and Innovation Indicators Survey* concluded in 2015 that Zimbabwe's GERD amounted to less than 0.001% of GDP.

The National Science Park and Innovation Hub programme was launched in 2018 to develop eponymous infrastructure at six universities, as well as an industrial park in in each of the ten administrative provinces. Funding allocated to the programme (US$ 60 million) is being used to build and purchase equipment for the six universities. By mid-2019, three of the six hubs were operational.[43]

Over 2012–2016, five universities took turns hosting an exhibition on Research and Intellectual Outcomes, Science Engineering and Technology. From 2020 onwards, it is planned to rebrand this exhibition as a package of ten provincial science fora; these will culminate in the Zimbabwe Science Forum, to be modelled on the Kyoto Science and Technology for Society Forum and South Africa Science Forum.

Education 5.0 expanding the mission of public universities

The Education 5.0 programme was launched in 2018, to expand the tripartite mission of public universities – teaching, research and community service – to include innovation and industrialization.

Under Education 5.0, public universities are being encouraged to work with local communities and start-ups to identify challenges and provide solutions. The programme tasks universities with establishing an innovation and industrialization fund drawing on tuition fees that is to be managed by non-university staff.

By 2019, at least one university, polytechnic, teachers' college or industrial training college had been established in each of Zimbabwe's ten administrative provinces. The government has also established four new science-focused universities since 2018.[44]

The Science, Technology, Engineering and Mathematics Enrolment Initiative was launched in 2015; it provided grants to over 2 560 candidates studying mathematics, physics, chemistry or biology at public secondary schools. The programme had to be suspended in 2018 for want of adequate financial support.

Over 2018–2019, the government introduced training programmes for science teachers at five institutions and launched a new teachers' training college in Mutare. A total of 780 qualified science teachers are expected to graduate and enter the education system by 2022.

Solar-powered streetlights

In 2015, the Harare City Council announced plans to install about 10 000 solar-powered streetlights, to put an end to the frequent power outages that had reportedly raised residents' fears of crime. It was anticipated that an investment of US$ 15 million would result in monthly savings for the city on electricity bills of US$ 200 000.

However, local media outlets have reported that most of the solar lights installed are dysfunctional and that four out of the five companies contracted have not met their obligations.[45]

In 2012, a memorandum of understanding was signed with Zambia to co-develop the Bakota Gorge Hydro-electric Power Station. Construction was expected to begin in 2020 but, as of November, the project is yet to get under way (CRO, 2020).[46]

CONCLUSION

A better environment for business and innovation

Successful regional integration in Southern Africa will take a cocktail of ingredients, including the removal of barriers to trade (especially non-tariff barriers), political and economic stability and greater freedom of movement for capital, goods, services and people.

Countries have been taking complementary steps, notably by investing in energy and digital infrastructure. Better public services through the development of e-governance and the availability of a more reliable electricity supply is making it easier for both local and foreign firms to do business in Southern Africa. Growing recourse to digital payment services is, meanwhile, offering opportunities for the development of e-commerce and fintech and should, ultimately, reduce the size of the informal economy.

Governments will now need to expand on these efforts, while harmonizing financial subsectors and actively implementing the African Union's *Protocol to the Treaty Establishing the African Economic Community Relating to the Free Movement of Persons, Right of Residence and Right of Establishment* to foster greater mobility. One impediment to greater uptake of digital services by consumers and businesses is their unaffordability. Greater competition in the market could help to lower costs.

Every SADC country now counts at least one active tech hub, incubator or accelerator. This trend should nurture nascent industries, promote diversification and feed an innovation-driven pattern of development. The Southern African Innovation Support Programme hosted by Namibia and funded by Finland is supporting this movement by developing a training curriculum for innovation-supporting organizations, mentoring innovation accelerators and holding hackathons and start-up weekends. Generally speaking, there is strong support at the regional level for greater co-operation and integration.

The Square Kilometre Array hosted by South Africa offers the region an opportunity for greater scientific co-operation. It has the potential to boost scientific mobility and, more generally, to develop cross-national capabilities in cutting-edge Industry 4.0 fields like artificial intelligence and big data.

More investment in renewable energy

Universal access to energy is a prerequisite for the development of every sector – from education and research to the economy and the efficient delivery of public services. SADC countries are expanding their electricity grid and have begun making a substantial investment in renewable energy sources. They have been developing partnerships with the African Development Bank, World Bank, Chinese Exim Bank, European Union and others to expand the grid and implement off-grid solutions like solar photovoltaics to reach the wider population.

Greater recourse to renewable sources of energy is a cornerstone of the regional strategy for achieving universal access to energy and coping with the effects of climate change, which is already taking its toll through more intense and frequent periods of drought and severe storms.

Large hydropower projects may not be an option for countries suffering from a chronic drop in rainfall. Even in countries blessed with abundant rainfall, such projects can exert a high environmental, social and economic cost for decades to come. In the desire to make up for lost time, there can be a temptation to think big but countries must take care not to sacrifice sustainability to oversized solutions that may bring the population little benefit and heighten debt exposure.

Digital technologies can potentially facilitate a move away from large-scale, centralized, dispatchable power to cleaner, decentralized and community-based means of energy production and consumption. However, progress on this front has been slow compared to other African regions like East Africa. Take, for example, the expansion of digital payment system M-Kopa into solar energy in Kenya (see Box 19.7).

Governments attuned to need for climate-sensitive development

Growth has been observed in scientific output from the region on renewable technologies such as biofuels, wind and solar energy. This is also the case for research on other SDG-related topics such as agro-ecology, help for smallholder food producers and climate-ready crops.

Governments have become much more attuned to the need for climate-sensitive development policies. Mozambique is investing in climate-resilient infrastructure, for instance, and Zambia has adopted a *Climate-Smart Agriculture Investment Plan*. Some SADC countries are collaborating on agricultural research, such as the joint calls for research proposals issued by Malawi, Mozambique and Zimbabwe in 2019.

This collaboration on agricultural research is part of a wider trend towards closer scientific ties. All but Angola, Madagascar and South Africa count another African country among their five top scientific collaborators, with South Africa being a pivotal partner for all but these two countries and Comoros.

KEY TARGETS FOR SOUTHERN AFRICA

- Angola seeks to develop five solar power plants for a total of 300 MW by 2022;
- Botswana's ambition is to become a high-income country by 2036;
- The Democratic Republic of Congo fixes two targets for research intensity in its draft STI policy: 0.80% by 2022 and 1% by 2030;
- Eswatini is striving to provide universal electricity access by 2022 and Mozambique by 2030;
- Madagascar plans to provide 70% of the population with access to electricity by 2030;
- Mauritius aims for renewables to account for 35% of total final energy consumption by 2025;
- Namibia aims to have a research intensity of 1% of GDP by 2022, Seychelles 2% of GDP by 2025 and South Africa 1.5% of GDP by 2030;
- Namibia aims to expand electricity access to 67.5% of the population by 2023, with an additional 220 MW to come from renewables;
- By 2030, South Africa expects to have granted more than 2 000 SKA bursaries at undergraduate, PhD and postdoctoral levels;
- Tanzania plans to achieve 10 GW of total installed electricity capacity by 2025.

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ENDNOTES

1 Burundi applied unsuccessfully for SADC membership in early 2017.
2 These countries are Botswana, Comoros, Eswatini, Lesotho, Malawi, Mauritius, Namibia, Seychelles, South Africa and Zambia. The services sector makes the greatest contribution to the economies of Seychelles, Mauritius and South Africa, at 70%, 67% and 61% of GDP, respectively.
3 The countries participating in the Trade Related Facility are Botswana, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, Swaziland, Tanzania, Zambia and Zimbabwe.
4 These are: Botswana, Lesotho, Mauritius, Namibia, Seychelles, South Africa, Eswatini and Zambia.
5 These three programmes are entitled: Support to Improving the Investment and Business Environment; Trade Facilitation Programme and Support to Industrialisation and Productive Sectors; and A Conducive Environment for Inclusive and Sustainable Industrial Development, Increased Intra-Regional Trade and Job Creation.
6 The first phase ran over 2011–2015, implementing training programmes and providing support for regional policy-making.
7 See: https://tinyurl.com/digital-governance-World-Bank
8 The seven aspirations of *Agenda 2063* are: a prosperous Africa based on inclusive growth and sustainable development; an integrated continent, politically united and based on the ideals of Pan-Africanism and a vision of the African Renaissance; an Africa of good governance, democracy, respect for human rights, justice and the rule of law; a peaceful and secure Africa; an Africa with a strong cultural identity, common heritage, shared values and ethics; an Africa whose development is people-driven, relying on the potential of the African People, especially its women and youth, and caring for children; and Africa as a strong, united, resilient and influential global player and partner.
9 This project received technical support from the United Nations Industrial Development Organization and financial assistance from Advanced Development for Africa.
10 See IRENA's Statistical Profiles: https://www.irena.org/Statistics/Statistical-Profiles
11 The World Bank (2020b) estimates that, in the Democratic Republic of Congo, two-thirds of the population could be given electricity access through off-grid solar home systems, for an investment of US$ 3.3 billion.
12 Zambia's *Climate-Smart Agriculture Investment Plan* (2019) was developed with World Bank support to guide policy-making but is not, itself, an official government policy. According to the plan, although climate-smart agriculture could mitigate the impact of climate change, productivity gains will not be sufficient to prevent further conversion of forest into agricultural land which, in turn, could impede progress towards Zambia's climate commitments.
13 Science granting councils distribute funds for R&D, as well as scholarships and bursaries; advise on policy-making; and co-ordinate bilateral and multilateral agreements in science and technology, among other things.
14 The ten countries to report data are: Angola, Botswana, the Democratic Republic of Congo, Eswatini, Seychelles, Lesotho, Mozambique, Namibia, South Africa and Tanzania. The first five of these were the new additions to the *African Innovation Outlook* (2019).
15 Sample sizes varied across countries for the third *African Innovation Outlook* (2019). Eswatini returned the highest number of questionnaires (149), followed by Namibia (68), Angola (41), Lesotho (36) and Seychelles (15).
16 The Southern Africa Network for Biosciences is operational in Botswana, Malawi, Mozambique, Namibia, Seychelles, South Africa, Zambia and Zimbabwe.
17 Now that the cable system is in place, data traffic between Angola and Brazil need no longer be directed through Europe and the USA.
18 See: https://tinyurl.com/EU-space-science-Botswana
19 See: https://www.mascom.bw/mascom-eschools-project/
20 The Democratic Republic of Congo ranked 183rd out of 190 countries in the World Bank's *Doing Business 2020* report.
21 Among the 56 SDG-related topics related to the SDGs analysed by UNESCO, the largest publishing increases concerned reproductive health and neonatology (+113%), traditional knowledge (+92%) and tropical communicable diseases (+72%) between 2012–2015 and 2016–2019.
22 About four-tenths of Eswatini's primary energy supply is imported, largely from South Africa and Mozambique (Govt of Eswatini, 2018).
23 Information regarding the level of activity presently taking place at the Royal Science and Technology Park was not available to the present authors.
24 Madagascar ranked 184th out of 190 countries for access to electricity in the World Bank's *Doing Business 2018* report.
25 See: https://tinyurl.com/y5d7vp8b
26 See: The Government Gazette of Mauritius (2019) General Notice No. 1036 of 2019. No. 51, 23 May.
27 See: https://tinyurl.com/y2jpcxnj
28 The cheapest prepaid broadband product cost US$ 4.78 in the first quarter of 2015, compared to US$ 1.88 in the same period in 2020 (RAMP, 2020).
29 The R&D surveys cover the following years: 2008, 2009, 2010, 2014, 2015, 2016 and 2017.
30 This project was also implemented in Indonesia; see chapter 26.
31 The National Innovation Conference in February 2019 was one outcome of the project Supporting the Development of Innovation Acceleration Platforms in Namibia.
32 These were the Innovation Design Lab and Fablab, hosted by the Namibian University of Science and Technology; the Innovation Hub at the National Commission on Research, Science and Technology; and the business incubators of the Ministry of Industrialization, Trade and SME Development.
33 Government institutions have also been re-organized since the new administration took office after the May 2019 elections. A Ministry of Higher Education, Science and Technology has been introduced, with responsibility for the Department of Science and Innovation and the Department of Higher Education and Training. These changes are expected to improve co-ordination and co-operation in formulating joint programmes.
34 The six additional types of infrastructure planned concern biobanks, a South African marine and Antarctic research facility, a nano-micro manufacturing facility, a solar research facility, a material characterization facility and a biogeochemistry research infrastructure platform. See the South African Research Infrastructure Roadmap (2016): https://tinyurl.com/y6jgf5ta
35 The South African Centre for High Performance Computing offers consultancy services in fluid dynamics, materials science, finite-element analysis, discrete element modelling and the design of high-performance system. It expanded its computational power in 2016, adding a 40 000-core petascale machine.
36 This gives effect to a 2015 recommendation for a multistakeholder ICT policy review panel.
37 The Interministerial Committee has six workstreams: infrastructure and resources; research, technology and innovation; socio-economic impact; human capital and the future of work; industrialization and commercialization; policy and legislation. Most universities have explicit plans to respond to Industry 4.0, including through the introduction of new courses. Since 2019, the University of Johannesburg has hosted the Department of Science and Technology/National Research Foundation/ Newton Fund Trilateral Chair in Transformative Innovation, the Fourth Industrial Revolution and Sustainable Development.
38 Other sources have estimated the total length at more than 2 000 km (Railway Gazette, 2017).
39 These are: Tanga, Arusha, Mwanza, Kigoma, Dodoma, Illemela, Mbeya and Mtwara. By 2017, the project had built 141 km of urban roads and 15 km of major drains (Tanzania Invest, 2017). The project has also supported local capacity-building to support future implementation of urban plans.
40 Access to electricity is much lower in rural parts of Zambia, at 8% (2018). The government has identified the connection fee as the main barrier to progress in rural electrification (Rep. Zambia, 2020).
41 Zambia's National Industrial Policy defines the blue economy as 'the transformation of marine and coastal sectors, as well as freshwater inland rivers and lakes, for economic growth through the development of fisheries and aquaculture, transport and logistics, including tourism.'
42 See Kraemer-Mbula and Scerri (2015) for more on this strategy.
43 Science parks have launched at Midlands State University (2018), the National University of Science and Technology (2019) and the University of Zimbabwe (2019). They are foreseen at the Chinhoyi University of Technology, Harare Institute of Technology and the Zimbabwe National Defence University.
44 These are Marondera University of Agricultural Sciences and Technology (est. 2018), Manicaland State University of Applied Sciences (est. 2018), Gwanda State University (est. 2018), and the Pan African Minerals University of Science and Technology (est. 2019).
45 See, for instance, Mushonga (2019) and The Herald (2018)
46 Once completed, the Bakota Gorge Hydroelectric Power Station will have a total installed capacity of 2.4 GW, to be shared between Zambia and Zimbabwe. Construction is expected to cost about US$ 5.2 billion and take until 2026 (CRO, 2020).

AT A GLANCE

Lifechangers stand at the Entrepreneurship Fair in Thimpu in October 2019. This social enterprise recycles textiles. In the past few years, Bhutan has developed a range of infrastructure to foster creative start-ups that includes the Thimpu TechPark, a Start-up Centre and a FabLab for young innovators. © Sirin Elci/UNESCO

- Bangladesh, Nepal, Pakistan and Sri Lanka all have explicit STI policies but implementation is being impeded by inadequate instruments, in a context of chronically low public research funding and a lack of incentives for mission-oriented research.
- Several countries are investing in major infrastructure projects through the Belt and Road Initiative.
- The Covid-19 crisis has galvanized new public–private partnerships. Bangladesh, Pakistan and Sri Lanka can all draw upon a growing manufacturing capacity in pharmaceuticals, even though they remain reliant on imports of raw materials.
- The digital economy is spawning a dynamic entrepreneurial culture among the young. Bhutan now has a FabLab for developers of digital products, for instance, telecommunications is one of Afghanistan's fastest-growing sectors and Pakistan counts several 'tech unicorns': start-ups that are valued at more than US$ 1 billion.
- All seven countries are vulnerable to climate change, which is exacerbating natural disasters such as flooding and drought. One challenge will be to ensure that the desired smart cities of the future are also climate-resilient.

21 · South Asia

Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, Sri Lanka

Athar Osama, Sohan Prasad Sha and Seetha I. Wickremasinghe

INTRODUCTION

Between the Elephant and the Dragon

Home to one-third of the world's most vulnerable populations, South Asia will need to redouble its efforts to reach the Sustainable Development Goals (SDGs). The challenge will be to balance jobs-oriented industrialization with environmental sustainability (UNESCAP, 2018).

On the surface, the seven South Asian economies analysed in the present chapter may look homogeneous but their underlying socio-economic structures are quite distinct. Whereas Bangladesh and Pakistan have a fairly sophisticated industrial fabric, the smaller economies of the Maldives, Nepal and Sri Lanka are primarily dependent on tourism and other service industries. Afghanistan's own economic development is being held back by ongoing political uncertainties and conflict.

Although most of these economies have flourished over the past five years – Nepal graduated to lower middle-income status in 2020 – their performance cannot rival that of Bangladesh (Figure 21.1). Bangladesh has not only managed to rein in population growth from 1.5% (2005) to 1.0% (2017); it has also embarked upon a major expansion of its exports, with emphasis on ready-made garments and, to a lesser extent, software services and pharmaceuticals. Exports of goods and services grew by 11% in 2019, according to the World Bank. This growth has had a knock-on effect on per-capita GDP and poverty reduction, transforming Bangladesh into an outward-looking, competitive economy. After acquiring lower middle-income country status in 2015, it is now on track to graduate out of the group of least developed countries by 2024.

The economic slowdown in Pakistan in 2019 (Figure 21.1) resulted from lower government spending and a higher borrowing rate mandated by the International Monetary Fund (IMF) to bring Pakistan's budget deficit down from 8.9% to 3% of GDP by 2020. At the time of writing in November 2020, the Covid-19 pandemic has made this target more elusive.

The pandemic has also depressed the economy of neighbouring India, a major driver of growth for South Asia. The economic fates of all seven countries remain entwined with those of the Elephant (India) and the Dragon (China).

In Pakistan, the steady decline in exports over the past five years has caused a balance of payments crisis that has precipitated the country into the IMF's fiscal consolidation programme.

The Maldives, Nepal and Sri Lanka are also experiencing a lull in trading competitiveness. To compound matters, these economies have been particularly vulnerable in 2020 to the drop in international tourism linked to the Covid-19 pandemic.

Covid-19 an opportunity for manufacturers

The local manufacture of pharmaceuticals has grown in Bangladesh, Pakistan and Sri Lanka over the past six years, even if these countries remain dependent on imports of raw materials. By the time the pandemic struck, Bangladesh and Pakistan had the capacity to manufacture remdesivir, for instance, and Sri Lanka was manufacturing most of the paracetamol consumed domestically.

Pakistan's pharmaceutical industry and manufacturers of medical devices and equipment have been galvanized by the Covid-19 crisis. In mid-2020, Ferozsons Laboratories signed an agreement with the US firm Gilead Sciences, the patent-holder of remdevisir, to produce the drug under license. In September, the National Institute of Health partnered with CanSino Biologics in China to participate in phase 3 clinical trials of a candidate vaccine, on the understanding that the vaccine would later be made available to Pakistan.

The Pakistan Engineering Council has brought together innovators, manufacturers and the regulator to produce a home-made, low-cost lung ventilator. The Sri Lankan Ministry of Health has partnered with Vega Innovations Pvt Ltd to do the same.

In October, Pakistan's first cardiac stent manufacturing facility, N-ovative Health Technologies at the National University of Science and Technology, began mass production of stents at a fraction of the import cost.

The global scale of the Covid-19 crisis has opened up new opportunities for export. The Sri Lanka Standards Institute developed guidelines in early 2020 for the manufacture of Covid-19 equipment and products, including face masks, hand sanitizer and gloves. These standards have been aligned with international specifications to ensure that manufactured products can be exported.

Sri Lankan pharmaceutical exports had been stagnating since 2016 but heightened demand during the Covid-19 crisis has led the government and private sector to invest US$ 30 million in a new pharmaceutical manufacturing plant within the Koggala Export Processing Zone.

Through its Solidarity Call for Action, WHO is creating a patent pool to ensure that essential medicines for Covid-19 are available to all countries. As of November 2020, Bangladesh, Bhutan, the Maldives, Pakistan and Sri Lanka had all signed up to the Call.

Intraregional forum contributing to pandemic response

Intraregional co-operation and collaboration in South Asia have always been a challenge, not least because of the strained relations between India and Pakistan (Nakandala and Malik, 2015). In 2018, the 19th SAARC summit was cancelled.

Beyond questions of trade, there is potential for the South Asian Association for Regional Cooperation (SAARC) to become a platform for scientific collaboration. This was the rationale behind the establishment of specialized regional centres in Agriculture and Meteorology (Bangladesh), Forestry (Bhutan), Coastal Zones (Maldives), Disaster Management (India), Tuberculosis and HIV Aids (Nepal) and Energy (Pakistan). However, in 2015, the three centres in Bangladesh, Bhutan and the Maldives were closed down, following a decision by the SAARC Secretariat, and their mandate transferred to the SAARC Disaster Management Centre in India (Islam and Karim, 2019).

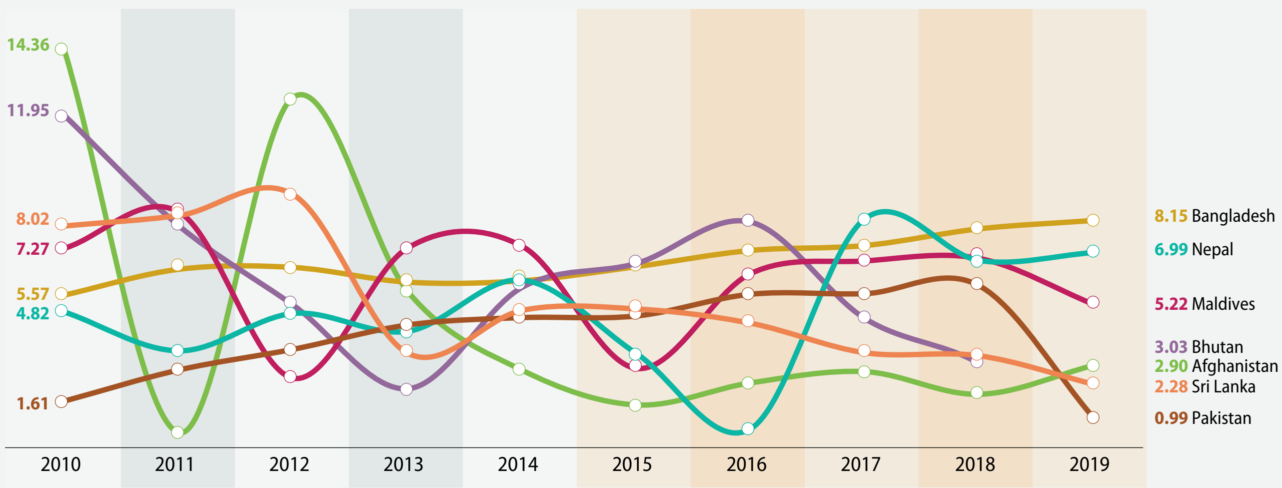
The Covid-19 crisis has highlighted the benefits of a shared intraregional forum. In March 2020, SAARC members agreed by videoconference to share information and establish a common fund to curtail the spread of the virus.

Ambitious projects within Belt and Road Initiative

At the bilateral level, China's Belt and Road Initiative (BRI) has made a considerable impact. The BRI seeks to link China with key trading partners and markets across Asia, Africa and Europe, through ambitious infrastructure projects along the historical 'Silk Road'. Bangladesh, the Maldives, Nepal, Pakistan and Sri Lanka have become major beneficiaries of the loans awarded within this project.

Figure 21.1: **Socio-economic trends in South Asia**

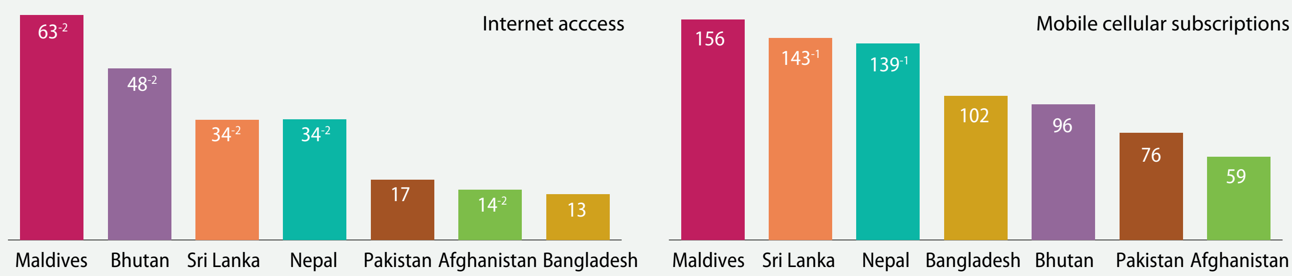
Rate of economic growth in South Asia, 2010–2019 (%)



Key socio-economic indicators for South Asia, 2019 or closest year

	Population (millions)	Population growth rate (%)	GDP per capita (constant 2017 PPP$)	FDI inflows as a share of GDP (%)	Remittances as a share of GDP (%)	Manufactured exports as a share of merchandise exports, 2017 (%)	High-tech exports as a share of manufactured exports, 2017(%)
Afghanistan	38.0	2.3	2 202	0.12	4.3	3.5^{-1}	
Bangladesh	163.0	1.0	4 754	0.53	6.1	95.8^{-4}	0.3^{-4}
Bhutan	0.8	1.1	$11\,345^{-1}$	0.11^{-1}	2.4^{-1}		
Maldives	0.5	2.9	18 914	10.11	0.1	0.4^{-1}	0.1^{-2}
Nepal	28.6	1.8	3 417	0.23^{-1}	26.9	68.3^{-2}	1.2^{-2}
Pakistan	216.6	2.0	4 690	0.80	8.0	74.1	2.3
Sri Lanka	21.8	0.6	13 078	1.82^{-1}	8.0	67.9^{-2}	1.0^{-2}

Internet access and mobile cellular subscriptions per 100 inhabitants in South Asia, 2019 (%)



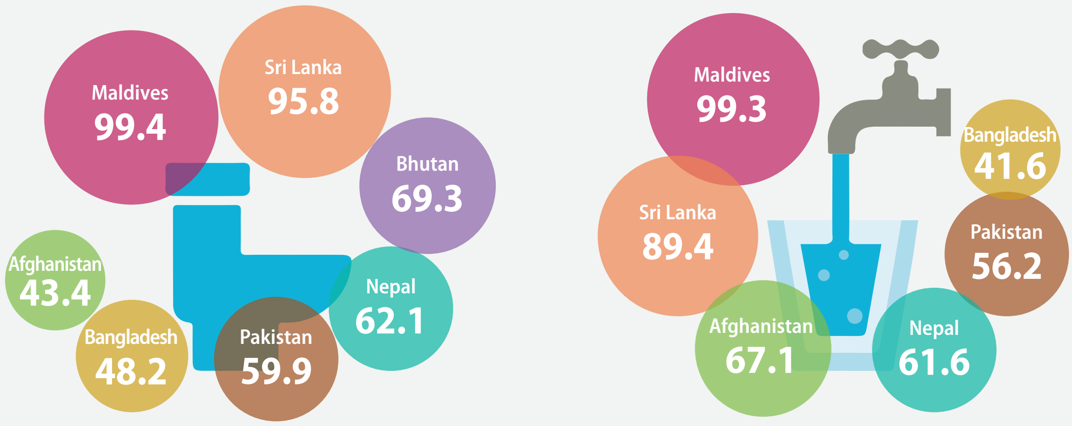
The Maldives is investing in three major projects with Chinese loans: an upgrade of the international airport, the development of a new population centre on reclaimed land and the relocation of the principal port.

According to the president of the Bangladesh Institute of Peace and Security Studies, investment in Bangladesh within the BRI framework will ultimately total US$ 40 billion. Of this, US$ 26 billion will be spent directly on BRI projects and a further US$ 14 billion on joint ventures. Projects include the US$ 4 billion Padma Bridge rail link being built to connect the northern and eastern regions of the country with the southwest (TDS, 2019).

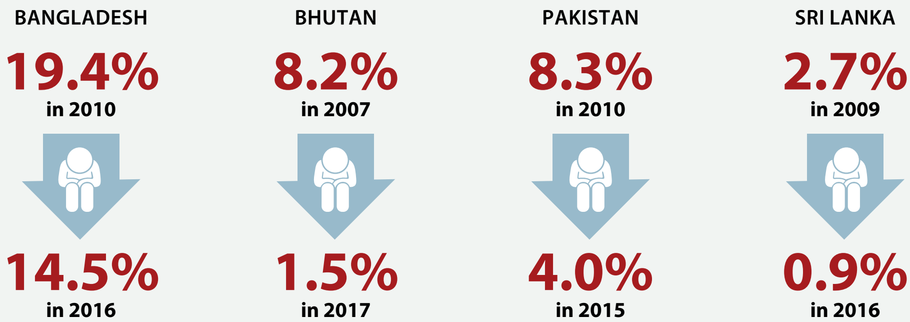
Sri Lanka's involvement has been confined to the Maritime Silk Road. The aim is to turn Sri Lanka into a hub for the transit of goods from China and other Asian economies. China is financing the development of the Colombo International Financial City on land reclaimed from the sea to the tune of US$ 8 billion. On the southern coast, the Port of Hambantota and an adjoining industrial estate are being established.

The China–Pakistan Economic Corridor remains the region's flagship BRI project. Loans estimated at about US$ 62 billion cover road and port infrastructure development linking Pakistan's northern region to Gwadar Port in the Arabian Sea, coupled with the development of primarily coal- and oil-fired

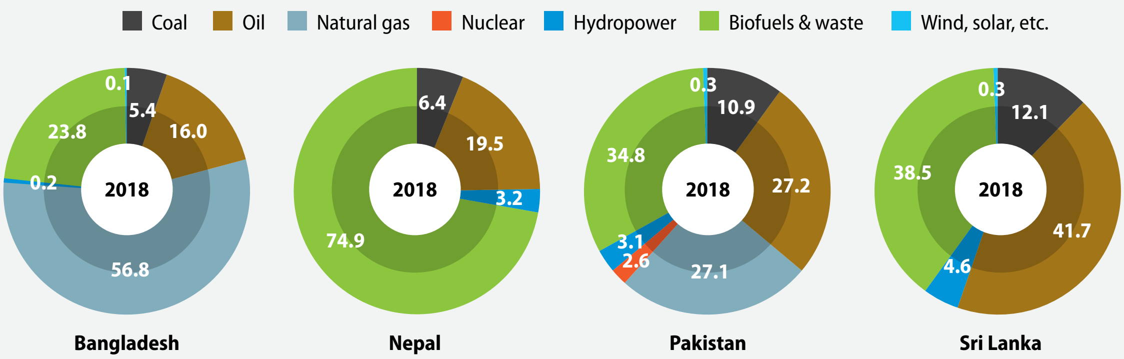
Share of South Asian population with access to at least basic sanitation and safe drinking water services, 2017 (%)



Share of population living in poverty, calculated at PPP$ 1.90 a day (constant 2011 values)



Share of total energy supply by source in South Asian countries, 2018 (%)

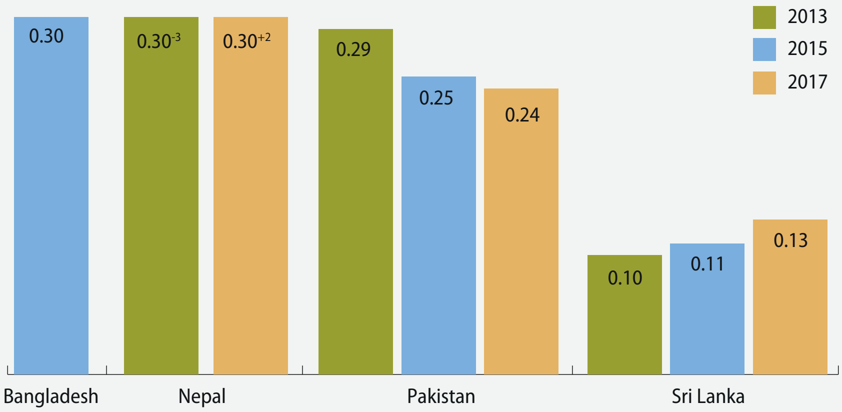


-n: data refer to *n* years before reference year

Source: World Bank's World Development Indicators, October 2020; for Internet use: ITU World Telecommunication/ICT Indicators Database, October 2020; for water and sanitation data: WHO/UNICEF Joint Monitoring Programme; for energy data: International Energy Agency

Figure 21.2: **Trends in research expenditure and researchers in South Asia**

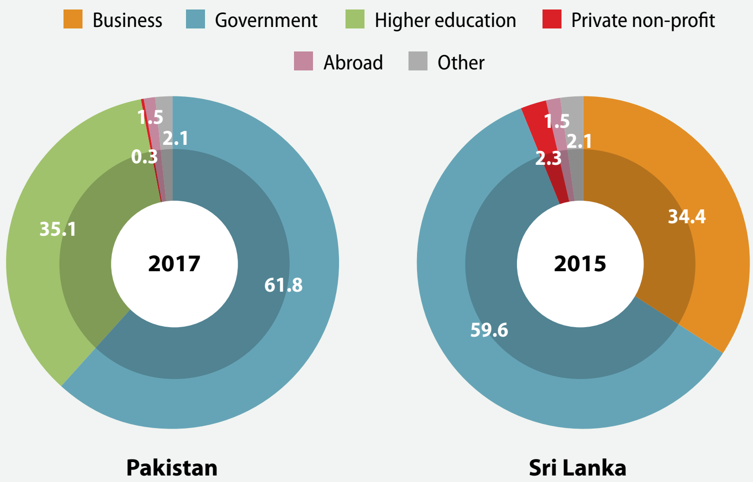
GERD as a share of GDP in South Asia, 2013, 2015 and 2017 (%)



107
Researchers (FTE) per million inhabitants in Sri Lanka in 2015

Researchers (FTE) per million inhabitants in Pakistan

GERD by source of funds in South Asia, 2017 or closest year (%)



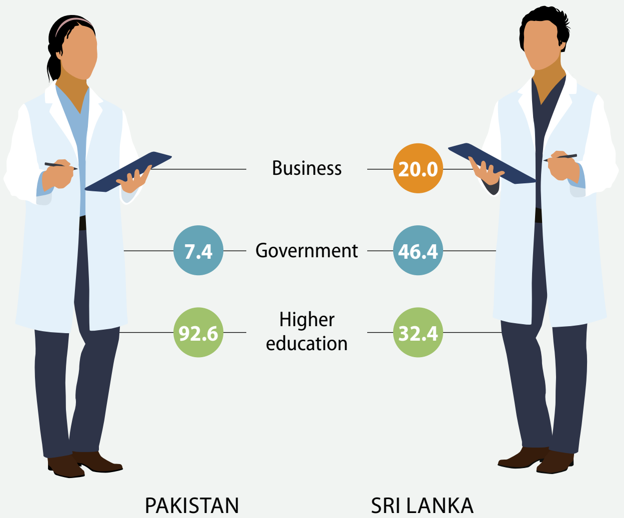
Share of female researchers (HC) in 2017

38.8% in Pakistan

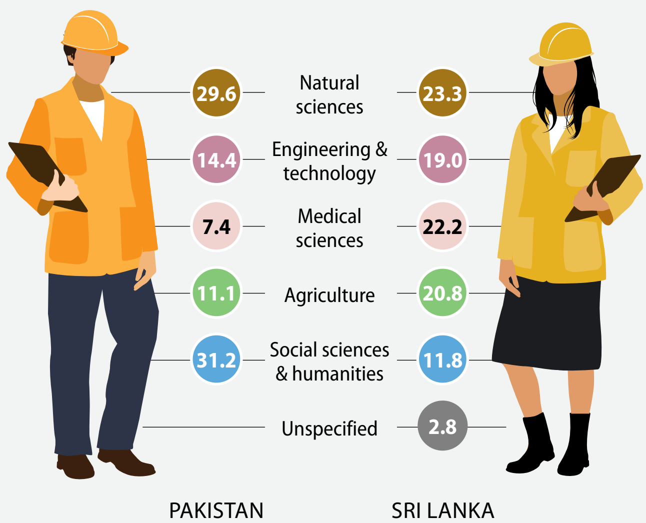
46.6% in Sri Lanka

Sri Lanka has attained gender parity for this indicator.

Researchers (FTE) in Pakistan and Sri Lanka by sector of employment, 2017 (%)



Researchers (FTE) in Pakistan and Sri Lanka by field, 2017



-n/+n: data refer to *n* years before/after reference year

Source: UNESCO Institute for Statistics; for Sri Lanka: National Science Foundation (2017) *National R&D Survey of Sri Lanka;* for Nepal's GERD/GDP ratio in 2019: NPC (2020); for Bangladesh's GERD/GDP ratio: Govt of Bangladesh (2020) power plants (Shaikh and Tunio, 2017). Among investments are a US$ 9.1 billion project to modernize Pakistan's railway network and an ambitious plan to set up special economic zones aimed at enticing Chinese industry (MoPDR, 2018).

RESEARCH TRENDS

Persistently low research spending

Science and technology will be paramount to achieving a healthy balance between industrialization and sustainability. However, chronic underspending on research and development (R&D) is undermining progress and confining the region to the role of recipient of foreign scientific expertise and technology. Often, the lack of scientific input or policy advice at the highest level has undermined the ability of science to address pressing challenges.

Recent data on expenditure reflect the low priority accorded to R&D (Figure 21.2). Nepal had fixed a target of doubling its research intensity to 0.62% of GDP by 2019 but this indicator remained stable at 0.30% in 2019 (NPC, 2020). Pakistan's research intensity (0.24% of GDP in 2017) has dwindled since 2009. The data for Pakistan may be underestimated, though, as they do not capture the defence and strategic sectors which concentrate a sizeable share of Pakistan's human and financial investment in research.

Given the modest expenditure on R&D in South Asia, it is logical that the size of the research pool[1] should be modest by international standards (Figure 21.2). This picture may change in the coming years for Bangladesh, Bhutan and the Maldives, in particular, which show rapid improvement in gross enrolment ratios at tertiary level. Nepal, on the other hand, has seen a decline for this indicator. Almost 83% of pupils drop out of school before completing their twelfth year.

In parallel to boosting student rolls, countries are also striving to improve the quality of education. For instance, the Bangladesh Accreditation Council was established in 2017 as an autonomous government agency to accredit higher education institutes and ensure quality assurance.

Nepal distances its neighbours at the five big patent offices (Figure 21.3). Since 2015, the great majority of Nepalese patents have been filed in China (140 in 2019). Pakistan, Sri Lanka and Bangladesh have the highest level of patenting activity at the US Patent and Trademark Office.[2] Nepal's *National Intellectual Property Policy (2017)* announced plans to replace the Patent, Design and Trademark Act to make patent filing a less cumbersome process in Nepal but this legislation has not yet been passed.

Despite low levels of research investment, the volume of scientific publications grew by more than 160% for all countries between 2015 and 2019 (Figure 21.4). There has been particularly strong growth in health sciences across the board.

Brain drain growing in some countries

Brain drain remains a chronic challenge in South Asia. Moreover, there are some signs that the flow is growing. The share of PhD-holders among Sri Lankan emigrants has grown slightly from 49.7% in 2010 to 50.4% in 2016, according to the Expatriate Scientists' Database of the National Science Foundation. More than four-fifths of Sri Lankan emigrants hold a postgraduate degree.

Nepalese students, who have a propensity to major in science, technology, engineering and mathematics (STEM) or related disciplines (Dilas *et al.*, 2018), are emigrating in growing numbers: outbound student mobility increased by 68% from 2012 to 2017.

Brain drain places a considerable strain on resources, since the government invests heavily in the student's university education only to see them emigrate.

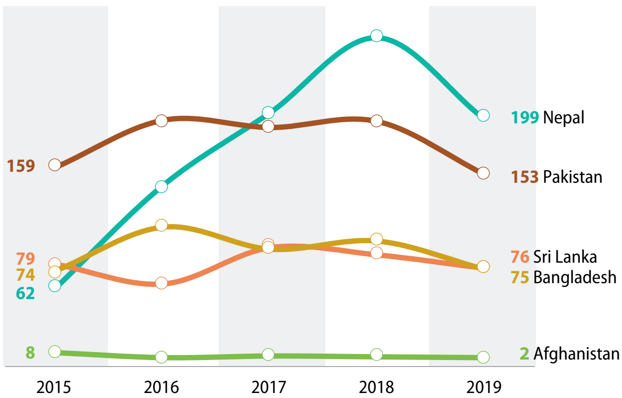
During the Covid-19 pandemic, many South Asian migrants have lost their jobs and returned home. The World Bank (2020) estimates that remittances have declined by 22.1% in South Asia. Since most of these remittances are used for daily consumption, the pandemic may severely impact education spending in the region.

Some intraregional scientific collaboration

With the exception of India, one of the closest scientific partners for all but Bangladesh and Pakistan, South Asian scientists tend to collaborate most with other G20 countries (Figure 21.4). China is the leading partner for Pakistani scientists and the fourth- and fifth-closest partner for Nepalese and Sri Lankan scientists. That Saudi Arabia should be Pakistan's second-largest partner can be explained primarily by links to the diaspora. Further research would be warranted, to determine whether other countries enjoy similar close ties with their diaspora.

There is limited scientific collaboration in the region. One current project focuses on Integrated Solutions of Water, Energy and Land in the Indus Basin, which is shared by Afghanistan, China, India and Pakistan. Since 2016, this four-year project has designed an inclusive stakeholder process, combined with integrated assessment modelling, to create an evidence-based discussion around critical issues for the

Figure 21.3: **Number of IP5 patents granted to inventors from South Asia, 2015–2019**



Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China. Bhutan and Maldives received no IP5 patents during the studied period.

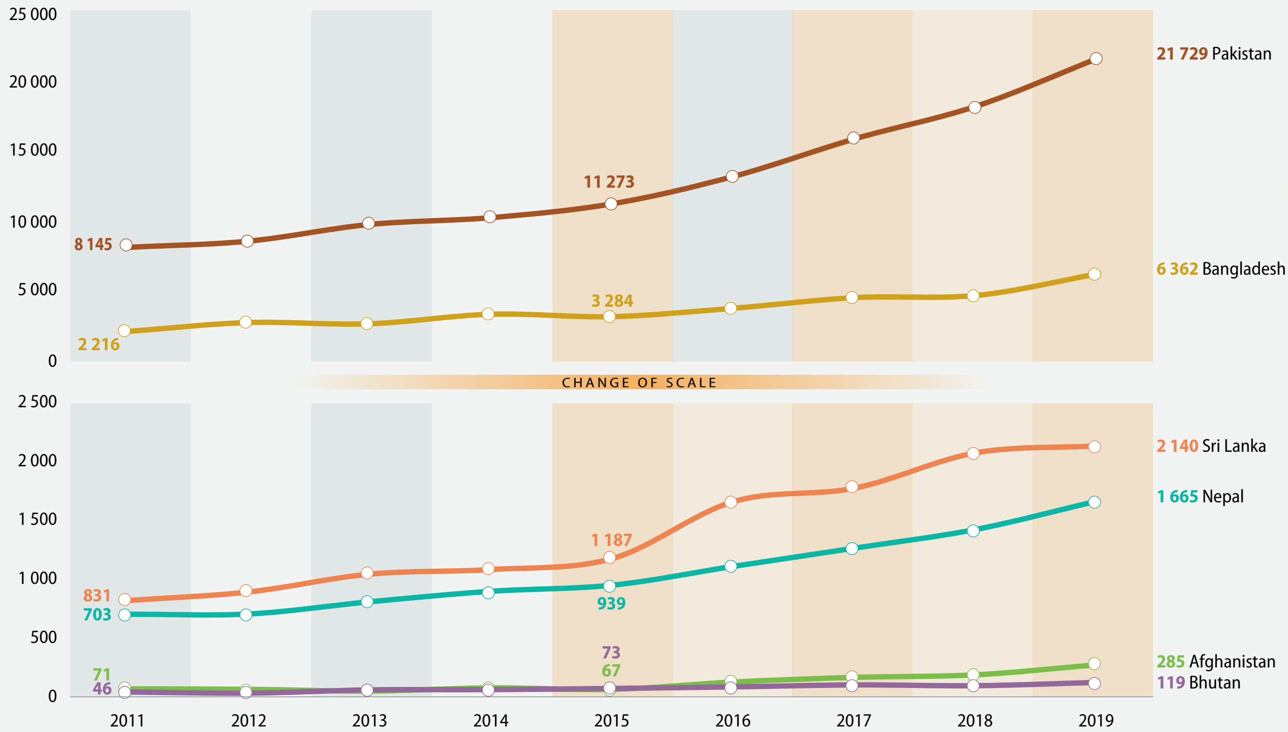
Source: PATSTAT, data treatment by Science-Metrix

Chapter 21

Figure 21.4: **Trends in scientific publishing in South Asia**

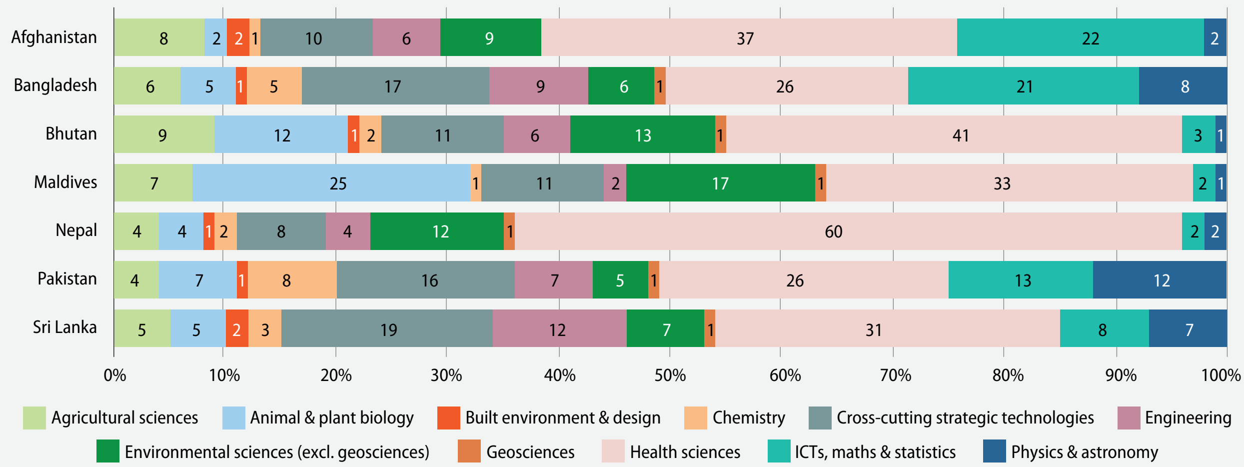
Volume of scientific publications in South Asia, 2011–2019

For countries with more than 100 publications in 2019

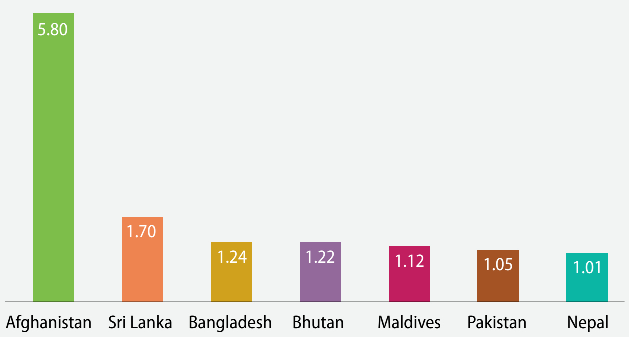


Note: Output by the Maldives peaked at 36 publications in 2019, up from 23 in 2015.

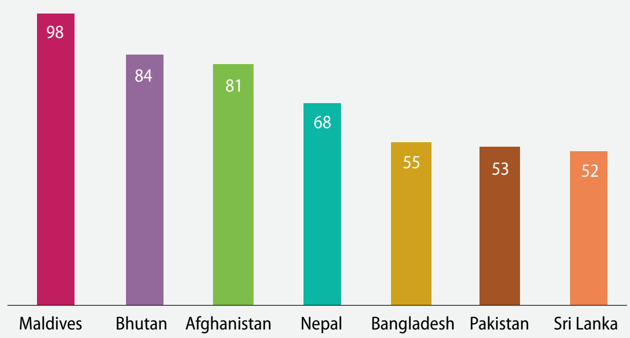
Scientific publications in South Asia by broad field of science, 2017–2019 (%)



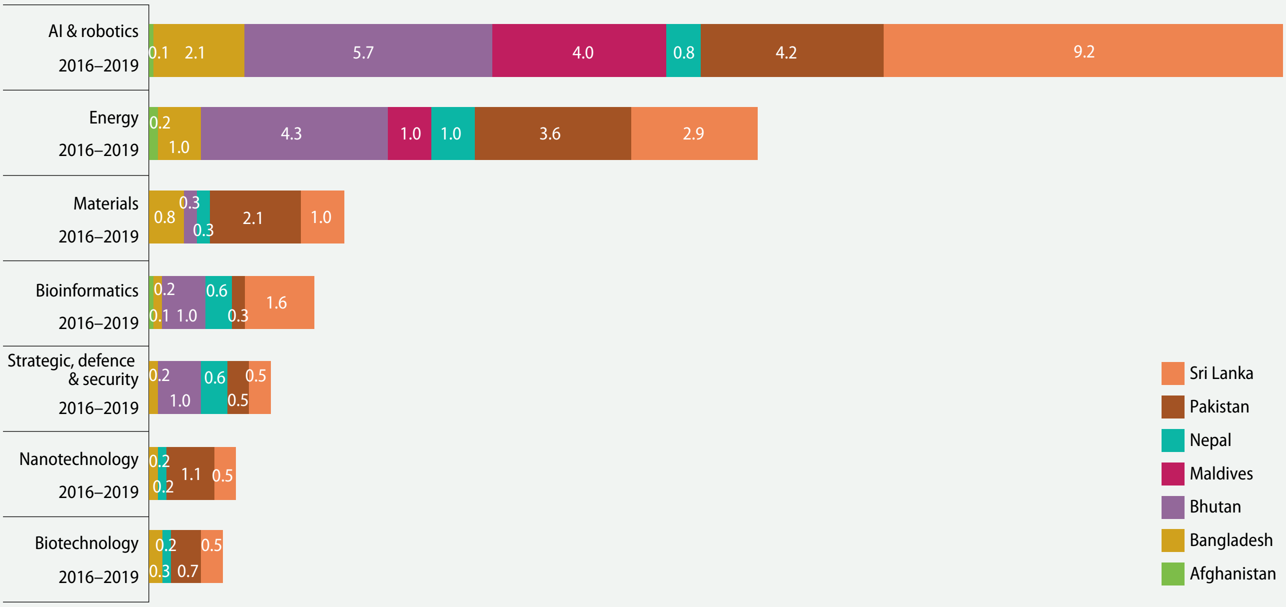
Average of relative citations for South Asia, 2014–2016



Share of publications with foreign co-authors in South Asia, 2017–2019 (%)



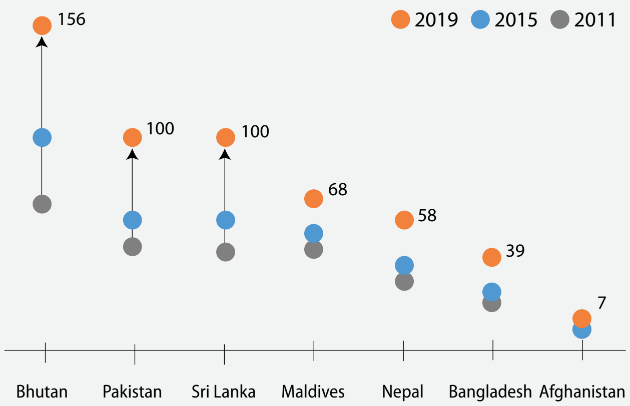
Scientific publications in South Asia per million inhabitants, by cross-cutting strategic technology, 2016–2019



Note: The length of the stacked bar does not reflect total regional output, owing to potential co-authorship among countries.

Scientific publications per million inhabitants in South Asia, 2011, 2015 and 2019

Data labels are for 2019



How has output on SDG-related topics evolved since 2012?

South Asian scientists (excluding India) published more on the following topics than would be expected, relative to global averages: tropical communicable diseases, sustainable use of terrestrial ecosystems, traditional knowledge, help for smallholder food producers, agro-ecology and the genetic diversity of food crops. The volume of publications on the sustainable use of terrestrial ecosystems at least doubled between 2012–2015 and 2016–2019 in Bhutan, Nepal and Sri Lanka.

Although clean energy is not yet a major specialization, output on several energy topics more than doubled in Bangladesh, Pakistan and Sri Lanka during the period under study, with Pakistan showing the most striking increase from 147 (2012–2015) to 756 (2016–2019) publications on smart-grid technologies.

Pakistani output on eco-industrial waste management also shot up from 132 (2012–2015) to 412 (2016–2019) publications, triple the average proportion of research in this field.

Researchers in Bangladesh are beginning to specialize in climate research, including as concerns disaster risk reduction, its impact on local communities and technologies to mitigate the same, with output doubling in each of these fields, albeit from low starting points.

For details, see chapter 2

Top five partners for scientific co-authorship, 2017–2019 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator(s)	5th collaborator
Afghanistan	USA (151)	Japan (94)	Pakistan (82)	India/UK (68)	
Bangladesh	USA (2 132)	Japan (1 513)	Australia (1 505)	Malaysia (1 070)	UK (1 059)
Bhutan	Australia (83)	USA (80)	India (67)	Thailand (46)	Nepal/UK (41)
Maldives	India (30)	UK (22)	Italy (21)	Australia (16)	Nepal (12)
Nepal	USA (932)	India (650)	UK (531)	China (415)	Australia (357)
Pakistan	China (9 216)	Saudi Arabia (5 691)	USA (4 674)	UK (3 444)	Malaysia (3 179)
Sri Lanka	USA (946)	UK (880)	Australia (831)	India (599)	China (577)

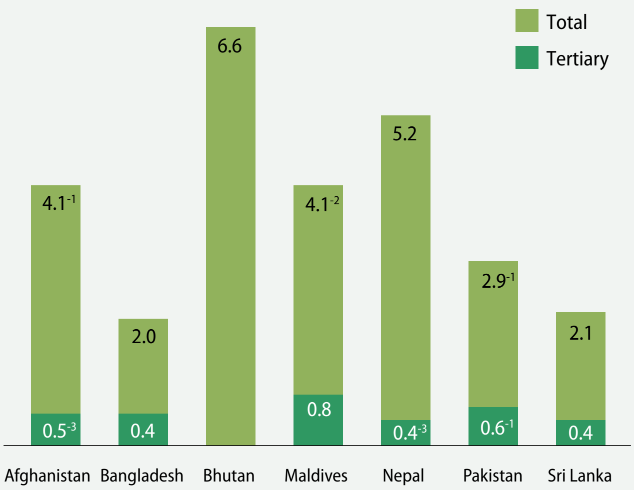
Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

region's future, such as water scarcity.[3] Synergies and trade-offs between the energy, hydro- and agro-economic systems in the basin have been analysed under different climate and development scenarios. One modelling exercise carried out collectively by researchers from the riparian countries concluded that annual investment in the Indus Basin would need to be ramped up to US$ 10 billion, to mitigate water scarcity issues and improve access to resources by 2050. However, these costs could shrink to US$ 2 billion per year, were countries to pursue more collaborative policies (Vinca *et al.*, 2020). The project is being led by the International Institute of Applied Systems Analysis, in partnership with the United Nations Industrial Development Organization and the Global Environmental Facility.

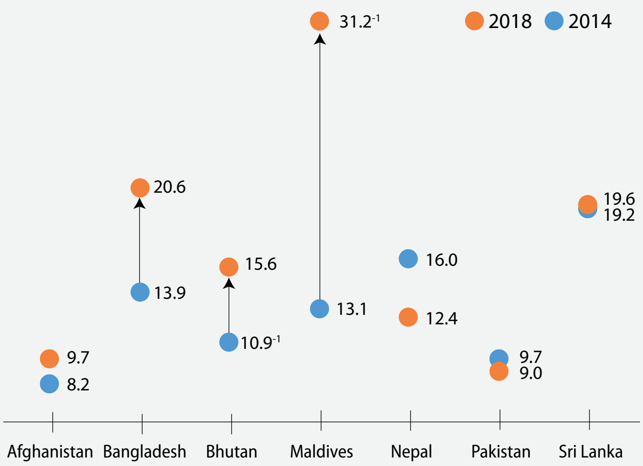
All seven countries are vulnerable to extreme weather events that are being exacerbated by climate change. Afghanistan experienced a severe drought in 2018 and as much as one-third of Bangladesh was flooded in mid-2020 after the heaviest rains in a decade (Hasine, 2020).

Figure 21.5: **Trends in higher education in South Asia**

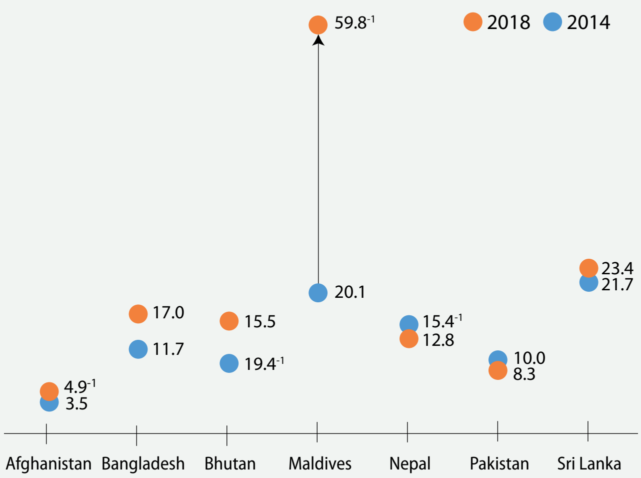
Government expenditure on education as a share of GDP in South Asia, 2018 (%)



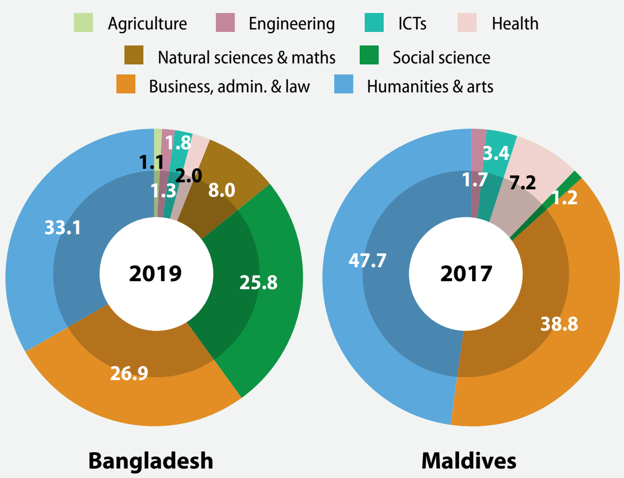
Gross enrolment ratio at tertiary level for both sexes in South Asia, 2014 and 2018 (%)



Gross enrolment ratio for women at tertiary level in South Asia, 2014 and 2018 (%)



Distribution of tertiary graduates by programme in Bangladesh and the Maldives, 2019 or closest year (%)



-n: data refer to n years before reference year

Source: UNESCO Institute for Statistics and MoEST (2017) Nepal Education in Figures

COUNTRY PROFILES

AFGHANISTAN

Largest hydropower plant rehabilitated

After experiencing rapid growth of 9% per year on average between 2003 and 2012, the Afghan economy has slowed. In 2018, drought limited growth to just 1.8% (Figure 21.1).

As Afghanistan recovered from the effects of drought in 2019, the agriculture sector grew by an estimated 7.5%, faster than the industrial (1.8%) and services (2.0%) sectors, which are being held back by ongoing political uncertainties and conflict.

The emergence of Covid-19 has brought heavy disruption to the domestic economy, regional trade and remittance flows and, thereby, applied great pressure to government finances. The Afghanistan Reconstruction Trust Fund (ARTF) has added three emergency projects to its portfolio to cushion the pandemic's socio-economic impact, which is expected to push up to 72% of the population into poverty (ARTF, 2020).

ARTF has been one of the biggest contributors to Afghanistan's development. This multidonor trust fund administered by the World Bank anticipated receiving resources of US$ 2.5 billion for the 2018–2020 period, most of which was effectively paid by donors (ARTF, 2020).

The fund has financed the rehabilitation of Afghanistan's largest hydropower plant, situated about 85 km east of Kabul. The Naghlu Hydropower Plant began supplying electricity again in 2018 after a six-year hiatus.

Another donor-funded project has brought community and hospital health services to rural Afghanistan.

A third project administered by the Ministry of Agriculture, Irrigation and Livestock is teaching farmers, who often have small plots of land, the techniques of high-density planting.

Encouraged by the success of the Afghanistan Rural Enterprise Development Programme, which has helped over 800 small and medium-sized enterprises (SMEs) to expand their markets and value chains since 2011, the Ministry of Rural Rehabilitation and Development launched a Women's Economic Empowerment Rural Development Project in 2020. This project is focusing on disadvantaged rural women with little access to finance.[4]

Emphasis on higher education: quantity and quality

Other ARTF funds have been channelled towards higher education, through the Strengthening Higher Education Project (2008–2012) and Higher Education Development Project (2015–2020). By 2017, the tertiary enrolment ratio had reached 9.7%, up from 8.2% (2011). For women, the figures were 4.9% (2017) and 3.5%, respectively (Figure 21.5).

These ratios could be higher, given the strong demand for higher education. The university system could only integrate 16% of school-leavers in 2014 (MoHe, 2019). The Ministry of Higher Education has been funding the construction of new facilities and related equipment to absorb the influx of students, such as lecture halls, laboratories, computer hardware and student accommodation, including dormitories reserved for women (Nakandala and Malik, 2015).

There is no Ministry of Science and Technology in Afghanistan, so the Afghan Ministry of Higher Education assumes this portfolio. It has prepared a *National Higher Education Strategic Plan* covering the 2015–2020 period to implement the Higher Education Development Project. The ministry is seeking to expand enrolment in higher education in a 'controlled' manner, to give graduates the requisite skills for the labour market, eliminate financial obstacles for applicants of a high academic standard and foster a fairer participation by women (MoHE, 2019).

In order to channel students towards degree programmes that will prepare them for the labour market, the Ministry of Higher Education has identified the following priority disciplines (MoHE, 2019):

- physical and life sciences: biology, chemistry, physics and Earth sciences;
- computing: computer science and computer programming;
- engineering, manufacturing and construction, including electromechanics, chemical technology and mining;
- health: pharmacy, general medicine, stomatology and nursing;
- environmental protection, including environmental engineering;
- agriculture, including veterinary science, forestry, crop and livestock production, agronomy, irrigation, animal husbandry and horticulture;
- information and communication technologies (ICTs);
- management and policy administration; and
- English language and literature.

A dual focus on quality and quantity

By 2018, 48% of students were enrolled in priority disciplines at public universities. Among women, the proportion dropped to 9%; however, among first-year students, this proportion rose to 22%. This is a consequence of the policy of reserving places in priority disciplines for female students: 4 972 places in 2018, up from 4 670 the previous year. Moreover, of the 336 scholarships awarded to master's students in priority disciplines in 2018, 35% targeted women (MoHE, 2019).

The size of the student body at public universities grew from 153 314 to 170 393 between 2014 and 2018 (MoHE, 2019). Women now make up 25% of university students, compared to 20% in 2014, suggesting that the government's *Higher Education Gender Strategy* (2013) is working.

A second objective is to improve the quality of university teaching and develop a research culture. Since 2016, the Higher Education Development Project has awarded grants to 97 development-oriented research projects submitted by public and private universities (MoHE, 2019).

A third objective is to encourage universities to show initiative and leadership. The government has already taken a decisive step in this direction by passing a bylaw authorizing universities to exercise fiscal autonomy (World Bank, 2015).

The installation of modern infrastructure and equipment is another priority. By the end of 2018, about two-thirds of Afghan public universities were connected through a national fibre optic network, through the SILK-Afghanistan Project sponsored jointly by the North Atlantic Treaty Organization's (NATO's) Science for Peace and Security Programme and the US Department of State. Afghanistan is now seeking to link the Afghan Research and Education Network to the Trans-Eurasia Information Network, which provides members with high-capacity Internet connectivity (MoHE, 2019).

An entrepreneurial ecosystem has emerged

More broadly, the introduction of mobile telephony, coupled with a young and technology-savvy population, has made telecommunications one of the fastest-growing sectors. This boom has been driven largely by private investment. An entrepreneurial ecosystem has emerged.

One example is Roya Mahboob, who became the first Afghan woman to found a software consulting company in 2010, the Afghan Citadel Software Co. Her employees, most of whom are women, develop software and databases for private companies, government ministries and NATO. *Time Magazine* named her one of its Top 100 Most Influential People in the World in 2013 when she was just 25 years old. Her Digital Citizen Fund is building 40 free Internet-enabled classrooms across Afghanistan (Sandberg, 2013).

Roya Mahboob is a sponsor of the Afghan Girls Robotics Team, a group of teenagers from Herat who came second in the first global robotics competition in the USA and won first prize at the Entrepreneur Challenge in Estonia in 2017 for their solar-powered robot designed to help farmers with seed-planting and other tasks.

BANGLADESH

Industry driving strong growth

Since 2015, Bangladesh's economy has flourished, recording annual growth of about 7% (Figure 21.1) until the Covid-19 pandemic struck in 2020. Much of this growth has been driven by the manufacturing sector. The ready-made garments industry[5] accounted for about 5% of GDP and 83% of national exports in the twelve months to June 2020, according to the Export Promotion Bureau.[6]

Between 2010 and 2015, the pharmaceutical industry almost doubled its earnings to US$ 1 635 million, according to the Bangladesh Association of Pharmaceutical Industries. Dominated by local companies, this sector contributed 1.85% of GDP in 2016–2017, according to the Bangladesh Bureau of Statistics. Bangladesh is, by far, the largest exporter of pharmaceutical products among least developed countries; the Export Promotion Bureau recorded export earnings of US$ 135.8 million in 2020, almost double the amount six years earlier (US$ 69.2 million).

Demand for consumables like medicines is rising as the middle class expands. The pharmaceutical industry is able to satisfy most of domestic demand for affordable drugs, 80% of which are generic and 20% patent-protected; under World Trade Organization rules, least developed countries like Bangladesh are exempted from paying patent protection on the drugs they imitate until 2033. Since Bangladesh is slated to graduate out of this group in 2024, it will no longer be eligible for preferential treatment beyond this earlier deadline.

Demand for processed foods is also rising, as the population becomes more urban and more affluent. The government has introduced cash incentives for farmers and export subsidies to nurture this trend. One challenge will be to reduce post-harvest losses from an inadequate storage and processing capacity. The industry will also need to overcome its dependence on imported packaging materials (USAID, 2019).

Software development and related services, such as web design and maintenance, are booming. A growing number of start-ups are offering next-generation digital services such as big data analytics, Internet of Things, three-dimensional (3D) imaging and Robotics Process Automation (USAID, 2019).

According to the Environment and Social Development Organization Dhaka, Bangladesh is one of the countries generating the most electronic waste: 2.7 million metric tonnes each year. Large conglomerates such as telecom operators, banks and corporations are obliged to sell their e-waste to licensed recycling companies but this rule does not apply to SMEs (USAID, 2019). In 2020, the Department of the Environment published the draft Hazardous Waste (E-Waste) Management Rules restricting the use of 15 chemical substances in certain electrical products and outlining procedures for company recycling of e-waste (Chemical Watch, 2020).

The automobile industry, meanwhile, is gradually migrating from the assembly of parts produced abroad towards value-added manufacturing (Govt of Bangladesh, 2020), in line with the draft *Automobile Development Policy 2020*. In September 2020, the Minister of Industries announced plans for a joint endeavour between the state-run company Pragati Industries and the Japanese company, the Mitsubishi Corporation, for the local manufacture of automobiles (SAM, 2020).

By 2019, value-added manufacturing was contributing 19% of GDP in Bangladesh, according to the World Bank, up from 16% in 2012.

A focus on economic zones and tech parks

In 2010, the Bangladesh Economic Zones Authority (BEZA) and Bangladesh High-Tech Park Authority (BHTPA) were established by two separate acts of parliament to develop related infrastructure.[7]

BEZA has been authorized to establish 88 special economic zones, according to its official website. However, a shortage of land has meant that many of these economic zones are located in coastal areas or along rivers, all of which are increasingly vulnerable to climate change-related hazards such as cyclones, floods, droughts and river erosion (World Bank, 2018). None of the public economic zones led by BEZA was operational by March 2019 (UNOSSC and UNDP, 2019).

Of the 88 special economic zones, 29 will be privately managed. The first of these, the Meghna Special Economic Zone, has been operational since March 2018. A number of special economic zones have been earmarked for country-specific investment, such as by China, India or Japan.

According to BHTPA's annual report for 2019–2020, three of the 28 high-tech and software technology parks being established are already operational, namely Sheikh Hosana Software Technology Park in Jashore, Janata Tower Software Technology Park and Bangabandhu High-Tech City in Kaliakoir. By 2020, these parks had received an investment of about BTD 327 crore (*ca* US$ 39 million) and generated revenue of BTD 24 crore (*ca* US$ 3 million).

The Active Pharmaceutical Ingredients Industrial Park at Munshiganj is expected to be operational by 2023,[8] according to the president of the Bangladesh Association of Pharmaceutical Industries. Once up and running, the park will enable companies to produce the main chemical components of pharmaceutical drugs. This should lower the cost of domestic drugs and boost their international competitiveness, since local firms currently import these raw materials from abroad, largely from China and India. The park intends to be environmentally friendly, with plans for a common effluent treatment plant.

Entities seeking to import machinery and other accessories for initiatives with an environmental focus, such as waste management, water conservation or energy efficiency, can now access the Green Transformation Fund managed by the national central bank, Bangladesh Bank. In 2019, the bank enlarged the scope of the US$ 200 million fund beyond the textiles, leather and jute industries to encompass all manufacturing and export-oriented entities (GFP, 2019).

Support for SMEs to bridge 'huge financing gap'

The government is stepping up its support for SMEs. Its *SME Policy 2019* sets the target of raising the economic contribution of SMEs from 25% to 32% of GDP by 2024. The cornerstone of this strategy is to facilitate SMEs' access to finance, markets, technology and innovation, training, business support services and information. For instance, the policy envisions developing standardized training modules and curricula for SMEs.

To simplify legal and administrative procedures, the government plans to establish a one-stop service centre for start-ups and to introduce a new online registration system.

A number of new financing instruments are foreseen: an SME Bank, an SME Credit Guarantee Fund and a Women Entrepreneurs Development Fund. These instruments could help to resolve what the government has referred to as the 'huge financing gap' faced by Bangladeshi enterprises of all sizes (Govt of Bangladesh, 2020).

The *SME Policy 2019* does not specify a budget for its implementation, which has been entrusted to the Bangladesh Small and Cottage Industries Corporation and the SME Foundation. The Ministry of Industries will be responsible for monitoring the policy's implementation.

A new Engineering Research Council

The *National Science and Technology Policy* (2011) continues to frame science and technology in Bangladesh. The policy sets a target of 2% for research intensity, double that mentioned in the *Voluntary National Review* (Govt of Bangladesh, 2020). Even the lower target would amount to a threefold increase over the domestic research effort in 2015 (Figure 21.2).

The policy identified the following priority areas for research:

- green technology, especially for 'harness[ing] natural resources';
- ecosystems as carbon sinks;
- ICTs, biotechnology and nanotechnology; and
- basic science.

The policy foresaw the establishment of an Engineering Research Council to identify priority areas for research, co-ordinate existing research bodies and support the commercialization of research results and the adaptation of imported technology. In September 2020, parliament passed the Bangladesh Engineering Research Council Bill (BSS, 2020). A 10-member governing body will run the council, with support from a 45-member advisory body headed by the Minister of Science and Technology.

The Bangladesh Council of Scientific and Industrial Research (BCSIR) is the country's largest research body. As of September 2020, it was conducting more than 200 research projects in areas that include food technology; renewable energy; microbiology; pulp, paper and biomass processing; chemistry; and soil and environmental science.

Since 2015, the BCSIR has signed memoranda of understanding with India's Council of Scientific and Industrial Research, Australia's Commonwealth Scientific and Industrial Research Organization and the Japan Development Corporation (BCSIR, 2018). The agreement with the latter, signed in 2018, focuses on improving soil quality at construction sites and the safety of drinking water in arsenic-prone areas (NAB, 2018).

Quasi-universal access to electricity

Vision 2021 (2007) set out to turn Bangladesh into a middle-income country by 2021. A first *Perspective Plan* (2012) operationalized this blueprint (Nakandala and Malik, 2015).

The *Second Perspective Plan (2021–2041)* was approved by the National Economic Council in February 2020. It prioritizes sustainable energy and the development of roads, transport and infrastructure on the path towards becoming a developed country by 2041 (Hossain Ovi, 2020).

Between 2015 and 2020, the share of the population with access to electricity leapt from 76% to 96%. The Ministry of Power, Energy and Mineral Resources has set the target of boosting power generation capacity to 24 000 MW by 2021 and 40 000 MW by 2030. Gains in power-generation capacity are expected to be made through imports of coal and liquid natural gas (Govt of Bangladesh, 2020).

According to forecasts by the Institute for Energy Economy and Financial Analysis, Bangladesh will have the capacity to generate 58% more power than required by 2030, if it follows through on its plans. Overcapacity has already led to a surplus generation of electricity. In parallel, government subsidies for energy companies are on the rise (IEEFA, 2020).

Several factors explain why the share of renewables in final energy consumption in 2019 was just one-third (3.3%) of the 10% target for 2030. For one thing, land suitable for solar parks is scarce and tends to be expensive. In addition, low wind speeds deter construction of wind farms. There is also a lack of local expertise. Bangladesh is dependent on foreign experts for the operation and maintenance of power plants, raising the cost of power generation (Govt of Bangladesh, 2020).

International financial flows to Bangladesh supporting clean energy R&D and renewable energy production increased by about 65% over the 2015–2019 period to US$ 497 million (Govt of Bangladesh, 2020). In July 2020, the Bangladesh North-West Power Generation Company entered into a US$ 400 million joint venture with the China National Machinery Import and Export Corporation to develop about 500 MW of power from renewable sources by 2023. At the time, the Ministry of Power, Energy and Mineral Resources unveiled plans to create floating and rooftop solar power plants to overcome the shortage of available land (Financial Express, 2020).

A project implemented by the Bangladesh Rural Electrification Board has introduced solar-powered irrigation pumps at eight locations at a cost of about US$ 1.3 million. This project has been financed by the Bangladesh Climate Change Trust Fund (2010), which the government has endowed with US$ 390 million.[9] The latest ten-year *Bangladesh Climate Change Strategy and Action Plan* dates from 2018.

An opportunity to create sustainable smart cities

In coastal regions and rural areas vulnerable to flooding and other climate-related hazards, the Ministry of Disaster Management and Relief has constructed bridges and culverts and procured a saline water treatment plant to mitigate disaster risk (Govt of Bangladesh, 2020).

The ongoing development of Purbachal New Town in flood-prone East Dhaka to alleviate the chronic housing shortage offers an opportunity to create a smart, sustainable city. However, Hasnat and Hoque (2016) found that planning for Purbachal 'lacks the provisions of introducing modern, futuristic amenities and misses out [on] the concept of sustainable city'. For instance, the master plan for Purbachal makes no provision for broadband connections, renewable energy or bike lanes. Even though wetlands in East Dhaka provide natural floodwater drainage, retention and storage, 'land filling by private developers has been threatening the very existence of these wetlands' (Bird *et al.*, 2018).

Digital Bangladesh improving service delivery

Achieving a 'Digital Bangladesh' was one of the ambitions of *Vision 2021* (Nakandala and Malik, 2015). The *National ICT Policy 2015* has been a means to this end. It has sought to expand and diversify the use of ICTs, develop skills and deliver strong public services. A *National ICT Policy 2018* has reportedly been drafted which builds on the previous iteration to account for the emergence of 5G technology and the challenges of the Fourth Industrial Revolution (BSS, 2018).

Several milestones have been reached. For instance, over 2015–2019, the proportion of the population having access to a 3G network increased from 71% to 95% (Govt of Bangladesh, 2020). In February 2018, the Bangladesh Telecommunications Regulatory Commission awarded 4G licenses to four mobile operators: Grameenphone, Robi Axiata, Bangalink Digital Communication and Teletalk Bangladesh (BTRC, 2018). Three months later, Bangladesh launched its first communications and broadcasting satellite, Bangabandhu-1, manufactured by the Franco-Italian firm Thales Alenia Space.

However, according to the *e-Government Master Plan for Digital Bangladesh* (2018), developed in collaboration with the Korea International Cooperation Agency, each government ministry is implementing ICT-related projects 'sporadically', leading to poor information-sharing and delays in implementation.

In 2018 and 2019, UNESCO supported the development of the *2019 Progress Review Report of the Master Plan for ICTs in Education 2012–2021*. The review recommended public awareness campaigns to familiarize people with existing ICT-based educational services, as well as the upgrading of

Box 21.1: **The Idea Bank: an originality of the iLab**

Established in 2017, the a2i Innovation Lab (or iLab) provides innovators with seed funding from the a2i Innovation Fund, as well as access to a Maker Lab and mentorship from industry experts. It also helps innovators to protect their intellectual property through copyright and patent filing.

As of September 2020, 247 projects had received funding for a total of US$ 4.5 million, resulting in 14 commercialized products (Yi Ming, 2019).

In order to benefit from the fund, potential innovators submit their ideas through an online Idea Bank. Once an idea has been selected, the innovator is given the means to develop a prototype with technical guidance from a panel of mentors. The maximum amount awarded is BDT 2.5 million (*ca* US$ 29 600).

The iLab also hosts two competitions geared towards solving national challenges through innovation, the Challenge Fund and Innov-A-thon. Under the Challenge Fund, the iLab launches a call for proposals to solve a specific problem, inviting participants to submit their ideas online for a maximum grant of BDT 2.5 million.

A joint initiative of the government and UNDP, the iLab has established partnerships with numerous public and private Bangladeshi universities.

Source: compiled by Jake Lewis; see: http://ilab.gov.bd/ and https://a2i.gov.bd/innovation-fund/

school facilities and the extension of Internet connectivity to all secondary, technical and Madrasah institutions across the country. The review recommended extending the *Master Plan for ICTs in Education* to 2030.

The Digital Security Act (2018) seeks to limit defamation and human rights violations via electronic media. This act has led to the establishment of the Digital Security Agency under the Ministry of Posts, Telecommunications and Information Technology, with a mandate for preventing cybercrime. Commentators have cautioned against the risk of the Digital Security Act placing excessive limitations on the press and social media users (AI, 2018).

Digital centres run by 'citizen entrepreneurs'

The Access to Information (a2i) programme bills itself as the flagship of the Digital Bangladesh agenda. Initially designed to digitize government services, further to the Right to Information Act (2009), its focus has expanded over the past decade to include the promotion of social innovation, pro-poor fintech and youth skills (UNDP, 2019). In 2017, it set up an innovation lab (Box 21.1).

The a2i programme is run by the Prime Minister's Office, with support from the United Nations Development Programme (UNDP) and United States Agency for International Development (USAID).

One of the programme's main achievements has been the 5 875 digital centres dotted across the country which offer government services and information to rural and underserved communities. Visitors can access land records and mobile financial and insurance services, renew their passport and follow online training courses, among other services. Each digital centre is co-run by 'citizen entrepreneurs' and local representatives (Chowdhury, 2017) who reportedly serve 5–6 million clients, on average (UNDP, 2019).

Between 2010 and 2017, the average time a person had to wait for a public service fell by 85%, as costs dropped by 63% and the number of physical visits required shrank by 40%. This prowess has been put down to the work of the digital centres (UNOSSC and a2i, 2017).

An AI strategy to overcome data and talent shortages

Bangladesh has developed a draft National Strategy for Artificial Intelligence for 2019–2024, with support from USAID and the United Nations Environment Programme.

The strategy identifies seven national priority sectors for artificial intelligence (AI): public service delivery; manufacturing; agriculture; smart mobility and transportation; skills and education; finance and trade; and health.

Data accessibility is considered a major challenge. One barrier is the unavailability online of administrative data collected by government ministries and departments. There is also a lack of technological infrastructure for AI, such as for data handling and storage.

Another challenge is the insufficient pool of talent. The strategy fixes the target of training 50 000 people in emerging technologies by 2024. There are also plans to fund 1 000 start-ups working in AI-related areas over 2019–2024.

BHUTAN

The world's only carbon-negative country

Landlocked Bhutan is characterized by deep valleys, snow-fed rivers, steep mountains and glaciers. Some 71% of the total surface area is covered by forests. Of the remaining land area, 51.4% is maintained as protected areas, 8.6% as ecological corridors and another 0.1% as Royal Botanical Parks.

Guided by Bhutan's Gross National Happiness philosophy (Box 21.2), the Constitution requires that 'a minimum of 60% of the country's total land be maintained under forest cover for all time'.

Bhutan is the only carbon-negative country in the world. The economy is dominated by the hydropower and agriculture sectors, which are highly sensitive to climate change. Climate change is often cited as posing 'the single greatest risk of derailing decades of development gains' in Bhutan (Elci, 2020).

Hydropower contributes about 25% of total annual GDP, accounts for 32% of exports and generates about 25% of public domestic revenue. However, the massive scale of hydropower projects with a high proportion of imported content has pushed up the country's external debt to 105% of GDP (ADB, 2019), without generating employment opportunities. Agriculture accounts for 54% of employment but produces only 10% of GDP. Two-thirds of the poorest household heads work in agriculture.[10]

Bhutan's *Voluntary National Review* for the *2030 Agenda* (Royal Govt of Bhutan, 2018) highlights the need to understand the impact of climate change on different economic sectors and build innovative capacities to provide local solutions. It also emphasizes the massive scale of investment required to deal with the impact of climate change and remain carbon neutral.

Aspirations for a higher development status by 2023

The transition of Bhutan's political system from an absolute monarchy to a democratic constitutional monarchy culminated in the country's first national elections in 2008.

After the third parliamentary elections in 2018, the incoming government endorsed the *Twelfth Five-Year Plan* (2018–2023) and its companion volume drafted by the Ministry of Agriculture and Forests, the *Twelfth Five-Year Plan for the Renewable Natural Resources Sector* (2018–2023). Bhutan plans to use this six-year period to graduate from least developed country status.

As one of the least corrupt countries in the world (TI, 2020), Bhutan attracts significant international financial assistance for programme implementation. It is also one of the countries currently under review for technical assistance from the new United Nations Technology Bank for Least Developed Countries, hosted by Turkey (see chapter 12).

Economic policy identifies 'five jewels'

The government is seeking to diversify the economy to achieve more inclusive and broad-based growth. To this end, it is implementing reforms to improve the business and

Box 21.2: **Gross National Happiness philosophy provides ideal framework for Sustainable Development Goals**

The development agenda of Bhutan is shaped by the Gross National Happiness philosophy, which seeks to maintain a balance between development and environmental conservation.

The idea of happiness as a guiding principle for governance is deep-rooted. Bhutan's 1729 legal code states that 'the purpose of the government is to provide happiness to its people. If it cannot provide happiness, there is no reason for the government to exist'.

During the mid-1970s, Bhutan's King Jigme Singye Wangchuck introduced the Gross National Happiness concept, arguing that GDP was less important because it could not deliver happiness and well-being. The *Constitution* also mandates the government to promote the conditions for gross national happiness.

The Gross National Happiness philosophy is built on four pillars: sustainable and equitable socio-economic development; preservation and promotion of culture; conservation, sustainable utilization and management of the environment; and the promotion of good governance.

In the *Twelfth Five-Year Plan* (2018–2023), these pillars have translated into 16 national key result areas which are highly correlated with the Sustainable Development Goals – all but the goal on oceans (SDG14), for obvious reasons.

In the *Eleventh Five-Year Plan* (2013–2018), Bhutan prioritized three SDGs to reflect its commitment to eliminating poverty (SDG2: no poverty), remaining carbon neutral (SDG13: climate action) and being a champion of biodiversity (SDG15: life on land). Efforts focused on implementing policies and programmes that would spill across multiple SDGs.

Between 2007 and 2017, poverty levels declined from 36% to 12% of the population, as measured against the US$ 3.20 poverty line (in constant 2011 PPP$), according to the World Bank.

Source: adapted from GNHC (2018)

investment climate and to develop entrepreneurship and cottage industries. The main improvements include (ADB, 2019): a new licensing policy; simplified property registration; revised rules for foreign direct investment (FDI); and regulations and lending to priority sectors to support cottage and small industries.

The *Economic Development Policy* (2016) sets out a strategy for the development of Brand Bhutan and industrial clusters in five priority sectors, the so-called 'five jewels': hydropower, cottage and small industries, mining, tourism and agriculture. Other sectors with economic potential are also being prioritized, including those grouped under the heading of Information, Media and Cultural Industries (Royal Govt of Bhutan, 2016).

The *Economic Development Policy* also prioritizes the development of wind and solar energy, as well as small hydropower and biomass projects. The Ministry of Economic Affairs is to adopt a feed-in-tariff policy to support this transition and the Department of Renewable Energy is to provide households with incentives to install rooftop solar systems. The policy outlines plans for a national energy efficiency and conservation policy, along with energy-efficiency building codes and guidelines.

A skills shortage

Several factors are impeding the development of a competitive private sector: a skills shortage, inadequate physical and ICT infrastructure, a small domestic market and limited access to foreign markets. For instance, the authorities have identified greater energy efficiency as one area where Bhutan is in need of technology transfer and skills development (Elci, 2020).

Youth unemployment remains a major challenge, estimated at 15.7% in 2018 by the National Statistics Bureau. Unemployment rates are especially high among educated youth.

Currently, master's programmes are limited and there are no PhD programmes, although the Royal University of Bhutan has made an effort to launch a doctoral programme in climate studies.

R&D now seen as ticket to development

Bhutan does not have an explicit science policy. Until recently, research has competed for investment with basic infrastructure and other pressing priorities, such as education, health care and poverty reduction.

This is changing. There is now strong interest among all stakeholders in research and innovation, which is regarded not only as a means of tackling pressing challenges but also as Bhutan's ticket out of the group of least developed countries (Elci, 2020).

One handicap is the lack of any body with a mandate for overseeing STI policy-making and implementation. There were plans to establish a National Council for Research and Innovation but this move seems to have been adjourned.

Another imperative will be to develop statistics on R&D, in order to inform policy-making. Meanwhile, the absence of a stand-alone STI policy prevents not only the take-up of research and innovation but also effective integration of STI in other policies (Elci, 2020).

This said, Bhutan has several active policy instruments. These include the Research Endowment Fund, managed by the Royal University of Bhutan, and the entrepreneurship programme implemented by the Ministry of Labour and Human Resources. There are also fiscal incentives in the form of tax holidays for the ICT sector and to help firms procure technology.

However, resources are tight. Research is conducted mainly by academia and research centres attached to the Ministry of Agriculture and Forests. However, research centres at the Royal University of Bhutan secured total research grant

Box 21.3: **Bhutan's absolutely fabulous Fab Lab**

Innovative ideas

The Fab Lab Bhutan was established in 2017 as a creative space for developers of digital products and prototypes.

A number of research projects have already been completed. For instance, an app has been developed which uses artificial intelligence to inspect the health of beehives and provide updates continually throughout the day (Beehive Monitoring Assistant).

Another project has developed a platform which uses robotic tools to compile research, data and shared documentation to help farming communities increase their productivity and improve their working conditions (Karma farmBot–Open Tool for Farming).

A project called Virtual 3D City Thimphu is creating a visual simulation of the entire capital city, in order to improve urban planning in terms of infrastructure and amenities.

The Lab team is also developing a National Database Centre for Cottage and Small Industries in Bhutan at the request of the Ministry of Economic Affairs and United Nations Economic and Social Commission for Asia and the Pacific.

The creation of the Fab Lab was financed through donations from the Center for Bits and Atoms at the Massachusetts Institute of Technology and the SolidWorks Corporation, part of Dassault Systèmes in France, in collaboration with Keio University in Japan.

Some 40% of resources are used for income-generating activities and the rest to give citizens free access to the lab's facilities. Income is generated through membership fees, consultancy services, training workshops and local productions, to cover direct expenses such as salaries, Internet access, rent and so on.

The Fab Lab Bhutan team plans to establish a Fab Lab Bhutan Association to foster an exchange of information and experience. The association's governing board will be composed of two staff members from each of the Fab Labs across the country, who will be nominated for a period of three years.

The first of many

It is planned to establish ten FabLabs across the country by 2023. A pilot Fab4Fab programme (Fab 2.0) is studying how to produce as many components of a FabLab locally as possible as a substitute for imports, to develop a more resilient ecosystem around decentralized manufacturing.

In December 2019, the team at Fab Lab Bhutan began construction of a more sophisticated Royal Super Fab Lab under the king's patronage. Due for completion within three years, the project has secured US$ 2 million in funding.

The Japan International Cooperation Agency (JICA) has donated another Fab Lab to the College of Science and Technology at the Royal University of Bhutan, which opened in March 2020. This donation followed a series of training programmes and workshops run by JICA.

Part of a global network

The Bhutan lab is part of a Global Fab Lab Network providing open-access, high-tech workshops to enable those who cannot access conventional industrial technologies to develop custom-made products and prototypes.

Nepal will soon be joining this community, since it plans to open its own Fab Lab in 2020.

The Bhutan lab is also part of the Fab City Global Initiative, which is creating a network of cities, regions and countries that have pledged to work towards producing everything they consume by 2054.

The biggest event ever in Bhutan

The Fab Lab Bhutan is getting ready to host the global Fab Summit (FAB17) in Thimphu in 2021. This eight-day event is expected to attract 2 500 'makers', researchers and innovators from fab labs to the largest event ever hosted by Bhutan.

Source: Elci (2020)

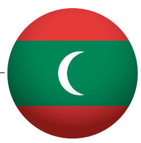
funding of just Nu. 49 million (*ca* US$ 690 250) for a total of 84 proposals in 2017–2018. Over the same period, the Khesar Gyalpo University of Medical Sciences could only fund 12 research projects with its budget of Nu. 1.5 million (*ca* US$ 21 239) [Elci, 2020].

FabLab turning into a success story

In the past few years, Bhutan has developed a range of infrastructure to foster creative start-ups. These include the Thimpu TechPark, a Start-up Centre and a Fab Lab. The Fab Lab, in particular, is turning into a success story, thanks to the quality and impact of the projects being developed by young innovators (Box 21.3).

Thimpu TechPark opened in 2012 with World Bank support (Nakandala and Malik, 2015). It is home to the country's first business incubator, the Bhutan Innovation and Technology Centre, which is state-owned. By 2019, the park was home to about ten innovative start-ups, including Thunder Motors (electric vehicles), Inohome (smart homes), SungJab (electric scarecrows for farmers), Mountain Mist (soap and sanitary products) and Eco-waste Solutions. The park also hosts a few foreign firms. It has been developed jointly by Assetz Property Group of Singapore and DHI, the government's commercial arm. One impediment remains the unreliability of Internet connectivity (The Bhutanese, 2019).

REPUBLIC OF MALDIVES



Covid-19 crisis has halved government revenue

For the past decade, economic growth has averaged 6%, helping the Maldives graduate to middle-income country status. Although per-capita GDP is the highest in South Asia, there are large disparities in income (Figure 21.1).

Even before the Covid-19 pandemic, the IMF debt sustainability assessment had categorized the Maldives as being at a high risk of debt distress, with a rising budget deficit (4.3% in 2019) and government-guaranteed debt of over 70% in 2018 (MoED and UNDP, 2020).

The Covid-19 crisis is expected to amputate 49% of government revenue in 2020, including through the vertiginous drop in tourism, responsible for 26% of GDP in 2019 (MoED and UNDP, 2020).

The Maldives' response to the pandemic has benefited from having a *Health Emergency Operations Plan* (2018), which has assigned specific roles and responsibilities to relevant agencies and operators.

The second-biggest economic sector, transportation and communication (13% of GDP), has also suffered from the drop in tourism. Boat-building for passenger transportation and the fishing industry is a major source of income, as is shipping. In 2020, the State Trading Organization launched the Maldives State Shipping company.

Agriculture and manufacturing play a minor role in the economy. Constrained by the limited availability of arable land and shortage of domestic labour, the Maldives imports most staple foods. The *Agricultural Development Master Plan* 2006–2020 has provided the policy framework for this sector up to now. Fisheries account for 3% of GDP, including exports of canned fish.

The Maldives invested 4.1% of GDP in education in 2016, according to the UNESCO Institute for Statistics. The *Maldives Education Sector Plan* covering 2019–2023 stipulates that technical and vocational students will be taught ICT and entrepreneurial skills and that ICTs will be used to improve education delivery, as part of the *Quality Assurance Framework 2018–2022*.

The *Maldives Education Sector Plan* to 2023 also announces plans to create a national research council 'to allocate, manage and fund research and to ensure research becomes an instrument of socio-economic development'. The strategy foresees the creation of a sustainable funding mechanism to support research and the identification of research areas for national development. The Maldives does not have a science policy.

The *Maldives Master Plan for Higher Education* (2017–2022) recommends undertaking a national needs assessment to address the skills shortage by aligning training on the needs of the job market.

Sustainable urban development proving costly

A low-lying island nation, the Maldives is threatened by rising sea levels and the related salinization of groundwater and soils. In parallel, ocean warming and acidification are threatening the coral reefs and mangroves appreciated by tourists.

The Maldives has adopted a *Strategic National Action Plan for Disaster Risk Reduction and Climate Change Adaptation* (2010–2020). This plan was developed in collaboration with the United Nations' International Strategy for Disaster Reduction. It has been followed by the Disaster Management Act (2015) and Maldives Climate Change Policy Framework (2015). The latter incorporates climate change adaptation and mitigation into sectoral planning, such as in the case of the Tourism Adaptation project (Govt of Maldives, 2017).

Some 80% of land is less than 1 m above sea level and 42% of the population and more than 70% of critical infrastructure

Table 21.1: **Strategies for adapting to climate change in the Maldives**

Technology	introduce alternative technologies to make local agriculture more resilient
	relocate Malé Commercial Port to the island of Thilafushi, less prone to high winds and seas
	increase resilience and climate proofing of all critical infrastructure, including utility services, health-care facilities and telecommunications
	introduce integrated water resource management schemes, including rainwater harvesting, groundwater recharge and more cost-effective desalination techniques
	undertake land elevation and reclamation and shore protection
	develop sewage treatment systems to protect coral reefs
	expand the meteorological network and weather-related early warning system to cover all communities
	undertake climate modelling to improve forecasting and support decision-making
Financial mechanisms	strengthen the existing climate risk insurance mechanisms for farmers and fishermen to reduce income loss from extreme weather events
	establish an insurance mechanism to reduce the impact of climate change on the tourism sector
	establish a green tax on tourism to finance environmental management, including adaptation
	facilitate access to finance to develop mariculture
	establish a Maldives climate resilient fund to finance adaptation and mitigation programmes
Legal instruments	update the national building code for planners, architects and engineers to integrate climate- and weather-related factors into construction
	establish a national development act to facilitate integration of climate change into development planning, considering economies of scale for public services, land use planning and population consolidation
	draft a climate change act

Source: Govt of Maldives (2015) *Intended Nationally Determined Contribution* is situated within 100 m of the shoreline. In 2016, over 45 islands faced water shortages during the hottest dry season recorded in 18 years. The government is developing food and water storage on inhabited islands to prepare for the extreme events to come.

Rapid demographic growth is exacerbating the impact of climate change. The population density doubled between 1996 and 2018 to 1 719 inhabitants per km^2. This challenge is encapsulated by the country's most ambitious urban development project to date. It is expanding the land area of the capital, Malé, by constructing the island of Hulhumalé on reclaimed land to accommodate 130 000 people by the project's completion in 2023; the island has been built 60 cm above the average land elevation of 1.5 m in the Maldives, in order to allow for future sea-level rise. Eight other islands have already been built to safeguard communities from the future effects of climate change (UNDRR, 2019). Thanks to this boom, the construction sector contributed 6% of GDP in 2019 (MoED and UNDP, 2020).

The government is focusing on 'resilient infrastructure based on sustainability and green technology' but has acknowledged that 'the high cost of developing cities and communities in a sustainable manner is a major concern' (Govt of Maldives, 2017).

In 2017, the Faculty of Engineering Technology at the Maldives National University signed an agreement with Utilico Pvt Lt to improve energy efficiency in the construction sector.

In 2011, imported diesel accounted for 82% of energy consumption, compared to 0.1% for solar energy. The government announced plans in 2015 to install hybrid solar photovoltaic-diesel systems on all inhabited islands before the end of 2018 that would be capable of absorbing up to 30% of daytime peak electricity use, as well as a number of wind masts. The aim is to scale up renewable energy installations from 2 MW to 21 MW (Govt of Maldives, 2015).

To facilitate the achievement of this target, the government introduced a feed-in tariff mechanism for the private sector and a net metering regulation in 2015 for households. In 2016, the government launched a 'green loan' facility in collaboration with the Bank of Maldives for both public and private customers, at a concessional rate (Govt of Maldives, 2017).

In its *Intended Nationally Determined Contribution* (Govt of Maldives, 2015), the government set out various strategies for adapting to climate change (Table 21.1).

Further to this strategy, the Ministry of Environment and Energy presented a draft Development of Maldives Climate Change Act in December 2017.

In August 2020, the ministry drafted a single-use plastic phase-out policy to 2023, to reduce marine litter and encourage non-plastic alternatives. The same year, it produced a five-volume Multihazard Risk Atlas of Maldives within an Asian Development Bank project to inform options for climate change adaptation and mitigating geophysical hazards.

In 2018, the Ministry of Environment and Energy embarked on a five-year US$ 84.4 million project with the Green Climate Fund and Japan International Cooperation Agency to Build Climate Resilient Safer Islands in Maldives, with a focus on coastal protection, early warning and systematic observation and, lastly, infrastructure resilience.

NEPAL

Constitutional support for scientists and intellectuals

Between 2007 and 2015, Nepal experienced a series of uprisings that led to the adoption of a federal system of governance through the promulgation of a new constitution in September 2015. Article 51(f)(4) of the Constitution makes it state policy to enhance 'investment in scientific study, research work and invention, progress and development in science and technology, while protecting scientists, technologists and intellectual and eminent talents'.

In 2015, a devastating earthquake took the lives of almost 9 000 Nepalese and affected a further eight million, almost one-quarter of the total population. Nepal has been recovering ever since (Box 21.4). In 2017, the economy surged by 8.2%, the highest rate in a decade.

One priority has been rural development. A series of roads and railway links have been built since the earthquake, a costly enterprise in such mountainous terrain. Access to electricity has also been extended to nine out of ten (88%) Nepalese by 2019, exceeding the government target of 81% (NPC, 2020).

Investment levels impeding policy implementation

Although a number of sectoral science and technology policies have been adopted over the past 15 years, their implementation has often been found wanting. This is partly

Box 21.4: A Nepalese tragedy inspires innovation

Recent history has demonstrated that, with the right kind of resources and political will, policies can make an impact. The period of reconstruction in the aftermath of the 2015 earthquake is rich in such stories.

Given the need to move swiftly after the earthquake, the government abandoned its traditional paper-based surveys in favour of mobile technology to assess the population's needs.

The company Kathmandu Living Labs was enlisted to help. Some 2 500 engineers were deployed with electronic tablets to survey 1.05 million buildings and 5.1 million individuals. They collected 9.3 million pictures in a record 120 days which were stored in a 10-terabyte database.

These data formed the basis for the allocation of grants to households to enable them to rebuild their homes and are now being stored for other purposes within government departments.

Source: compiled by authors; see also https://tinyurl.com/y5g9a8rd because Nepal has historically set low targets for research intensity, limiting the effectiveness of sectoral policies. Moreover, it has fallen short of its 2019 target of 0.62% for research intensity, as this still stood at 0.3% in 2019 (NPC, 2020).

A number of planned initiatives have failed to materialize. These include a national fund for research in information and communication technologies proposed by the *National Information and Communication Technology Policy* (2015) and a national biotechnology research centre proposed by the *Biotechnology Policy* (2006), as well as three other planned research centres: the national nanotechnology centre, nuclear research centre and space research institute (Nakandala and Malik, 2015).

Although the *Nuclear Policy* was adopted in 2007, it was only in 2019 that parliament adopted the *Nuclear Act* facilitating the peaceful use of nuclear science and technology transfer for the health and environmental sectors, in particular.

Despite the *Renewable Energy Subsidy Policy* (2016) having introduced subsidies for mini- and microhydropower, solar and wind energy through its delivery mechanism, the Central Renewable Energy Fund, the share of this type of energy in final energy consumption actually dropped between 2015 and 2019, from 11% to 5% of the total. By 2019, installed hydropower capacity (1 250 MW) fell well short of the target (2 301 MW) for the same year. Most hydropower projects have fallen behind schedule, adding to the cost of developing this infrastructure (NPC, 2020).

A common grievance of the Nepali scientific community is that, although policies themselves are well designed, poor implementation, coupled with a lack of resources, have resulted in unmet expectations. For instance, plans to create a smart city or to digitize Nepal have not materialized.

Whenever there has been an absence of effective policy implementation, other players have stepped up to the plate to deliver knowledge transfer and technological absorption, including through public–private partnerships.

Examples are the National Innovation Centre, created through crowdsourcing organized by individuals in 2012 and constructed on land donated by Tribhuvan University in 2019; the Centre for Molecular Dynamics Nepal (est. 2007), created through a non-governmental organization (NGO); and the Smart Urban Technology Challenge, a public–private partnership involving the Kathmandu municipality that organizes regular competitions for entrepreneurial teams to solve problems related to urban development.

A need for responsive institutions, funding and data

The *National Science, Technology and Innovation Policy* (2019) identifies six priority areas: industrial research; agriculture and land use; infrastructure development; optimum use of biodiversity and mining; climate change and disaster management; and better governance.

The policy has pinpointed a number of challenges for science governance, such as a lack of political leadership, a weak administrative capacity and poor co-ordination between line ministries. To improve co-ordination, the Ministry of Science and Technology was merged with the Ministry of Education in 2018 to form the Ministry of Education, Science and Technology.

Despite receiving the lion's share of public research budgets, the majority of research institutes tend to be largely bureaucratic, with an inadequate investment in dedicated research. This explains the lack of a sense of community or concrete goals for knowledge creation and transfer. There is also an absence of mission-oriented research programmes to meet national economic objectives (Sha, 2021).

The *National Science, Technology and Innovation Policy* (2019) has proposed creating a science, technology and innovation fund but, as of late 2020, no budget had yet been allocated to such a fund. Achieving the policy's objectives will require responsive institutions and adequate funding. The same is true for the *Three-Year Plan* (2016–2018) and *Fifteenth Five-Year Plans* (2019–2023). Responsive institutions and adequate funding will be vital, for instance, to reach the targets in the *Three-Year Plan* of a 35% gross enrolment rate in higher education and a 65% Internet connectivity rate by 2018. The plan also foresees support for start-ups through the creation of business incubators at universities and the creation of 11 000 jobs in science and engineering by 2018.

The government's objectives for the *Fifteenth Five-Year Plan* covering the period from 2019 to 2023 are no less ambitious: inculcating a science culture and evidence-based research, harnessing science and technology to enhance living standards, promoting emerging technologies and supporting linkages between industry and academia, including with entrepreneurs (Table 21.2).

In order to measure progress towards these targets and objectives, the government will need to collect and analyse comprehensive data on a regular basis. However, Nepal still lacks a robust system of data collection for STI indicators. For instance, it does not measure the national research effort on a regular basis. No innovation survey has ever been conducted, nor any systematic attempt made to measure the business sector's contribution to R&D, particularly at a time when value addition by manufacturing to the economy has slipped beneath the 5% threshold since peaking at 9% in 1996, according to World Bank data. The lack of evidence to inform policy-making is a major weakness of the Nepalese research system.

Lack of opportunity boosting brain drain

Despite Nepal having 11 universities and five degree-awarding autonomous institutions, Tribhuvan University still accounts for more than 80% of enrolment. Until the 1990s, it was the country's only university teaching science and engineering disciplines. Other institutions have since joined it, following policy changes authorizing private, self-financing universities. However, the three universities established by law over the past decade do not yet have any students (MoEST, 2017): Karnali Academy of Health Science (2011), Nepal Open University (2016) and Rajarshi Janak University (2017).

Expenditure on higher education has dropped from 13.8% (2010) to 8.3% (2017) of the national annual budget allocation, according to the Ministry of Education, Science and Technology. The insufficient level of investment is impeding the establishment of a vibrant scientific community in academia capable of generating new knowledge and applications in specialized fields to support industry and

Table 21.2: **Selected targets for Nepal's *Fifteenth Five-Year Plan 2019–2023***

	Situation in 2018	Target to 2023
Economic growth rate (%)	6.8	10.3
Contribution of agriculture, forestry and mining to GDP (%)	27.6	23.0
Contribution of industry, electricity, gas, water and construction to GDP (%)	14.6	18.1
Enrolment in secondary education (grades 9–12, %)	46	65
Enrolment in higher education (%)	12	22
Share of population with Internet access (%)	66	80
Per-capita income (PPP$)	1 047	1 595

Source: Government of Nepal (2019) *Fifteenth Five-Year Plan 2019– 2023*, pages 37–39

training at other universities and public research laboratories (Sha, 2021).

With eight out of ten Nepalese workers lacking a secondary education, according to the *Nepal Labour Force Survey 2017–2018*, and remittances accounting for about one-quarter (26.5%) of Nepalese GDP between 2008 and 2018 (Figure 21.1), the country's labour policy encourages those with a modest level of education to emigrate. The government has sought to promote technical and vocational education and training, to give those who emigrate more skills; this programme has grown from 100 pilot schools initially in 2013 to 434 schools in 2019, according to the Ministry of Education.[11]

University students tend to major in STEM fields (Dilas *et al.*, 2018). However, they are leaving Nepal in growing numbers. Outbound student mobility increased by 68% from 2012 to 2017 to 49 451 students, 29% (14 445) of whom headed for North America and Western Europe. In the 2016/2017 academic year, Nepal was the 13th biggest supplier of international students to the USA. Of these, 54% enrolled at US universities at undergraduate level and 34% in graduate programmes. The US Chamber of Commerce has estimated the economic contribution of these Nepali students at US$ 369 million (US Dept of State *et al.,* 2017).

Salaries and grants offered by Nepali institutions are insufficient to retain graduates. For instance, nearly half of advertised positions at the *Nepal Agriculture Research Council* remained vacant in 2018 (Sha, 2021). The three-year PhD fellowships provided by the University Grant Commission amount to just Rs 8 000 (less than US$ 70) per month.

The Nepalese National Academy of Science and Technology has initiated the Return Scientists, Return Home programme (*Farka Hai Farka Baigyanik*), to foster ties between the government and the diaspora. However, interviews conducted by the authors suggest that this programme has elicited little response from scientists working abroad. The programme has been unable to propose financial incentives, such as support for setting up a laboratory in Nepal, or to offer the diaspora an opportunity to contribute to existing research programmes run by the academy in nanotechnology, biotechnology, molecular research, environmental science and other fields.

Ultimately, the government's ability to persuade well-qualified expatriates to return home will depend on whether it can create the right kind of productive research and work environments in Nepal.

PAKISTAN

Crisis spending has affected macro-economic stability

Although Pakistan punches above its weight in science and technology, rapid demographic growth over the past three decades, coupled with moderate economic growth of 4–4.5%, on average, has left very little room for manoeuvre.

The absence of stable, long-term policies over the course of the past half-century – with the exception of the defence and strategic sectors – has also spawned 'policy uncertainty' that has manifested itself in the form of a dual commitment and implementation gap. In primary education, for instance, Pakistan now lags far behind its South Asian neighbours. In 2017, Pakistan's public expenditure on education amounted to just 2.9% of GDP (Figure 21.5), despite the pledge in the *New Education Policy* (2010) to raise this share to 7% of GDP by 2015.

A costly package of infrastructure projects under the China–Pakistan Economic Corridor (CPEC) has fuelled investment in the power sector and helped to generate industrial growth since 2013. However, industrial competitiveness has failed to recover, as evidenced by stagnating exports. The Pakistan Business Council has attributed this outcome to the country's premature de-industrialization, among other causes.

Anaemic economic growth has pushed up poverty levels (Figure 21.1). The previous government came to power in 2013 on the back of a pledge to reverse the power shortages that were causing rolling blackouts across the country and a decline in industrial output. The government initiated an economic reform programme based on public spending financed by taxation and borrowing. The doubling of tax revenue, coupled with borrowing through CPEC-related arrangements primarily, boosted economic growth rates from 4.4% in 2013 to 5.8% in 2018 but this crisis spending, in turn, exacerbated foreign debt liabilities and caused a severe deficit in current accounts and the balance of payments.

There has been a sharp drop in public spending, in line with an economic programme agreed with the IMF in June 2019. By mid-2020, Pakistan's macro-economic vital signs were improving but low levels of tax collection and export growth remained a challenge. The IMF and other multilateral institutions have forecast a low-growth trajectory for the next 2–3 years. Coupled with the fallout from the Covid-19 pandemic, this bodes ill for the chances of higher public spending on science and technology in the foreseeable future.

Pakistan's public-sector infrastructure for science and technology is complemented by academic institutions and the strategic and defence sectors. Over the years, these three components have vied for political patronage and societal recognition, leading to duplication and competition between the different bodies.

The lion's share of public research funding tends to go to the academic and strategic and defence sectors. On the whole, public research laboratories remain bureaucratic institutions that perform little mission-oriented R&D. A relatively immature private sector that performs little R&D completes the country's innovation ecosystem.

A novel approach to policy-making

Up until now, policy has been driven primarily by two policy frameworks, *Pakistan Vision 2025* (2014) and *the National Science, Technology and Innovation Policy* (2012).

Policy implementation within both frameworks has been impeded notably by the inoperative status of the National Science and Technology Commission, despite attempts by the Ministry of Science and Technology (MoST) to revive this apex policy-making body.

Pakistan Vision 2025 rests on seven pillars that include investment in human capital, creation of the conditions for a knowledge economy and laying the foundations for growth in a process led by the private sector, in general, and entrepreneurship, in particular. Its design and implementation have been spearheaded by the Ministry of Planning, Development and Reforms, which has linked all development spending to *Vision 2025* targets. Despite the establishment of specific task forces, some areas have received more attention than others; key targets have been missed for exports, industrialization and revenue collection, whereas large strides have been made in improving regional connectivity, power generation and infrastructure development.

Together with the Pakistan Council for Science and Technology (PCST), MoST has attempted to revive the *National Science, Technology and Innovation Policy* since 2018 through the creation of a *National Science, Technology and Innovation Strategy and Action Plan*. MoST sought approval for over 50 projects worth a total of PKR 30 billion to implement the plan but the proposal does not appear to have gained traction.

In a break with tradition, the new science minister has set up two task forces since 2019, one on Science, Technology and the Knowledge Economy and the other on Science and Technology. These task forces have been mandated to undertake science planning and implementation outside formal government structures. The first of these task forces, chaired by the prime minister himself, has met several times and produced proposals for various initiatives and projects. The majority of these projects have been placed, for administrative purposes, under MoST, a move which appears to have given the ministry a new lease of life.

Higher education tightening its belt

Pakistan Vision 2025 envisions raising public expenditure on higher education from 0.2% to 1.4% of GDP and expanding university enrolment from 1.5 million to 5 million by 2025. To fulfill this ambition, public expenditure allocated to the Higher Education Commission (HEC) for development grants more than tripled between 2013 and 2018 from about PKR 13 billion to PKR 47 billion,[12] although the release and utilization of these funds has not lived up to expectations. By 2017, expenditure on higher education amounted to 0.6% of GDP, the same level as three years earlier (Figure 21.5).

The government also made it a priority to have a 'university in every district' to reduce regional disparities (GN, 2017). By 2025, the HEC (2018) aims to double the number of public universities from 99 (2015) to 195 and to boost the number of private universities from 76 to 105.

Notwithstanding this push, the gross enrolment ratio actually dropped between 2014 and 2018, from 9.7% to 9.0% of the 18–25-year-old cohort (Figure 21.5). One achievement of the reform has been gender parity, with women accounting for 45% of enrolled students by 2018 (HEC, 2018).

The HEC regulates all universities and funds more than 120 of these in the public sector, which provide heavily subsidized tuition fees. Funding to cover the operational costs of most public universities has been cut by about 50% as part of the government's economy drive, throwing most universities into turmoil.

Three new competitive research programmes

For the next five years, much of the HEC's discretionary expenditure, along with some operational expenditure, will be financed by a World Bank loan of US$ 400 million negotiated under the previous government and concluded in 2019. A substantial part of this loan will fund R&D. In particular, it will go towards creating three competitive research programmes to address different needs and audiences.

The first of these is the Grand Challenge Fund. It will address issues of national importance, such as urbanization, climate change, health care, education and economic development through exports, etc., through competitive research and innovation grants awarded to university-led consortia.

The second programme, the Local Challenge Fund, will enable universities to conduct cross-disciplinary research targeting any of the 17 SDGs at the local level.

The third programme is the Technology Transfer Support Fund. It will finance university–industry collaboration in pursuit of specific products and processes or services deemed likely to have immediate commercial value. Originally established as the Technology Development Fund in 2012, this scheme offering competitive grant funding matched by industry has shown some degree of success in igniting industrial support for R&D conducted by university labs.

Additional support for academic innovation is also available within the World Bank grant, through the strengthening of universities' Offices of Research, Innovation and Commercialization, as well as their Business Incubation Centres.

Meanwhile, the existing National Research Programme for Universities will continue to fund the efforts of individual researchers, with emphasis on basic research.

Still a disconnect between science and industry

The Technology Transfer Support Fund is all the more vital in that, in the past five years, exports have declined even as imports have surged, particularly imports of luxury goods and high-tech products for power and infrastructure development projects related to the China–Pakistan Economic Corridor.

Industry remains largely focused on producing low-end and low-tech products (Figure 21.1) through primarily imported manufacturing plants, on the one hand, and the import of raw materials and kits to assemble for the domestic market, on the other (Osama *et al*., 2015). The percentage of high-tech exports has not grown (Figure 21.1). There is still a major disconnect between laboratory science and its deployment in industry, with linkages at an embryonic stage. R&D is not playing an adequate role in industrialization, as illustrated by the pharmaceutical industry (Box 21.5).

In academia, faculty lack the requisite support and reward structures that could incentivize them to commercialize their research findings either directly or by licensing their intellectual property. Promotion is still tied to a faculty member's publication record, rather than their capacity to commercialize research (Haque *et al.,* 2019).

Even in a strategic area like nanotechnology, there has been no comprehensive national plan to support the commercialization of research findings. A 2018 review of this field by the Planning Commission, conducted under the stewardship of the present author, identified wide gaps in existing infrastructure, much of which has been established at universities in a piecemeal fashion over the past two decades by the National Commission of Nanotechnology. Plans to establish a national centre for nanoscience and nanotechnology with the mission of commercializing technology have been provisionally shelved for lack of resources, among other reasons.

Outward-looking research and training programmes

Against the backdrop of the ongoing debate about the quality and relevance of current investment in higher education, the HEC has introduced a new programme to fund 2 000 PhD and 1 000 postdoctoral students at universities in selected countries. These programmes built upon similar programmes in the past but have been redesigned to improve the quality over time.

Since 2015, USAID has funded three centres of advanced studies in energy, water and food security at Pakistani universities, at a total cost of about US$ 100 million over five years. The objective is to create 'islands of excellence' capable of turning out highly trained professionals, while at the same time solving key development challenges.[13]

In parallel, the US–Pakistan Knowledge Corridor was launched in 2017 to support high-level collaboration. Initiatives include a collaborative research programme and 10 000 PhD scholarships for Pakistanis at the top 200 universities in the USA. The scholarship has been interrupted in 2020, in light of the Covid-19 crisis.

A similar UK–Pakistan Education Gateway was initiated with the British Council in 2018; it focuses on collaborative research, distance learning, leadership in higher education, quality assurance and standard-setting, transnational education and researcher mobility. The programme is supporting the ambitions of the HEC set out in *Pakistan Vision 2025*, including the targets of increasing gross enrolment by 15%, the number of faculty with a PhD by 40% and the number of universities to 300.[14]

Research centres for Industry 4.0

In 2018, the HEC established four national centres to build research capacity in areas critical to the Fourth Industrial Revolution, namely: the National Centres for Artificial Intelligence; Robotics and Automation; Big Data and Cloud Computing; and Cybersecurity.

For the first time in recent history, these centres were established through a highly competitive multi-stage process, during which critical clusters of expertise across the country were identified. Each of these four national centres is a consortium of 10–12 laboratories spread across the country, co-ordinated by the national hub. Over 300 postdoctoral researchers work across these 46 laboratories, along with hundreds of PhD and master's students, research associates and assistants.

Each of the 46 labs is responsible for pursuing a scientific area of interest, such as medical applications of AI, the security of devices for the Internet of Things, or the creation and utilization of cancer genomics data. Each contributes to publications and spin-off commercial applications, whenever possible.

This major initiative has turned Pakistan's traditional development model of focusing primarily on 'bricks and mortar' on its head by seeking to enable and fund talent wherever it exists across the country.

First to adopt *The 2030 Agenda*

In 2015, Pakistan became the first country to adopt *The 2030 Agenda for Sustainable Development* through a unanimous resolution of parliament. As focal point for all related efforts, the Ministry of Planning, Development and Reform established its own SDG support unit to work on implementation with the UNDP.

The SDGs have become an important element of the government's discourse on development, in a concerted effort to collect critical data, inform policy and planning and push the SDG agenda out to provincial and even local levels.

However, in the wake of the far-reaching decentralization of power to the provinces instigated through the 18th amendment to the Constitution in 2010, efforts to co-ordinate initiatives centrally have met with mixed results. For instance, most programmes related to higher education (Nakandala and Mali, 2015) and health have been devolved to the provinces, even though the central government continues to fund these, with the help of international donors, through a range of vertical programmes.

Entrepreneurial ecoysystem coming of age

Over the past five years, the Ministry of Information Technology and Telecommunications (MoITT) has championed the Fourth Industrial Revolution, business incubation and entrepreneurship. MoITT led the process to create national incubation centres in Islamabad and

Box 21.5: **Seven steps that could transform Pakistan's pharmaceutical industry**

Pakistan's pharmaceutical industry comprises more than 750 SMEs, about 17 of which are subsidiaries of multinational corporations. Growth averaged 10–12% between 2012 and 2017, thanks to rising incomes, self-medication and awareness of health issues created by the Internet.

Growth rates have since declined. Price controls on drugs and weak protection of intellectual property have seen multinational corporations close shop and repatriate their profits since 2012. Their retreat has spawned generic copycat drugs by local producers and reduced prospects for new drug development. Inflows of FDI for pharma have sunk close to zero.

In 2017, annual turnover amounted to US$ 3.2 billion, equivalent to about 1% of GDP. Pharmaceutical exports brought in US$ 200 million.

This compares with US$ 14 billion for Indian pharmaceutical exports in 2015 and about US$ 800 million for Jordanian exports, despite the latter country having a population of only 9 million. Production plants certified by the US Food and Drug Administration can export to the USA, which comprises 60% of the global market; India has 201 certified plants and Jordan four (Dawani and Sayeed, 2019).

Pakistan could derive substantial impetus from the export of generics and contract manufacturing. In the more distant future, there is no reason why it could not become one of the emerging economies that is active in the drug-discovery business with its own multinational corporations – but getting there will require regulatory reforms, entrepreneurship and investment.

The following seven steps could transform Pakistan's pharmaceutical industry:

- The price ceilings imposed on drugs since 2001 should be lifted in a transparent process, as these ceilings are squeezing profits, stifling growth and limiting the availability of some medications, such as for tuberculosis.
- Although industry meets 90% of domestic demand, 95% of the main chemical components of drugs are imported. The large-scale production of generics will call for investment in capital-intensive facilities to produce active pharmaceutical ingredients in Pakistan. Investment on this scale is only possible by large companies and could require support from the government's industrial policy in the early stages. FDI could assist.
- There is a need for industrial restructuring to reduce the number of pharma firms while boosting their size to enable them to upscale the production of generics, produce under contract and raise exports. Currently, the industry is fragmented, with more than 500 small firms engaged in compounding and packaging medications.
- In order to compete in the global marketplace, Pakistani industry needs the underpinning of an innovation system. The pharmaceutical industry engages in virtually no R&D. The government should take the lead by stimulating research in leading public universities, incentivizing research by larger pharma firms and promoting more university–industry linkages.
- For the major firms to attract FDI, the business environment will need to improve, including through adequate protection for intellectual property and incentives that channel foreign investment into the type of activity that will generate the highest returns for Pakistan's economy.*
- Pakistan needs a well-funded Food and Drug authority to set and maintain quality standards, to certify drugs and to weed out substandard and counterfeit drugs.
- Membership of the Pharmaceutical Inspection Convention/Cooperation Scheme would provide Pakistan with sound manufacturing guidelines and enable it to export to high-income countries. This will also require certification of Pakistani factories by the FDA and European Medicines Agency, which is currently not the case, even if a couple have been certified by WHO.

Source: Yusuf (2019)

* The experience of Argentina, Bangladesh, Colombia, Indonesia, Jordan and Uganda suggests that technology transfer from multinational corporations can accelerate the development of domestic capabilities (UNCTAD, 2011).

four provincial capitals in 2016 and 2017. This programme is spearheaded by the Ignite National Technology Fund.[15] Outsourced to private-sector providers, these incubators were operational in record time, recruiting start-ups to incubate within a year. This initiative has helped to create a buzz around entrepreneurship.

Another major initiative from the MoITT has been the launch of a Skills Portal offering training, in particular, to those living in areas where freelancing opportunities are readily available. Since Payoneer's Global Gig Economy Index, published by Forbes, ranked Pakistan as the fourth-fastest-growing market for freelancing in the world (Pofeldt, 2019), these findings have become a rallying cry for the government.

The past five years have seen the entrepreneurial ecosystem come of age in Pakistan. Starting with *Plan9* in 2012, Pakistan now hosts a number of private incubators and accelerators.[16] Start-up funds such as Sarmayacar, Invest2Innovate, 47 Ventures, Fatima Ventures, TPL e-Ventures and Planet N have begun investing hundreds of thousands, or even millions, of US dollars in early-stage start-ups, alongside several foreign funds.

There are a number of other non-traditional and grant-based funding vehicles supporting entrepreneurs and start-ups through sector-specific and general grants. Examples are Karandaz, Ilm Ideas, the Sub-National Governance Programme

(2018–2024) funded by the UK Department for International Development and the Small and Medium Enterprise Assistance Programme funded by USAID.

The local start-up ecosystem seeks to emulate Silicon Valley or its clones in neighbouring India and elsewhere. The following have all managed to raise tens of millions of dollars or more, making them among Pakistan's few technology unicorns. Daraz has become Pakistan's largest e-commerce platform. There is also Zameen, an online real-estate portal, PakWheels for online automotive sales and Easypaisa, Pakistan's first mobile money platform, which was acquired by Chinese giant Ant Financials for US$ 185 million in 2018.[17]

Another positive trend has been the faster than anticipated growth in the penetration of smartphones and high-speed mobile broadband after the country's much-delayed initiation into the 3G/4G spectrum in 2013. At the time, smartphone penetration stood at about 5% of the total market, compared to 35–40% today.

The dissemination of mobile broadband tells a similar story; Pakistan still has one of the lowest average revenues per user in the world, a major challenge for telecom providers struggling to transition from being voice operators to data- and value-added service providers. However, buoyed by demand and the rapid increase in smartphone penetration and mobile broadband usage, the country is gearing towards limited testing and deployment of 5G systems in the near future (PT, 2019).

Digital Pakistan: a shift in policy focus from supply to demand

In December 2019, the government launched the Digital Pakistan Initiative and appointed a high-level official within the Office of the Prime Minister to co-ordinate and lead the efforts of various ministries and departments.

Digital Pakistan is the concrete expression of a a major shift in policy focus and rhetoric within the MoITT. The aim is to develop demand-side policies by favouring mass investment in the public procurement of information technology from private vendors. This, the logic goes, will help to develop large-scale private-sector capacity which will then translate into the development of products and services for global markets.

The extent to which this shift can be effectively operationalized remains to be seen. For instance, efforts over the past decade to install e-governance across the country have encountered delays and departmental inefficiencies. The newly reformed National Information Technology Board, with a former private-sector executive at its helm, intends to address this shortcoming by outsourcing the implementation of e-government services, rather than developing them inhouse.

Digital Pakistan has identified five strategic pillars, namely: access and connectivity; digital infrastructure; e-governance; digital literacy; and innovation. A year later, details of the initiative remain relatively vague.

The knowledge economy agenda has been well-funded, thus far, and is likely to be driven by a mixture of supply- and demand-side initiatives – the impetus for both exists within the coalition that is pushing this agenda. However, it is likely to remain centred around information technology.

In 2020, the government was contemplating a major AI initiative along the lines of those adopted by Canada (see chapter 4) and India (see chapter 22). There is a possibility that this initiative would be led by the private sector and housed within MoST, both of which could prove challenging. A proposal to establish a Knowledge Economy Authority to spearhead the related agendas seems to have been shelved, for now.

Ambitious plans for the China–Pakistan Economic Corridor

The launch of the China–Pakistan Economic Corridor in 2015 was part of China's broader thrust for access to global markets through its Belt and Road Initiative. The programme was initially divided into a set of 'early harvest' projects, followed by medium- and long-term projects to be completed by 2018, 2023 and 2030, respectively.

Much of the initially agreed investment of US$ 53 billion took the shape of private investment in Pakistan's power sector (mostly coal- and oil-fired plants), followed by smaller investments in regional connectivity: three north–south corridors, to be funded in phases, connecting China's western region through the Pakistani port city of Gwadar to the Arabian Sea, complete with fibre-optic connectivity and a special development package for Gwadar comprising an airport, a sea port and other infrastructure.

The Ministry of Planning, Development and Reform became the focal point for the planning and implementation of the China–Pakistan Economic Corridor in Pakistan and the National Development Research Institute served as its counterpart in China.

In 2018, as the last of the early harvest projects were nearing completion, the Pakistani government launched the ambitious *China–Pakistan Economic Corridor Long-term Plan*, which intends to populate the China–Pakistan Economic Corridor with special industrial zones occupied by Chinese companies that had migrated to Pakistan and joint ventures between Pakistani and Chinese industrial entities. The *Long-term Plan* envisions further investment in infrastructure projects, such as the refurbishment of the railway track connecting the north and south of Pakistan, as well as, potentially, the construction of water reservoirs and dams.

Over the years, there has been some debate in the popular media and economic circles about the cost of the China–Pakistan Economic Corridor and the country's ability to pay back the loans.

The overall consensus, however, seems to be that the China–Pakistan Economic Corridor is too important a venture for both China and Pakistan to be affected by these relatively minor misgivings and that the two countries should continue to deepen economic ties.

Pakistani–Chinese collaboration extending to science

Only recently have there been conversations on co-operation in science and technology at both the level of government and business. China has expressed interest in helping to fund a number of research institutes, including a research centre in the north specializing in natural disaster risk reduction and a state-of-the-art university to be housed in the building that was formerly the prime minister's official residence.

Box 21.6: **An aerospace project that could become a game-changer for Pakistan**

A decade ago, the Pakistan Aeronautical Complex partnered with the China National Aero-technology Import and Export Corporation on a joint venture to develop and manufacture the JF-17 fighter aircraft.

This aircraft has been in the service of the Pakistan Air Force since 2011. By 2020, more than 120 planes were in use and the government was contemplating exporting the model to several countries in the region.

Buoyed by the success of the JF-17 programme, the government has decided to leverage this acquired knowledge to design and develop a fifth-generation fighter in Pakistan (Grevatt, 2019). To this end, it established the Aviation Research, Innovation and Design Centre in 2016, which is currently defining the parameters of the project.

In December 2019, the government inaugurated both the National Aerospace Science and Technology Park and Kamra Aviation City, which hosts the Air University Aerospace and Aviation Campus. The aim is to encourage local and foreign vendors and contractors to support this massive undertaking by establishing offices in, or relocating their businesses to, these two high-tech parks.

This project has the potential to become a game-changer for Pakistani science and technology. It could have significant spillovers in commercial areas ranging from aerospace and electronics to computing and manufacturing, as long as the project ensures the participation of the academic sector and civilian vendors.

Source: compiled by authors

A Consortium of Business Schools connected to the China–Pakistan Economic Corridor has been established and subsequently expanded to include universities, in order to enhance academic co-operation between the two countries. Business-to-business collaboration, particularly in high-tech areas, is also being explored.

On the back of the successful launch of a Chinese-built remote sensing satellite (PRSS-1) and an endogenously developed test satellite (PAK-TES1) on 9 July 2018, the Pakistan Space and Upper Atmosphere Research Commission, Pakistan's space agency, has entered into a strategic collaboration with China to set up a US$ 250 million Pakistan Space Centre – Satellite Assembly, Integration and Testing Facility that would be the first of its kind in Pakistan.[18] The Pakistan Space Centre will contribute to the country's *Space Vision 2047* (2017), which sets the goal of launching a range of remote sensing, telecommunication and navigation satellites over the next 20–30 years.

Together, these projects represent a significant commitment to investing in space sciences and technology over the decades to come.

Pakistan's aerospace sector has already benefited from its collaboration with China a decade ago to develop and manufacture the JF-17 fighter aircraft (Box 21.6).

SRI LANKA

Development agenda encountering hurdles

The government's *Vision 2025: a Country Enriched* (2015) has sought to transform Sri Lanka into the knowledge hub of the Indian Ocean, a country characterized by a highly competitive market economy.

However, a slump in industrial activity in construction, mining and quarrying, in particular, has slowed economic growth to just 2.3% in 2019. According to the World Bank, the economy contracted by 1.6% year on year in the first quarter of 2020 as a result of the Covid-19 crisis, the first such contraction in 19 years. In the first four months of 2020, the central government debt-to-GDP ratio surpassed 90%, up from 78% in 2015.

A high of US$ 961 million in FDI flowed into the country in 2017 to finance key development projects but progress has been impeded by political deadlock, undermining confidence among local businesses and foreign investors.

One such development project is Colombo Port City, also known as the Colombo International Financial City. Through a partnership with the BRI, Sri Lanka is reclaiming land from the sea to expand the financial district and port in the capital city, amid concerns from local environmental groups. The Port of Hambantota in the south has been developed under a second BRI project but the government's inability to repay the loans has resulted in the port being handed over to China on a long-term operational lease.

The *National Export Strategy 2018–2022* has identified six priority sectors, namely: IT in business process management; tourism and logistics; spices and concentrates; boat building; processed foods and beverages; and electrical and electronic components. The aim is to generate inflows of US$ 5 billion in FDI and export earnings of US$ 28 billion by 2022.

More recently, pharmaceutical products have become a priority. Exports had been stagnating since 2016 but, with the Covid-19 crisis having spurred demand, the government and private sector invested US$ 30 million in a new pharmaceutical manufacturing plant in 2020 within the Koggala Export Processing Zone.

One priority is to foster technology transfer to SMEs, which account for 90% of firms. The *National Policy Framework for the Development of SMEs* (2016) is accompanied by a national technology development fund co-financed by the government and private sector. In June 2020, the German international co-operation agency GIZ contributed 11 million euros to the fund through a five-year agreement for three projects. GIZ is helping those universities and research institutes which have not yet done so to establish incubators for tech-based start-ups (on campus) and assistance bureaux (at institutes) to foster technology transfer to SMEs.

A drive for more sustainable development

The Sustainable Development Act (2017) provided for the development and implementation of a national policy and strategy and for the establishment of a Sustainable Development Council in October 2017. Declaring 2017 the Year of Poverty Alleviation, the government launched a range of ambitious projects to improve access to basic services such as health, education, electricity, safe drinking water and sanitation (Govt of Sri Lanka, 2018). The World Bank estimates that poverty declined from 9.4% to 8.9% of the population between 2018 and 2019.[19]

Sri Lanka has been incorporating the SDGs into its *National Policy Framework Vistas of Prosperity and Splendour 2020–2025* (2020). This framework has ten overarching thrusts: prioritizing national security, without compromising the democratic space; a friendly, non-aligned foreign policy; an administration free from corruption; a new constitution that fulfills the wishes of the people; productive citizenry; people-centric economic development; a tech-based society; the development of natural resources; sustainable environmental management; and a disciplined, law-abiding and values-based society.

In health care, the priority is to invest more in delivery, quality and infrastructure.

Gender equality is being promoted by sharing the costs of maternity benefits, making it easier for businesses and schools to offer childcare services and encouraging a greater participation by women on corporate boards of directors.

Growing dependency on fossil fuels, coupled with the rising cost of these imports, 'has become a significant burden to the economy'. The size of Sri Lanka's vehicle fleet has more than tripled since 2000, driving demand for petrol. To offset this trend, the government has introduced tax incentives and other fiscal measures which have boosted imports of hybrid cars since 2012 (Govt of Sri Lanka, 2018).

For Sri Lanka, major hydropower plants are not an option for electricity generation, owing to the increasing uncertainty of rainfall patterns. Hydropower contributed 6% of the energy supply in 2016, compared to 56% for oil and coal and 36% for biomass (mainly fuelwood). With renewable energy accounting for just 2% of the energy mix in 2016, the Ministry of Power and Renewable Energy has launched a community-based power generation project entitled *Soorya Bala Sangramaya* (Battle for Solar Energy) through a public–private partnership to promote small rooftop solar power plants for households and businesses. Under this scheme, consumers may sell any surplus electricity generated to the national grid or bank it for later use (Govt of Sri Lanka, 2018).

A skills mismatch for the job market

To bolster quality education, the *National Policy Framework Vistas of Prosperity and Splendour 2020–2025* outlines plans to reform curricula to enable students to study a combination of science, technology, engineering, mathematics and the arts. Parallel goals are to enhance continuous teacher training and introduce more technology into education delivery.

The current mismatch between curricula and the skills required for the job market is of concern to education planners. The education system is examination-based, with a sole focus on the subject matter. Such an approach neglects development of the soft skills required by the job market, such as innovative, 'out of the box' thinking.

Also of concern is the drop in the proportion of students enrolling in science and engineering streams, despite a rise in student numbers overall. Even those who study these fields are often drawn towards better-paid professions such as accountancy or business administration.

Public universities compete for students with private universities, which tend to offer study programmes that respond better to the needs of the job market. This is because private universities recognized by the University Act (1978) offer degree courses from internationally recognized universities, having only been entitled to grant undergraduate degrees themselves since the act was amended in 1999.

As part of the project for Improving the Relevance and Quality of Undergraduate Education, funded by the World Bank since 2010 (Nakandala and Malik, 2015), a new Quality Assurance Process was introduced in 2015 that evaluates the standards of all public universities and categorizes them on the basis of their degree programmes.

A *National Adaptation Plan* for climate change

The *National Policy Framework Vistas of Prosperity and Splendour 2020–2025* outlines plans to strengthen resilience to climate change by improving the quality of irrigation infrastructure, strengthening ecosystem conservation and expanding the natural disaster insurance scheme.

Farmers will be one beneficiary of improvements to this scheme. Other priorities in agriculture are to link smallholder farmers to the value chains of larger enterprises and to invest in climate-proof warehousing to protect produce.

The priority accorded to climate change is also reflected in the *National Adaptation Plan for Climate Change Impacts 2016–2025*, which is co-ordinated by the Climate Change Secretariat. The *National Adaptation Plan* focuses on the following vulnerable sectors: food security; water resources; coastal and marine resources; health; ecosystems and biodiversity; agriculture for export; tourism and recreation; and human settlements and infrastructure.

All development and management projects are to include policy recommendations on how to address vulnerability to the impact of climate change. Among other features of the plan, a National Adaptation Fund is to be established in collaboration with the Ministry of Finance and the Global Environment Facility to support implementation of the *National Adaptation Plan*.

In parallel, a national network is to be set up of agencies and universities carrying out research on adaptation to climate change to improve co-ordination of related research and the dissemination of information.

The National Science Foundation, National Research Council and Council for Agricultural Research Policy, among others, are to develop and manage a co-ordinated multidisciplinary small research grant programme on thematic areas relating to climate change adaptation, which will be facilitated by the Climate Change Secretariat.

Technology for smart decision-making

The draft national digital policy covering the 2020–2025 period was still under review in late 2020. It recognizes the need for an innovative economy, with a primary focus on helping entrepreneurs and SMEs to achieve greater competitiveness and create digital jobs.

Digitalization of the economy and wider society is already under way. The first steps can be traced back to the launch of the e-Sri Lanka roadmap in 2002 (Nakandala and Malik, 2015).

In December 2018, the Information and Communication Technology Agency (est. 2003) launched the first phase of the National Spatial Data Infrastructure project to improve the use of spatial data in 'smart' decision-making through institutionalized data-sharing and use of common standards, formats and policies. The Colombo Digital Public Library was launched in March 2019 on the physical library's premises.

In 2019, the government initiated a number of digital projects, including the Smart City and the Smart Classroom. Their viability will depend upon upgrading related infrastructure to avoid power cuts and other technical hiccoughs.

The Smart Classroom project aims to introduce 4G technology into 25 pilot schools.

The Smart City is introducing 5G technology into the Polonnaruwa District to foster a better quality of life and engage actively with citizens. The project is being piloted by Sri Lanka Telecom and its mobile arm, Sri Lanka Telecom Mobitel, which allocated US$ 14 million to the project in 2019.

In September 2019, the government also inaugurated the Colombo Lotus Tower, a multifunctional television and telecommunications tower which is the tallest in South Asia (350 m). China has financed 80% of the cost (US$ 104 million) of building the tower.

Policy instruments needed to boost science–business ties

In 2020, the *National Science and Technology Policy* (2008) continues to frame the government's current strategy. This is because the draft science, technology and innovation strategy covering the 2011–2015 period was never endorsed. A *National Research and Development Framework* (2016) has, nevertheless, been approved.

The lack of adequate policy instruments has proved a greater impediment to implementation of the *National Science and Technology Policy* than lack of funds. The multidisciplinary nature of the scientific enterprise has made the task even more challenging.

The low level of domestic investment reflects the status of R&D: 0.11% of GDP in 2015 (Figure 21.2). This ratio has been stable for the past 20 years. Current limitations on public spending have prompted the government to make overtures to the private sector but the two parties have yet to come up with an effective mechanism for collaborative R&D.

In successive budgets over the past decade, the government has granted tax concessions of more than 50% to business enterprises involved in R&D, the exact percentage being determined by the Inland Revenue Department based on eligible investment categories. However, this scheme has been hamstrung by the requirement for businesses to conduct R&D in tandem with government institutions. In its budget for 2020, the government proposed introducing new tax incentives for companies that invest in R&D. Only an interim budget was approved, owing to the holding of elections in 2020, but the new tax incentives should be announced in the budget for 2021 (Chandrasena, 2019).

One success story in terms of collaboration between industry and public institutions is the Sri Lanka Institute of Nanotechnology (SLINTEC, est. 2008). Between 2012 and 2018, SLINTEC developed seven new technologies with the private sector related to agriculture, apparel, health care and minerals.

In August 2017, the government recognized SLINTEC as a degree-awarding institute. The SLINTEC Academy has since become the knowledge dissemination arm of the parent institute, functioning as a private non-profit graduate school that offers MPhil and PhD degrees in nanotechnology and advanced sciences.

CONCLUSION

Chronically low research funding

The innovation systems of the seven countries analysed in the present chapter are not yet underpinning industrialization, with most industries conducting virtually no R&D.

The lack of industrial expenditure on R&D is reflected in countries' low research intensity, with only Bangladesh and Nepal currently managing to devote 0.30% of GDP to R&D. Even in Nepal, funding levels remain too low to achieve ambitious policy objectives, such as the desired creation of research centres in biotechnology and nanotechnology, sufficiently high salary levels to retain skilled graduates, or the creation of business incubators at universities to support start-ups.

Bangladesh, Nepal, Pakistan and Sri Lanka all have explicit STI policies but implementation is being impeded by the lack of adequate instruments. For instance, Nepal's *National Science, Technology and Innovation Policy* (2019) foresees creating a science, technology and innovation fund but, as of late 2020, no budget had yet been allocated to such a fund.

Given their modest size, public research budgets can easily be spread too thin by the multiplication of public research centres in a wide range of areas. This costly investment in terms of infrastructure can leave little over for research itself, turning these institutions into bureaucratic shells that contribute little to the national development agenda, particularly in the absence of mission-oriented research programmes.

The current push for infrastructure development and industrialization is largely taking place on a parallel path to research and development when each could be nurturing the other. Public research institutions need to be incentivized through reward schemes to engage in mission-oriented research and to forge ties with industry, such as through competitive funding grants and contract research.

Pharmaceuticals a potential growth area

Pharmaceuticals is one potential growth area. Bangladesh, Pakistan and Sri Lanka already have nascent industries in this sector. Global demand for pharmaceuticals and other products during the Covid-19 crisis has opened up new opportunities for the region's exporters.

However, home-grown industries will need to be innovative to capture and retain foreign markets. In 2017, Pakistan's pharmaceutical exports brought in US$ 200 million, compared to US$ 14 billion for Indian pharmaceutical exports two years earlier.

None of the three countries currently has the capacity to manufacture the chemical components used in the medication they manufacture, obliging them to import these raw materials. In Bangladesh, the pharmaceutical industry is tackling this shortcoming by establishing the Active Pharmaceutical Ingredients Industrial Park; it will foster a domestic capability in the production of core chemical components which, in turn, should lower the cost of domestic drugs while boosting firms' international competitiveness.

The Covid-19 crisis has recalled the desirability of strong linkages between the public and private sectors, a prerequisite for the production of equipment such as lung ventilators, masks or medication. However, for this type of collaboration to be long-lasting, it needs to be rooted in institutional support mechanisms. One positive example is Pakistan's Technology Transfer Support Fund providing grant funding to university laboratories matched by industry.

Avenyo *et al.* (2015) suggested that policy-makers focus not only on designing incentives for firms to engage in R&D but also on facilitating non-research-related innovation, particularly in relation to technology transfer, since the acquisition of machinery, equipment and software is generally the most important activity tied to innovation. Bangladesh's *SMEs Policy* (2019) recognizes the need to give SMEs greater access to finance, markets, technology and innovation. This policy will be supported by the new Engineering Research Council for the commercialization of research results and adaptation of imported technology which is, itself, an outcome of the *National Science and Technology Policy* (2011).

Innovation is disruptive, by definition. One challenge for education systems in South Asia will be to foster the soft skills that are required by the job market, such as the kind of creative, 'out of the box' thinking that fosters innovation.

An entrepreneurial ecosystem has emerged

An entrepreneurial ecosystem has emerged in many countries where the young are embracing the digital economy. In Afghanistan, the introduction of mobile telephony, coupled with a young and technology-savvy population, has made telecommunications one of the country's fastest-growing sectors. Bhutan now has a Fab Lab for developers of digital products and Pakistan counts several 'tech unicorns', start-ups that are valued at more than US$ 1 billion.

Public–private partnerships can be an effective stimulus for entrepreneurship. By outsourcing the IgniteNational Technology Fund to private firms, the Pakistani government has enabled these to recruit enough start-ups to make its five new national incubation centres operational within a year.

The digital economy has captured the national imagination. Governments are planning to establish 'smart infrastructure' such as smart cities and smart mobility. The viability of these will depend upon upgrading related infrastructure. It will also depend upon whether or not these smart cities follow a sustainable development model. In a region buffeted by climate change, there is a real enthusiasm for *The 2030 Agenda for Sustainable Development*. The challenge will be to ensure that 'green' development permeates the region's ambitious projects for new infrastructure and industrialization.

KEY TARGETS FOR SOUTH ASIA

- Bangladesh aims to raise SMEs' contribution to GDP from 25% to 32% by 2024;
- Power generation capacity in Bangladesh is to jump to 40 000 MW by 2030;
- Bangladesh is to generate an additional 500 MW of power through a joint venture with the China National machinery Import and Export Corporation by 2023;
- Bhutan aims to graduate from least developed country status by 2024;
- Pakistan has a range of targets to 2025 for higher education, including those of raising public expenditure on higher education to 1.4% of GDP, expanding university enrolment from 1.5 million to 5 million, augmenting the share of faculty with a PhD by 40% and doubling the number of universities to 300;
- The Colombo International Financial City should serve as Sri Lanka's primary financial and business district by 2030;
- Sri Lanka's export strategy targets inflows of US$ 5 billion in FDI and export earnings of US$ 28 billion by 2022.

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ENDNOTES

1 Recent data on the share of female researchers (HC) are only available for Pakistan (39% in 2017) and Sri Lanka (47% in 2017). Women accounted for barely one in four (24%) Sri Lankan researchers in 2006 (see chapter 3). Sri Lanka has also attained gender parity in secondary and tertiary education since 2015 (Govt of Sri Lanka, 2018).

2 Of the 199 patents granted to Nepalese inventors by the top five patent offices in 2019, the Korean Intellectual Property Office accounted for 27, the Japanese Patent Office for 30 and the State Intellectual Property Office of the People's Republic of China for 140. Over the seven years to March 2018, some 44 946 Nepalese students emigrated to Japan, the second-most popular destination after Australia. A further 5 240 outbound students headed to China. Data for outbound students travelling to the Republic of Korea are only available for the last two years; they total just 1 729. Source: MoEST (2015, 2016, 2017) *Nepal Education in Figures.*

3 *Pakistan Vision 2025* (2013) observes that, 'with an estimated population of 227 million by 2025, Pakistan's current water availability of less than 1 100 m3 per person, down from 5 000 m3 in 1951, classifies it as a water-stressed country that is headed towards becoming a water-scarce country if action is not taken urgently'.

4 For details of these and other ARTF projects, see: www.artf.af

5 Since the collapse of the eight-storey Rana Plaza building in 2013, which took the lives of more than 1 100 mainly female workers, numerous ready-made garment factories have improved their safety standards, in accordance with the five-year, legally binding Accord on Fire and Building Safety in Bangladesh signed in May 2013 by global clothing brands, trade unions and retailers, with government backing.

6 See: http://epb.gov.bd/site/view/epb_export_data

7 These are the Bangladesh Economic Zones Authority Act (2010) and the Bangladesh High-Tech Park Authority Act (2010).

8 The Active Pharmaceutical Ingredients Industrial Park was initially approved in 2008 by the Executive Committee of the National Economic Council (TBS, 2019).

9 As of June 2016, 440 projects had been funded by the Bangladesh Climate Change Trust Fund (2010), 377 of which were implemented by government bodies and autonomous agencies and the remainder by NGOs. One example is the Climate Change Community-based Adaptation in the Ecologically Critical Areas through Biodiversity Conservation and Social Protection Project, which has built submersible greenbelts and ten village conservation centres, among other things. It attracted about US$ 2.3 million in funding over the 2010–2015 period.

10 See: https://www.worldbank.org/en/country/bhutan/overview

11 See the ministry's 2019 factsheet on technical and vocational education (in Nepali): https://moe.gov.np/assets/uploads/files/TVE_Factsheet_2019.pdf

12 These data are based on documents related to the Public Sector Development Programme available from the website of the Pakistani Ministry of Planning, Development and Reform.

13 The three centres are the U.S.–Pakistan Center for Advanced Studies in Water at Mehran University of Engineering and Technology in Jamshoro, Pakistan; the U.S.–Pakistan Centre for Advanced Studies in Energy at the National University of Science and Technology in Islamabad; and the U.S.–Pakistan Centre for Advanced Studies in Energy at the University of Engineering and Technology in Peshawar.

14 See: https://www.britishcouncil.pk/programmes/education/higher-education/pak-uk-education-gateway

15 The Ignite National Technology Fund was formerly called the Information and Communication Technology Research and Development Fund.

16 Examples are NEST I/O, PlanX, 10xC, Invest2Innovate, SEEDVentures, VentureLab and WECREATE.

17 Other companies with a significant Pakistani contribution not headquartered in Pakistan include KeepTruckin; Careem, acquired by Uber for US$ 3.1 billion in 2019; and Afiniti, an AI-based recommendation engine developed by entrepreneur Zia Chishti.

18 See: https://fp.brecorder.com/2018/11/20181115423788/

19 In its 2020 overview of Sri Lanka, the World Bank calculated poverty levels in 2018 and 2019 using the US$ 3.20 poverty line (in 2011 PPP$).

An electric taxi in Bankura, West Bengal, in 2017. The government has introduced increasingly generous subsidies since 2015 to persuade Indians to purchase electric and hybrid vehicles. Currently, there are more than 400 000 electric two-wheelers and several thousand electric cars on Indian roads. Apart from the sales price, there are two main technological barriers to faster adoption of electric vehicles in India: the relative scarcity of both lithium-ion batteries and charging stations spaced at reasonable intervals. © Arpan Chatterjee

AT A GLANCE

- In 2015, the government launched Digital India to transform public services. Blockchain technology is now used extensively by government departments.
- Digital India has linkages to Make in India, Start-up India and the Smart Cities Mission. The government is fostering a digital marketplace and smaller informal economy by encouraging Indians to open bank accounts and embrace cashless payment systems.
- The number of start-ups has grown steadily since 2016 but most are in the services sector, especially software development, rather than in manufacturing, the focus of the Make in India programme.
- Coal power plants pushed up carbon emissions in 2018. India is hastening the diffusion of clean technologies such as solar panels and electric vehicles.
- Foreign multinationals and Indian enterprises are spending more but overall research intensity is stagnant and domestic patenting remains low.
- The government is encouraging more students to enrol in science and engineering degree programmes. The relatively low employability of graduates remains a concern.

22 · India

Sunil Mani

INTRODUCTION

Easier to do business

India remains one of the fastest-growing economies in the world (Figure 22.1). The country has recorded a respectable average growth rate of 7–8% since 2014 but the dip in savings and investment rates since 2016 may impinge on future performance (Figure 22.1).

Income inequality is high and expected to rise. The *World Inequality Report 2018* estimated that 10% of the Indian population earned 55% of the national income in 2016, compared to 37% of the population in Europe. Since 2014, the government has introduced flagship social programmes to increase public access to sanitation (*Swachh Bharat* programme), the electricity grid (*Saubhagya* programme) and financial services such as bank accounts (*Pradhan Mantri Jan-Dhan Yojana* programme) [Figure 22.1].

The elections of 2019 returned the National Democratic Alliance government led by Narendra Modi to power with a stable majority, thus improving the chances of public policies following the same trajectory in the years to come.

Since 2015, India's performance in international composite indices has varied: it climbed 14 places in a single year to rank 63rd in the World Bank's *Ease of Doing Business 2020* report and five places to 52nd position in the *Global Innovation Index 2019* but dropped ten rungs in the *Global Competitiveness Index*. There were about 9 000 start-ups in 2019. India now has the world's largest pipeline of potential 'unicorns', privately held start-ups valued at over US$ 1 billion. The number of these 'unicorns in the making' surged from 15 to 52 between 2018 and 2019 (NASSCOM, 2019).

Improving the ease of doing business was one of the objectives of the Make in India programme launched by the government in 2014, so it has been a success from this perspective. Another objective was for the manufacturing sector to contribute 25% of GDP by 2022. However, this sector is not growing fast enough (7.8% per year) to meet this target. Make in India is yet to make a tangible difference to manufacturing, for reasons that we shall explore later.

Make in India is one of a series of government strategies designed to nurture the adoption of emerging technologies across the wider economy. In May 2020, the government announced a series of measures to make India more technologically self-reliant in eight strategic sectors, as part of a comprehensive stimulus package to cope with the concurrent economic slowdown and Covid-19 epidemic. Known as *Atmanirbhar Bharat* (Make India Self-reliant), the stimulus package allows for greater private-sector participation in sectors hitherto largely reserved for state-owned bodies, namely: coal, minerals, defence manufacturing, airports and airspace management, power distribution, social infrastructure, space and nuclear energy.

The government has responded to the Covid-19 crisis with a stringent lockdown. Some states have shown that it is possible to contain a pandemic within a short period of time, provided that the government gives paramount importance to the technical advice of public health authorities and can win the trust of the general population, so that people comply fully with the measures imposed.

The hospital system has been straining to accommodate the massive influx of Covid-19 patients. In 2019, the Indian central and state governments spent INR 2.6 trillion, or 1.3% of GDP, on health. Public expenditure on health covers salaries, gross budgetary support to hospitals and other institutions, as well as budgetary transfers to states under centrally sponsored schemes like *Ayushman Bharat Yojana*. It is estimated that the private sector contributes a further 2.3% of GDP to health care (MHFW, 2019).

Manufacturing a response to Covid-19

Since the Covid-19 outbreak, India has been mobilizing its considerable capabilities to produce low-cost solutions for public health systems around the world in three areas: vaccine research and manufacturing; the manufacture of generic versions of 'game-changer' drugs; and frugal engineering of medical devices that are currently in short supply.

Six Indian firms are actively developing a vaccine for Covid-19 (Table 22.1). Among these, the Serum Institute of India has earned a reputation for being the cheapest vaccine manufacturer in the world; most of the 20 or so vaccines that it manufactures are exported to 165 countries at an average price of US$ 0.50 per dose. In June 2020, it reached a licensing agreement with pharmaceutical multinational AstraZeneca to supply one billion doses of what became known as the Oxford–AstraZeneca Covid-19 vaccine (also known as Covishield).

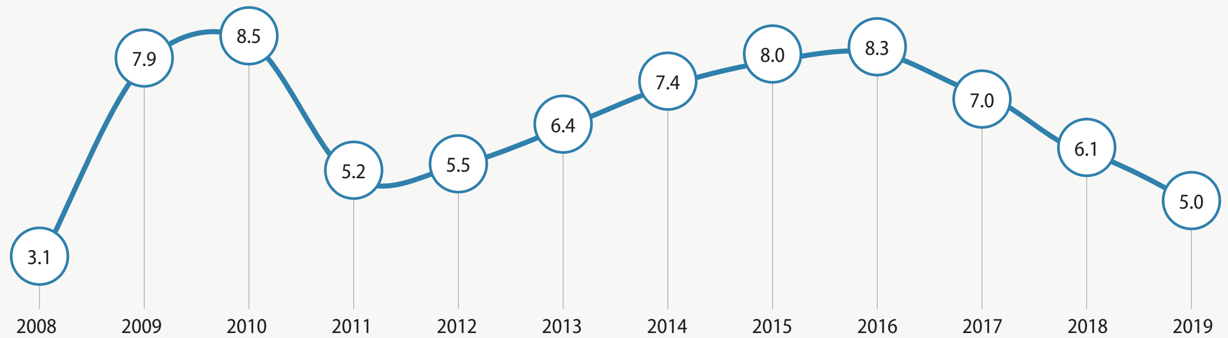
Indian pharmaceutical manufacturers are hoping that the patent-owner of remdesivir, the US-based company Gilead Sciences, will grant licensing provisions for the drug, as it did with the hepatitis C drug Sovaldi in 2014 (Chandana, 2020). According to Gilead, trials of remdesivir by the National Institute of Allergy and Infectious Diseases in the USA indicate that it may speed up recovery in Covid-19 patients (O'Day, 2020). The drug is under patent protection until 2035, with external formulation permitted strictly for research purposes.

India's manufacturing sector has been developing a number of frugal technologies. In early 2020, at least one domestic manufacturer, AgVa Healthcare was able to produce invasive ventilators which will go on sale at 20% of the standard international price.

The start-up Nocca Robotics, which is incubated by the Indian Institute of Technology Kanpur, began commercializing a low-cost ventilator in 2020 which, according to the developers, would cost about 6% of the international price.

Figure 22.1: **Socio-economic trends in India**

Rate of economic growth in India, 2008–2019 (%)



Selected socio-economic indicators for India, 2012–2018

	2012	2013	2014	2015	2016	2017	2018
Savings rate (% of GDP)	35.3	33.9	33.5	32.5	31.7	31.2	30.9
Investment rate (% of GDP)	36.7	35.6	32.6	32.6	30.6	29.1	29.7
Foreign direct investment, net inflows (% of GDP)	1.3	1.5	1.7	2.1	1.9	1.5	1.5
Foreign direct investment, net outflows (% of GDP)	0.5	0.1	0.6	0.4	0.2	0.4	0.4
Share of global exports of computer software services (%)	51	52	52	53	54	55	55
Inflation, consumer prices (%)	9.3	10.9	6.4	5.9	4.9	2.5	4.9
Growth rate of digital payments (%)	–	–	10.7	9.07	24.4	12.0	13.9
Growth rate for volume of cashless payments (%)	–	–	–	29.1	29.3	25.3	40.1
Growth rate for value of cashless payments (%)	–	–	–	9.1	24.4	12.0	14.2
Population growth (annual %)	1.3	1.2	1.2	1.2	1.1	1.1	1.0
People using at least basic sanitation services (% of population)	46.6	49.2	51.8	54.3	56.9	59.5	–
Access to electricity (% of population)	79.9	80.9	83.6	88.0	89.6	92.6	–
Access to bank accounts and other financial services (% of population)	–	–	53.0	–	–	80.0	–
Unemployment rate (% of total labour force)	5.7	5.7	5.6	5.6	5.5	5.4	5.3
Employment to population ratio (15+ years), total (%)	49.2	48.8	48.4	48.0	47.6	47.2	46.8

Share of Indian population using the Internet

34.5%
in 2017

26.0%
in 2015

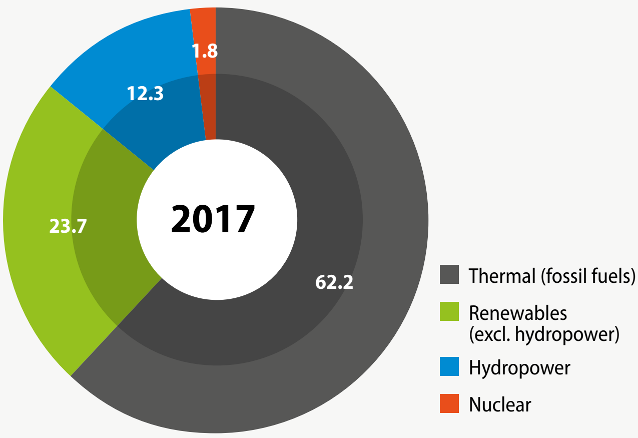
Share of Indian population with mobile cellular subscription

86.9%
in 2018

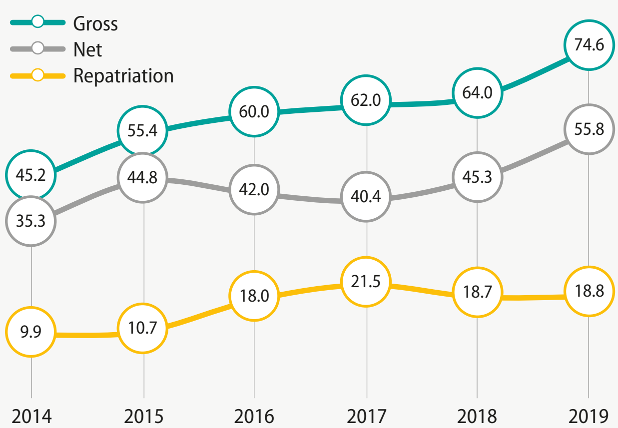
76.4%
in 2015

Electricity supplied 13% of India's final energy consumption in 2020.

India's installed capacity for electricity generation by source, 2017 (%)



Trends in gross and net FDI inflows to India, 2014–2019
In US$ billions



Note: Renewable installed capacity, as of July 2020, includes small hydro projects, biomass gasifier, biomass power, urban and industrial waste power, solar and wind energy. Coal (part of thermal) accounts for 54% of electricity generation.

Source: World Bank's World Development Indicators, October 2020, and Ministry of Statistics and Programme Implementation, Government of India; for financial inclusion: Ravi (2019); for unemployment rate: modelled estimate by International Labour Organisation; for FDI and growth rate for digital payments: computed from payment systems indicators, Reserve Bank of India; for energy: Ministry of Power, Government of India (2020) *Power Sector at a Glance*

Table 22.1: **Indian pharmaceutical companies active in Covid-19 vaccine research, 2020**

Company	Number of vaccine types	Details
Zydus Cadila	2	initiated an accelerated research programme with multiple teams in India and Europe to develop a vaccine for Covid-19
The Serum Institute of India	1	partnered with American biotechnology firm Cadagenix to develop a vaccine, expected to be ready by early 2022, and with Oxford Vaccine Group to manufacture their vaccines currently under development; aims to manufacture 4–5 million doses
Bharat Biotech	1	developing and testing a vaccine called CoroFlu alongside US-based FluGen and virologists at the University of Wisconsin-Madison
Indian Immunological	1	collaborating with Australia's Griffith University to develop a vaccine candidate using the latest codon de-optimization technology
Mynvax	1	start-up nurtured by the Indian Institute of Science, Bangalore

Source: compiled from Economic Times (2020) Seven Indian pharmaceutical companies race to develop vaccine for deadly coronavirus, 19 July; Biswas (2020) and Corum J., Grady D., Wee S.-L. and C. Zimmer (2020) Coronavirus vaccine tracker. *The New York Times*

Nocca Robotics is expected to manufacture about 30 000 ventilators by May 2020, further to an agreement with Ansys, a US-based engineering simulation company.

The Chitra GeneLamp-N test kit can confirm Covid-19 in about two hours at less than 1 000 rupees (INR, *ca* US$ 13) per test; it has been developed by a public laboratory, the Sree Chitra Tirunal Institute of Medical Sciences and Technology.

India's technological response to Covid-19 could be impeded, however, should it fail either to identify new ways of financing relevant research projects or to effect changes to international rules with respect to intellectual property rights, in general, and patents, in particular, to facilitate domestic development of technologies. Such changes could entail exempting vaccines and therapeutic drugs for Covid-19 from a product patent regime and relaxing the conditions under which a compulsory license may be issued for the manufacture of generic versions of patented Covid-19 drugs.[1]

HARNESSING EMERGING TECHNOLOGIES TO MODERNIZE INDIA

Digital India

A lot has changed since the previous edition of the *UNESCO Science Report* (Mani, 2015). Through the establishment of the National Institution for Transforming India (NITI Aayog)[2] in 2015, which serves as a think tank, the government has been attempting to modernize the country; one thrust has been to promote innovation and diffuse modern digital technologies. Another focus has been the diffusion of renewable energy technologies and electric vehicles, as we shall see later.

In July 2015, the government launched Digital India, in order to use information technology to transform the entire ecosystem of public services. Digital India has linkages to other new tech-based government schemes analysed in these pages, such as Make in India, Start-up India and the Smart Cities Mission.

India has one of the fastest-growing telecommunications networks in the world. The government has been making a conscious attempt to extend Internet access to rural areas. One in three (34.5%) Indians had access in 2017, up from just 15% four years earlier. The total number of Internet subscribers stood at 644.08 million as of 31 October 2019, 87% of whom were broadband subscribers , according to the Indian Telecom Regulatory Authority's *Yearly Performance Indicator*s (2019).

In 2018, out of the 1.176 billion mobile phone subscribers in India, half (*ca* 578 million) were wireless data subscribers. This phenomenal growth in data usage has been fuelled by significant reductions in the cost of data. This, in turn, has fuelled the digital economy, boosting e-commerce and the use of app-based food-ordering and taxi-hailing services, as well as hospitality-booking services.

The digital economy is at the heart of the Fourth Industrial Revolution, also known as Industry 4.0 (Table 22.2). The digital economy is fuelled by data and closely associated with seven state-of-the-art technologies: blockchain, data analytics, artificial intelligence (AI), three-dimensional (3D) printing, the Internet of Things, automation and cloud computing (UNCTAD, 2019).

In February 2019, the prime minister inaugurated the first supercomputer to be designed through the National Supercomputing Mission. Known as PARAM Shivay, this supercomputer has been built at the Indian Institute of Technology Varanasi and will form part of a planned network of over 70 high-performance computing facilities.[3]

A drive to improve public services

The uptake of Industry 4.0 technologies has mostly occurred in the government sector. Blockchain technology is now used extensively within the central government and, in one form or another, by nearly half of state governments. It is primarily used to prepare land registry data, provide farm insurance and issue digital certificates. London-based blockchain consulting firm Dappros reports that India had 19 627 blockchain developers in 2018, second only to the USA (with 44 979) [Filatov, 2018].

In an attempt to improve public services, the government launched the direct benefit transfer scheme in 2016 to transfer subsidies directly to people through their bank accounts. By 2020, this scheme had been applied to about 439 schemes across 55 ministries. The estimated savings come to a phenomenal INR 141 677 crores (*ca* US$ 19.7 billion). In the case of the Mahatma Gandhi National Rural Employment Guarantee Scheme, the share of payments made within 15 days doubled from 43% to 90% over the two years to 2018.

Swamy and Rajendran (2019) analysed whether blockchain technology improved the efficiency of the Mahatma Gandhi National Rural Employment Guarantee Scheme. The authors found that, while it took less time for blocks to generate electronic fund-transfer orders and send them digitally to the central government, the time taken by the central government to process these transfer orders and wages for workers remained the same.

In 2014, only half of Indians had a bank account (Figure 22.1). The direct benefit transfer scheme could be implemented on a much larger scale, were this proportion to be higher. As a result of the government's *Pradhan Mantri Jan-Dhan Yojana* programme, eight out of ten Indians had a bank account by 2018.

A bold economic experiment

In 2016, the government embarked on one of the boldest economic experiments of modern times. India is a cash economy, with the vast majority of business transactions involving banknotes changing hands. To reduce the size of the informal economy, the government took the radical step of demonetizing two of the largest circulating bank notes, those for 1 000 (*ca* US$ 13) and 500 rupees, which accounted for about 86% of the notes in circulation at the time.

The scheme has been controversial abroad but there has been surprisingly little opposition in India itself. A survey of 200 families in 28 Mumbai slums showed the counterintuitive result that, despite experiencing a fall in their monthly incomes by as much as 10%, the majority welcomed the demonetization policy (Krishnan *et al*., 2017).

Although the initial objective was to limit the informal economy, the government has since shifted the aim of its demonetization policy to ushering in a fully cashless economy, which *inter alia* may promote better tax compliance and, as a result, higher government tax collection. It should also facilitate the development of a digital marketplace, now that more potential customers have access to credit cards and bank accounts.

To promote the growth of a cashless economy, a number of incentives have been put in place, including a Goods and Services Tax (GST). Nevertheless, there are signs that people have been reverting to using cash. The value of transactions has been much lower than that observed during the period of demonetization (Figure 22.1). Currency in circulation as a percentage of GDP reached 11% in 2018, just 1% less than prior to demonetization.

The Union Ministry of Finance has adopted the following two mandatory measures to foster cashless transactions, effective from 2019 onwards:

Table 22.2: **Indian strategies and policies for Industry 4.0 technologies**

Industry 4.0 technology	Government policies and actions
Blockchain	• The Reserve Bank of India set up a unit in 2018 to research/supervise emerging technologies for blockchain applications in a decentralized and cashless banking system.
	• NITI Aayog is exploring opportunities in the drug and fertilizer industries.
	• State governments have been supportive of blockchain technology, particularly those of Karnataka, Andhra Pradesh, Maharashtra and Kerala. The Telangana state government announced that blockchain would be used to digitize land records and upgrade other data.
Data analytics	• Big data analytics for e-governance is the subject of several funded state and national programmes.
	• Only Telengana state has a formal *Data Analytics Policy* (2016).
Artificial intelligence (AI)	• NITI Aayog published a *National Strategy for Artificial Intelligence* (2018) to leverage AI technologies to improve health care, education and agricultural yields and to enable smart cities infrastructure, smart mobility and smart transportation.
3D printing	• Adoption has been slow. The *National Strategy for Additive Manufacturing* dates from December 2020.
Internet of Things (IoT)	There is a draft national policy on the Internet of Things with the following objectives:
	• create an IoT industry in India worth US$ 15 billion by 2020, increasing the number of connected devices from about 200 million units to over 2.7 billion by 2020.* India would have a 5–6% share of the global IoT industry; and
	• develop IoT products specific to Indian needs in agriculture, health, natural disaster management, transportation, security, supply chain management, smart cities, automated metering and monitoring of water and other utilities, waste management, oil and gas industries, etc.
Automation	• The Council for Robotics and Automation, a not-for-profit organization, is the apex body setting standards in robotics and automation and in education. It has begun providing support systems to institutions, such as quality assurance, technical backstopping, information systems and train-the-trainer academies.
	• Multipurpose industrial robots have been diffused primarily in the automotive sector.
Cloud computing	• The Department of Electronics and Information Technology published the Government of India's GI Cloud (Meghraj) Strategic Direction Paper in 2013.
	• Meghraj, the National Cloud of India, was set up by the National Informatics Centre (see: https://cloud.gov.in/). These cloud-based services are restricted to government departments.
	• The Telecom Regulatory Authority of India provided recommendations on cloud services, adopted by the government in 2018, and initiated a consultation in 2019 on a framework for registration of an industry body for cloud service providers.

*According to Deloitte & NASSCOM (2017) *The Internet of Things: Revolution in the Making*, the market value of India's IoT solutions industry would reach *ca* US$ 9 billion by 2020.
Source: compiled by author; see Telecom Regulatory Authority of India: https://trai.gov.in/

- account holders pay a 2% tax, deducted at source, on cash withdrawals exceeding INR 1 crore (*ca* US$ 139 000) in a year from a bank or post office account; and
- business establishments with an annual turnover of more than INR 50 crore (*ca* US$ 7 million) are obliged to offer customers low-cost digital modes of payment. Customers and merchants are not charged the Merchant Discount Rate.

The demonetization policy appears to have augmented the filing of income tax returns. According to data from the Income Tax Department, these surged by 20.5% in 2017 and by another 23.1% in 2019. The availability of a wide variety of cashless and contactless payments has proved a boon during the Covid-19 crisis when physical distancing has had to be observed for financial transactions, making online payments an attractive option.

Facilitator of Industry 4.0

In addition to spearheading adoption of Industry 4.0 technologies in the public sector, the government is facilitating the diffusion of the seven state-of-the art technologies listed earlier through three key measures:

- the *National Manufacturing Policy 2011*, which focuses on boosting the share of the manufacturing sector in GDP to 25% by 2022;
- the Centre of Excellence on Information Technology for Industry 4.0, established in 2017 to enable micro-, small and medium-sized enterprises to embrace Industry 4.0; and
- the National Mission on Interdisciplinary Cyber-Physical Systems, launched in 2018 to create a strong foundation and a seamless ecosystem for cyberphysical technologies by co-ordinating and integrating nationwide efforts in knowledge generation, human resource development, research, technology and product development, innovation and commercialization.

Moreover, NITI Aayog published a *National Strategy on Artificial Intelligence* in 2018 to leverage improvements in health care, education and agricultural yields. The strategy also sets out to foster smart cities, smart mobility and smart transportation. NITI Aayog is currently also exploring opportunities for deploying blockchain technology in the drug and fertilizer industries.

Despite the government's initial efforts, Industry 4.0 technologies and processes, which form part of the Fourth Industrial Revolution, are yet to be fully embraced in India for four main reasons:

- India's organized manufacturing sector is very small: it contributed just 18% of India's gross value added across all economic sectors at basic prices in 2019, according to the Reserve Bank of India's 2019 *Annual Report*.
- There are shortages of investment, infrastructure, know-how and cybersecurity norms.
- The cost of digital technologies is high, even though data have become cheaper to purchase.
- There is a persistent skills and talent gap.

Smart Cities Mission

In 2015, the government selected about 100 cities across the country with a cumulative population of 99.63 million to become the country's first smart cities.

There is no universally accepted definition of a smart city. India considers such a city to offer the following core elements, each impregnated with a sustainable environmental footprint: a satisfactory supply of water, electricity, sanitation, education and health services, safe and affordable housing, alongside efficient urban mobility and public transport systems; this ensemble must be supported by robust connectivity and digitalization and good governance, especially e-governance and citizen participation.

The implementation of the Smart Cities Mission at the municipal level is led by a Special Purpose Vehicle. There are two essential features of this mission. Firstly, the projects developed in the city are to be decided upon by the citizens of that city in a participatory way. Secondly, it is project-based and therefore does not result in the holistic development of the entire city.

Four years on, just ten cities account for 48% of the completed projects. It is likely that the practice of limiting development to small areas within cities will amplify existing inequalities because the upgraded services will not be available to all citizens (Deka, 2019).

According to the Ministry of Housing and Urban Affairs (MoHUA), 80% of the Smart Mission's funding will be spent on area-based development, which benefits only part of a city's population. To speed up project implementation and monitoring, an Indian Urban Observatory has been created under MoHUA. Among the various Industry 4.0 technologies, it is the Internet of Things that is being used most by the Smart Cities Mission (Deka, 2019).

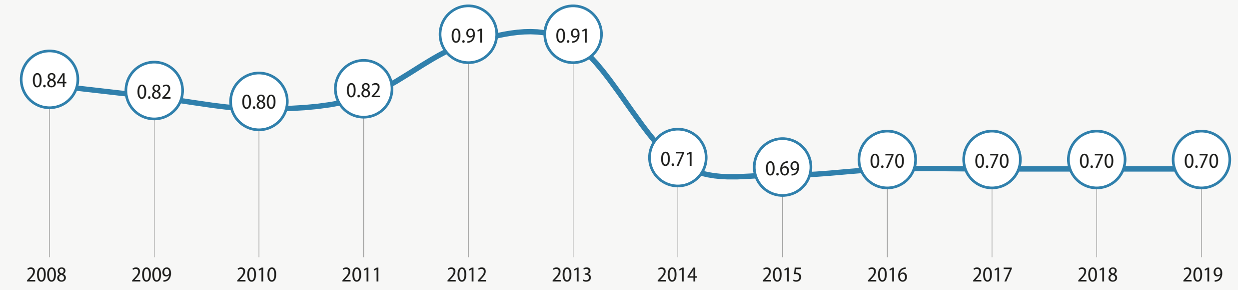
Anxiety about automation displacing jobs

Anxiety about the prospect of automation displacing jobs on a large scale dominates academic and public debate in India and abroad. These fears have been heightened by the phenomenon of 'jobless growth' that has plagued India since 1991 (Mani, 2015). In 2004, about 58% of the population entering the workforce – based on age – was absorbed but this proportion had fallen to 15% by 2011 and even to -5% by 2017, implying that some of the working age population had actually left the workforce, according to the National Statistical Office. This has happened even as India recorded a positive aggregate economic growth rate of about 7% in 2017. Worst affected have been rural women and those employed in sectors like agriculture, mining and quarrying or manufacturing. The jobless growth phenomenon has, thus, been accentuated, with job losses in the economy in 2017 for the first time since independence.

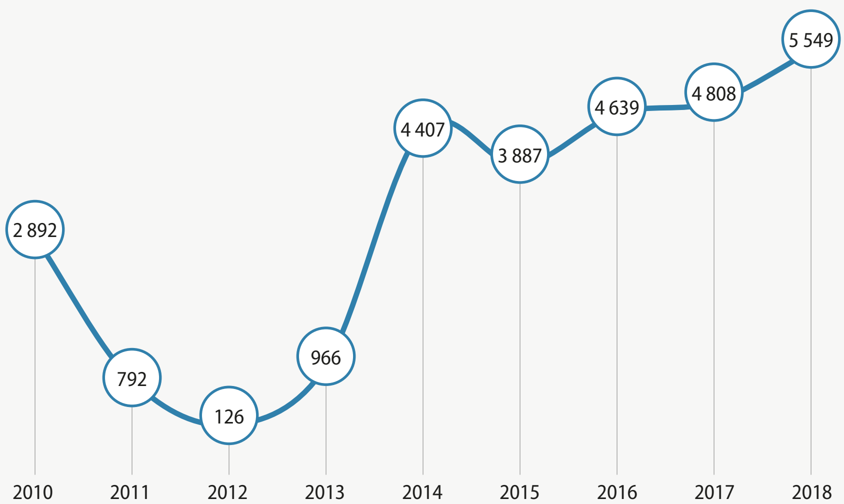
The manufacturing sector accounts for the greatest share of delivered robots in India. Within manufacturing, the majority of robots have been installed in four industries, in descending order: automotive; chemicals, rubber and plastics; metal; and electrical and electronics. On average, the number increased by 64% per year from 2000 to 2016. The booming automotive

Figure 22.2: **Trends in research expenditure in India**

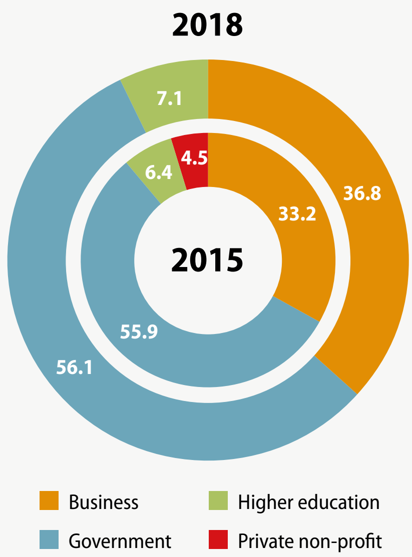
GERD as a share of GDP in India, 2008–2019 (%)



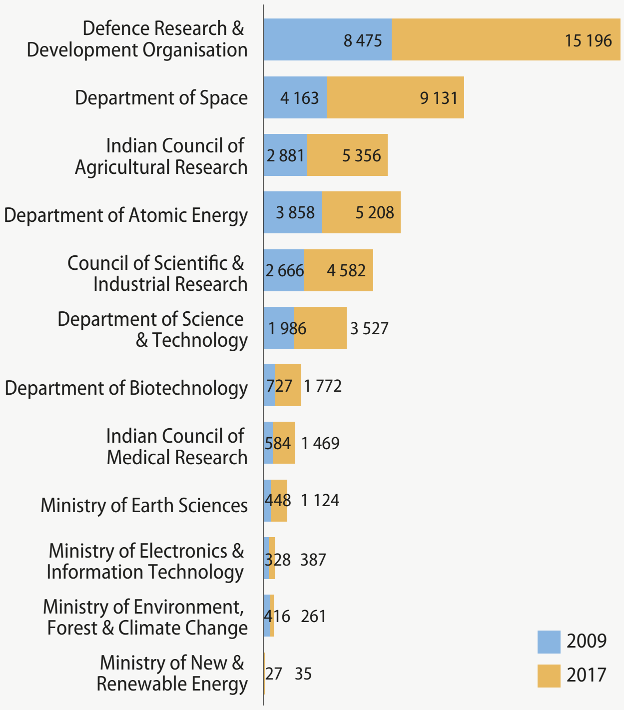
Investment in R&D by foreign multinationals in India, 2010–2018
In INR crores



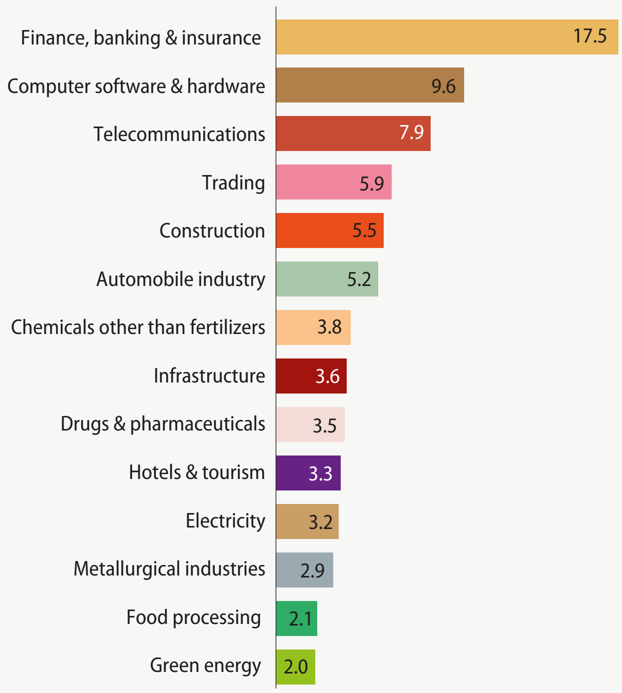
GERD in India by sector of performance, 2015 and 2018 (%)



GERD by research council, 2009 and 2017
INR crores, current prices



Share of total investment in priority areas by foreign multinationals in India, 2000–2020 cumulative (%)



Source: UNESCO Institute for Statistics; DST (2017 and 2020); Reserve Bank of India

Note: Data are restricted to selected fields representing at least 2% of the total.

industry accounts for most of the growth in robot installations in India, mimicking the international pattern. Robot usage in India is confined to two tasks: welding and soldering, as well as handling and machine tending (Mani, 2019a).

The density of robots in India is one of the lowest among robot-using countries. Total employment in all industries using industrial robots does not exceed 10% of total manufacturing employment and, within these industries, only a few tasks are automated: those that require precision and those that come with high occupational hazards.

At present, automation does not present a serious threat to manufacturing employment. However, with related technologies developing quickly, many tasks previously considered beyond the realm of automation might become automated in the near future. This could radically alter the employment landscape in India and beyond.

Make in India

Make in India sets out to stimulate investment in manufacturing and related infrastructure, foster innovation and make it easier to do business in India. Action plans for 21 key sectors have been targeted for policy initiatives, fiscal incentives, infrastructure creation, research and innovation and skills development.

The Make in India programme has sought to increase domestic manufacturing of a host of high-tech products, such as cell phones and electric locomotives. The government announced a series of strategies for 2017–2019 for new and emerging technologies such as AI and robotics, blockchain, the Internet of Things and electric vehicles, among others.

To boost economic growth and the Make in India programme, the Minister of Finance announced a scheme, in a statement on the Union Budget for 2019–2020, whereby global companies would be invited, through a transparent, competitive bidding process, to set up megamanufacturing plants in 'sunrise and advanced technology' areas, such as semiconductor fabrication, solar photovoltaic cells, lithium storage batteries, solar electric charging infrastructure, computer servers and laptops.

The mode of support envisaged in the budget is to provide investment-linked income tax exemptions under the Income Tax Act and other indirect tax benefits.

Domestic manufacture of most of these technology products involves lumpy investments that are sizeable but infrequent. As a consequence, India does not seem to have acquired the requisite technology to manufacture these products itself. Past attempts to precipitate domestic investment, especially in semiconductor fabrication, have proven inconclusive.

Moreover, incentive-induced stimulation of investment has a social cost because it involves taxing citizens and passing on the benefits to a private entrepreneur who ultimately may or may not set up a manufacturing facility in the chosen area of technology. At the same time, the very lumpiness of investments requires some sort of subsidy.

The success of the scheme announced by the Minister of Finance will depend on how the government spells out the finer details of the new budgetary policy.

The mobile phone sector is another important industry for the Make in India programme. India has become the second-largest manufacturer of mobile phones in the world, with annual production exceeding 200 million. However, the manufacturing sector is adding less value to the finished product than it did just a few years ago: the ratio of imported components to imports of mobile phones increased from 0.45 in 2014 to 7.51 in 2019 and the ratio of value added to output declined sharply from 0.30 in 2009 to 0.13 in 2017 (Mani, 2019b).

Make in India has sought to encourage both domestic and foreign firms to manufacture goods in India. Although gross inflows of foreign direct investment (FDI) have risen since 2014, multinational corporations have been repatriating about 27% of this amount (Figure 22.1). Moreover, only 26% of investment by foreign multinationals has actually gone towards the manufacturing sector, the remainder benefiting the services sector.

Over the past 20 years, one-quarter of FDI inflows has gone to finance, banking and insurance, as well as computer software and hardware. Just 2% has been invested in the green economy (Figure 22.2).

Diffusion of green energy technologies

Despite there being many legal instruments in place to deal with environmental issues, especially air and water pollution, air quality in some of the major cities remains a matter of serious concern. According to the *State of Global Air 2019* report, poor air quality is the third-leading cause of death in India, contributing to more than 1.2 million deaths per year in the country (HEI, 2019). Half of the 50 cities in the world with the worst air quality are in India and Delhi tops the list for capital cities (IQAir, 2019).[4]

In November 2019, air pollution hit record levels in Delhi, prompting the Supreme Court to warn that state governments failing to provide citizens with clean air and water would be obliged to pay them compensation. The authorities in Delhi reacted by spraying water into the air to force the pollutants to the ground. A longer-term solution under discussion is to replace fossil fuels with hydrogen-based technology.

One of the most important issues for the country's sustainable development is the effect of climate change on economic activity. India remains primarily an agricultural economy. Extreme weather and climatic events, such as drought and torrential rain, have caused enormous material damage to the economy over the past five years or so.

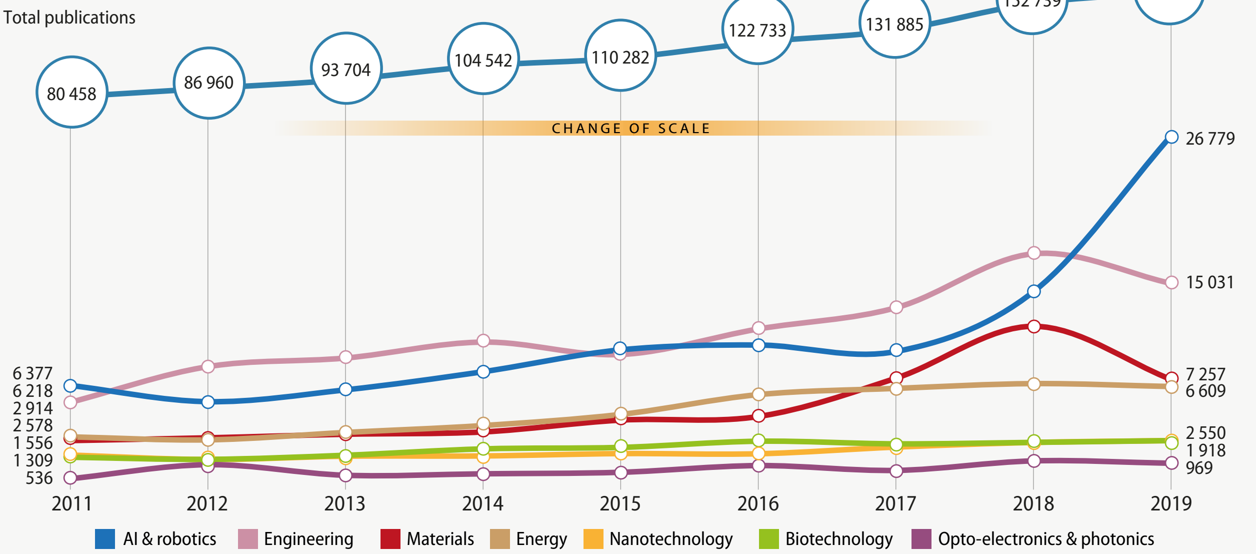
India's commitment to reducing its dependence on fossil fuels has two broad components: promoting green energy and hastening the diffusion of electric vehicles.

India's high reliance on new technologies has been accompanied by some recognition of the accompanying resource consumption and socio-environmental cost. As part of its *Paris Agreement* (2015) commitments, the government set an ambitious target of achieving 175 gigawatts (GW) of green energy capacity by 2022, increasing the current installed capacity 2.5-fold. Green energy sources are expected to meet 40% of India's electricity needs by 2030.

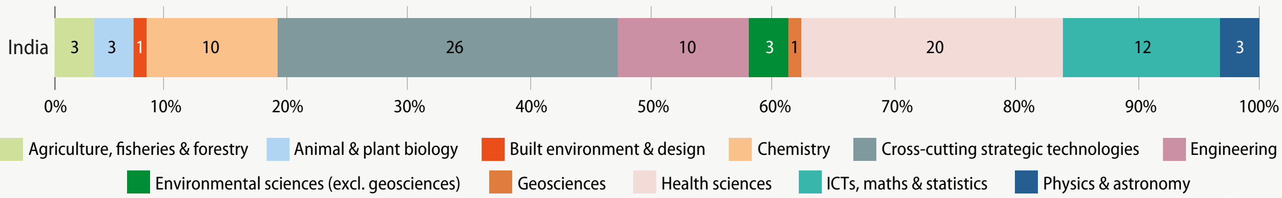
Figure 22.3: **Trends in scientific publishing in India**

Volume of scientific publications in India, 2011–2019

Total publications and output on cross-cutting strategic technologies



Scientific publications in India by broad field of science, 2017–2019 (%)



Engineering publications per million inhabitants in India, 2015 and 2019

11

in 2019

8

in 2015

0.86

Average citation rate for Indian scientific publications, 2013–2015; the G20 average is 1.02

18%

Share of Indian papers with foreign co-authors, 2016–2018; the G20 average is 25%

How has output on SDG-related topics evolved since 2012?

Indian researchers are publishing more than would be expected on key topics related to agricultural production, health and sustainable energy, relative to global averages. The proportion of output on climate-ready crops is even triple the global average. Output is also more than twice the global average on medicines and vaccines for tuberculosis, traditional knowledge, water harvesting, maintaining genetic diversity and pest-resistant crops.

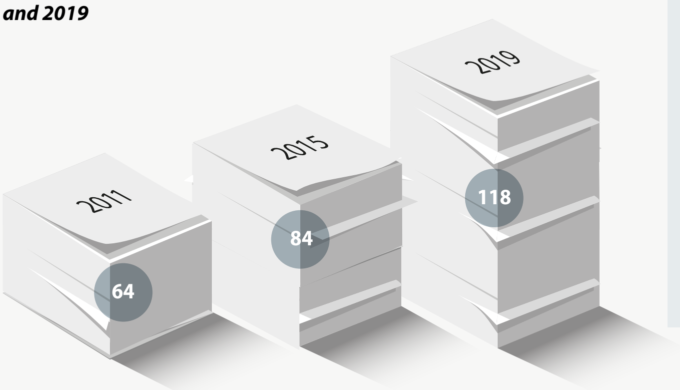
Indian researchers are publishing between 1.5 and 1.8 times the global average on smart-grid technologies, photovoltaics, biofuels and biomass and wind turbine technologies, complementing the government's push to expand green energy sources.

They are publishing no more than would be expected, however, on the impact on health of soil, freshwater and air pollution, despite counting 17 of the world's 25 most-polluted cities (IQ Air, 2019). Indian publications on this topic have, nevertheless, doubled from 893 (2012–2015) to 1 895 (2016–2019).

One of the fastest-growing topics has been sustainable transportation, with publications quadrupling from 754 (2012–2015) to 2 989 (2016–2019). Publications on greater battery efficiency almost tripled over the same period, from 1 091 to 3 188. These trends reflect the push to develop electric cars in India.

For details, see chapter 2

Scientific publications per million inhabitants in India, 2011, 2015 and 2019



India's top five partners for scientific co-authorship, 2017–2019 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
India	USA (23 628)	UK (9 421)	China (7 244)	Germany (6 825)	Korea, Rep. (6 676)

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

The government's aim of achieving universal household electrification is also a boon for the power sector. India added a record 11 788 megawatts (MW) of green energy capacity in 2018 through systematic support and has one of the lowest capital costs per megawatt for solar photovoltaic plants.

For three consecutive years, investment in renewable sources has exceeded that in fossil fuels (IEA, 2019). The Union Budget for 2019–2020 allocated US$ 728.32 million to the green energy sector.

With the adoption of the *National Electricity Plan* in 2018, India's efforts are considered 2°C compatible but insufficient to meet the *Paris Agreement* target of 1.5°C. India's carbon emissions rose by 4.8% in 2018, largely driven by emissions from coal power plants. The main challenge will be to abandon further investment in such plants. The *National Electricity Plan* foresees adding 46 GW of coal-fired capacity by 2027, even though plans to build nearly 14 GW of coal-fired power plants across India were cancelled in May 2017 after being deemed uneconomical.

The total installed capacity in green energy sources (wind, solar, biofuels and small hydro-electricity generators) in 2018 was about 72.6 GW, with wind energy accounting for an estimated 48% of the installed capacity, followed by solar energy at 34%.

As a share of total installed capacity for electricity generation, green energy sources rose from 13% in 2015 to 22% in 2018. However, both total consumption and consumption per capita have also increased each year since 2015 (CSO, 2019).

Although most Indian states now have explicit policies for the installation, generation and use of green energy, only a handful have achieved substantial progress in reaching their renewable energy targets, beginning with the southern states of Karnataka (83%) and Telangana (155%) [Bhati *et al*., 2019].

In 2018, the government allocated INR 1 billion (*ca* US$ 15.8 million) to 60 cities across the country to develop projects for a combined 8.1 MW of solar panels and to install solar water heating systems covering 7 894 m^2 of collector area. The city of Chandigarh has made it mandatory to install solar water heating systems in public and industrial buildings, as well as in any new residential units (Busch *et al*., 2019). The Delhi Metro Rail Corporation, meanwhile, is gradually equipping its trains with solar photovoltaic systems.

A push for electric vehicles

Nearly 80% of all vehicles sold in India are two- and three-wheelers. The government has been considering a ban on all internal combustion engine-driven two-wheelers under 150 cc by 2025 and three-wheelers by 2023.

The *National Electric Mobility Mission Plan 2020* (2013) has sought to populate India with a fleet of 6–7 million electric and hybrid vehicles by 2020.

However, the electric vehicle industry in India is still at a nascent stage. According to the Society of Manufacturers of Electric Vehicles, 2.18 million such vehicles were sold in 2018, just 1% of total vehicle sales. At present, there are more than 400 000 electric two-wheelers and a few thousand electric cars on Indian roads. Over 95% of electric vehicles are low-speed electric scooters that do not require registration or a license.

To date, the volume of electric vehicles on the roads has fluctuated, depending on the government incentives of the moment. The government has introduced increasingly generous price subsidies, through the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme, which was launched in 2015 and moved into its second phase in 2019.

Through FAME II, the government is offering people incentives to purchase certain types of electric and hybrid vehicles between 2019 and 2022, combined with a reduction from 12% to 4% in the goods and services tax on electric vehicles. The target is to incentivize the purchase of 7 090 electric buses by State Transport Undertakings, 35 000 four-wheelers, 50 000 three-wheelers and 20 000 hybrids.

The Union Budget for 2019 provides an additional income tax deduction of INR 1.5 lakh (*ca* US$ 21 000) on the interest paid on loans taken out to purchase electric vehicles, which works out to a saving of about INR 2.5 lakh (*ca* US$ 35 000) over the loan period.

Apart from price, there are two main technological barriers to faster adoption of electric vehicles: the relative scarcity of both lithium-ion batteries and of charging stations spaced at reasonable intervals. The Union Budget for 2019 addressed the domestic manufacturing of lithium storage through investment-linked exemptions from income tax; in the past, such incentive-induced promotion had not managed to generate the required investment. In parallel, the Ministry of Power delicensed Public Charging Stations in December 2018, provided they meet the standard specifications and protocols laid down. The target is to have 1 000 charging stations across the country by 2030. Charging stations at private residences are also authorized.

TRENDS AND ISSUES IN RESEARCH

A moving target for research intensity

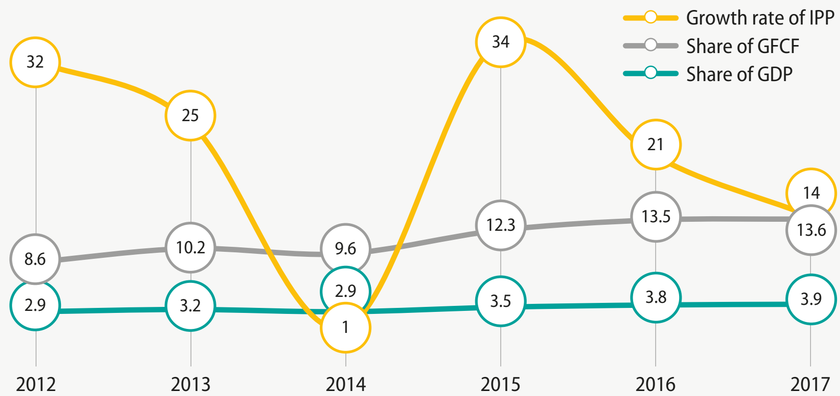
India has made solid progress towards some of its targets for the Sustainable Development Goals (SDGs), especially those under SDG9 concerning the development of industry, infrastructure and innovation.

India's research effort remains unsatisfactory, however. With an average overall gross domestic expenditure on research and development (GERD) over the past two decades of 0.75% of GDP (Figure 22.2), India has one of the lowest GERD/GDP ratios among the BRICS (Brazil, Russian Federation, India, China and South Africa), even if, in absolute terms, research expenditure has risen consistently over the past 14 years.[5]

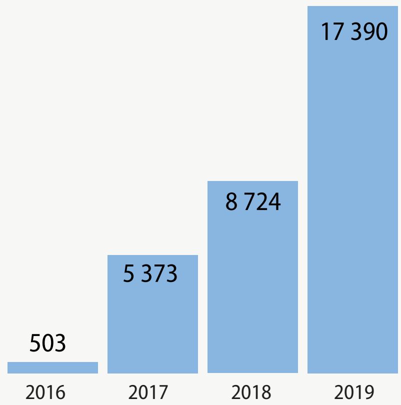
India's research intensity has been declining since 2014. The *Science and Technology Policy* of 2003 fixed the threshold of devoting 2% of GDP to research and development (R&D) by 2007. This target date was set back to 2018 in the new *Science, Technology and Innovation Policy* (2013) then again to 2022 by the Economic Advisory Council of the Prime Minister. In 2020, the task force drafting the country's new *Science and Technology Policy* recommended pushing back the target date to a more realistic 2030. As of October 2020, no date had yet been set for the policy's official release.

Figure 22.4: **Trends in Innovation in India**

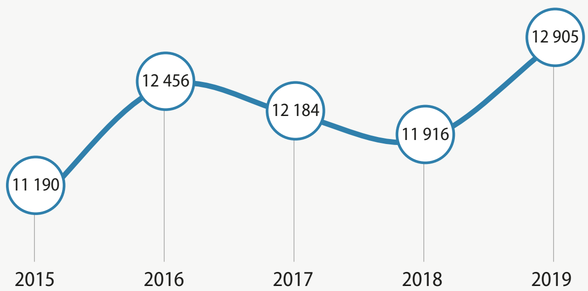
Investment in intellectual property products (IPP) as a share of India's GDP and gross fixed capital formation (GFCF), 2012–2017 (%)



Growth of start-ups in India, 2016–2019

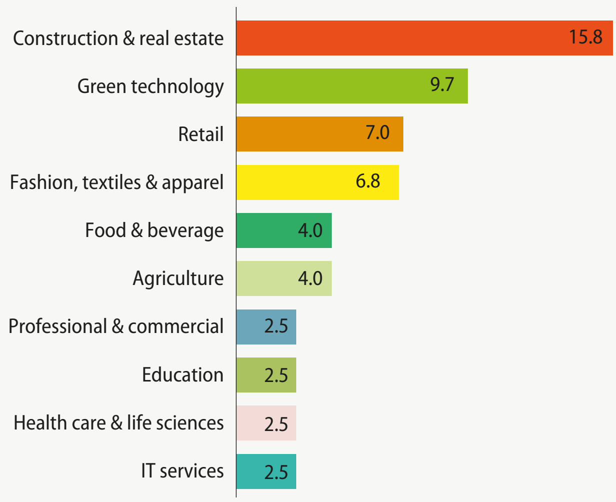


Number of IP5 patents granted to Indian inventors, 2015–2019



Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China.

Industry-wide distribution of start-ups in India, 2018 (%)



175

Indian resident patent applications per 100 billion GDP (2011 constant US$), 2018

Indian trade balance in intangible intellectual property, 2015

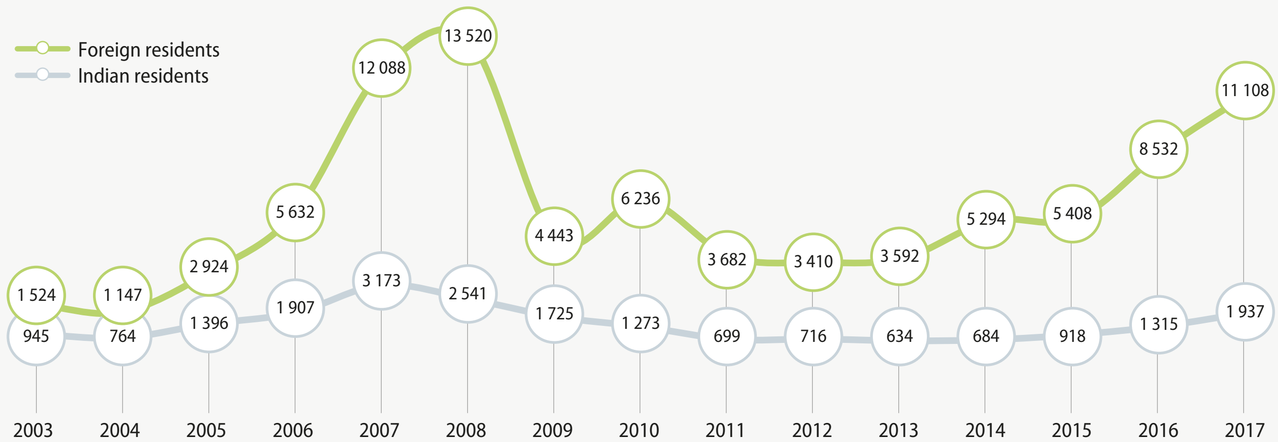
US$ 67 billion

including computer software services

US$ -4 billion

excluding computer software services

Patents granted by India's national patent office to inventors residing in India and abroad, 2003–2017



Source: Central Statistical Organization (2019), trade deficit computed from UN Comtrade; DIPP (2018) Department for Promotion of Internal Trade and Industry; for IP5 patents: Science-Metrix using PATSTAT data; for resident patent applications, World Intellectual Property Organization; for India's national patent office, Office of the Controller General of Patents, Designs and Trade Marks (2018)

Whereas the new Science and Technology Policy is being piloted by the Department of Science and Technology, it is the Department of Pharmaceuticals which is overseeing preparation of an updated research policy.

Since 2015, there has been a steady decline in share of R&D performed by the government sector (Figure 22.2). In parallel, the private business enterprise sector has raised its own contribution to 42% of the total. In theory, this is a positive trend, as it means that R&D is increasingly being performed by the same sector that has the capacity to convert research output into commercial products and processes. The challenge for India will be to ensure that the current increase in business expenditure on R&D becomes *systematic,* as has been the case for countries such as China and the Republic of Korea.

GERD remains concentrated in a handful of industries, firms and states, led by the pharmaceutical, automotive, information technology and defence sectors (Mani, 2015). According to the Economic Advisory Council of the Prime Minister, the three private companies that spent the most on R&D in 2017 all specialize in software development.

The top spenders at state level in 2017 were Maharashtra, Tamil Nadu, Karnataka, Gujarat and the Undivided Andhra Pradesh; this is primarily due to the dual presence of top firms in terms of research expenditure and leading public laboratories in these states.

Of the seven research councils in the country, the top research spenders continue to be those responsible for defence, space and atomic energy (Figure 22.2). However, the spillover effects of public research for broader civilian use, although on the increase, remain very limited. It must be added that all three agencies have been making stronger efforts to involve both public and private enterprises in their activities. In fact, the state-owned undertaking Electronics Corporation of India was initiated in 1967 as an offshoot of the research done by the Department of Atomic Energy.

Investment in R&D by foreign multinationals is on the rise (Figure 22.2). According to the most recent R&D survey (DST, 2020), they accounted for as much as 16% of private-sector investment in R&D in 2019, or 13% when public-sector enterprises were included in the calculation.

More investment in intellectual property

Scientific output has maintained an upward trajectory since 2015, despite the country's modest research intensity. Scientists have even overtaken their Japanese peers for the sheer volume of publications (Figure 22.3).

Investment in intangibles has also increased (Figure 22.4). Intangibles include intellectual property such as R&D, mineral exploration, software and databases, literary and artistic original works and so on. Investment in intangibles, which is largely done at the level of firms, spills over into other companies within the same industry and, thereby, benefits the industry as a whole. Greater investment in intangibles can, thus, lead to higher productivity and economic growth. In India, investment in intangibles now contributes about 4% of GDP and 14% of gross fixed capital formation (Figure 22.4).

Trade in intangibles has also been growing but is overreliant on software services. India has a surplus in trade in intangibles when trade in software services is included but a deficit when exports of software services are excluded (Figure 22.4). This growth was noted in the 2015 edition of the *UNESCO Science Report* and is a reflection of low investment in R&D (Mani, 2015).

The trade deficit in intangibles is concentrated in three areas: royalties and license fees, which includes charges for the use of trademarks; franchises and similar rights; and other royalties, including the license fee for patents.

India has a growing positive trade balance in R&D services but these services are largely created and exported by multinational corporations to their parent companies abroad, many of which are located in the USA.

Greater output in innovation

Inventive activity has grown tremendously, judging from trends in the number of patents issued to Indian inventors by the India Patent Office and those issued to Indian inventors by the US Patent and Trademark Office (Figure 22.4).

However, a closer look at the data shows that about 85% of the assignees of these patents are foreign inventors, commonly represented by multinational corporations. Very few patents have been granted to Indian firms, research institutions and individuals and the number of resident patent applications per 100 billion GDP has grown at a more pedestrian pace (Figure 22.4). Patents from the US Patents and Trademark Office were largely issued to inventors in just two industries: information technology services and pharmaceuticals.

The landscape for patents described in the previous edition of the *UNESCO Science Report* (Mani, 2015) has not changed:

- Indian inventors are primarily active in two industries: software development and pharmaceuticals, with the former continuing to dominate utility patents (Mani, 2015).
- The majority of software-related patents are obtained by multinational corporations operating from India, whereas almost all the pharmaceutical patents are obtained by domestic pharmaceutical companies.

India is the only country with a stringent policy on commercial exploitation of patents (Mani, 2019c). The country also sets the bar higher than any other country for the criteria used to assess inventiveness in pharmaceutical products. Patent legislation is used to effectively cull the practice of 'evergreening', whereby pharmaceutical firms extend the patent life of a drug by obtaining additional 20-year patents for minor reformulations or other iterations of the drug, without necessarily changing its therapeutic efficacy.

Pre- and post-grant opposition to patenting is another important feature of the patent system. India developed a new *National Intellectual Property Rights Policy* in 2016 but this does not fundamentally change any of the policies with which India's own patent regime had been compliant since 2005 under the Agreement on Trade-Related Aspects of Intellectual Property Rights (Mani, 2016).

A less generous tax regime for R&D

India's tax regime with respect to R&D has four important features:

- Firstly, within India, there are no requirements for the domestic use of intellectual property arising from R&D financed through tax concessions.
- Secondly, both domestic and foreign companies are eligible to seek the subsidy but their R&D must be conducted within India.
- Thirdly, if a firm is in deficit, unused benefits may be carried forward for the next eight years but not backwards to previous years.
- Fourthly, qualifying expenditure includes wages, supplies, utilities and other expenses directly related to R&D. The deduction of R&D expenditure shall be the net sum of grants, gifts, donations, etc.

The R&D tax subsidy manifests itself in terms of the amount of tax foregone, which the Ministry of Finance has been estimating on a regular basis. Over the years, the amount of tax foregone as a result of this subsidy scheme has grown at an annual rate of 14% per annum and now accounts for about 8% of all corporate subsidies (Figure 22.5).

By 2015, the Indian tax regime had become one of the most generous in the world (Mani, 2014). However, the Union Budget for 2016 reduced the tax incentive for performing R&D in business enterprises from 200% to 150% of research expenditure from 2017 onwards and to 100% from 2020 onwards. This shift follows an observation made in the 2015 *UNESCO Science Report* that India's generous tax regime '[had] not resulted in the spread of an innovation culture across firms and industries' (Mani, 2015).

Most industries seem to have taken the drop in their stride but it has come as a rude shock to the pharmaceuticals and life sciences industry, which had been lobbying the government to adopt a budget proposing a 250% tax break. Companies had also been lobbying to expand the scope of the benefit to cover expenses incurred outside research facilities, such as bio-equivalence studies, clinical studies, patent filings and product registrations.

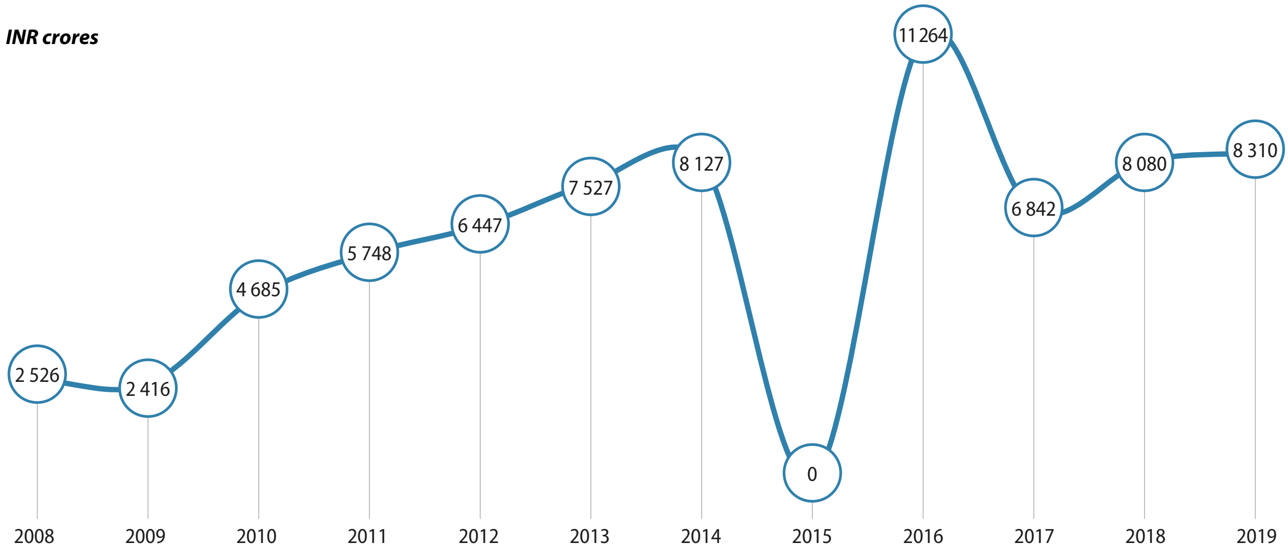
The move, thus, came as a double blow to the pharmaceuticals industry. Saumen Chakraborty, president and chief financial officer of Dr Reddy's Laboratories Ltd, reacted by saying that 'the decrease in R&D weighted deduction to 150% may have an impact on innovation, as it could de-incentivise the industry to spend more on R&D'. Venkat Jasti, CEO of Suven Life Sciences Ltd, opined that the cut in the R&D tax break went against the government's 'Make in India' slogan (Pilla, 2016).

Simultaneously, the finance minister announced a patent-box type of incentive for the first time, wherein income received by Indian companies in the form of royalties and technology license fees received would be taxed at a reduced rate of 10% from the fiscal year 2016/2017 onwards. This move was designed to stimulate innovation by raising the revenue that companies could earn from their intellectual property. The introduction of the patent box encourages output of R&D, whereas the reduction of R&D tax incentives discourages input to innovation.

Start-up India: incentivizing tech

Innovation is promoted in two ways. In addition to the traditional avenue of tax incentives, the government has improved the ecosystem for start-ups by providing them with a range of incentives through the Startup India initiative since 2016. This incentive system ranges from 'simplification and hand-holding,' 'funding support and incentives' to 'industry–academia partnership and incubation.'

Figure 22.5: **Revenue foregone in India as a result of the R&D tax incentive, 2008–2019**



Source: Ministry of Finance

One of the main barriers to the creation of start-ups has been the availability of risk capital. One source of such capital is from angel investors but there was a long-standing income tax issue known as the angel tax. This is a term used to refer to the income tax payable on capital raised by unlisted companies via the issue of shares where the share price is seen to be in excess of the fair market value of the shares sold. The excess realization is treated as income and taxed accordingly.

To resolve this issue, the Union Budget for 2019–2020 stipulated that those 'start-ups and their investors who file requisite declarations and provide information in their returns will not be subjected to any kind of scrutiny in respect of valuations of share premiums.' Furthermore, the budget extended tax breaks to investments in start-ups. In short, the proposals in the recent budget are a logical sequencing of the government's efforts to improve the ecosystem for start-ups. Consequently, the number of start-ups in the country has been increasing steadily since 2016 (Figure 22.4).

Although there has been a significant improvement to the ease with which start-ups can be established and developed in India since 2016, most start-ups are still concentrated in Maharashtra (specifically the cities of Mumbai and Pune), Karnataka (specifically Bangalore) and Delhi. Most of the start-ups are in the services sector, with software development services taking the lead (Figure 22.4). There are very few start-ups in manufacturing.

Startup India has been working with various line ministries, including those responsible for water and sanitation and agriculture, to develop start-ups that will address specific problems faced by these sectors. In this way, the emergence of new start-ups may result in innovative solutions incorporating emerging technologies.

Moreover, start-ups in the manufacturing and services sectors may manage to leapfrog over certain stages in developing their business through recourse to Industry 4.0 technologies, such as cyberphysical systems on the factory floor and the digitalization of service industries.

DEVELOPMENT OF HUMAN RESOURCES

Schemes to nurture an innovation culture

In 2018, India had 253 full-time equivalent (FTE) researchers per million inhabitants (Figure 22.6), about 11% of the researcher density of Italy. This is, nevertheless, a marked improvement on the situation in 2011 (157 per million) and 2015 (216 per million).

The density of FTE researchers per 10 000 labour force has increased very slowly, from 9 in 2005 to 11 in 2015 and 14 in 2018, the latest year for which such data are available (DST, 2020).

Since 2015, the government has put in place a range of incentive schemes to boost the scientific workforce.[6] One of the first was the Atal Innovation Mission (AIM), established by NITI Aayog in 2016, which is striving to develop an innovation culture in schools, universities and businesses. The government granted this programme US$ 24.84 million in 2016 to boost innovation by academicians, entrepreneurs and researchers.

In July 2018, AIM and MyGov launched the Innovate India Platform with the aim of providing a common entry point for information on developments in innovation across India.

As of 2020, AIM had incubated more than 620 start-ups, more than 100 of which were led by women.[7]

In parallel, the AIM programme is giving schoolchildren problem-solving and innovation skills. Atal Tinkering Labs are being established in 30 000 schools between 2018 and 2021 to familiarize pupils with hands-on technologies such as 3D printers, robotics, miniaturized electronics, the Internet of Things and computer programming. By 2020, AIM had selected 5 441 schools to host these labs; these cover 93% of the districts in India and 98% of the upcoming smart cities. By this time, more than 6 million pupils had already participated in an Atal Tinkering Lab.

In February 2018, the Union Cabinet approved implementation of the Prime Minister's Research Fellows scheme to promote innovation at university by funding PhD fellowships at a total cost of INR 1 650 crore (*ca* US$ 246 million) for seven years beginning in 2018.

The same month, the Union Government announced a grant of INR 1 000 crore (US$ 156 million) for the second phase of Impacting Research Innovation and Technology (IMPRINT), a fund created by the Department of Science and Technology and the Ministry of Human Resource and Development. In its first phase (2015–2019), IMPRINT had funded research projects worth INR 5 949 million (*ca* US$ 84 million) addressing national challenges.

Meanwhile, the Department of Biotechnology is using a scheme called Boost to University Interdisciplinary Life Science Departments for Education and Research (DBT-BUILDER) to support advanced education and promote interdisciplinary research and technological development. In practice, universities are using these funds to upgrade research infrastructure in life sciences.

Since having a critical mass of technicians will be a vital component of Industry 4.0, the Council of Scientific and Industrial Research launched the first of 30 vocational skills training programmes in 2016 in technical areas. These include: leather processing; paints and coatings; electroplating and metal finishing; industrial maintenance engineering; bioinformatics; mechatronics; and glass-beaded jewellery. The relevant teaching institutions are scattered across the country.

Plans for a National Research Foundation

The university sector performed 7.1% of GERD in 2018, up from 4.0% in 2015 (Figure 22.2) [Mani, 2015]. The *National Education Policy* (2019) envisages establishing a National Research Foundation to fund research in the education system, primarily at colleges and universities. This could provide a much-needed boost for academic research in India. It would appear that other schemes summarized in the previous edition of the *UNESCO Science Report* have not had the desired result (Mani, 2015).

The India-based Neutrino Observatory (INO) is a megaproject designed to nurture cutting-edge basic research. INO is being built in the State of Tamil Nadu, using funding approved in the government's *Twelfth Five-Year Plan* (2012–2017).

INO will ultimately consist of an underground laboratory, an iron calorimeter detector and an Inter-Institutional Centre for

High Energy Physics. More than 120 physicists, engineers and students from 25 research institutes, universities and Indian Institutes of Technology are involved in the project, which also runs a graduate training programme.

Concern over the employability of graduates

University graduates in science, technology, engineering and mathematics (STEM) still represent a little over one in four graduates (Figure 22.6). Science graduates also make up a greater share of the total than graduates in engineering and technology.

Although the government bemoans the country's low researcher density, there is actually very little quantitative evidence to show that demand for STEM graduates has increased, as investment in R&D has not kept pace with the rise in GDP (DST, 2020).

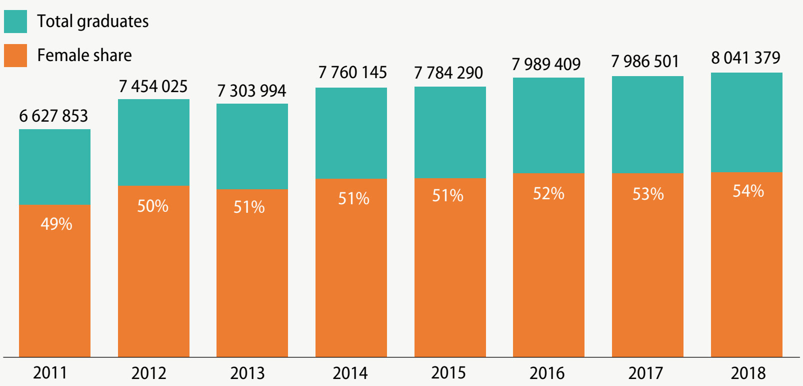
One perennial concern relates to the employability of Indian graduates, given the varying quality of education in STEM subjects, in particular. At one end of the spectrum, there are prestigious higher education institutions like the Indian Institutes of Technology. The CEOs of some of world's leading technology companies, among them Microsoft and Google, are Indians who were trained at these premier institutes. At the other end of the spectrum are a swath of provincial universities and polytechnics.

Employability increased from 34% in 2014 to almost 47% in 2019, meaning that one out of two graduates is still not employable (Figure 22.6). In technical fields, courses in electronics and communications engineering shared the highest employability rates (60.3%) with information technology (60.2%) in 2019, whereas civil engineering had the lowest.

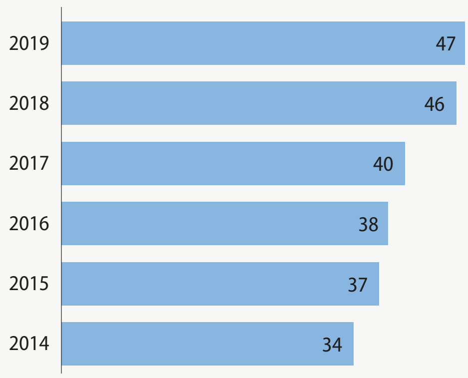
Despite the focus on improving the quality of higher education, the employability of Industrial Training Institute

Figure 22.6: **Trends in human resources in India**

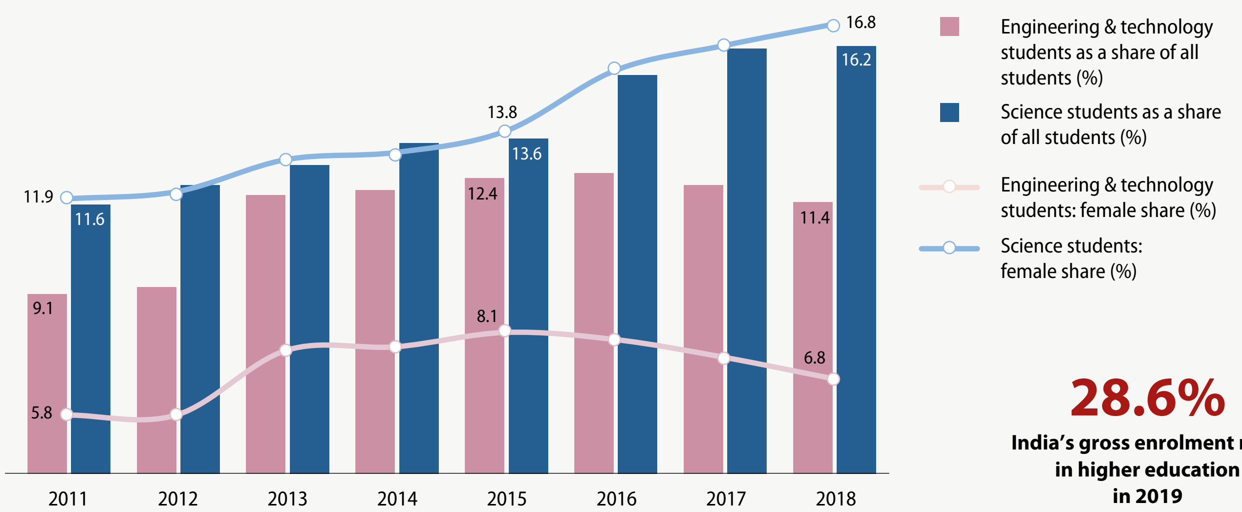
Tertiary graduates in India, 2011–2018



Employability of Indian graduates, 2014–2019 (%)



Students of science, engineering and technology as a share of total Indian students, 2011–2018 (%)



28.6%

India's gross enrolment ratio in higher education in 2019

Note: Science students include those completing undergraduate, post-graduate, MPhil and doctoral degrees in STEM subjects. The total of all students includes graduates of engineering, technology, science, medicine, humanities, social sciences and management degrees.

and polytechnic graduates has been falling, primarily due to a lesser focus on alliances with industry and core skills.

The Skills Development Mission

The prime minister officially launched the National Skills Development Mission on 7 July 2015, on the occasion of World Youth Skills Day. The aim is to create convergence across sectors and states, in terms of skills training.

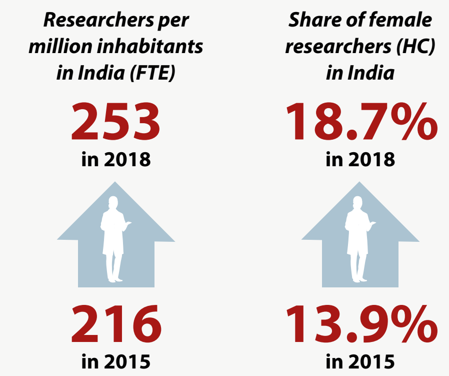
To achieve the vision of a 'skilled India', the mission is not only consolidating and co-ordinating efforts to develop skills but also expediting decision-making across sectors to achieve rapid change to a high standard.

The mission is being implemented through a streamlined institutional mechanism driven by the Ministry of Skills Development and Entrepreneurship. Under the mission, about 400 million people across the country are to be trained by 2022.

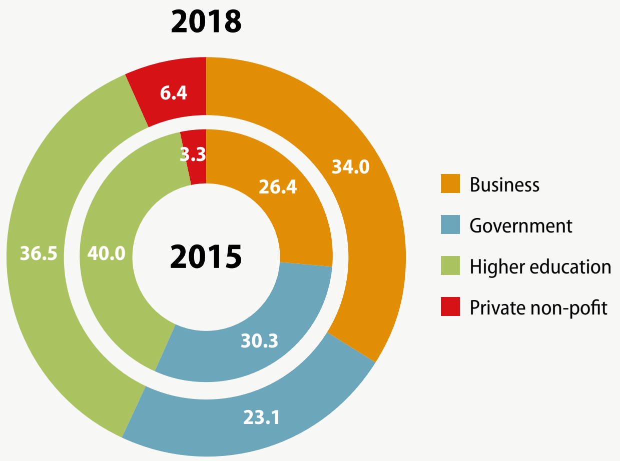
E-learning approaches galvanized by Covid-19

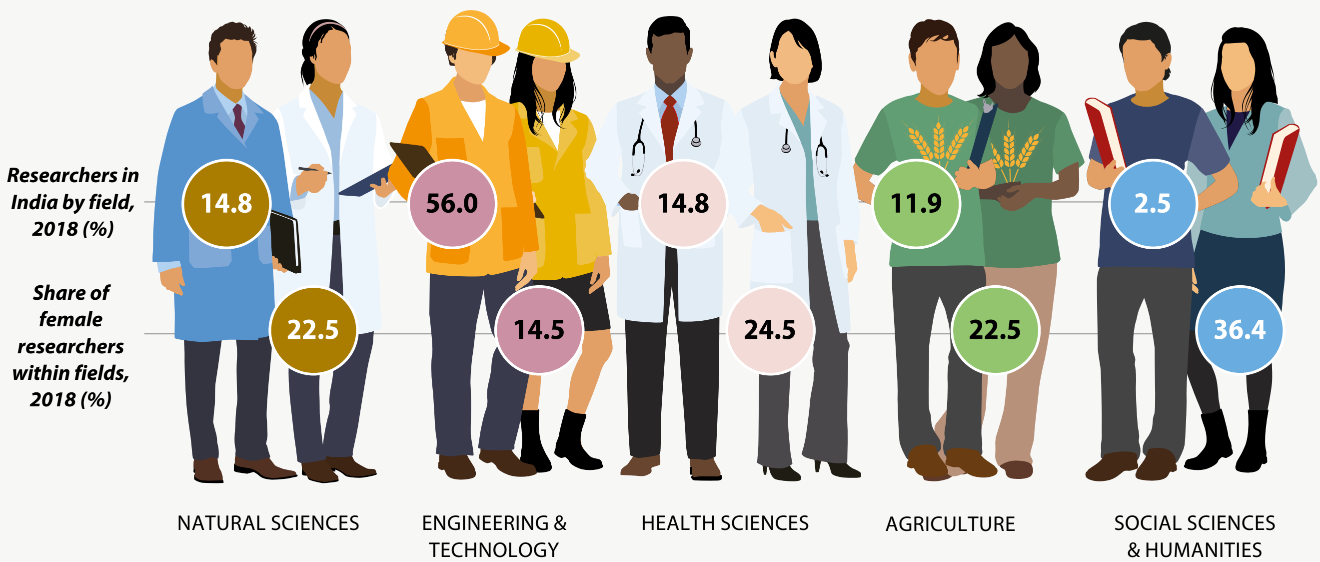
The Covid-19 epidemic has stimulated interest in e-learning approaches. This year, several Indian start-ups in education technology (edtech) have sprung up. The National Skill Development Corporation (NSDC) now proposes more than 450 online courses via its e-Skill India learning platform, which aligns with the Skill India Mission.

Since its inception in 2008, the NSDC has developed partnerships with the private sector to provide open access courses in a wide range of fields, including health care, electronics and English proficiency. For instance, through the company SAS, courses are available on data analytics, machine learning, predictive modelling and statistical business analytics, all of which can be applied in the retail and financial sectors, among others. The platform



Indian researchers (FTE) by sector of employment, 2015 and 2018 (%)





Note: All researcher values are based on full-time equivalents.

Source: UNESCO Institute for Statistics; All India Survey on Higher Education Final Reports (2011 to 2018), Ministry of Human Resource Development, Government of India; for employability, Wheebox (2019); Government of India (2020) *S&T Indicator Tables 2019-20.* Ministry of Science & Technology: New Delhi has also partnered with the British Council, English Score, the Saylor Academy (USA) and UpGrad, among others.

Two schemes to address chronic brain drain

India has been losing highly skilled personnel, primarily to the USA, for some time. In 2017, half of the foreign-born individuals in the USA with a higher degree in science and engineering came from Asia, with India (23%) and China (10%) being the leading countries of origin (NSB, 2020).

The government introduced two schemes in 2017 to address this chronic brain drain. The first is the Visiting Advanced Joint Research (VAJRA) Faculty Scheme established by the Department of Science and Technology. It enables non-resident Indians and the overseas scientific community to contribute to R&D in India. The Science and Engineering Research Board, a statutory body of the Department of Science and Technology, is implementing the scheme. The VAJRA faculty undertakes collaborative research in publicly funded institutions in priority areas for India where capabilities and capacity need reinforcing.

The second scheme is the National Post-Doctoral Fellowship Programme. In order to encourage PhD recipients to stay in India, the programme offers them two-year fellowships. This, too, is administered by the Science and Engineering Research Board, which awarded 2 500 fellowships from 2017 to 2019.

Sabharwal (2018) has shown, through a field study of 83 returnees, that some reverse brain drain from the USA to India is occurring. The scientists and engineers interviewed by Sabharwal cite better career prospects in India as the reason for their decision to return home, welcoming what they perceive to be ample funding for research, less competition for grants, the ability to work on theoretical topics and the freedom to choose research objectives. However, given the small sample, there are doubts as to whether the findings of the study can be generalized.

CONCLUSION

A stronger scientific workforce is the way forward

The period from 2015 to 2020 has been a watershed moment for India. This period has been characterized notably by a stable government, especially with respect to policy-making. A large number of policies and programmes have been developed to encourage an innovation culture and absorb major emerging technologies such as artificial intelligence, blockchain and electric vehicles.

One impediment to the percolation of these technologies through the economy is the persistent shortage of well-trained scientists and engineers. As we have seen, the government has put in place a number of policies and schemes to remedy the situation.

Another impediment is the insufficient level of domestic investment in R&D. Research intensity is stagnant and patenting by domestic corporations, research institutes, universities and individuals remains low. On the positive side, intangible investments by private corporations are on the rise, as is investment in R&D by foreign multinational corporations.

A need for more 'policy' bridges

Given the large number of multinational corporations now engaged in R&D, it is imperative that the host economy benefit from this activity. The adoption of internationally accepted policy instruments could foster a more effective interaction between foreign research centres and local firms.

The eternal problem of inadequate links between public laboratories and manufacturers also demands policy attention, in order to improve technology spillovers and the commercialization of research output.

There is also a need to improve linkages between the start-up ecosystem and manufacturers, in order to push technological development in sectors in which India has a global presence, such as health care. There is potential for start-ups to develop medical devices for export, for instance.

Industry should be encouraged to mentor start-ups. One model could be the Companies Act (2013), which made it mandatory for firms to use 2% of their net profits to fund non-profit organizations, as part of their corporate social responsibility. This approach could be adapted to encourage firms to invest in start-ups in their economic sector.

Although the number of start-ups has grown steadily since 2016, these tend to be concentrated in the cities of Bangalore, Delhi, Mumbai and Pune. Good examples of institutional practises in the states hosting these start-ups, such as Kerala, Maharashtra and Telangana, could be replicated in other states. States should be encouraged to learn from one another.

Currently, every state is designing its own policies for areas such as biotechnology and information technology. They should also be encouraged to do more within the national framework, while focusing on local challenges. Moreover, rather than trying to invest across the board, states should focus on their own particular strengths. It is a positive sign that states are increasingly involving individuals from the private sector and younger talents in the development and implementation of their policies.

At the level of the union government, entrusting the co-ordination of innovation policies to a single office would avoid the current 'silo approach' to policy-making. This office would ideally be backed by a committee of experts (an epistemic community of sorts) charged with guiding policy implementation not just at the level of the union government but also between the union and the states.

Another policy challenge will be to put research programmes in place to develop the desired Industry 4.0 basket of technologies and ensure that domestic businesses have access to them, since it is these technologies which will define the nation's future competitiveness. Institutions like the Economic Advisory Council of the Prime Minister must take up the gauntlet by monitoring the country's readiness for the challenges ahead.

KEY TARGETS FOR INDIA

India plans to:

- raise GERD to 2% of GDP by 2030;
- achieve 175 GW of green energy capacity by 2022;
- meet 40% of India's electricity needs through green energy sources by 2030;
- populate India with a fleet of 6–7 million electric and hybrid vehicles by 2020;
- raise the number of charging stations for electric vehicles to 1 000 by 2030; and
- train about 400 million people by 2022 under the National Skills Development Mission.

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ENDNOTES

1 In 2020, WHO established a Solidarity Call to Action for a patent pool to ensure broad access to new treatments for Covid-19. By July 2020, 37 countries had signed up to the initiative, including the Maldives, Pakistan and Sri Lanka.

2 NITI Aayog has replaced the Planning Commission, which used to prepare five-year development plans. Consequently, the *Twelfth Five-Year Plan* (2012–2017) has been the last in the series. See: Mani (2015).

3 See: https://nsmindia.in/

4 This study measured the level of particulate matter of up to 2.5 microns in size (PM2.5). PM2.5 is able to penetrate deep into the human respiratory system and, from there, the entire body. The WHO recommends an annual mean exposure threshold of 10 μg m–3 to minimize the risk of health problems.

5 At current prices, GERD increased five-fold between 2004 and 2018, from INR 242 billion (ca US$ 3.4 billion) to INR 1 238 billion (ca US$ 17.82 billion). In 2016, GERD amounted to INR 1 049 billion (ca US$ 14.6 billion).

6 For details, see India Brand Equity Foundation: www.ibef.org/industry/science-and-technology.aspx

7 See the AIM brochure: https://aim.gov.in/AIM_Brochure.pdf

AT A GLANCE

China opened its first national gene bank in Shenzhen in 2016. 'China's Noah's Ark', as some media have dubbed it, aims to collect hundreds of millions of genetic samples, ultimately, for storage and study at the facility. © Aleksander Plavevski

- Made in China 2025 intends to help ten strategic industries to reduce China's reliance on certain core foreign technologies and escape the current 'middle-income trap.'
- By 2030, China aims to be 'the world's primary centre for innovation in artificial intelligence (AI).' It is already the world's biggest owner of AI patents but lacks top-tier talent in this field. It has launched megaprogrammes in science and engineering to 2030 that include quantum computing and brain science.
- High tech, technology transfer and intellectual property protection are among sources of tension in the current trade dispute between China and the USA. The Foreign Investment Law (2020) sets out to make it easier to do business in China.
- China is targeting carbon neutrality by 2060. In order to reach its 20% target for non-fossil energy consumption by 2030, it is developing nuclear power, hydropower, wind and solar energy. The number of permits granted for new coal plants has risen since 2019.
- Chinese companies are being encouraged to engage in scientific co-operation with countries partnering in the Belt and Road Initiative. The adoption of a series of guidelines in 2017 aims to set this initiative on a 'greener' trajectory.

23 · China

Cong Cao

INTRODUCTION

Per-capita income on track to reach target

The past five years have witnessed a succession of milestones. For example, in October 2015, the Fifth Plenary Session of the Eighteenth Central Committee of the Chinese Communist Party (CCP) introduced the concepts of innovation, co-ordination, greening the economy, open access and information sharing to chart the trajectory of China's future development.

Another milestone was reached in 2018, when per-capita income hit the US$ 15 000 mark (PPP$ 15 243) [Figure 23.1]. China is on track towards becoming a 'moderately prosperous' (*xiaokang*) society by 2020.

This means that China has achieved the first of its nine priority areas for the Sustainable Development Goals (SDGs), that of eradicating poverty and hunger. The other eight priority areas to 2030 are: maintaining economic growth; promoting industrialization; improving social security and services; fairness and justice; better environmental protection and an active response to climate change; effective use of energy resources; improving national governance; and promoting international co-operation (Govt of China, 2016).

Some of these challenges remain formidable. For instance, China's population crossed the 1.4 billion threshold for the first time in 2019 but, in parallel, demographic growth fell to a record low as the birth rate tumbled for the third consecutive year, despite the government having abandoned its one-child policy in late 2015 (Figure 23.2). There were 1.67 births per woman in 2015 and 1.69 in 2018.

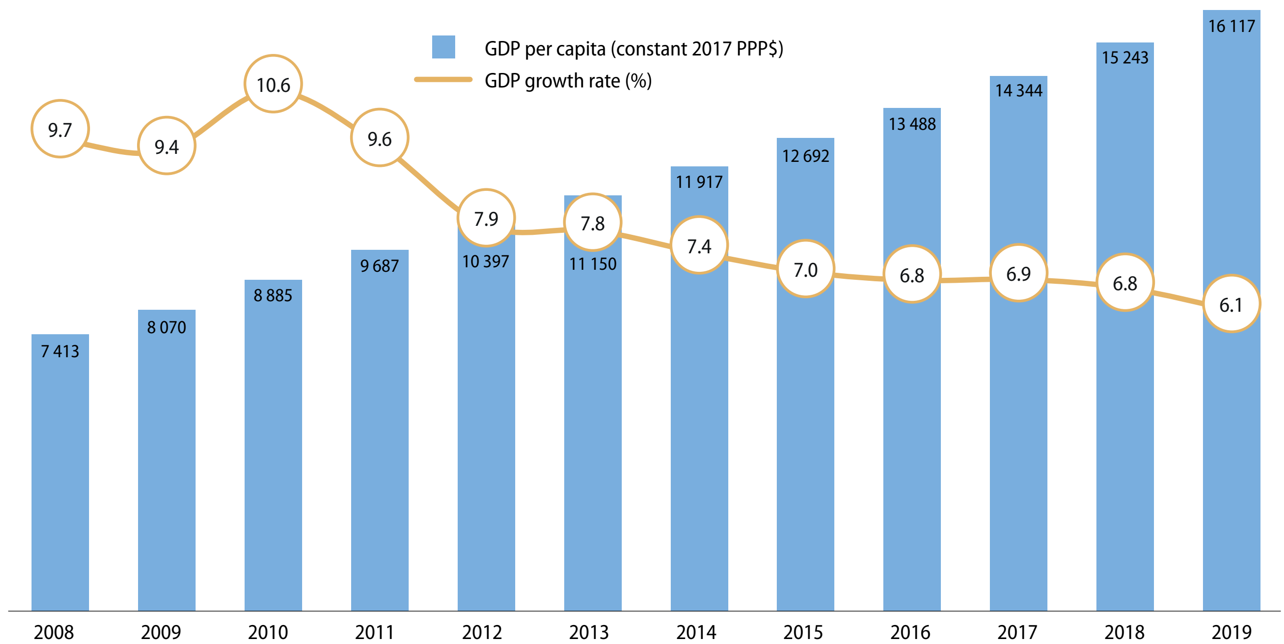
China finds itself with an ageing population and shrinking labour force, a situation more often associated with Europe, Japan and the Republic of Korea. Almost one-fifth of China's population is now aged 60 years or more (NBS, 2020). This growing cohort of elderly citizens will push up medical spending, even as the shrinking working-age population erodes productivity and pushes up labour costs, potentially threatening China's socio-economic development and making it harder to improve social security and services.

A focus on the environment

On the global stage, China has been advocating a 'win–win' global climate governance system and has emerged as a vocal supporter of multilateralism, in general, and the *Paris Agreement* (2015) on climate action, in particular. As co-leader for 'nature-based solutions', it participated actively in the preparatory work for the 2019 United Nations Climate Action Summit. At the United Nations General Assembly in September 2020, which was held virtually, President Xi Jinping announced plans for China to become carbon-neutral by 2060.

Chapter 23

Figure 23.1: **Rate of economic growth in China, 2008–2019**



Source: World Bank's World Development Indicators, October 2020

In December 2017, the government released a *National Carbon Emissions Trading Market Construction Plan (Power Generation Industry)*, which kicked off the national carbon emissions trading system. The government has decomposed carbon-related indicators by region, introducing measures tailored to each situation to promote low-carbon development. These include energy savings through greater efficiency and an emphasis on high-tech manufacturing and services to the detriment of low-end manufacturing.

These measures translate policy documents such as the *Workplan to Control Greenhouse Gas Emissions in the Thirteenth Five-year Plan Period* (2011–2015), the *National Climate Change Plan* (2014–2020) and *National Climate Change Adaptation Strategy* (2007).

The rapid pace of economic development over the past 20 years has left its mark. Although air quality has improved in many Chinese cities, it remains at least five times higher than the threshold recommended by the World Health Organization (WHO)[1] in 16 major cities, including Hotan, Kashgar and Beijing (IQAir, 2018). In the past few years, the government has put in place the world's most extensive air quality monitoring network, along with stringent policies to improve air quality.

The government has also established a big data platform to monitor water quality, within one of the 16 mega-engineering programmes established under the *Outline of the Medium and Long-Term Plan for the Development of Science and Technology (2006–2020)* [Cao, 2015, Box 23.4]. Scientists have developed a number of core technologies and equipment to treat water pollution that have been deployed in the Beijing–Tianjin–Hebei region and Taihu Lake Basin. Between 2015 and 2018, the ratio of major rivers and lakes complying with water quality standards reached 77% (Ministry of Foreign Affairs, 2019).

Meanwhile, China's *Revolutionary Strategy for Energy Production and Consumption* (2016–2030) has fixed targets for non-fossil energy consumption of 15% by 2020 and 20% by 2030. The focus has been on developing core technologies and a manufacturing capability in nuclear power, hydropower, wind and solar energy.

Under another mega-engineering programme, two key demonstration projects for more efficient nuclear power plants have been completed (Cao, 2015, Box 23.5). One is a 200 000-kilowatt reactor that is cooled using high-temperature gas (helium), rather than water; it was connected to the grid for power generation in 2017. The second is the Chinese AP 1 400 (for 1 400 MW) demonstration project, which was due for completion by 2020. The potential of nuclear power for desalination is also being explored (Fisher, 2019).

By 2018, China had 48 nuclear power plants in operation – double the number three years earlier – and a further nine under construction. Today, nuclear power contributes 4% of total power generation in China, a proportion that could more than double by 2030 (Fisher, 2019).

China has invested heavily in upgrading technology for manufacturing hydropower units and pumped storage units. This hydropower capacity, along with natural gas, nuclear and wind power, has enabled China to reduce its consumption of coal by about 540 million tonnes and energy consumption per unit of GDP by about 11.4% since 2006 (Ministry of Foreign Affairs, 2019).

More recently, the loosening of restrictions on coal plant development since 2019 has seen the number of regions obtaining permits for new coal plants climb from three in 2016 to 15 in 2019 and 19 in 2020 (GEM and CRECA, 2020).

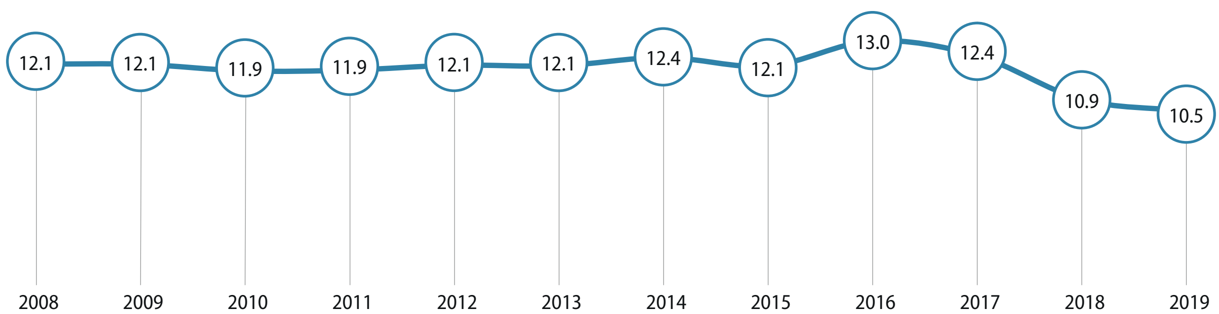
By 2018, China's carbon intensity had weakened by about 46% over 2005 levels, exceeding the target of reducing carbon intensity by 40–45% by 2020. Renewable energy sources accounted for 27% of total electricity generation, a year-on-year increase of 0.2% since 2016. In 2017, three-quarters of renewable energy came from hydropower, 18% from wind and 8% from solar power, according to the International Energy Agency, which noted that modern renewables accounted for 8% of China's final energy consumption. The annual output of photovoltaic modules has reached 85.7 million kW (Ministry of Foreign Affairs, 2019).

A sweeping epidemic

The year 2019 ended with a new pneumonia-like illness in Wuhan, the capital city of Hubei province in central China. A novel strain of coronavirus, dubbed coronavirus disease 2019 (Covid-19) by WHO, spread rapidly around the world. By the end of February, it had infected about 85 000 people in China, primarily, and killed more than 2 700 (Wang *et al*., 2020).

Figure 23.2: **Trend in China's birth rate, 2008–2019**

Birth rate per 1 000 inhabitants



Source: World Bank's World Development Indicators, September 2020

On 23 January 2020, the government took the drastic step of locking down Wuhan and swaths of other Chinese cities to contain the virus. The move proved effective, as China was able to announce on 19 March that there had been no new domestic cases of Covid-19 for the first time since the start of the outbreak.

On 11 March 2020, WHO declared the outbreak a pandemic. By early March 2021, the virus had caused more than 2.5 million deaths worldwide.[2]

Following the epidemic of Severe Acute Respiratory Syndrome (SARS) in 2002–2003, which had also started in China, the government established the China Network Reporting System of Infectious Disease Epidemics and Public Health Emergencies; this system claims to cover all public health institutions above the township level, including centres for disease prevention and control. It is this system which was put to the test during the Covid-19 pandemic.

Chinese researchers at the Shanghai Public Health Clinical Centre released the first sequence of the virus' genome on an open access platform on 11 January 2020, enabling Germany to develop a screening test rapidly that it then shared with other countries via WHO. By mid-2020, several Chinese candidate vaccines were undergoing third-phase clinical trials outside China.

In early October 2020, China announced that it had joined the Covid-19 Vaccines Global Access Facility (Covax), a mechanism co-ordinated by WHO that is designed to guarantee rapid, fair and equitable access to Covid-19 vaccines worldwide.

Studies have analysed whether the Covid-19 outbreak began at one of China's many wildlife food markets (see, for example, Zhou *et al.*, 2020; Wu *et al.*, 2020). In January 2020, the State Administration for Market Regulation, Ministry of Agriculture and Rural Affairs and National Forestry and Grassland Administration banned all trading of wild animals at markets, restaurants and on e-commerce platforms (Shuo, 2020). A month later, the National People's Congress released new measures restricting wildlife trade, banning consumption of bushmeat and market sales of farmed wild animals like civets until such time as the Wildlife Protection Law could be amended.

A trade dispute with wider ramifications

The Covid-19 crisis caused the economy to shrink by 6.8% in the first quarter of 2020, the first contraction for almost three decades.

The world's second-largest economy after the USA had already been growing at a slower pace than in earlier years (Figure 23.1). In 2018, China recorded its lowest growth rate since 1990 (6.6%), before dipping to 6.1% in 2019 (Areddy and Deng, 2019). Along with structural issues, such as export-oriented growth and insufficient domestic consumption, the economy has been perturbed by a disruptive, prolonged trade dispute with the USA since 2018.

This dispute has spilled over into issues which may undermine China's efforts to become an innovation-driven nation. Sources of tension include high technology, technology transfer, intellectual property protection and even China's Thousand Talents Programme.[3] There is a real risk of decoupling between the two countries in terms of technology and talent.

Should this decoupling become a reality, this would jeopardize the commercial and scientific bonds between the two countries, which may end up having two distinct digital and technology jurisdictions. For example, the Internet might be split into 'splinternets' and there might be two 5G networks, one for the USA and its allies and another for China and its allies. This would have far-reaching implications for both China and the USA and, by ricochet, for the rest of the world.

An increasingly sophisticated manufacturing sector

The Chinese manufacturing sector has become technologically sophisticated. China's efforts to enhance its endogenous innovation capability have paid off, as exemplified by home-grown giants Huawei and ZTE, the world's two largest manufacturers of telecommunications equipment. Huawei is the global leader in 5G technology, whereas ZTE and Qualcomm Technologies, Inc. have, together, developed a 5G-enabled voice-over for mobile phone operators (Qualcomm, 2020).

China has also made great strides in financial technologies (fintech), such as mobile payment systems, blockchain, cryptocurrencies and digital currencies.

In parallel, Chinese firms have made some high-profile acquisitions in recent years. For instance, in February 2016, the state-owned China National Chemical Corp (ChemChina) made a successful bid for the Swiss agrochemical giant Syngenta, the biggest foreign purchase to date by a Chinese firm. Another example is the acquisition in 2016 of Kuka, Germany's biggest manufacturer of industrial and advanced robots, by one of its clients, Chinese manufacturing firm Midea.

Despite an increasingly sophisticated manufacturing sector, China remains dependent on imports of some core foreign technologies like semiconductors (Sun and Grimes, 2018; Lovely and Huang, 2018). Three of China's top fabless companies in 2020 are former US companies that were acquired by Chinese investors; these are OmniVision, Shenzhen FocalTech and Beijing ISSI (Grimes and Du, in press) [see also the next section on Research Trends].

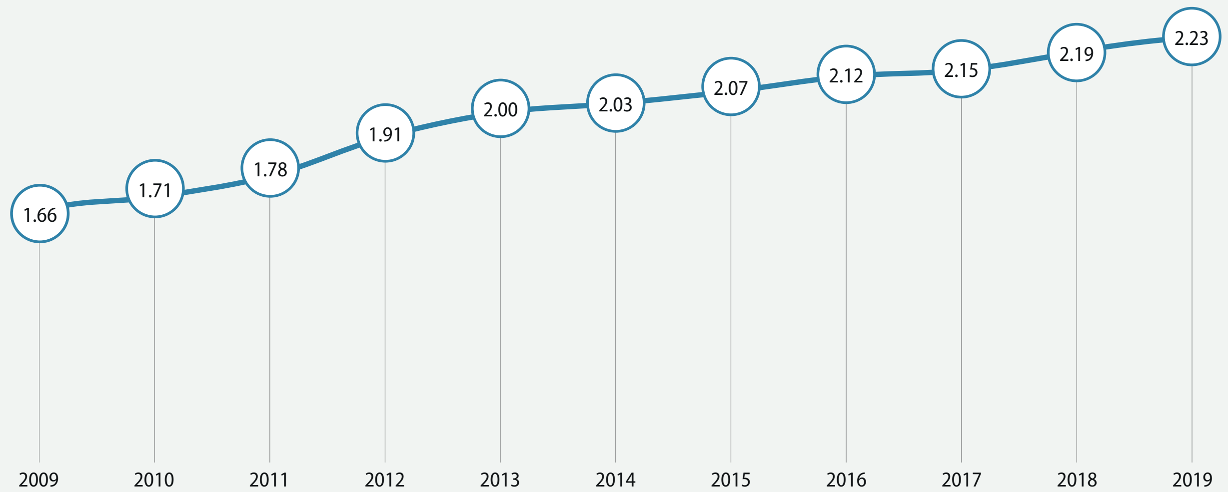
This vulnerability was exposed by the decision by the US Department of Commerce to impose sanctions on ZTE in April 2018 for violating a trade embargo against Iran and the Democratic People's Republic of Korea. ZTE was cut off from its US suppliers of hardware components (such as Qualcomm and Intel) and Android services (Google). This forced the company to shut down most of its operations in the following weeks, bringing the company to the verge of bankruptcy and imperiling the jobs of its 75 000 employees. Ultimately, ZTE survived after paying a consequential fine and agreeing to allow the US government to monitor its operations.

The launch of Made in China 2025

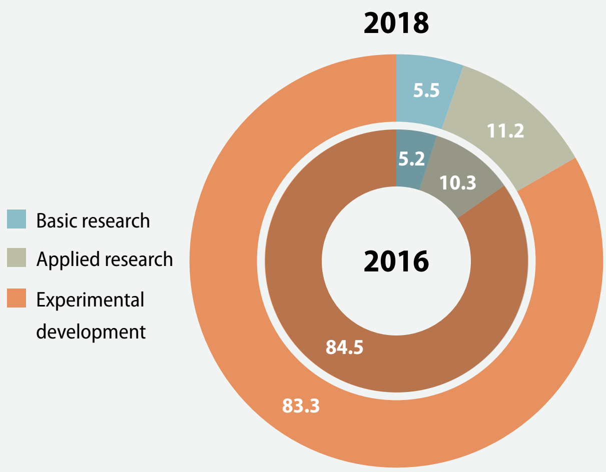
It was partly out of a desire to reduce reliance upon, or decouple from, American high-tech suppliers that the Chinese government launched a ten-year, state-led industrial policy in 2015 called

Figure 23.3: **Trends in research expenditure in China**

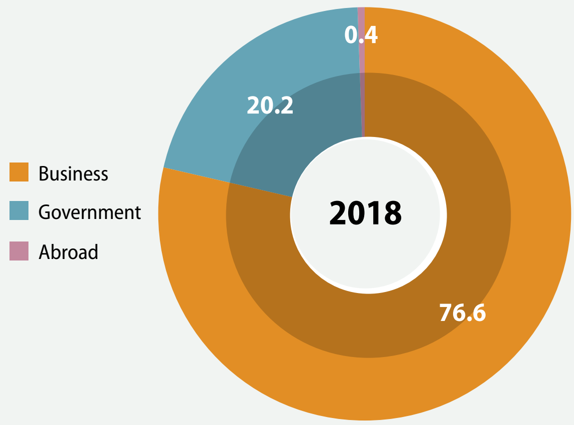
GERD as a share of GDP in China, 2009–2019 (%)



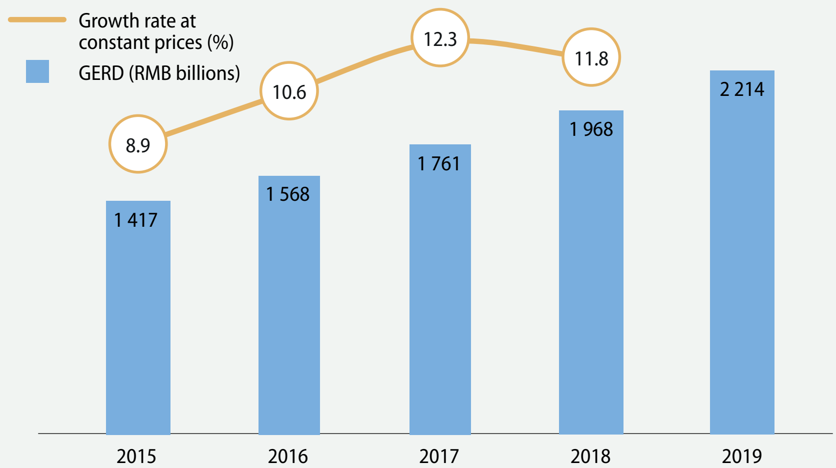
GERD by type of research in China, 2016 and 2018 (%)

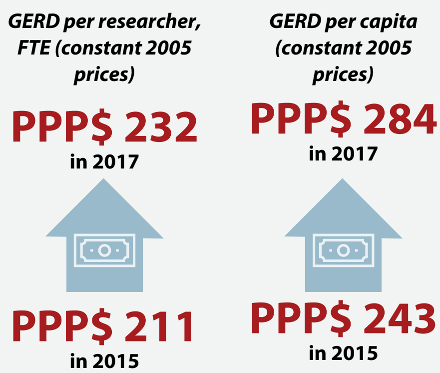


GERD by source of funds, 2018 (%)



Trends in GERD in China, 2015–2019





Note: The source of 2.8% of China's GERD is not specified.

Source: China Statistical Yearbook of Science and Technology (2017); National Bureau of Statistics, Ministry of Science and Technology, and Ministry of Finance, Statistical Communiqué on National S & T Fund Inputs in 2018, at www.stats.gov.cn (20 January 2020); for GERD by source of funds: UNESCO Institute for Statistics

Made in China 2025. This policy was inspired by a similar German programme, Industry 4.0 (Hollanders and Kanerva, 2015).

This policy urges Chinese companies to compete worldwide in ten cutting-edge sectors of manufacturing, with specific sector-by-sector goals for expanding their global market share of:

- electric cars and other new energy vehicles;
- next-generation information technology and telecommunications;
- advanced robotics and artificial intelligence;
- agricultural technology;
- aerospace engineering;
- new synthetic materials;
- advanced electrical equipment;
- emerging biomedicine;
- high-end rail infrastructure; and
- high-tech maritime engineering.

By using government subsidies, mobilizing state-owned enterprises and pursuing intellectual property acquisition, Made in China 2025 intends to help these ten strategic industries to leapfrog over their Western competitors, thus reducing China's reliance on foreign technology and escaping the current 'middle-income trap' (Atkinson and Foote, 2019).

Whereas Chinese companies in these sectors enjoy massive state backing, their foreign competitors in China face barriers to accessing new markets. These include being excluded from the market for information technology (IT) and from local subsidies, the low level of data security and the intensive collection of digital data by the Chinese state.

The straw that broke the camel's back

The US government has complained in the past about unfair trade practices, the theft of US intellectual property through espionage and forced technology transfer through mandatory joint ventures (US Trade Representative, 2018).

However, Made in China 2025 seems to be the straw that broke the camel's back. In early 2018, the USA took steps to prevent Chinese state-owned enterprises from buying American technology companies, on the one hand, and to stop US companies from handing over their core technologies to China in return for access to the Chinese market, on the other (US Trade Representative, 2018).

Some European countries share US concerns about China's approach to state capitalism. The Chinese government persuaded Airbus to transfer aerospace technology to China in 2008, for example, as part of a joint venture for its first assembly plant in Tianjin for the A320 (Cao, 2015).

In 2018, the European Commission filed a complaint with the World Trade Organization, alleging that foreign companies were induced to transfer intellectual property to their Chinese partners and to set up research centres in China as 'performance requirements' for obtaining government approval to operate in sectors like electric vehicles.

Better protection of intellectual property

In response to international pressure, the government has passed landmark legislation to open up the Chinese market and level the playing field for foreign businesses competing with domestic, state-owned enterprises and private firms. The Foreign Investment Law came into effect on 1 January 2020, replacing existing laws on wholly foreign-owned enterprises, Sino–foreign contractual joint ventures and Sino–foreign equity joint ventures. The intention is to make it easier to do business in China, as well as to demonstrate China's lack of appetite for a decoupling.

The issue of intellectual property protection and enforcement has complicated trade talks between China and the USA for some time, although this is a diminishing concern for foreign enterprises (Prud'homme and Zhang, 2018). However, China's own strategic industries expect better government protection of their intellectual property, including through stricter enforcement.

Consequently, the Anti-Unfair Competition Law was amended in April 2019 and the Patent Law in 2020[4] to offer better protection for trade secrets and patent-owners' rights, respectively.

The Law on Promoting the Transformation of Scientific and Technological Achievements (1993), also known as China's Bayh-Dole Act, had already been amended in 2015 to help universities and public research institutes transfer technology to industrial organizations. This may encourage both central and local governments and enterprises to invest more in basic research, as long as they recognize the link between new knowledge (basic research) and its translation into innovative technologies.

China also established the first courts specializing in intellectual property in Beijing, Shanghai and Guangzhou in late 2014, followed by 20 specialized tribunals across several provinces between 2017 and 2020, and a new national-level intellectual property court within the Supreme People's Court on 1 January 2019.

To improve institutional efficiency, the China National Intellectual Property Administration was merged with the State Administration for Industry and Commerce in March 2018 to form the State Administration for Market Regulation, thus streamlining work related to intellectual property, among other measures.

RESEARCH TRENDS

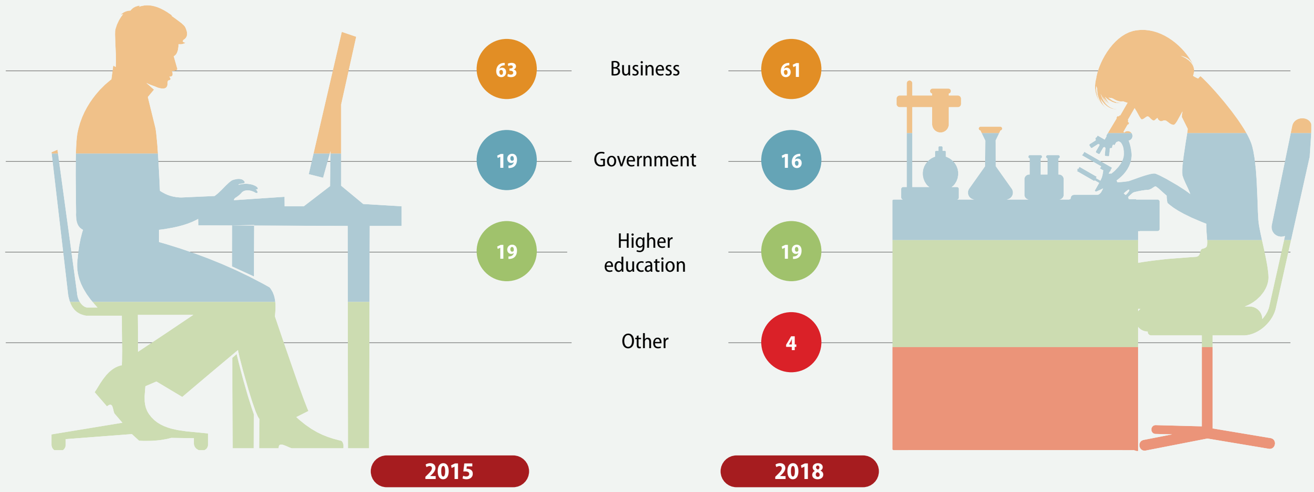
A rise in research spending

In May 2016, the Chinese Communist Party's Central Committee (CCPCC) and China's State Council issued an *Outline of the National Innovation-Driven Development Strategy*[5] setting out a three-step goal for China: to become an innovation-driven nation by 2020, to count among the top innovation-oriented nations by 2030 and to lead the world in innovation by 2050.

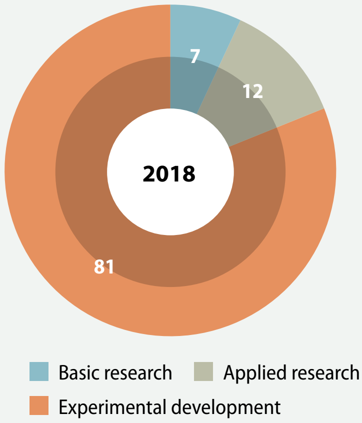
As the *Outline of the Medium and Long-term Plan for the Development of Science and Technology* (2006–2020) nears its

Figure 23.4: **Trends in human resources in China**

Researchers (FTE) in China by sector of performance, 2015 and 2018 (%)



Researchers (FTE) in China by type of activity, 2018 (%)



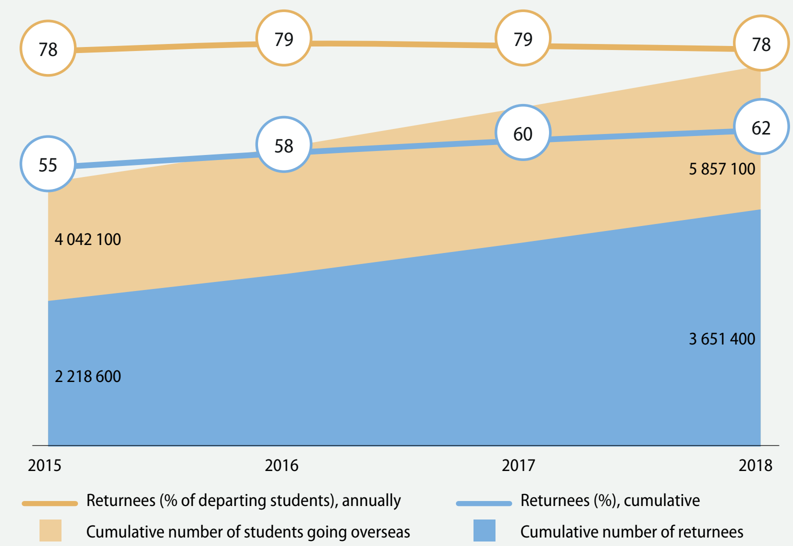
Tertiary graduates in China, 2015–2018

In thousands

	2015	2016	2017	2018
With doctoral degrees	54	55	58	61
With master's degrees	498	509	520	544
Total postgraduates	**552**	**564**	**578**	**604**
Bachelor's courses	3 586	3 744	3 842	3 868
Short-cycle courses	3 223	3 298	3 516	3 665
Total undergraduates from general institutions of higher education	**6 809**	**7 042**	**7 358**	**7 533**
Bachelor's courses	962	1 022	1 091	996
Short-cycle courses	1 400	1 423	1 379	1 182
Total undergraduates from adult institutions of higher education	**2 363**	**2 445**	**2 470**	**2 177**

Note: Bachelor's or equivalent is International Standard Classification of Education (ISCED) category 6; short-cycle courses are ISCED category 5.

Trend in outbound and inbound Chinese students, 2015–2018



Total researchers (FTE) in China, in thousands

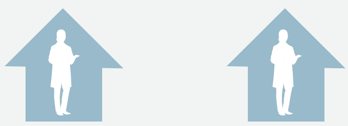
1 866
in 2018

1 619
in 2015

Researchers (FTE) per million inhabitants in China:

1 225
in 2017

1 159
in 2015



Source: Chinese Ministry of Education: www.moe.gov.cn/s78/A03/moe_560/jytjsj_2018/ (20 January 2020), *China Statistical Yearbook of Science and Technology* term, can it be said that China is now an innovation-driven nation?

China doubled gross domestic expenditure on research and development (GERD) between 2012 and 2019 to more than RMB 2.2 trillion.[6] This corresponds to 2.23% of GDP.

Admittedly, this falls short of the *Medium and Long-term Plan*'s target of 2.5% by 2020 and the USA's own research intensity (3.1% of GDP in 2019) but it does surpass the average for the European Union (2.0% in 2018).

The *Medium and Long-term Plan* stipulated that, by 2020, dependency on foreign technology was to be reduced to less than 30%. According to the Ministry of Science and Technology (MoST), this ratio has actually declined to 31.2% (2016).[7] The main reason for the drop is obvious: domestic investment in research and development (R&D) has been growing rapidly, while expenditure on foreign technology imports has been shrinking (Cao *et al.,* 2018).

However, the share of GERD spent on basic research has been hovering around the 5% mark for many years (Figure 23.3), compared to 13% for the European Union under its Horizon 2020 programme.

Not only has the proportion of expenditure allocated to applied research been declining (11% in 2018) but the issue of the chronic imbalance in favour of experimental development has been largely underestimated in policy circles.

A bigger pool of high-quality talent

The number of university students and researchers is on the rise (Figure 23.4). Leading Chinese universities have also started to appear on global university league tables. For example, Tsinghua and Peking Universities are now ranked 23rd and 24th, respectively, on the Times Higher Education's 2020 World University Ranking.

China's booming economy is attracting a growing number of returnees who are staffing universities, research institutes and enterprises (Figure 23.4). These agents of change are enriching China's political, socio-economic and technological fabric.

More publications, more patents

Scientific output has increased by as much as 49% since 2015 (Figure 23.5). Although there is a larger pool of researchers today, each individual researcher has also become more productive.

Also of note is that almost one-quarter of articles over this period focused on cross-cutting strategic technologies such as artificial intelligence, robotics, biotechnology or nanotechnology. This reflects the focus of government policy documents.

Chinese scientists published more than the global average between 2011 and 2018 on a number of topics that reflect the current policy emphasis on more sustainable development (see chapter 2). Topics include national and urban greenhouse gas emissions, hydropower and the sustainable withdrawal of freshwater. Since China decided to ban imports of contaminated goods for recycling purposes in 2018 as part of the implementation of the *National Sword Policy*, the number of Chinese articles on floating plastic debris in the ocean has increased markedly (Figure 23.5). China is now phasing out plastics across the country, with plastic bags due to be banished by 2022 and single-use plastics in the restaurant industry to drop by 30% by 2025.

Chinese inventors have filed a growing number of patents domestically and globally, making China the world leader for the volume of patenting (Figure 25.6). According to the World Intellectual Property Organization, in 2018, China nestled between the USA (56 142) and Japan (49 702) for the number of applications (53 345) filed under the Patent Cooperation Treaty (PCT).

This represents growth of 9.1% over 2017, which may sound impressive but this is also the first time since 2002 that growth did not reach double-digits (WIPO, 2019). Huawei and ZTE led China's PCT patent applications.

Research yet to translate into productivity gains

It is a global phenomenon that research productivity is falling sharply everywhere, suggesting a diminishing return on R&D (Bloom *et al*., 2020). According to Conference Board data, total factor productivity, a measure of economic efficiency and innovation, declined annually by 0.4% between 2010 and 2018.[8]

China is no exception. Macro-economic estimates by the World Bank and the Development Research Centre of the State Council in their joint publication on *Innovative China: New Drivers of Growth* (2019) indicate that total factor productivity grew by just 1.55% in China over the 2008–2017 period, compared to 3.51% in the ten years prior to the Great Recession. The same source indicates that growth in total factor productivity has slowed farther to a little over 1% since the middle of the decade. This suggests that it may take time for Chinese investment in R&D to translate into productivity gains.

Meanwhile, Chinese technology is being taken up by other countries, as demonstrated by the increase in receipts and royalty payments earned by Chinese firms for the use of their intellectual property, according to World Bank data. Receipts rose by as much as 570% between 2010 (US$ 830 million) and 2018 (US$ 5.6 billion). The increase in payments and the balance of payments over the same period was less rapid: 174% and 148%, respectively.

China's first Nobel Prize in science

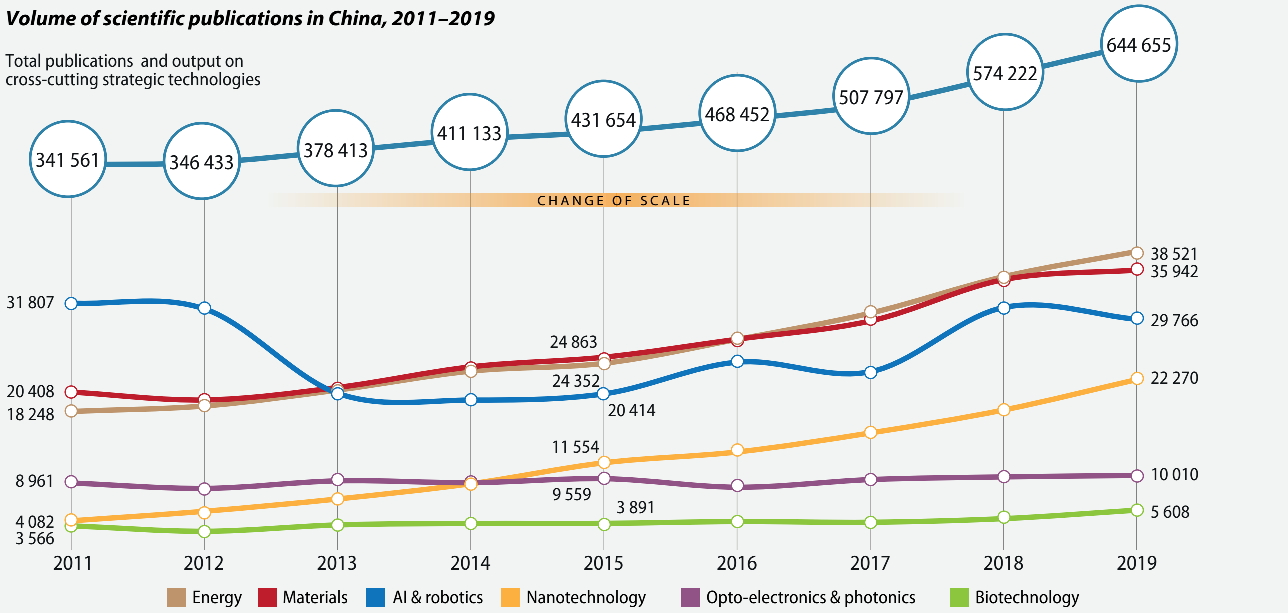
The year 2015 witnessed the long-awaited award of a Nobel Prize in science to a Chinese scientist. Tu Youyou shared the Nobel Prize in Physiology or Medicine 'for her discoveries concerning a novel therapy against malaria' that she had developed in a Chinese laboratory 40 years earlier.

The prize also underscored the laureate's atypical profile. Tu herself was not well-known in China before winning the coveted prize. She is not an honorific academician (*yuanshi*) of either the Chinese Academy of Sciences or the Chinese Academy of Engineering. She does not hold a doctoral degree and she has no foreign experience.

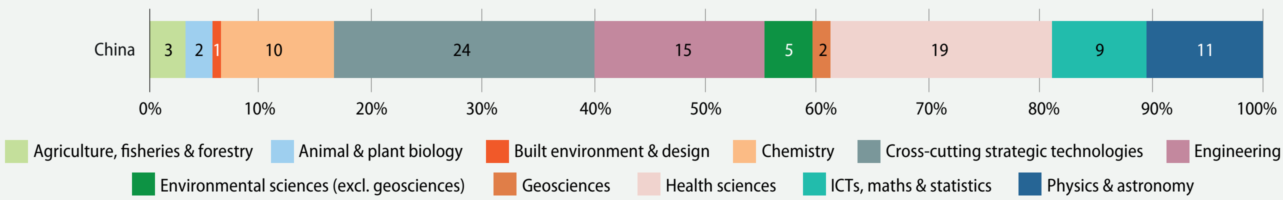
Her case has shone the spotlight on the shortcomings of China's innovation system when it comes to evaluating the performance of academic researchers and rewarding excellence.

Figure 23.5: **Trends in scientific publishing in China**

Volume of scientific publications in China, 2011–2019



Scientific publications in China by broad field of science, 2017–2019 (%)



China's publication output accounted for 14% of the world total in health sciences in 2019, up from 8% in 2011.

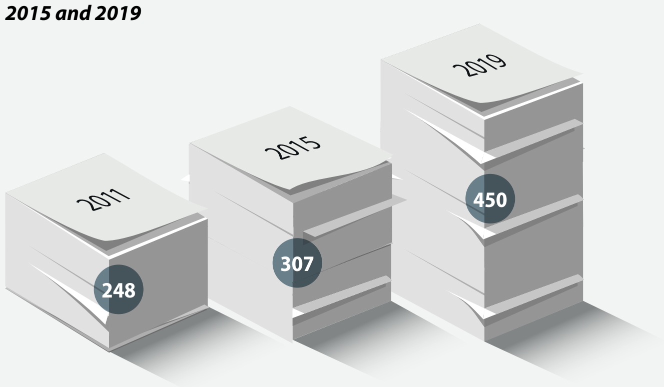
0.98

Average of relative citations for China, 2014–2016; the G20 average is 1.02

22%

Share of publications with foreign co-authors in China, 2017–2019; the G20 average is 25%

Scientific publications per million inhabitants in China, 2011, 2015 and 2019



How has output on SDG-related topics evolved since 2012?

Scientists in China are publishing more than would be expected, relative to global averages, on greater battery efficiency (SI = 2.12), national and urban greenhouse gas emissions (1.73), coastal eutrophication (1.72), hydropower (1.53), cleaner fossil fuel technology (1.52), hydrogen energy (1.52) and the sustainable withdrawal of freshwater (1.49). Chinese output on greater battery efficiency doubled from 12 946 (2012–2015) to 29 008 (2016–2019) publications.

China's output on nuclear fusion (SI = 0.97) grew from 2 379 (2012–2015) to 3 082 (2016–2019) publications. China is a member of the project building an International Thermonuclear Experimental Reactor in France, which will be used to develop nuclear fusion technology.

Following the government ban on imports of plastic and other solid recyclable waste in January 2018, the number of academic articles on floating plastic debris in the ocean rocketed from 23 in 2017 to 163 in 2019. In 2015, Chinese scientists had produced just four articles on this topic, which is now the fastest-growing topic in China.

For details, see chapter 2

China's top five partners for scientific co-authorship, 2017–2019 (number of papers)

	1st collaborator(s)	2nd collaborator(s)	3rd collaborator(s)	4th collaborator(s)	5th collaborator(s)
China	USA (141 424)	UK (34 972)	Australia (30 914)	Canada (23 248)	Japan (21 111)

Note: The totals here exclude the Taiwan Province of China and the Hong Kong and Macao Special Administrative Regions.

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

In 2020, the Ministry of Education and the Ministry of Science and Technology issued a directive[9] discouraging universities from rewarding researchers who had a high publication output with bonuses, awards, jobs or promotions, in a drive to remove counter-productive incentives that encouraged scientists to publish one paper after another, rather than focus on high-impact work.

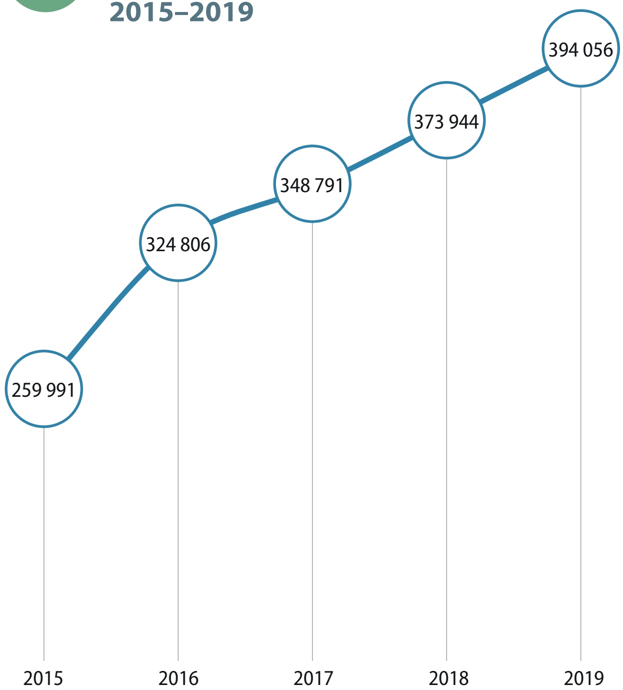
An ethical loophole

China has yet to inaugurate specific laws and regulations in relation to the ethics of science and technology. This has left a loophole that certain researchers have tried to exploit. Perhaps the starkest illustration of this ethical crisis is the 'gene-editing baby' scandal, which has been condemned globally (Lei *et al.,* 2019).

Gene-editing technologies (such as CRISPR-Cas9) allow scientists to erase and insert fragments of DNA in living organisms. This ability has obvious implications for curing genetic diseases but also runs the risk of leading to custom-made babies.

The first step along the latter path was taken in 2015, when Junjiu Huang at Sun Yat-sen University in China announced that his team had made the first-ever genetic modifications to human embryos using the CRISPR technology. The embryos were not viable and the procedure was only partially successful but the research nevertheless crossed an ethical line, igniting a heated debate within the global scientific community.

Figure 23.6: **Number of IP5 patents granted to Chinese inventors, 2015–2019**



Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China. The totals here exclude the Taiwan Province of China and the Hong Kong and Macao Special Administrative Regions.

Source: PATSTAT; data treatment by Science-Metrix

Three years later, Chinese scientists unfortunately took a bigger step across the ethical line. In November 2018, He Jiankui, then affiliated with the Southern University of Science and Technology in Shenzhen, claimed that he had edited the genomes of two embryos that were then implanted via *in vitro* fertilization into the mother's womb. Twin girls, Lulu and Nana, who were born in October 2018, have become the world's first known gene-edited babies.

It turned out that He had edited a gene called CCR5 with the intention of making the girls less likely to contract the HIV virus carried by their father.

Many scientists were appalled that He Jiankui should take the reckless step of editing the girls' genes when preventive antiretroviral treatment could have achieved the same goal.

He's data also suggest that he had actually induced a previously unknown genetic mutation with unknown side-effects for the girls.

The scientific community in China and beyond condemned He's actions. On 21 January 2019, he was fired by his university. On 30 December of the same year, the Shenzhen Nanshan District People's Court sentenced He Jiankui to three years in prison and fined him RMB 3 million for having 'forged ethical review documents and misled doctors into unknowingly implanting gene-edited embryos into two women'.

Meanwhile, the Central Comprehensively Deepening Reforms Commission, a body headed by President Xi Jinping, approved a plan in July 2019 to form a national committee to advise the government on regulations with regard to research ethics. The committee is expected to reform the current system of ethics governance to make it more comprehensive and consistent (Jia, 2019).

The mega-engineering programme on genetically modified organisms (GMOs) has also been using new technologies such as non-endosperm specific expression and gene editing to make staple food crops such as rice and wheat more resistant to insects, disease, drought and cold. As early as 2001, China had established a standardized biosafety evaluation system to ensure the safety of GMO products. In 2020, a biosafety law was being considered by the National People's Congress amid the Covid-19 outbreak which may include articles on biosecurity.

RESEARCH HORIZON TO 2035

AI at core of megaprogrammes to 2030

In 2016, when the *Thirteenth Five-Year Plan for the Development of Science, Technology and Innovation* (2016–2020) got under way, China's innovation capacity was found to be wanting.

China still possessed relatively few core technologies, innovative enterprises and entrepreneurs (Sun and Grimes, 2018; Lovely and Huang, 2018).

Development between regions was uneven and the role of scientific research and innovation in supporting and leading socio-economic development left room for improvement.

Meanwhile, the Fourth Industrial Revolution, a concept championed by the World Economic Forum, had been disrupting the trajectory of technologies and bringing about profound socio-economic changes such as the spread of AI-based facial identification and AI-assisted health care. China found itself at a crossroads, if it wished to succeed in its strategic transformation from being a follower to a leader of innovation.

Against this backdrop, the Ministry of Science and Technology (MoST) undertook four rounds of broad consultations with more than 1 000 experts drawn from the public and private sectors. The result was a series of new megascience and mega-engineering programmes to 2030 that are introduced in the *Thirteenth Five-Year Plan for the Development of Science, Technology and Innovation* (Table 23.1).

The first four programmes have been launched: quantum communication and quantum computing; brain science and brain-inspired intelligence; a deep-sea space station; and an integrated space–Earth information network.

Visibly, these four programmes build on the mega-programmes of the *Medium and Long-term Plan for the Development of Science and Technology* (2006–2020) and will be integrated into its successor to 2035.

More attention to market dynamics in next plan

The new *Outline of the Medium and Long-term Plan for the Development of Science and Technology* (2021–2035) is in the process of being developed. Its working group first met on 24 June 2019.

MoST set up an office led by Minister Wang Zhigang to prepare the planning phase. The General Office of the State Council and 27 other ministries and commissions with a portfolio for science and innovation have been invited to participate in this exercise, as well as academic scholars and think tanks.

Based on a stock-taking exercise, the first phase of planning has identified strategic research orientations broken down into more than 50 priority themes, including the terrestrial environment, oceans, biology, population and health, public safety, urbanization and urban development.

The final draft documents are due for release in late 2020, once they have been approved by the State Council and the CCPCC. They are expected to propose strengthening research ethics and the country's intellectual property regime, incentivizing young talent and giving fresh impetus to both basic research and business innovation, along with priority areas to be supported.

The State Administration of Foreign Experts Affairs, now part of MoST, has also organized symposia to solicit the views of foreign experts; they have been asked, in particular, to deliberate on themes such as modes of technological innovation and industrial development, the areas where basic science may achieve breakthroughs, where disruptive and cross-cutting technologies may emerge and how to strengthen international co-operation and stimulate innovation.

MoST has also set up a website entitled Crowdfund Technology 2035: My Advice on the Medium and Long-term Plan, to mobilize the collective wisdom of the broader scientific and technological community, industry and society.

The new *Medium and Long-term Plan* to 2035 is still work in progress but it is expected to pay more attention than its predecessor to the role played by market dynamics. There should also be a focus on how to cultivate open innovation, integrate China more deeply in the global innovation network and ensure better environmental protection.

At this stage, an analysis of China's research priorities and the share of research being conducted by state-owned enterprises would be timely. Research projects focusing on AI and brain research, image recognition, space exploration and quantum computing are prestigious but may be contributing little to China's overall development and welfare.

The new *Medium and Long-term Plan* to 2035 will need to adapt to challenges that did not exist a few years ago. For example, R&D in the field of population and health care in the plan to 2020 was based on China's low but stable fertility rate; consequently, the development of key technologies includes fertility monitoring and reproductive health. Now that China's birth rate has dropped, the new *Medium and Long-term Plan* may have to stress how to maintain fertility in middle-aged women, for instance, to ensure a stable number of births (O'Meara, 2020).

Table 23.1: **China's megaprogrammes in science and engineering to 2030**

Advanced manufacturing	Aviation engines and gas turbines
	Smart manufacturing and robotics
	R&D and application of key and new materials
Space ocean development and utilization	Deep-sea space station
	Deep space exploration and space vehicle on-orbit service and maintenance system
	Integrated space–Earth information network
Electronics and information technology	Quantum communication and quantum computer
	National cybersecurity
	Big data
	Artificial intelligence 2.0
Biotech and health	Brain science and brain-inspired intelligence
	Health care
Agriculture	Seed industry independent innovation
Environment and energy	Clean and efficient use of coal
	Smart grid
	Beijing-Tianjin-Hebei integrated environmental management

Source: MOST (2016) *Thirteenth Five-Year Plan for the Development of Science and Technology* (2016–2020)

Pockets of excellence being prioritized

In the years to come, China's pockets of excellence in scientific research will remain a priority for support. These include: 5G telephony; advanced computing; artificial intelligence; brain research; catalysis and chemical engineering; fuel cells; life sciences/biotechnology; inhabited space travel; materials science, including nanotechnology; mathematics; micro-satellites; physics; rare-Earth chemistry; and the Internet.

A head start in AI

Unlike in other areas of technology where China was initially left behind then struggled to catch up (Cao, 2015), China has got a head start when it comes to AI, enabling it to secure a place in the top echelons for both technological development and applications. Papers published by Chinese scientists increased from 4.3% in 1997 to 27.7% of the global total in 2017, far outstripping other countries (CISTP, 2018).

None of this would have been possible without government support. On 20 July 2017, China's State Council released its *Plan for the Development of Next Generation Artificial Intelligence*. This move reflected the importance accorded to AI by the scientific and political leadership for giving China a new competitive advantage, stimulating the development of new industries and enhancing national security, while following the USA's lead.

Specifically, the plan outlined a strategy for ensuring that China caught up to the USA in AI technologies and applications by 2020 and became 'the world's primary centre for AI innovation' by 2030.

To realize this ambitious strategy, the plan stipulated that the State Leading Group of Science and Technology System Reform and Innovation System Construction would supervise the plan's implementation.

MoST is responsible for launching AI-related national research programmes and for ensuring co-ordination and integration with other existing programmes, through the new Interministerial Joint Conference mechanism established to improve co-ordination among ministries as part of the ongoing reform of the national innovation system (Cao, 2015).

According to the plan, a new AI planning and promotion office was established in 2018 within MoST, which also hosts the Strategic Consultation and Review Committee responsible for advising on policy issues and approving AI-related research. This office comprises members from the National Development and Reform Commission as well as the Ministries of Finance, Education, Industry and Information Technology, along with other government agencies.

The plan highlighted six key tasks:

- the establishment of an open and co-operative AI technology innovation system;
- the cultivation of a high-end and highly efficient smart economy;
- the building of a safe and convenient smart society;
- the strengthening of civil–military integration in the field of AI;
- the establishment of ubiquitous, safe, smart infrastructure; and
- a forward-looking deployment of a new generation of AI-related megaprogrammes.

The plan evokes a forward-looking 1+N cluster strategy whereby the numeral '1' refers to the establishment of a new megaprogramme in areas such as intelligent big data, swarm intelligence, hybrid enhanced intelligence and autonomous control technologies and the letter 'N' refers to linkages with other national research programmes (EU, 2017).

The latter include the mega-engineering programmes under the *Medium and Long-Term Plan* to 2020 for core electronic devices, high-end general chips, fundamental software and extremely large-scale integrated circuit manufacturing equipment and technologies. They also include aforementioned programmes under the *Thirteenth Five-Year Plan for the Development of Science, Technology and Innovation* and are likely to be part of the new Medium and Long-Term Plan to 2035.

In addition to the creation of a government-guided but market-driven funding mechanism, the plan also calls for the formation of clusters of AI innovation centred around national laboratories at universities and research institutes, while taking advantage of the Thousand Talents Programme and Belt and Road initiative.

In 2020, MoST designated the cities of Jinan, Xi'an, Chengdu and Chongqing as trial zones for new-generation AI innovation and development.

A race to the top in AI

International collaboration is having a significant effect on China's publications related to AI, accounting for as many as 42.6% of the country's top papers.

China has become the largest owner of AI patents, followed closely by the USA and Japan. Combined, these three countries account for 74% of patents granted in AI worldwide. More than half (52%) of China's top 30 institutional owners of AI patents are universities and research institutes, demonstrating the science-based nature of these technologies (CISTP, 2018).

China also has a growing talent pool. By the end of 2017, it counted 18 232 AI specialists, or 8.9% of the global total, second only to the USA (13.9%). Tsinghua University and the Chinese Academy of Sciences are the world's largest 'factories' for turning out AI talent (CISTP, 2018). China, like all countries, is facing the question of how well women are represented in that talent pool (see chapter 3).

Chinese AI companies have been mushrooming since 2012 when the technologies of deep learning and natural language processing were mastered. China counted 1 011 companies in AI as of June 2018, ranking second behind the USA, which had 2 028 (CISTP, 2018).

More often than not, these Chinese firms have global ambitions. From 2013 to the first quarter of 2018, China received 60% of the world's total venture capital investment in AI but, in terms of the number of AI-related venture-capital deals, the USA remained the most active country. In 2017, the value of China's AI market reached RMB 23.7 billion, up 67% year on year, with the top three segments being computer vision (34.9%), voice (24.8%) and natural language processing (21%). Hardware and algorithms combined accounted for less than 20% of the market. Looking forward, the market was expected to grow by 75% in 2018 (CISTP, 2018).

A dearth of top-tier talent

China still has ground to make up when it comes to core AI technologies, however, such as computer hardware and algorithms. More significantly, China's AI development lacks top-tier talent. There is still a skills gap with the USA, in particular. For example, only 977 Chinese AI specialists figure among the world's top-tier AI talent pool based on the H-index, one-fifth of the number in the USA (CISTP, 2018).

China may count the second-largest number of researchers to have published papers or been granted patents in the field of AI in the past decade but the proportion of those considered to be in the top 10% of their field is smaller than in other AI-leading nations (CISTP, 2018).

Data will be the key resource

Compared to the USA and Europe, there is also less of a focus in China on data privacy and a lesser expectation of consensus on the issue of the ethical use of data (O'Meara, 2019). This is a handicap.

According to Kai-Fu Lee, an AI scientist-turned venture capitalist at China-based Sinovation Ventures, there have been four overlapping waves of AI displaying a clear USA–China duopoly. In the first wave of AI for the Internet, the odds of winning were tilted 60/40 in favour of China. In the second wave of business AI, the winner turned out to be the USA by a margin of 90/10. In the third wave of perception AI, China has tipped the balance back in its favour with a 60/40 win over the USA. When it comes to the fourth wave of autonomous AI, the USA should again turn the tables on China with a 90/10 margin (Lee, 2018).

China's win during the first and third waves of the AI revolution can be attributed to the combination of a larger population and the massive amount of data generated through the ubiquitous use of smartphones to access the Internet. Having more data creates a virtuous cycle: more data leads to products that are better trained with AI which, in turn, creates more users and helps companies make more money, enabling the hiring of more scientists and the acquisition of more machines to process and mine even more data.

Since the average smartphone-user in China generates more data than their US counterpart and there are far more smartphone-users in China, this creates a yawning data gap between the two countries. However, in terms of computer power and big data, advanced algorithms and, especially, knowledge accumulation for AI, China does not have clear advantages (CISTP, 2018). Therefore, it is still too early to conclude that China will eventually win the global competition to dominate AI.

Brain research a growing priority

Brain research is not new to China but it has assumed growing priority in recent years. In the new era of big data, it has become imperative to develop brain-inspired computing methods and systems, in order to improve AI systems and harness the ever-increasing amount of information.

The *Medium and Long-Term Plan* to 2020 included brain science and cognition as one of its eight scientific frontiers for basic research. This followed funding of basic research over the years by both the State Basic Research and Development Programme (973 Programme) and the State High-Tech Research and Development Programme (863 Programme), along with the National Natural Science Foundation of China. In 2012, the Chinese Academy of Sciences had launched a pilot programme to develop an atlas of brain function. All of the aforementioned programmes have also supported research on brain–computer intelligence.

The China Brain Project: one body, two wings

The *Thirteenth Five-Year Plan for the National Economy and Social Development (2016–2020)* and the accompanying *Thirteenth Five-Year Plan for the Development of Science, Technology and Innovation* have both launched a programme on brain science and brain-inspired intelligence known as the China Brain Project. It has been inspired by similar initiatives in Europe, Japan, the Republic of Korea and USA.

The escalating societal burden of major psychological and neurodegenerative disorders in China has also made it imperative to develop new preventive, diagnostic and therapeutic tools.

The China Brain Project is characterized by a 'one body, two wings' approach. The 'body' refers to basic research on the neural circuit mechanisms underlying cognition. The body provides input to, and receives feedback from, the two applied 'wings'. One wing represents the diagnosis and treatment of neural disorders and the other brain-inspired intelligence technology (Poo *et al.,* 2016).

The best illustration of the status accorded the China Brain Project is the founding of two specialized institutions in 2018, in collaboration with Chinese academies and universities: the Chinese Institute for Brain Research, Beijing[10] and the Shanghai Research Centre for Brain Science and Brain-inspired Intelligence.[11]

The Beijing institute encourages its scientists to conduct 'blue sky' research to gain deeper insights into how the brain functions, with a view to curing major cognitive disorders, promoting cognitive development to turn out high-performing teenagers and developing technology capable of mimicking brain function. Facilities are being built to provide researchers at the Beijing institute with technical assistance; they will also have access to new databases storing biological and medical resources (Cyranoski, 2018).

The Shanghai centre has a cross-disciplinary focus, with research spanning experimental neuroscience using animal models, brain imaging, brain pathologies and medicine, computational neuroscience, machine learning and AI, intelligent chip design and intelligent computation technology, as well as the brain–machine interface and robotics (Cyranoski, 2018).

There is also a Centre for Excellence in Brain Science and Intelligence Technology based at the Chinese Academy of Sciences' Institute of Neurology in Shanghai. A year after the centre's inception in 2014 as part of the academy's Pioneer Initiative (Cao, 2015), its mandate was extended to encompass intelligence technology.

Brain science, nevertheless, remains an emerging field in China with a small research community. It will be a challenge to staff these newly established centres, especially since they will be competing, domestically and globally, for a small pool of talent.

Given that basic science is also the 'poor cousin' when it comes to research expenditure, the China Brain Project will need to be selective in its research focus and establish a clear division of roles between various institutions, to avoid overlap and wastage of the growing but still scant resources for basic research.

Novel approach to national labs in new plan

Since the 1980s, China has designated some 300 'national laboratories' and other similar laboratories and centres.[12] These research facilities are administered respectively by MoST, the Ministry of Education, the National Development and Reform Commission and other government ministries.

President Xi is of the view that China needs large, multidisciplinary organizations capable of executing complex projects, especially in areas of innovation that will have major strategic implications for China. At the Fifth Plenum of the 18th CCPCC in October 2015, he called for the next national laboratories to reflect this new orientation. The directive concerning national laboratories has since been transcribed into various government policy documents but none of these high-profile documents has clearly specified what the administrative structures, line ministries and co-ordination mechanisms will be for this new generation of national laboratories.

This ambiguity partly explains why no 'new' national laboratories have been established since the Qingdao National Laboratory for Marine Science and Technology (QNLM) was approved by MoST in December in 2013. This facility in Shandong Province remains the only national laboratory to have been piloted under the new scheme. Universities and research institutes located in Qingdao and beyond are members of the new national laboratory, which is the fruit of a joint effort by central government ministries, Shandong Province and Qingdao City.

MoST has also approved the establishment of six national research centres since 2015 but it is unclear whether they will evolve into 'new' national laboratories. These centres specialize in molecular sciences (Beijing), opto-electronics (Wuhan), condensed matter physics (Beijing), information science and technology (Beijing), materials science (Shenyang) and microscale materials science (Hefei).

Since the construction of 'new' national laboratories will be a key area for the new *Medium- and Long-term Plan* to 2035 and a major output of the ongoing reform of the national innovation system (Cao, 2015), the Chinese scientific community believes that these national laboratories will need to have relatively clear mandates in priority areas for national development. Scientists would like to see national laboratories established in core materials, key experimental equipment and industrial instruments, as well as strategic frontiers (Di and Rui, 2019).

Scientists also favour the establishment of a National Laboratory Academic Steering Committee to ensure efficient decision-making at each national laboratory in its field of specialization.

BELT AND ROAD INITIATIVE

The biggest infrastructure project since the Marshall Plan

Unveiled in 2013, the Silk Road Economic Belt and the 21st Century Maritime Silk Road, better known as the Belt and Road Initiative (BRI), is President Xi's signature strategy for developing overland and maritime routes connecting Eurasia with the Indian and Pacific Oceans (Figure 23.7) to make China an international hub for business and technology.

Now covering some 70 countries, the BRI is the single largest infrastructure project since the *Marshall Plan* set about rebuilding Europe after the Second World War. Conservative estimates suggest that the total cost will run to around US$ 1 trillion over the ten years to 2027.

A tool of science diplomacy

Scientific co-operation is an important element of the BRI. In September 2016, China issued a *Special Plan for Promoting Cooperation in Science, Technology and Innovation in the Construction of the Belt and Road Initiative*.

Released jointly by MoST, the National Development and Reform Commission, Ministry of Foreign Affairs and Ministry of Commerce, the *Special Plan* established the following basic principles for co-operation:

- fully respecting the development needs and strategies of BRI countries;
- sharing scientific achievements and experience, including through the exchange of talent;
- building a community of common interests and destiny; and
- promoting sustainable development and common prosperity.

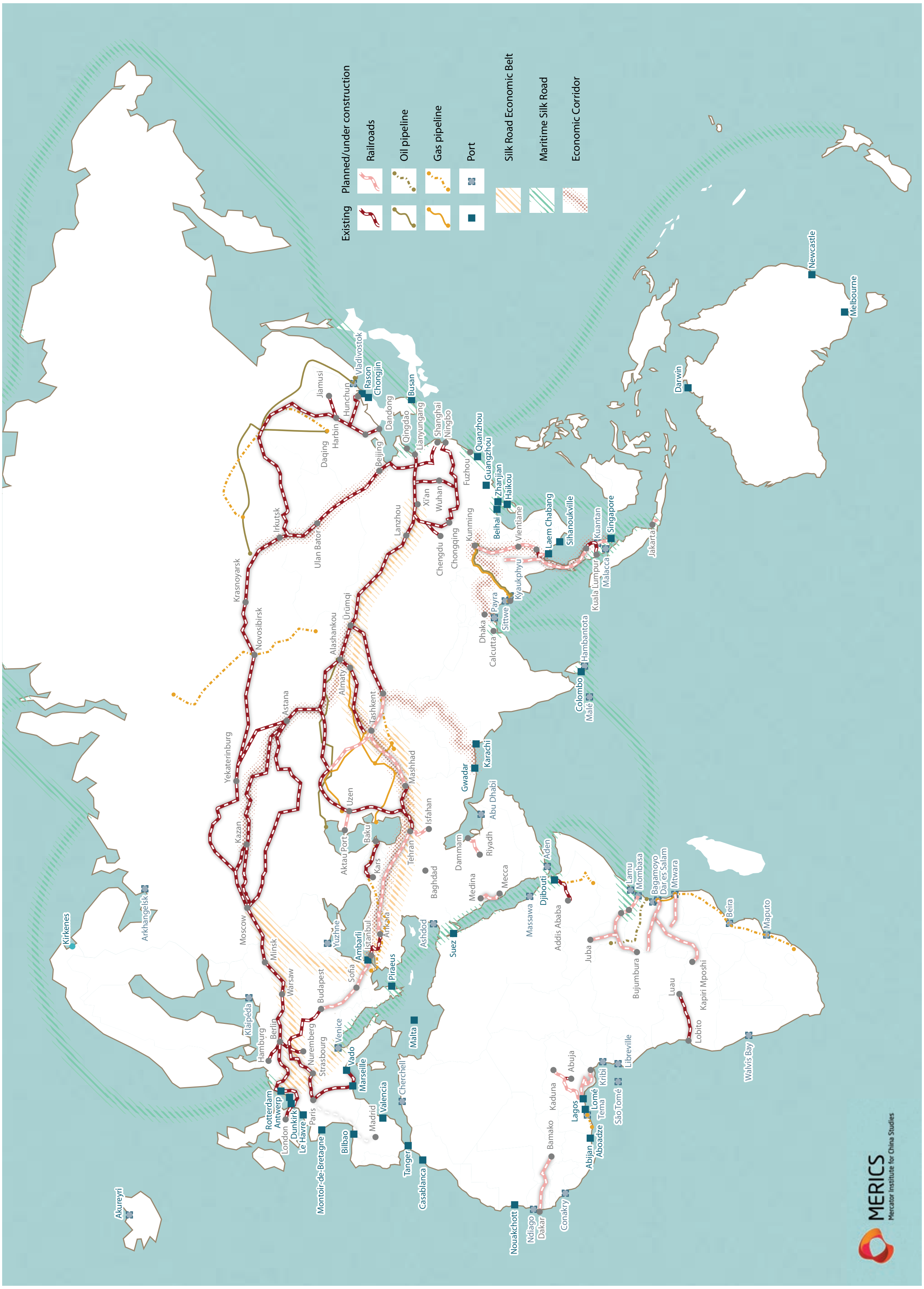
The *Special Plan* defined the near-term goal of having 5 000 outstanding young scientists from BRI countries working in China and more than 150 000 researchers on exchange and training programmes in China within five years.

China has since hosted more than 500 young researchers from BRI countries on short-term exchanges and trained over 1 200 at a technology training programme tailored to their needs.

Under the *Special Plan,* Chinese enterprises are being encouraged to implement key research projects in BRI countries and to build joint research laboratories, technology transfer centres, science and technology parks and so on. The plan, nonetheless, acknowledges that more could be done for BRI countries.

The plan also identifies key areas for co-operation. These range from agriculture, energy, transportation, information and communication technologies, natural resources, the environment, oceans, advanced manufacturing, new materials, aerospace and medicine to disaster prevention and mitigation.

Figure 23.7: **Geographical extent of the Belt and Road Initiative, 2020**



Source: adapted from Mercator Institute for China Studies, Berlin

UN Disclaimer

Making the BRI 'a road to innovation'

On 14 May 2017, in his opening keynote speech at the first Belt and Road Forum for International Cooperation, President Xi proposed turning the BRI into a road to innovation. He announced the *BRI Science, Technology and Innovation Cooperation Action Plan*, which consists of the Science and Technology People-to-People Exchange Initiative, the Joint Laboratory Initiative, the Science Park Cooperation Initiative and the Technology Transfer Initiative.

Under the plan, five technology transfer platforms are to be created in the countries of the Association of Southeast Asian Nations, Arab States, Central Asia and Central and Eastern Europe, along with a batch of joint research centres in Africa.

In Africa, China's big data and artificial intelligence service providers have helped Angola to build a nationwide population database. At the Sino-Africa Joint Research Centre in Kenya, Chinese and African scientists have jointly developed a type of toothpaste out of the molar toothsticks that are frequently used by locals.

In 2018, the Chinese Academy of Sciences and 36 international institutions, including UNESCO, set up an Alliance of International Scientific Organizations in the Belt and Road Regions (ANSO).

ANSO promotes the BRI principles of 'joint consultation, joint effort and joint sharing'. Headquartered in Beijing's Huairou Science City, ANSO now has 52 members, who participate in thematic alliances such as the BRI Health Corridor or the BRI Food Security Corridor.

Each year, ANSO also provides 300 PhD students and 200 master students from BRI countries with scholarships to study at Chinese universities.

A Digital Belt and Road

The Chinese Academy of Sciences' own Digital Belt and Road programme has inaugurated eight international centres of excellence in Morocco, Pakistan, Thailand, Zambia and other countries. By 2019, the academy had invested more than RMB 1.8 billion (US$ 268 million) in BRI-related science projects.

China's BeiDou Navigation Satellite System, the Chinese equivalent of the US Global Positioning System, now covers many BRI countries, providing support for transportation and port management in Pakistan, land planning and coastline mapping in Indonesia and agricultural automation in China and the Russian Federation.

A Green Belt and Road?

It is official policy for BRI investment projects to promote the *Paris Agreement* and *The 2030 Agenda for Sustainable Development*.

Between 2014 and 2017, 43% of state policy bank loans granted to BRI countries by the China Development Bank and Export Import Bank of China went to oil, gas and petrochemicals, 18% to coal, 3.4% to solar and 3.9% to wind projects. When loans for the development of coal, nuclear and hydropower stations are combined, they are almost seven times higher than loans to solar and wind projects. This compares with 25% of active World Bank loans targeting solar and wind power (Zhou *et al*., 2018; Chen *et al.,* 2019).

Moreover, direct overseas greenfield investments and acquisitions by Chinese companies in the power sector of BRI countries between 2015 and 2017 included US$ 5.5 billion for wind and US$ 7 billion for solar, compared to US$ 33.5 billion for coal, oil and gas-fired power plants (Zhou *et al*., 2018; Chen *et al.,* 2019).

It has also been suggested that some transportation routes are being built close to biodiversity hotspots. For instance, 17% of key biodiversity areas in BRI countries are within 50 km of proposed roads and 61% within 50 km of proposed rail routes (Hughes, 2019).

The adoption of a series of guidelines[13] in May 2017 may help the BRI onto a green trajectory. *The Belt and Road Ecological and Environmental Cooperation Plan,* for example, states that 'we will actively participate in scientific and technological co-operation and exchange in the field of eco-environmental protection to improve the capability of scientific and technological support' (Chen *et al.,* 2019).

CONCLUSION

Great expectations

China has made tremendous progress since 2015 in science, technology and innovation, as illustrated by related metrics in the present chapter, such as the consistent rise in research expenditure, the large talent pool producing work of growing quality and the dynamism of patenting. China has become a driving force in space technology, supercomputing, artificial intelligence and other cutting-edge strategic technologies.

At this stage, China's ambitions of becoming an innovation-driven country have reached a crossroads. The path ahead will be arduous (Suttmeier, 2020). China will have to overcome domestic barriers to innovation, such as inadequate intellectual property protection and excessive state support for innovative enterprises, if it is to allay the concerns of its key trading partners and pursue the open-door policy that has served it so well up to now. It is unimaginable that China could have come so far without opening the country to foreign technologies, ideas and institutions.

The prioritization of AI and brain research in the next 15 years may not pay off in terms of contributing sufficiently to China's development and welfare. By enlarging the role of state-owned enterprises in initiatives such as Made in China 2025 and Industry 4.0, China may also find it challenging to reverse the downward trend in productivity or expose research to market dynamics.

These and other factors suggest that China will need to pursue the current reform of the national innovation system. One priority should be to tackle issues of an ethical nature, such as that demonstrated by the gene-editing baby scandal. AI applications such as facial recognition have also been used liberally without sufficient consideration for privacy. In addition, recent years have witnessed the withdrawal of a large number of papers published by Chinese scientists, damaging the integrity and reputation of the Chinese scientific community as a whole.

China has yet to inaugurate specific laws and regulations in relation to the ethics of science and technology.

Plans to form a national committee to advise the government on regulations with regard to research ethics are a step in the right direction but any future law should also define ethical limits on the use of technology in society as a whole.

On the international scene, the Belt and Road Initiative has become a dynamic tool of science diplomacy and there are indications that it will strive to burnish its 'green' credentials in the coming years.

Going forward, China should tackle the current challenge to globalization by playing an increasingly prominent role in global science governance. China needs to embrace the global trend towards open access, open data and open science, for instance, and to support calls for global data governance, in order to protect the individual's data privacy.

KEY TARGETS FOR CHINA

China plans to:

- achieve carbon-neutrality by 2060;
- raise the share of non-fossil fuels in energy consumption to 20% by 2030;
- eliminate the use of plastic bags by 2022 and reduce single-use plastics in the restaurant industry by 30% by 2025;
- count among the top innovation-oriented nations by 2030 and lead the world in innovation by 2050;
- lift the GERD/GDP ratio to 2.8% by 2030;
- become the 'world's primary centre for AI innovation' by 2030.

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ENDNOTES

1 WHO recommends an annual mean threshold of 10 µg m–3 of airborne particulate matter up to 2.5 microns in size (PM 2.5). The level is at least five times higher in 16 major Chinese cities, including Hotan (116 µg m–3), Kashgar (96 µg m–3) and Beijing (51 µg m–3) [IQ, 2018].
2 The source of these data is the Johns Hopkins Coronavirus Resource Center in the USA. See: https://coronavirus.jhu.edu/map.html
3 The Thousand Talents Programme was set up by the Chinese government in 2008 to attract prominent academics back to China (Cao, 2015, Box 23.2).
4 This is the fourth amendment since the law's enactment in 1985.
5 This strategy fixed the target of a GERD/GDP ratio of 2.8% by 2030.
6 In terms of purchasing power parity, China's spending on R&D now exceeds that of the USA and EU.
7 Dependency on foreign technology is a purely Chinese indicator. The government has since stopped using this indicator, on account of its misleading nature, according to a private communication with an analyst at the Chinese Academy of Science and Technology for Development in 2019.
8 See: https://conference-board.org/data
9 See: MoE and MoST (2020) Opinions on Regulating the Use of Indexes Related to SCI Papers and Upholding Correct Evaluation Orientation at Institutions of Higher Education. Ministry of Education and Ministry of Science and Technology: https://tinyurl.com/y2ohdfna
10 The Chinese Institute for Brain Research, Beijing is supported by the Beijing municipality through six participating institutions: Chinese Academy of Sciences, Peking University, Tsinghua University, Beijing Normal University, Chinese Academy of Medical Sciences and Chinese Academy of Military Medical Sciences.
11 The Shanghai Research Centre for Brain Science and Brain-inspired Intelligence is a collaboration between the Shanghai municipal government and the Chinese Academy of Sciences, structurally designed to foster cross-disciplinary and collaborative research.
12 These may also be referred to as 'national key laboratories' and 'key laboratories'.
13 The other documents adopted in May 2017 are entitled *Guidance on Promoting the Green Belt and Road* and *Visions and Actions on Energy Cooperation in Jointly Building the Silk Road Economic Belt and 21st Century Maritime Silk Road* (Chen *et al.*, 2019).

ROBEAR has been developed by RIKEN as an experimental project to see if robots can be used to help people with restricted mobility move between their wheelchair and other furniture. It is capable of carrying a reclining adult in its arms and can travel in different directions. © RIKEN

AT A GLANCE

- Nine years after the Great East Japan Earthquake and nuclear disaster, the government is striving to balance the need for greater self-sufficiency in energy with its commitments to the Paris Agreement on climate action.
- The futuristic concept of Society 5.0 is the centrepiece of the government's new growth strategy. The hope is that widespread adoption of digital technologies will nurture Japan's strengths in engineering and, by introducing artificial intelligence into the workplace, ensure that depopulation and ageing cease to be disadvantages in a less labour-intensive economy.
- Japanese companies have, meanwhile, reacted to the shrinking domestic market by purchasing overseas companies to 'buy time and labour'. As a result, investment is leaving Japan's shores, hollowing out the industrial base.
- The government is backing stronger ties with industry and high-risk 'moonshot' innovation, in a context of declining academic output and disillusion among the young with an academic career.

24 · Japan

Mari Jibu and Yoshiyuki Osabe

INTRODUCTION

Persistently high public debt

Nine years on, the Japanese economy is gradually recovering from the triple catastrophe of March 2011, in which an underwater earthquake caused a tsunami that, in turn, flooded the Tohoku area and set in motion the Fukushima nuclear disaster. Economic growth has been lethargic ever since. It peaked at just 2% in 2013 and languished at 0.8% in 2018 (Figure 24.1).

Over this period, Abenomics has dominated the landscape. Designed to revitalize the economy, this programme has enjoyed the same longevity as its namesake, Shinzo Abe, who was prime minister between 2012 and 2020, making him the longest-serving prime minister in Japanese history.

The Abenomics policy package consists of three arrows: monetary easing, fiscal stimulus and a growth strategy (Sato and Arimoto, 2015). Thanks to Abenomics's Womenomics programme, women's overall participation in the workforce has risen steeply since 2012 to a record 71% (2018), surpassing the USA (66%) and European Union (62%), according to the Organisation for Economic Co-operation and Development (OECD, 2019a).

According to Cabinet Office statistics, the first six years of Abenomics have succeeded in raising employment levels and reducing the fiscal deficit. However, unemployment was low to begin with and the fiscal deficit remains extremely high. Japan has the highest debt-to-GDP ratio of any OECD member (Figure 24.1).

In October 2019, the government bowed to pressure to reduce the fiscal deficit by raising value-added tax from 8% to 10%. This move also enabled the government to raise social security payments for the elderly. Even with this hike, Japan's consumption tax is still the lowest of any OECD member (OECD, 2019b). Despite the increase in tax revenue, the government is far from achieving its target of running a primary balance surplus by 2025. Moreover, such a surplus would only be a first step towards inversing the government debt-to-GDP ratio. Were there to be no further fiscal consolidation after 2025, the government debt-to-GDP ratio would rise to around 560% by 2060. This sobering statistic prompted the Bank of Japan to set a 2% target for consumer price inflation and launch quantitative and qualitative monetary easing in 2013.

A new era

Meanwhile, Japan has entered the new era of Reiwa (beautiful harmony), following the ascension to the throne of Emperor Naruhito in 2019, after his father, Emperor Emeritus Akihito, became the first living Japanese monarch to abdicate in over 200 years.

THE SEXTUPLE WHAMMY

A multifaceted structural problem

In the nine years since the Great East Japan Earthquake, the economy has confronted six multifaceted structural challenges commonly referred to in Japan as the 'sextuple whammy' (Karakama, 2019):

- the yen appreciated, making exports more expensive;
- the combination of a high corporate income tax rate and strict labour laws created a difficult environment for business;
- the population kept ageing, with 27.5% of Japanese aged 65 years or more by 2018, owing to a persistently low fertility rate of 1.43 children per woman, according to World Bank data;
- the planned Comprehensive and Progressive Agreement for Trans-Pacific Partnership stalled after the USA withdrew support in early 2017;
- rising global oil and gas markets pushed up domestic power prices in the industrial sector to US $145 per MWh in 2017, according to the Ministry of the Economy, Trade and Industry (METI), a level 2.6 times higher than in France; and
- the government introduced strict environmental regulations, to respect its pledges under the *Paris Agreement* (2015) for climate action.

A difficult business climate

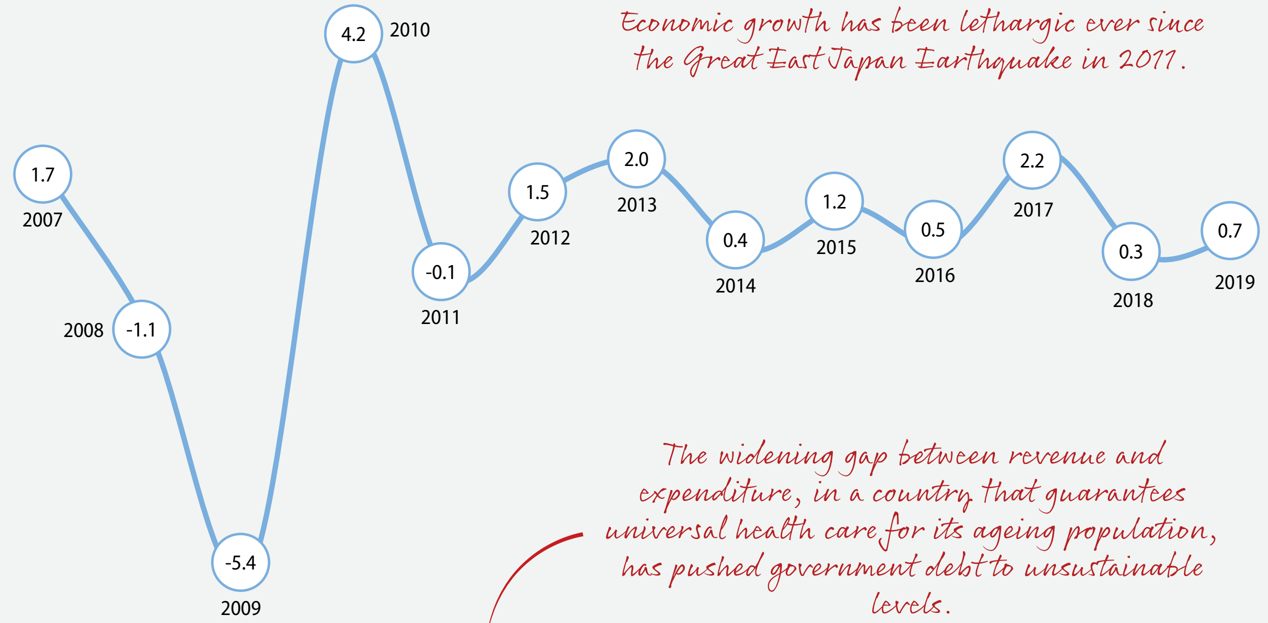
The sextuple whammy has penalized Japanese industry, in particular. Although some of the aforementioned challenges have been resolved, others persist. For instance, the strict labour laws have not been relaxed. The yen also remains strong, even though the nominal effective exchange rate index (relative to 2015) increased to 116.5 by 2019 (OECD, 2019c), thanks to the policy of quantitative easing under Abenomics. This relief has come rather late in the day for the manufacturing industry, which has seen its exports eroded by two decades of deflation.

Although Japan's corporate income tax rate dropped to 29.7% in 2018, it remains higher than that of Australia, France, Germany Mexico or Portugal (OECD, 2019a). Between 2010 and 2012, Japan's corporate income tax rate had been the highest in the world, at 39.5%.

Employers largely bear the brunt of the third 'whammy', the low fertility rate. Japan is facing the limitations of its traditional employment system, which assumes a lifetime working for the same employer. According to the OECD indicators of employment protection, Japan's protection of permanent employees is stronger than the OECD average. The World Economic Forum also suggests that Japan is one of the

Figure 24.1: **Socio-economic trends in Japan**

Rate of economic growth, 2007–2019, (%)



Economic growth has been lethargic ever since the Great East Japan Earthquake in 2011.

The widening gap between revenue and expenditure, in a country that guarantees universal health care for its ageing population, has pushed government debt to unsustainable levels.

Population of Japan (millions)

127.0 in 2015

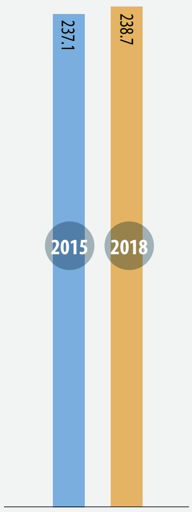
126.5 in 2018

Share of population aged 65 or above

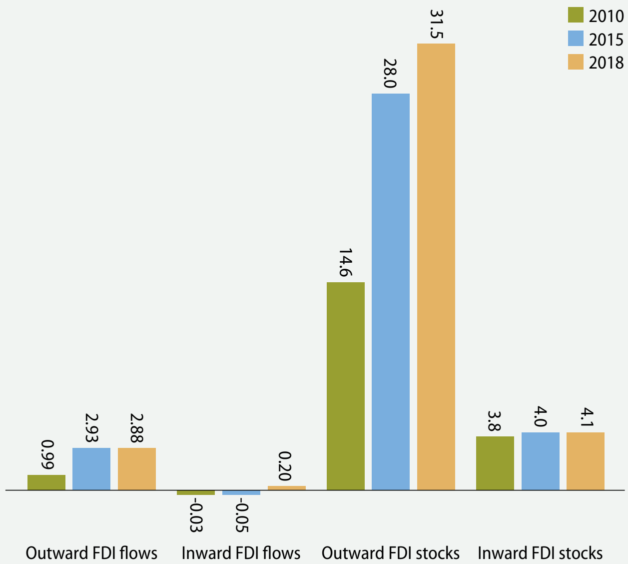
27.5% in 2018

26.1% in 2015

Government debt as a share of GDP, 2015 and 2018 (%)



FDI flows and stocks to and from Japan as a share of GDP, 2010, 2015 and 2018 (%)



Impact of Abenomics, 2011, 2015 and 2018

	2011	2015	2018	
Nominal GDP (¥ trillions)	494	533	548	
GDP per capita (current US$)	48 168	34 524	39 290	
Total employment in millions (women)	62.9 (26.5)	64.0 (27.6)	66.6 (29.5)	RECORD HIGH
Employment rate (%)	56.5	57.6	60.0	
Corporate pre-tax profit (¥ trillions)	43.8	72.1	91.6	RECORD HIGH
Unemployment rate (%)	4.6	3.4	2.4	
Private non-residential investment (¥ trillions)	68.0	83.3	87.3	
Tax revenue (¥ trillions)	42.8	56.3	60.4	

Source: www.japan.go.jp/abenomics/index.html; for corporate pre-tax profit and private non-residential investment: https://www.esri.cao.go.jp/; for GDP per capita: World Bank's World Development Indicators. For other socio-economic trends: OECD Economic Outlook; UN Department of Economic and Social Affairs; IMF World Economic Outlook database most restrictive countries in the world when it comes to the right of employers to dismiss their permanent workers.

As the population declines, the Japanese market itself is shrinking. This has incited companies to purchase enterprises abroad as a way of 'buying the market' and, at the same time, 'buying time and labour'. For example, Takeda Pharmaceuticals purchased the British biotech company Shire in 2018 at a reported cost of US$ 62 billion, making it Japan's biggest acquisition to date. Shire focuses on rare diseases. Two years earlier, SoftBank had purchased the British semiconductor and software design company, ARM Holdings (METI, 2019).

This trend is likely to continue. Outward foreign direct investment (FDI) flows hit a record high in 2017 (Figure 24.1). This exodus of business capital is hollowing out industry in Japan.

By contrast, inward FDI flows remain the lowest in the developed world, even though they have shown some growth since 2015 (Figure 24.1). This would seem to confirm fears that Japan is losing its attractiveness as a business destination relative to other Asian nations (Sato and Arimoto, 2015).

A rejection of protectionism

The fourth 'whammy' concerns the Comprehensive and Progressive Agreement for Trans-Pacific Partnership. Despite the US withdrawal from the deal, this free trade agreement entered into force on 30 December 2018, after being ratified by Canada, Australia, Japan, Mexico, New Zealand and Singapore. Vietnam followed suit two weeks later.

Once all 11 signatories[1] have ratified the agreement, they will form a trading bloc grouping almost 500 million consumers, 13.5% of global GDP and about 15% of the value of global trade.

According to the government, Japan's economy will most likely get a ¥ 8 trillion (*ca* US$ 72.6 billion) boost from the Trans-Pacific Partnership, although it may cost the agricultural and fishing industries up to ¥ 150 billion (Japan Times, 2018).

Japan celebrated the entry into force of another momentous free trade deal on 1 February 2019, namely the Economic Partnership Agreement with the European Union.

Taken together, these two agreements give Japan access to a free market of about 1 billion consumers. They send a powerful message that two of the world's leading economies reject protectionism.

Moreover, in 2020, Japan was in the process of negotiating a third free trade agreement, this time with the ten member states of the Association of Southeast Asian Nations (ASEAN, see chapter 26). These negotiations were formally launched at an ASEAN Summit in Cambodia in 2012.

The fifth and sixth whammies concern the high price of electricity for industry and the financial burden of respecting Japan's commitments to the *Paris Agreement*. These are analysed in the following section.

SUSTAINABLE DEVELOPMENT AGENDA

Priority: greater energy self-sufficiency

In the wake of the Great East Japan Earthquake (2011), the country's nuclear power plants were shut down for mandatory inspections and upgrades between 2013 and 2015. To compensate for the loss of nuclear power, Japan increased its dependence on imports of oil, gas and coal. The share of fossil fuels in Japan's energy mix consequently rose from 81.2% to 87.4% between 2010 and 2017 (METI, 2019). This pushed up the country's greenhouse gas emissions to record levels in 2013 before these subsided once more to just above 1990 levels (Figure 24.2).

Following the shutdown of the country's nuclear reactors, Japan's energy self-sufficiency rate plummeted from about 20% in 2010 to 6.4% in 2014. Improving this rate has been a focus of energy policy ever since. It had risen to 9.6% by 2017 (ANRE, 2018) but remains one of the lowest among OECD members.

Renewable energy use has not developed as quickly as planned. In 2012, the government introduced the feed-in tariff scheme to accelerate the installation of solar energy systems, in particular. Through this scheme, photovoltaic companies were guaranteed a fixed rate for a given period of time for the sale of the electricity they generated to power companies; the latter then recovered the purchase costs by means of a surcharge paid by electricity users. These purchase costs have remained high, however, slowing the spread of renewable energy (ANRE, 2018).

This state of affairs led the Agency for Natural Resources and Energy (ANRE) to lower the fixed price consumers paid for solar and wind power in 2018. The government also decided to liberalize the retail market for energy in 2016 to give consumers the freedom to choose their preferred power suppliers; it detached the entity responsible for power transmission from the entity responsible for power generation by law, in order to guarantee fair competition.[2]

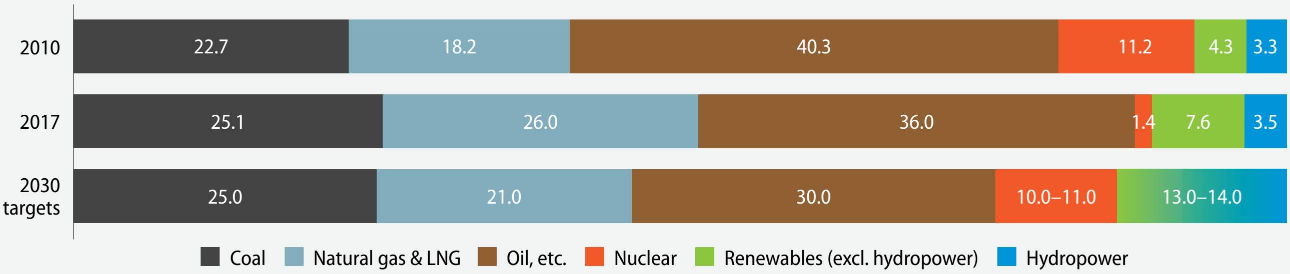
The government has also been promoting the development of more cost-efficient technologies (Figure 24.2), in line with its *Long-term Energy Supply and Demand Outlook* (2015), itself based on the *Strategic Energy Plan* (2014). Hydrogen fuel cells are one focal technology. They will generate power for all of the residential villages for athletes competing in the forthcoming Olympic and Paralympic Games in Tokyo, for instance. In 2021, Panasonic plans to commercialize hydrogen fuel cells.

The government is also developing new technologies and promoting industrial clusters in the decontaminated zone in Fukushima Prefecture (Box 24.1). Construction of the world's largest hydrogen production facility (10 000 kW) should be complete in Fukushima Prefecture by early 2020.

By 2017, the evacuation order for 'restricted residence areas' around Fukushima had been lifted, following decontamination, with the exception of the towns of Okuma and Futaba, situated closest to the abandoned nuclear plant. In 2019, about 40% of Okuma was declared sufficiently safe for residents to return. The handling and storage of water stored *in situ* in tanks contaminated with radioactive tritium, nevertheless, remains problematic (ANRE, 2018).

Figure 24.2: **Trends in Japan's greenhouse gas emissions and power supply**

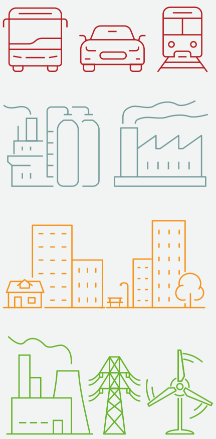
Japan's primary energy supply in 2010 and 2017 and energy targets to 2030 (%)



Note: The 2030 target for renewable energy includes hydropower. ANRE (2018) forecasts that renewable energy will make up 22–24% of energy consumption by 2030. Of this, one-third should come from solar energy and hydropower. The remainder of the energy mix should be made up of nuclear power (20–22%) liquid natural gas (27%), coal (26%) and oil (3%).

Key areas of innovation in Japan to achieve zero carbon emissions by 2050

Figures in parentheses represent 2015 emissions

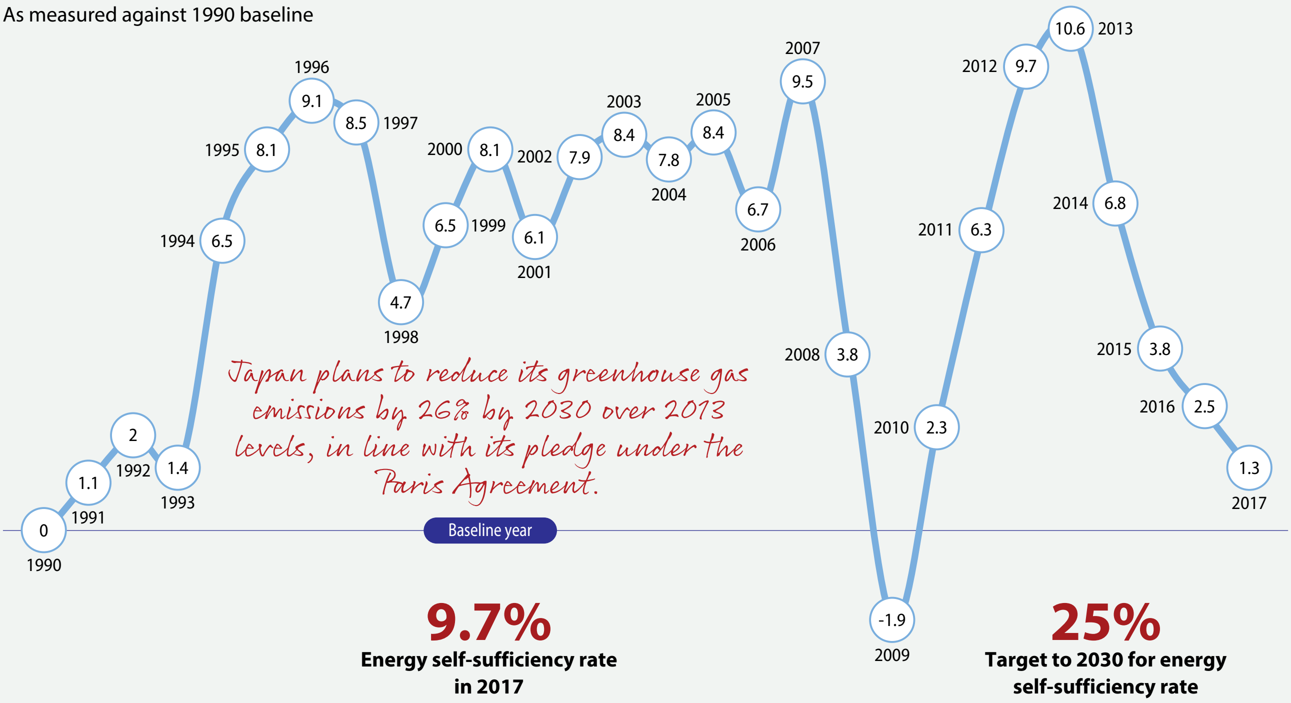


	Main elements	Decarbonization-oriented future
Transport (210 million tonnes)	Vehicles, systems	Electrification, autonomous vehicles, materials
	Fuel	Electricity, hydrogen, biofuels
Industry (310 million tonnes)	Processes	CO_2 capture, utilization and storage; hydrogen reduction; smarter use of energy
	Products	Non-fossil energy materials
Consumers (120 million tonnes)	Heat sources	Electricity, hydrogen, other
	Devices	Expanding Internet of Things to more devices, machine-to-machine control
Electric power (520 million tonnes)	Thermal power	CO_2 capture, utilization and storage; hydrogen power generation, etc.
	Nuclear power	Next-generation nuclear reactors
	Renewable energy	Electricity storage & system innovation

Innovations

Change in Japanese greenhouse gas emissions, 1990–2017 (%)

As measured against 1990 baseline



Source: Adapted from ANRE (2018) and Greenhouse Gas Inventory Office of Japan, National Institute for Environmental Studies

Box 24.1: **Fukushima: from nuclear tragedy to renewable powerhouse**

Fukushima Prefecture has been promoting renewable energy as one of the pillars of its post-earthquake reconstruction. Leading this effort is the Fukushima Renewable Energy Institute, which was established in April 2014 by the National Institute of Advanced Industrial Science and Technology to develop new technologies.

Today, the third-largest prefecture in Japan is turning its back on nuclear energy. Fukushima Prefecture intends to be entirely powered by renewable energy by 2040, compared to 40% of its energy needs today.

The construction of 11 solar and 10 wind farms on abandoned farmland and in mountainous areas by March 2024 will cost an estimated ¥ 300 billion.

The project will generate up to 600 megawatts of electricity, roughly two-thirds the output of an average nuclear power plant. The generated electricity will not only be used in the prefecture itself but also across an 80 km grid connecting Fukushima's power generation with the Tokyo metropolitan area.

In 2019, the Development Bank of Japan and Mizuho Bank decided to finance the construction of power grid facilities. A power grid service is less likely to make a profit than a power generation business that can recover its operating costs by selling electricity.

This effort parallels the installation of a solar power plant at Chernobyl in 2018, which now produces enough energy for 2 000 apartments (see also Chapter 12). Chernobyl was the site of the world's worst nuclear disaster in 1986. The 1 MW plant is a joint project by Ukrainian company Rodina and Germany's Enerparc AG and has cost about US$ 1.2 million. Feed-in tariffs guarantee electric power companies a fixed rate for the purchase of the electricity generated (WEF, 2018).

Source: adapted from www.pref.fukushima.lg.jp/site/portal-english/en03-04.html

'Safety comes first'

The overriding principle of the *Strategic Energy Plan* (2014) is 'safety comes first'. The plan prioritizes raising the self-sufficiency rate to 25% to bolster energy security and reduce Japan's greenhouse gas emissions by 26% by 2030 over 2013 levels, in line with the country's pledge under the *Paris Agreement* (2015).

A growing number of nuclear reactors have been restarted since 2016 to help reach these targets but the government's plans to build new coal power plants tend to favour one target at the expense of the other. In addition, nuclear power remains a controversial issue in Japan.

Smart tech for a resilient society

In 2018, the government estimated that damage from abnormal weather and natural disasters such as typhoons and torrential rain was costing agriculture, forestry and fisheries ¥ 567.9 billion (*ca* US$ 5.164 billion) annually. In the past ten years, this figure has been surpassed only by the damage caused by the Great East Japan Earthquake (¥ 2.71 trillion).

Under the *Climate Change Adaptation Act* of 2018, the government formulated a *Basic Policy on Economic and Fiscal Management Reform 2018: Realizing Sustainable Economic Growth by Overcoming the Decreasing Birth Rate and Ageing Population,* approved by the Cabinet in June 2018. This policy promotes the establishment of an adaptation platform and outlines measures related to agriculture and disaster prevention, among other areas. For example, the government is promoting 'smart agriculture' to compensate for labour shortages, by developing drones, autonomous tractors and other technologies.

In parallel, the government is developing smart, green cities to tackle global warming while providing the country's ageing population with basic services. Smart cities are part of the government's Society 5.0 strategy of using information and communication technologies (ICTs) to create smart infrastructure, such as home energy management systems, and deploy digital technology to provide depopulated areas with key services (Box 24.2).

In June 2019, Japan hosted the G20 summit in Osaka where innovation for a low-carbon future was one of the key topics. Environment and energy ministers from the G20 agreed in Osaka on the outline of a new international framework for tackling the problem of marine plastic waste. The G20 did not turn out to be the starting point for global data governance, however (Box 24.2).

In June 2019, the Cabinet approved Japan's *Long-term Strategy under the Paris Agreement*. By 2050, Japan is to have a 'circular and ecological economy' that is carbon-neutral, including with regard to community buildings, homes and distributed energy systems. The country's development model will be decarbonized by measures such as carbon capture, storage, use and recycling, greater renewable energy use and, ultimately, a 'hydrogen society' free of carbon dioxide. This led the government to set up a Carbon Recycling Promotion Office at ANRE in 2019. In manufacturing, decarbonization translates into the goal of zero-carbon steel production, for instance. In transportation, the aim is to achieve 'well-to-wheel zero emissions'[3] by developing the world's most environmentally sound car by 2050. Big data and the Internet of Things will be used to improve traffic flows in cities and energy efficiency.

Society 5.0 has made STI a mainstream political agenda

Society 5.0 has turned science, technology and innovation (STI) policy into a mainstream political agenda (Box 24.2). It was in 2016 that the concept first appeared in the *Fifth Basic Plan for Science and Technology (2016–2020)*. This plan incorporates the findings of expert committees convened by the Ministry of Education Sport, Culture, Science and Technology (MEXT) and METI between 2014 and 2016.

This process led to Society 5.0 becoming the centrepiece of the Abe Cabinet's revised *Growth Strategy* (2017) and a government-wide vision for the future of Japan. The longevity of the Abe cabinet has also created an environment that is conducive to fine-tuning the government's vision over time. Society 5.0 will also be one of the pillars of the *Sixth Basic Plan for Science and Technology* (2021–2025), due to be approved by the Cabinet in January 2021.

Society 5.0 will also serve as a pillar of Japan's strategy for achieving its Sustainable Development Goals (SDGs). In December 2017, the prime minister announced that the Council for Science, Technology and Innovation (CSTI) would be responsible for preparing an STI roadmap for the SDGs (Cabinet Office, 2018).

Box 24.2: **Society 5.0: the centrepiece of Japan's new growth strategy**

Japan's blueprint for a super-smart society, Society 5.0, is a more far-reaching concept than Industry 4.0, for it envisions a complete transformation of the Japanese way of life.

Society 5.0 was adopted in 2017 to overcome chronic social challenges such as an ageing population, social polarization, depopulation and constraints related to energy and the environment. Both the government and business leaders have high hopes for the strategy.

The idea is that Society 5.0 will follow Society 1.0 (hunter-gatherer), Society 2.0 (agricultural), Society 3.0 (industrialized) and Society 4.0 (information). Society 5.0 will be characterized by a sustainable, inclusive socio-economic system powered by digital technologies such as AI and robotics. Any product or service will be optimally delivered to people and tailored to their needs.

An autonomous future

In Society 5.0, autonomous vehicles and drones will bring goods and services to people in depopulated areas. Customers will be able to choose the size, colour and fabric of their clothing online directly from the garment factory before having it delivered by drone.

Doctors will be able to consult their patients in the comfort of their own home, via a special tablet. While they examine a patient from a distance, a robot may be vacuuming the carpet.

At the nursing home down the road, another robot may be helping to care for the aged. In the nursing home's kitchen, the refrigerator will be monitoring the condition of stocked foods to cut down on waste.

The town will be powered by energy supplied in flexible and decentralized ways to meet the inhabitants' specific needs while conserving energy.

On the outskirts of town, autonomous tractors will be toiling in the fields while, downtown, advanced cyberphysical systems maintain vital infrastructure and stand by to replace retiring technicians and artisans, should there not be enough young people to step into their shoes.

Robust support from industry

In 2016, the Japan Business Federation (Keidanren) published its own policy proposal for Society 5.0. Following consultations, a close relationship developed between the government and Keidanren, giving Society 5.0 the momentum to move forward rapidly.

Under the umbrella of the Growth Strategy Council: Investing for the Future, composed of ministers, company chief executive officers and academicians, joint industry–government committees were established under five key themes: next-generation mobility and the smart city; smart public services; next-generation infrastructure, fintech (financial technology) and the cashless society; and next-generation health care.

These joint committees comprised business representatives and divisional directors from ministries. They discussed strategies for deploying digital technologies and challenges with regard to human resources, regulatory reform, open data and cybersecurity.

The Growth Strategy Council also discussed the need for legislation to regulate the digital data market. This links to the prime minister's decision to use Japan's chairing of the G20 Summit in June 2019 to promote the idea of expanding World Trade Organization rules beyond goods and services to encompass trade in data. The prime minister stated at the World Economic Forum in January 2019 that he would 'like the Osaka G20 to be remembered as the summit that started worldwide data governance'.

Pillars of Society 5.0: AI and *The 2030 Agenda*

Japan's *Artificial Intelligence Technology Strategy* is a key pillar of Society 5.0. It plans to generalize the use of data-driven AI across all services, including the three priority areas for Society 5.0: health, mobility and productivity.

The strategy was published in March 2017 by the Council for an Artificial Intelligence Technology Strategy. This body was set up in April 2016 by CSTI and comprised presidents of universities and national research bodies as well as business moguls like the former Chair of Toyota. In March 2019, the government released its *Social Principles of a Human-centric AI*.

Both the Abe Cabinet's growth strategy and Keidanren's own policy proposals expect Society 5.0 to make a major contribution to *The 2030 Agenda for Sustainable Development*. Keidanren even revised its *Charter of Corporate Behaviour* in November 2017, calling for its member corporations to 'proactively deliver on the SDGs through the realization of Society 5.0'.

Society 5.0 may yet offer Japan the means to overcome its chronic economic stagnation. Even though it has not taken the lead in digital industries so far, the nation may be able to take advantage of its traditional strengths in mechanical and material engineering to develop advanced cyberphysical systems. By actively introducing AI into the workplace, depopulation and ageing might cease to be disadvantages in a less labour-intensive economy.

Source: Sato (2019)

Disruptive innovation the key to recovery

CSTI's *Fifth Basic Plan* for *Science and Technology* (2016–2020) came into effect in April 2016. CSTI added the term 'innovation' to its name in 2014 to reflect the government's conviction that disruptive innovation would be the key to recovery from Japan's chronic economic stagnation.

Since 2013, CSTI has combined this longer-term vision in the multiyear *Basic Plan* through a succession of comprehensive strategies each lasting one year. These have a common focus on international collaborative research and development (R&D), open science, intellectual property protection and spreading Japanese technology worldwide, in order to create an international standard for realizing Society 5.0.

In 2018, CSTI published its first *Integrated Innovation Strategy* with the stated objectives of 'aggressive use of new technologies' and becoming 'the world's most innovation-friendly country'. The strategy targets five fields:

- the construction of a cross-cutting data-exchange platform linking government departments, business and academia to facilitate the realization of Society 5.0, open science, evidence-based policy-making and implementation of the current university reform;
- using the ongoing university reform to create an innovation ecosystem and promote strategic budgets funded by CSTI which encourage high-risk, high-impact R&D, such as the Cross-ministerial Strategic Innovation Promotion Programme (SIP, since 2014), the Public/Private R&D Investment Strategic Expansion Programme (PRISM, since 2018) and the Impulsing Paradigm Change through Disruptive Technologies Programme (2017–2019);
- building innovation ecosystems by improving staff mobility, university reform and tech start-ups, along with the promotion of innovation in government programmes;
- the Sustainable Development Goals (SDGs); and
- a review of strategies for technologies in five key fields: artificial intelligence (AI); biotechnology (bio-economy); environmental energy (energy efficiency, renewable energy, energy storage, nuclear energy, energy infrastructure and energy security); safety and security (including cybersecurity); and agriculture.

With regard to the bio-economy, the second *Integrated Innovation Strategy* (CSTI, 2019) stresses developing new markets in agriculture, industry and health by accelerating the integration of data-driven technologies such as AI and the Internet of Things, in order to follow the global shift from deductive to inductive thinking in biotechnology.

The *Integrated Innovation Strategy* (2019) espouses the thinking of *Beyond Disciplines,* a study produced by the Centre for Research and Development Strategy (CRDS, 2019) which considers transdisciplinary research as being vital for sustainability science. CRDS proposes a set of 11 transdisciplinary enabling technologies, including the design of digital twins for physical assets or processes in manufacturing; the integration of Biomedical Things; the use of the Internet of Things to develop a future energy network; information science and technology for complex decision-making; robotics; controlling the interaction between new materials and the biological environment; and technologies at the nexus of food, water and energy (CRDS, 2019). *Beyond Disciplines* should feed into the *Sixth Basic Plan for Science and Technology* (2021–2025).

Meanwhile, the Cross-ministerial Strategic Innovation Promotion Programme has been working with public and private partners to implement the *Artificial Intelligence Technology Strategy* (2019). One focus area is the use of AI to improve disaster readiness and recovery (Box 24.3).

Shooting for the Moon

The second *Integrated Innovation Strategy* (CSTI, 2019) added three new priority areas:

- 'Moonshot' R&D as a strategic budget;
- smart cities to further the Society 5.0 agenda; and
- quantum technology and other fields required to achieve integrated innovation, in addition to the five fields identified in 2018.

Japan's new Moonshot programme[4] has been designed to develop disruptive technologies capable of solving challenging social problems, including large-scale natural disasters, cyberterrorism, global warming and an ageing society. By setting ambitious targets, the programme hopes to attract researchers from around the world. By using basic research to develop innovation, it hopes to attract positive feedback that will translate into greater investment in basic research. To take some examples, disruptive technologies could potentially:

- maximize use of solar energy by generating power from space;
- use super micro-organisms to dispose of marine plastic waste;
- lay the groundwork for artificial photosynthesis to make effective use of carbon dioxide;
- lead to self-made medicines using insects to combat tomorrow's pandemics;
- enable artificial hibernation to prolong the life of an accident victim until emergency services arrive; and
- allow for multiple robots to be controlled simultaneously through brain functions.

The third thrust of the Moonshot programme is to develop a speedy, challenging research management system. With CSTI acting as 'control tower', the programme is being implemented jointly by MEXT, METI, the Japan Science and Technology Agency and the New Energy and Industrial Technology Development Organization (NEDO). NEDO is responsible for issuing calls to domestic and foreign researchers for innovative proposals.

Box 24.3: AI to improve Japan's disaster readiness and response

A central goal of Japan's *Artificial Intelligence Technology Strategy* (2017) is to 'carry out resilience-oriented urban development utilizing AI' to provide advance warning of an impending disaster and streamline the disaster response by improving evacuation protocols and reducing the demands on staff from disaster management agencies in terms of data collection and analysis.

The Cross-ministerial Strategic Innovation Promotion Programme is working with public and private partners to implement the strategy.

For instance, the National Research Institute for Earth Science and Disaster Resilience (NRIESDR) has developed a Shared Platform for Disaster Management which pools information collected by ministries.

Chubu University is leading the development of an AI system capable of calculating the extent of a disaster in real time from satellite data. The goal is to compress a job that took people five days in 2018 into a five-minute calculation. This system should be operational by 2023.

Kyushu University, meanwhile, is developing an AI system capable of guiding evacuation efforts for deployment nationwide by 2027.

For its part, the Japanese firm Weathernews Inc. is designing a chatbot for smartphones to inform citizens during a disaster about evacuation procedures and where to find relief supplies, for instance. The system is capable of collecting and analysing audio-visual information, including photos provided by users. Japan plans to deploy this chatbot nationwide in 2022.

More emphasis on AI for disaster prevention

The *Basic Disaster Management Plan* was revised in May 2019 by the Central Disaster Management Council to make it obligatory 'to use ICTs such as AI, the Internet of Things, cloud computing technology and social networking services for disaster prevention'.

This focus on using AI for disaster prevention is fairly new. Up until now, more emphasis has been laid on the response and rescue phase. For example, Sendai City has tested a prototype with private companies for a tsunami alert using AI and blockchain technology, whereby the AI system automatically launched a drone, sending an alert through mobile phones and radios and using facial recognition software to identify victims *in situ* (UNESCO, 2019).

No AI without the right kind of data

AI systems can be used to track storms and monitor flood conditions, making it possible to ready the population for these impending disasters hours or even days in advance.

This possibility does not extend to earthquakes, however. The most that ground sensors can do is provide about ten seconds' advance warning of an impending earthquake. A panel set up by the Japanese government in 2017 concluded that 'no methods have been established, so far, to predict earthquakes using AI' (UNESCO, 2019).

This is because the field of seismology has not yet determined which type of data can best follow the processes signaling a build-up to an earthquake. Without the right kind of data, machine-learning algorithms will be unable to develop an appropriate model for predicting earthquakes (UNESCO, 2019).

Specialized agencies in Japan are in the process of harmonizing their disaster response for both geological and climate-change related hazards, in order to create sufficiently large datasets.

Technology can only do so much, however. When lives are on the line, one decision can never be automated: whom to entrust with acting upon the information provided by an AI system.

One issue that may come to the fore in coming years is the cost:benefit ratio between erecting engineered coastal defences like seawalls and offering communities the option to relocate away from vulnerable coastal zones (IPCC, 2019).

Source: compiled by Makoto Kobayashi, NRIESDR, and Soichiro Yasukawa and Masaya Sasaki, UNESCO

The government plans to spend a total of ¥ 100 billion (*ca* US$ 914 million) on the Moonshot programme, of which ¥ 2 billion has been allocated for 2019.

Quest for more international collaboration

The Moonshot programme is one expression of Japan's bid to halt its slide in research performance (*see opposite* Research Trends). It is part of the government's strategy to create more opportunities for internationally collaborative science through funding schemes.

The Moonshot programme comes on the heels of the World Premier International Research Centres launched by MEXT in 2007. These centres cost close to ¥ 100 billion over ten consecutive years, until the programme was wound up in 2017.

Meanwhile, the Japan Science and Technology Research Partnership for Sustainable Development (SATREPS) has been providing grants since 2008 to enhance scientific co-operation with developing countries, to help address global problems.

SATREPS involves collaboration between the Japan Science and Technology Agency, which provides competitive research funds, the Japan Agency for Medical Research and Development and the Japan International Cooperation Agency.

Since its inception, SATREPS has launched a total of 145 joint research projects in 51 countries, including 12 new projects in 2019 (Table 24.1).

Table 24.1: **New projects under the Japan Science and Technology Research Partnership for Sustainable Development, 2019**

Project	Counterpart
Strengthening Resilience in Arid Agro-ecosystems Vulnerable to Climate Change, through Research on Plant Resources and Technological Applications	Bolivia
Comprehensive Solutions for Optimum Development of Geothermal Systems in the East African Rift Valley (see Box 19.1)	Kenya
Interdisciplinary Research for an Integrated Community-led Strategy to eliminate Malaria in Tropical Africa	Kenya
Implementation of Low-Emission Affordable Apartments in the Hot–Humid Climate of Indonesia towards the *Paris Agreement* 2030	Indonesia
A Sustainable Community Development Model Harmonized in Lake Malawi National Park, a UNESCO World Heritage site	Malawi
Development of Management Systems for Cultural Utilization of Biodiversity in the Tropical Rainforests of National Parks in Sarawak	Malaysia
Rational Use of Wild Pasture Forage Plants Based on Traditional Knowledge of Nomadic Mongolians	Mongolia
Control of Tuberculosis and Glanders in Mongolia	Mongolia
Development of a Hybrid Water-related Disaster Risk Assessment Technology for Sustainable Local Economic Development Policy	Philippines
Development of Early Warning Technology for Rain-induced Rapid and Long-travelling Landslides	Sri Lanka
Establishment of a Centre of Excellence for Marine Plastic Pollution Studies in the Southeast Asian Seas	Thailand
Acceleration of the Livestock Revolution in ASEAN for a Kitchen of the World: Development of Novel Technologies Yielding Stable Livestock Production and Food Safety	Thailand

Source: compiled by author

A new priority: regenerative medicine

Shortly after Professor Shinya Yamanaka of Kyoto University was awarded the Nobel Prize in Physiology or Medicine in 2012, three sweeping laws were enacted in quick succession. In 2013, the Regenerative Medicine Promotion Law was promulgated, followed by the Law on Ensuring the Safety of Regenerative Medicine (2013) and the Law on Securing the Quality, Efficacy and Safety of Products, including Pharmaceuticals and Medical Devices (2013).

The second of these laws regulates clinical trials by medical institutions in regenerative medicine and provides for free medical care.

The third law regulates the manufacture and sale of products that deal with regenerative medicine and cell therapy, among other things, by amending the Law on Pharmaceutical Affairs, which was subsequently enacted in 2014. The new law is unique, in that it establishes a 'conditional and time-limited approval system' for new therapies and medicines in regenerative medicine. This system ensures that a regenerative product is approved only once its innocuousness has been proven and that patient data are collected on the product's effects.

In 2015, the Japan Agency for Medical Research and Development (AMED) was established to address the decline in medical research in Japan. AMED's mission spans basic research and practical applications. It also provides a one-stop service for the allocation and management of government research expenditure shared among MEXT, METI and the Ministry of Health, Labour and Welfare (MHLW). Its 2018 budget amounted to ¥ 126.6 billion (0.024% of GDP).

Every year, the government evaluates the implementation status of medical research by attributing one of three grades. AMED's research projects were considered generally satisfactory in 2019.

The fact that AMED is expected to achieve a societal return on investment in the form of new medical drugs led various academic societies in Japan to express deep concern in 2015 that this could lead to a reduction in budgets for basic research. To date, funding for basic research has not shown the feared decline.

RESEARCH TRENDS

Public research spending down

Between 2014 and 2016, gross domestic expenditure on R&D (GERD) dipped before recovering in 2017 to levels last seen just before the Great East Japan Earthquake, in 2010 (Figure 24.3). The government's stagnating research expenditure reflects the extremely tight fiscal situation.

By any measure, though, the ratio of government spending on R&D to GDP remains low. Both the *Fourth* (2011) and *Fifth Basic Plans* (2016) had fixed the target of raising this ratio to 1% or more of GDP by 2015 but this deadline has been missed. No new target has been established to date.

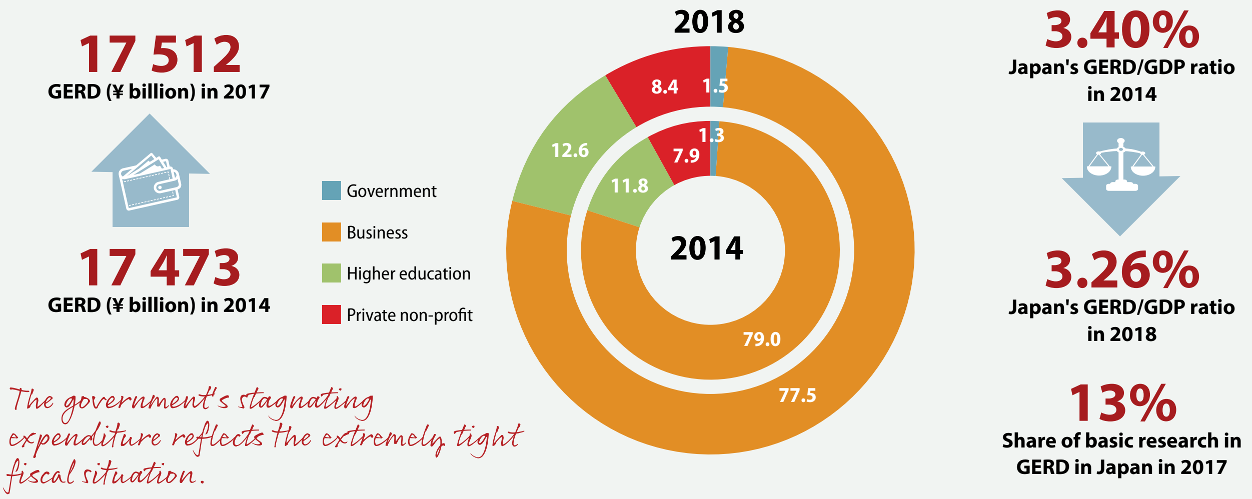
Nanotech falters as space industry takes off

Industry was the only sector that saw research expenditure rise between 2014 and 2017. The most remarkable trends in industrial research have been the substantial decrease in investment in nanotechnology and steep rise in space-related R&D (Box 24.4).

In 2015, a strong yen eroded industrial earnings, harming nanotech companies, in particular. This vertically disintegrated industry is characterized by relatively small companies operating in a niche market that reduce costs by outsourcing product development and commercialization. When the market shrank in 2015, nanotech companies were penalized by their dependence on other suppliers to complete a finished product.

Figure 24.3: **Trends in Japanese research expenditure**

GERD by sector of performance, 2014 and 2018 (%)

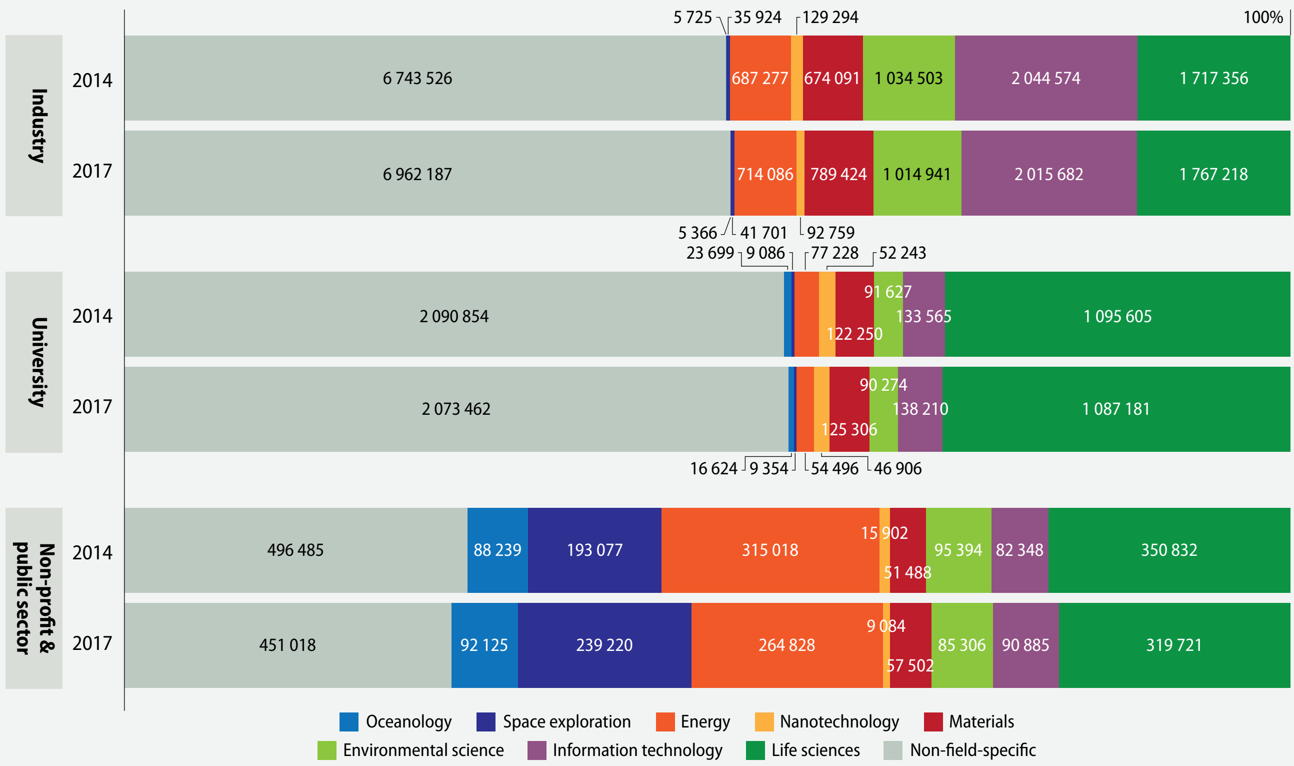


Collaboration between Japanese universities and industry, 2013, 2015 and 2017

	Joint research projects (number)	Funds received by universities from joint research (¥ millions)	Contract research projects (number)	Funds received by universities for contract research (¥ millions)	New university start-ups (number)	Universities adopting cross-appointment system (number)	Patent licensing contracts (number)	Patent licensing contracts (¥ millions)
2013	21 336	51 666	22 212	169 071	52	–	9 856	2 212
2015	24 617	61 444	25 763	226 621	95	54	11 872	1 684
2017	29 906	73 191	27 066	231 000	185[+1]	124	15 798	3 179

Note: Here, universities include technical colleges and inter-university research institutes.

GERD in Japan by field, 2014 and 2017 (¥ millions)



Source: MEXT; for GERD data: MIAC (2019) *Report on the Survey of research and development.* Survey by Statistics Bureau of Japan. Ministry of Internal Affairs and Communications: Tokyo

Box 24.4: **Japan's new frontier: a home-grown space industry**

New to the 'space business'

Japan is a relative newcomer to the 'space business'. Space companies are still dependent on government contracts for more than 80% of their revenue. The situation is gradually changing, however.

With the *Basic Plans for Space Policy* (2009 and 2013) and *Basic Space Law* (2008), the government established a roadmap for developing the national space industry. To encourage spin-off products for use on Earth, the Japanese Aerospace Exploration Agency (JAXA) created the New Enterprise Promotion Department* in 2016. The department offers a framework for mutual benefit, with private companies gaining access to JAXA's expertise, intellectual property and facilities to develop new products, and JAXA breathing new life into its own patents and other intellectual property through the commercial applications developed by its industrial partners.

Plans to explore the Moon and Mars

JAXA hopes to explore the Moon and Mars in the coming decades. In 2015, it established the Space Exploration Innovation Hub Centre (TansaX) to attract industrial partners for the development of technologies that will be needed by the space travellers of tomorrow. TansaX is funding a project to develop cultivation methods to 'farm' on the Moon, alongside researchers from Tamagawa University and the Panasonic Corporation Eco Solutions Company. Another joint project, this time with the Sony Corporation, is developing a low-powered optical system for long-distance communications.

As of 2017, there were over 40 firms operating in space exploration fields with capital of ¥ 100 million or more, according to the Statistics Bureau Survey of Research and Development, a 25% increase over 2013. Growth has been particularly strong in the field of Earth observation, where the leading companies specialize in mapping and surveying**, as well as digital technologies***.

Plans to remove space debris

One Japanese entrepreneur, Nobu Okada, has chosen to focus on eliminating a growing threat to human space exploration: the estimated 128 million pieces of space debris smaller than 1 cm in diameter that were orbiting the Earth as of January 2019. To this end, he founded Astroscale Pte. Ltd. in 2013, which has a primary research centre in Japan and its corporate headquarters in Singapore.

In 2017, Astroscale used a Russian Soyuz rocket to launch its first microsatellite, IDEA OSG1, into low-Earth orbit to monitor the size and position of space debris, in order to create debris distribution maps. On 31 October 2018, Astroscale announced that it had raised US$ 50 million for the launch of its ELSA-d satellite in 2020 from a range of Japanese investors, including the Innovation Network Corporation of Japan, the SBI Investment Company Ltd. and Mitsubishi Estate Company Ltd.

In 2017, the World Economic Forum selected Astroscale as one of its Technology Pioneers of the year.

Source: https://astroscale.com/missions/; Foust (2018); JAXA (2016); Dunphy (2016)

*Since renamed the JAXA Business Development and Industrial Relations Department

** Corporate leaders: Aero Asahi Corporation, Air Asia Survey, Kokusai Kogyo and Naka-Nihon Air Survey

***Corporate leaders: Fujitsu, Hitachi Solutions, NTT Data, NEC, Mitsubishi Space Software and PASCO

Fewer scientific publications since 2015

The volume of scientific publications in Japan slumped in 2018 for the fourth year in a row. This decline in the publication record may be related to changes in the nature of public research funding, since it is visible across all fields of science (Figure 24.4). It will be a real challenge to realize the *Fifth Basic Plan's* target of positioning 100 institutions among the world's top 50 for the citation of research papers in specific fields by 2025.

Fewer patent applications overall in Japan…

There were a record 3.17 million patent applications worldwide in 2017. The number of international applications under the Patent Cooperation Treaty (PCT) also hit a record high of 252 000 in 2018.

In both cases, the number of applications to the top five patent offices (IP5) accounted for more than 80% of the total. This is because corporate research has become globalized and the importance of intellectual property is now universally acknowledged.

In Japan, however, the number of patent applications has dropped since 2016, although the number of PCT applications filed with the Japanese Patent Office (JPO) has consistently risen. In 2018, these numbered 48 630, up 2.5% from the previous year.

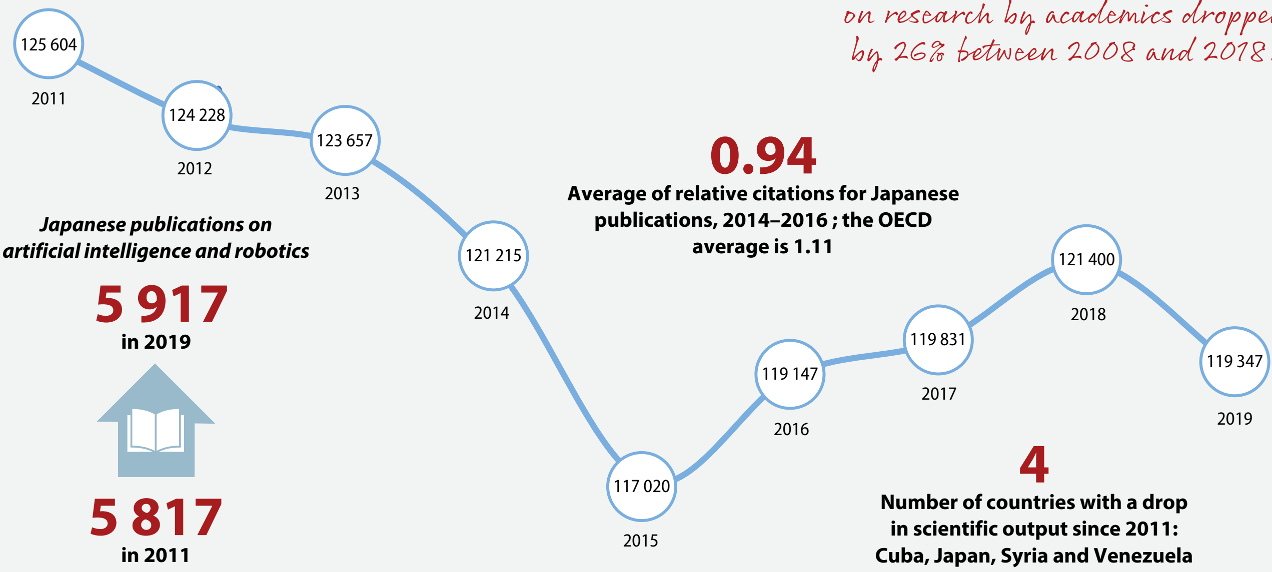
The decrease in the number of Japanese patent applications may be symptomatic of Japan's weakening innovative capabilities. Although there are many studies on patent quality, there is no established indicator that could compare with the average citation rate for papers. This makes further research necessary to decipher the meaning of this decrease.

Another explanation could lie in JPO's revision of the patent fee structure in 2004. Prior to 2004, fees relating to patent applications and examination requests were low, whereas patent maintenance fees were high. As a result, companies tended to apply liberally for patents without much regard for the fees. Since JPO increased the fees for patent applications and decreased those for maintenance, corporate behaviour has changed. Companies now tend to submit applications to

Figure 24.4: **Trends in scientific publishing in Japan**

Volume of scientific publications in Japan, 2011–2019

The average amount of time spent on research by academics dropped by 26% between 2008 and 2018.



Japanese publications on artificial intelligence and robotics

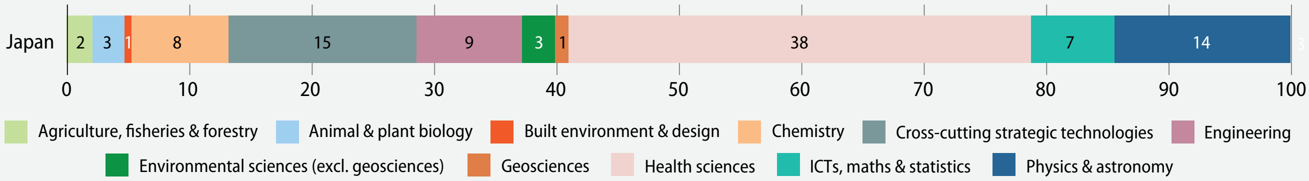
5 917
in 2019

5 817
in 2011

0.94
Average of relative citations for Japanese publications, 2014–2016 ; the OECD average is 1.11

4
Number of countries with a drop in scientific output since 2011: Cuba, Japan, Syria and Venezuela

Share of scientific publications in Japan by broad field of science, 2017–2019 (%)



30%
Share of Japanese publications with foreign co-authors, 2017–2019; the OECD average is 34%

Scientific publications per million inhabitants in Japan, 2011, 2015 and 2019

How has output on SDG-related topics evolved since 2012?

Japanese researchers are publishing more on nuclear fusion and radioactive waste management than would be expected, relative to global averages. Japan's output on nuclear fusion is nearly twice the global average (SI = 1.89), with 1 456 (2012–2015) and 1 279 (2016–2019) publications. Japan is a member of the project building an International Thermonuclear Experimental Reactor in France, which will be used to develop nuclear fusion technology.

Japan's push for alternative energy sources is not yet spawning a sizeable specialization in photovoltaics (SI = 1.21), hydrogen energy (SI = 1.21) or geothermal energy (SI = 0.58). Output on geothermal energy has risen most among these but from a low starting point: from 170 (2012–2015) to 251 (2016–2019). For comparison, over 2016–2019, China produced 1 339 papers on geothermal energy, the USA 1 323, Germany 612 and Turkey 246.

Among the selected topics with at least 100 publications during the period under study, the fastest-growing topic was that on the impact on health of soil, freshwater and air pollution, with the number of publications nearly doubling from 424 (2012–2015) to 690 (2016–2019), even though the topic is underrepresented in Japan relative to global averages (SI = 0.35).

SI = specialization index

For details, see chapter 2

Japan's top five partners for scientific co-authorship, 2017–2019 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Japan	USA (34 260)	China (23 322)	Germany (12 817)	UK (12 268)	France (9 541)

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

JPO only when their inventions stand a good chance of being patented. The change to the fee structure has, thus, had the desired effect, reducing the waiting time for patent approval from 28 to 11 months.

… but patenting is high in AI

Although the total number of patent applications has slipped, patent activity in Japan is dominated by AI. According to the OECD (2017), Japanese companies have obtained the most AI patents worldwide (Figure 24.5).

This is because the Internet of Things, AI and consumer electronics are providing Japanese manufacturers of integrated electronics with tremendous opportunities to capitalize on their technological expertise. Although IBM and Microsoft top the rankings for AI patents, six Japanese manufacturers of integrated electronics rank in the Top 10 and a further six in the Top 30 (Figure 24.5). Interestingly, the list of Japanese leaders in AI spans not only the electronics and computer industries but also the automotive industry, with companies like Toyota and Mitsubishi figuring on the list. This, no doubt, reflects their efforts to develop autonomous cars. In 2020, the supercomputer Fugaku at the RIKEN Center for Computational Science in Kobe swept global performance rankings and will support the Society 5.0 plan.

Japan's technology balance of payments has recorded a surplus since 1996. This surplus soared to a record high in 2015, driven chiefly by the pharmaceutical and automotive industries (Figure 24.5).

AI needed to translate patent documents

Owing to the surge in patent applications from China, Japan and the Republic of Korea over the past decade (UNESCO, 2015), three-quarters of patent documents were written in languages other than English in 2015: 66% in Chinese and Korean and about 10% in Japanese. This means that both Japanese and English-speaking researchers conducting infringement analysis, for example, will find it difficult, in future, to search for relevant patent documents.

In light of this trend, JPO decided to improve its patent information service (J-PlatPat)[5] in 2019, in order to provide users with English translations obtained through neural machine translation. In 2020, it is planned to apply this technique to translating Chinese and Korean patent documents.

UNIVERSITY REFORM

The chequered path to stronger university–industry ties

Stronger university–industry collaboration has been a major policy agenda of Abenomics. In 2014, the government fixed the target of tripling industrial investment in the academic sector by 2025. This target reappeared in the government's *Growth Strategy* (2017). According to the MEXT website, joint research funding amounted to ¥ 80.3 billion in 2018, a 9.7% increase over the previous year (see also Figure 24.3).

In 2015, the government published *Guidelines for Intellectual Property Management in Government-commissioned Research and Development* to facilitate implementation of the Japanese version of the Bayh-Dole Act.[6]

The government has also been encouraging national universities to promote researcher mobility and innovation through the cross-appointment system. This system enables a researcher or expert to have more than one employer. Two days per week, a university professor may be involved in R&D at a public research institute that is likely to be commercialized. Alternatively, a researcher employed by a company may be involved, two or three days per week, in open innovation (joint R&D) at a university or public research institute.

The current university reform got under way in 2004 with the semi-privatization of national universities, which were renamed national university corporations.[7] Henceforth, these would be expected to help finance themselves by obtaining more research grants, more private-sector funding and more donations (Sato and Arimoto, 2015).

This has obliged national universities to develop ties with the private sector. Between 2013 and 2017, the value of collaborative research projects between universities and firms rose by 38% to ¥ 304.2 million. By 2018, there were 185 university start-ups, more than three times the number five years earlier (Figure 24.3).

Despite these encouraging figures, Japanese companies contributed just 2.8% of academic research in 2016, according to Mallapaty (2019), about half as much as in the USA and far less than in the Republic of Korea (12.6%) and China (29.0%).

In 2013, the government committed ¥ 100 billion to the major Universities of Tokyo, Tohoku, Kyoto and Osaka to enable them to invest venture funds in university through technology licensing offices. The University of Tokyo has since spawned several successful spin-offs, including the biotech firm PeptiDream, worth US$ 5 billion today, and Vedanta Biosciences, which moved to Massachusetts in the USA after failing to attract investors in Japan. There is also Preferred Networks, which specializes in AI and edge computing (Mallapaty, 2019).

These success stories would appear to be the exception to the rule. By 2019, the four universities had invested just one-quarter (26%) of the ¥ 100 billion at their disposal. When Koichi Sumikura from the National Graduate Institute for Policy Studies surveyed 264 Japanese companies in 2014, many expressed the view that Japanese technology licensing offices were 'unable to provide the administrative infrastructure and services needed to support collaboration with academia'. They were also worried that trade secrets might be leaked to competitors (Mallapaty, 2019).

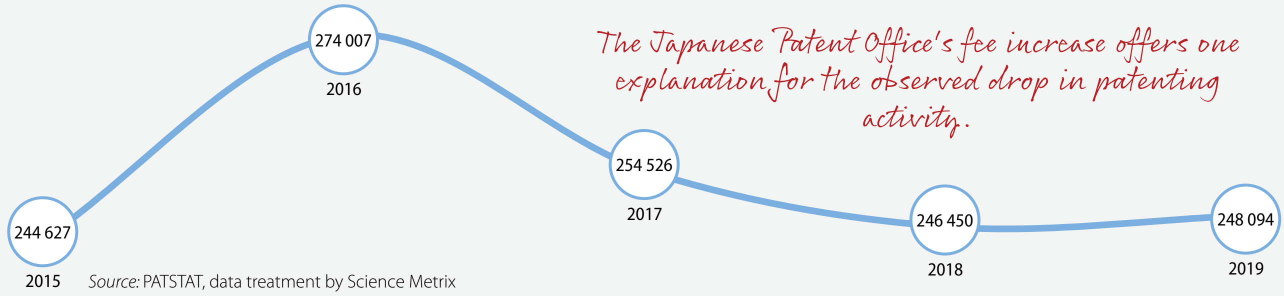
Just two universities in top 100

Another government priority is to enhance the global competitiveness of Japanese universities. In 2013, Prime Minister Shinzo Abe declared that his government would carry ten Japanese universities into the top 100 for global rankings by 2023. However, by 2020, only two figured in the top 100 of the World University Rankings published by the *Times Higher Education Supplement*, namely the University of Tokyo (36th) and Kyoto University (65th).

There are several reasons for this. For one thing, Japan is falling behind in terms of its capacity to send its own students

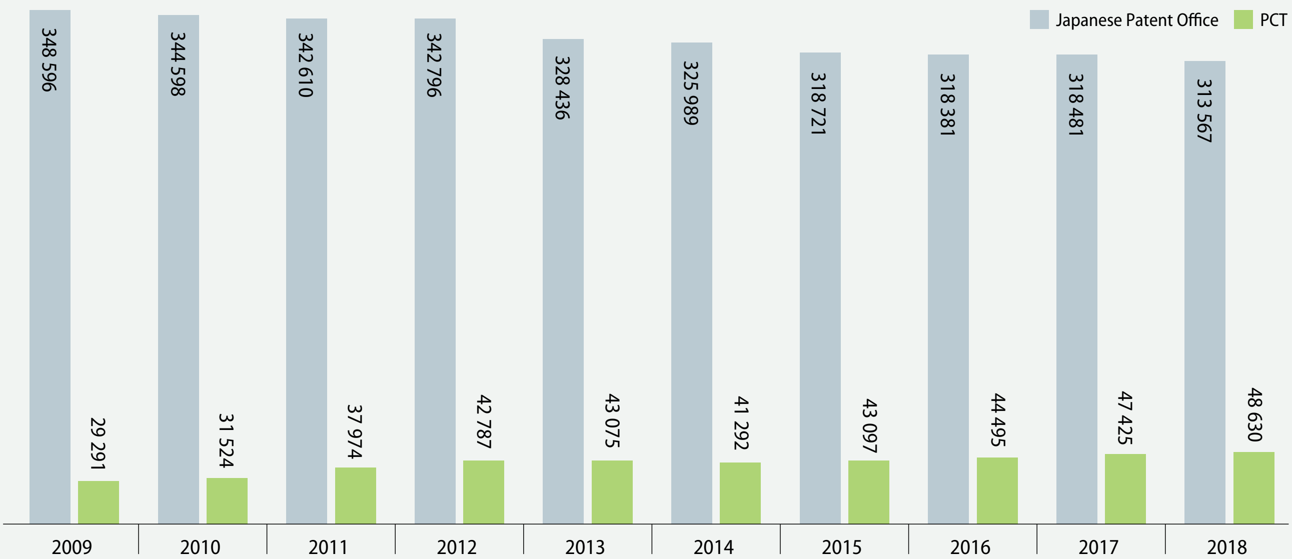
Figure 24.5: **Trends in intellectual property in Japan**

Number of IP5 patents granted to Japan, 2015–2019



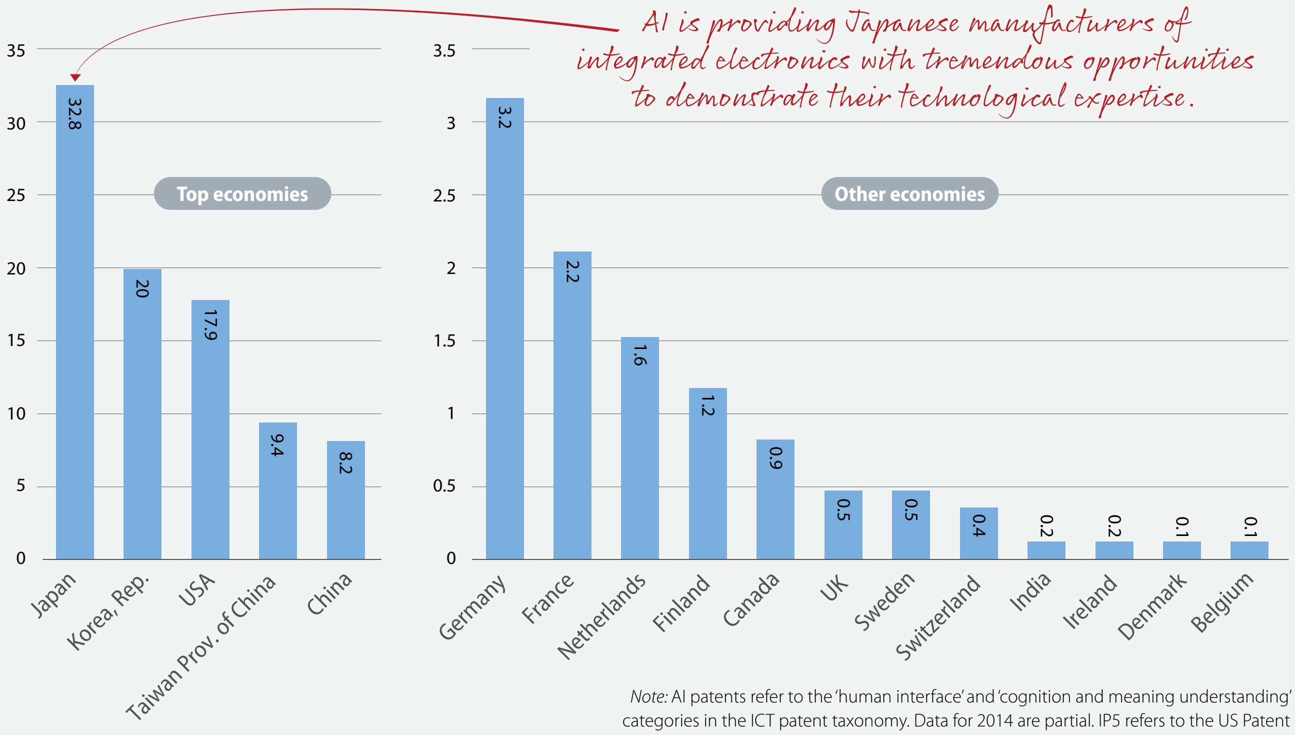
Source: PATSTAT, data treatment by Science Metrix

Trends in patent applications by Japanese companies, 2009–2018



Source: Japanese Patent Office (2019) *Annual report*

Share of IP5 patents in artificial intelligence owned by the world's top 2 000 R&D companies and filed over 2012–2014 (%)
By headquarters' location



Note: AI patents refer to the 'human interface' and 'cognition and meaning understanding' categories in the ICT patent taxonomy. Data for 2014 are partial. IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China.

Source: OECD (2017)

Top 30 patent applicants by number of patent families in AI, 2018

	Name of applicant	Country	Patent families
1	IBM	USA	8 290
2	Microsoft	USA	5 930
3	Toshiba	Japan	5 223
4	Samsung	Rep. Korea	5 102
5	NEC	Japan	4 406
6	Fujitsu	Japan	4 303
7	Hitachi	Japan	4 233
8	Panasonic	Japan	4 228
9	Canon	Japan	3 959
10	Alphabet	USA	3 814
11	Siemens	Germany	3 539
12	Sony	Japan	3 487
13	Toyota	Japan	2 890
14	Nippon Telegraph and Telephone	Japan	2 772
15	State Grid Corporation of China	China	2 685
16	Mitsubishi	Japan	2 683
17	Chinese Academy of Sciences	China	2 652
18	Ricoh	Japan	2 593
19	LG Corp.	Rep. Korea	2 213
20	ETRI	Rep. Korea	1 936
21	Bosch	Germany	1 874
22	Sharp	Japan	1 745
23	Nuance Communications	USA	1 671
24	Philips	Netherlands	1 668
25	Nokia	Finland	1 628
26	Baidu	China	1 532
27	Intel	USA	1 513
28	Hewlett Packard	USA	1 494
29	Xidian University	China	1 423
30	Zhejiang Univeristy	China	1 394

Note: Fujitsu includes PFU Ltd; Panasonic includes Sanyo; Alphabet includes Google, Deepmind Technologies, Waymo and X Development; Toyota includes Denso; Nokia includes Alcatel.

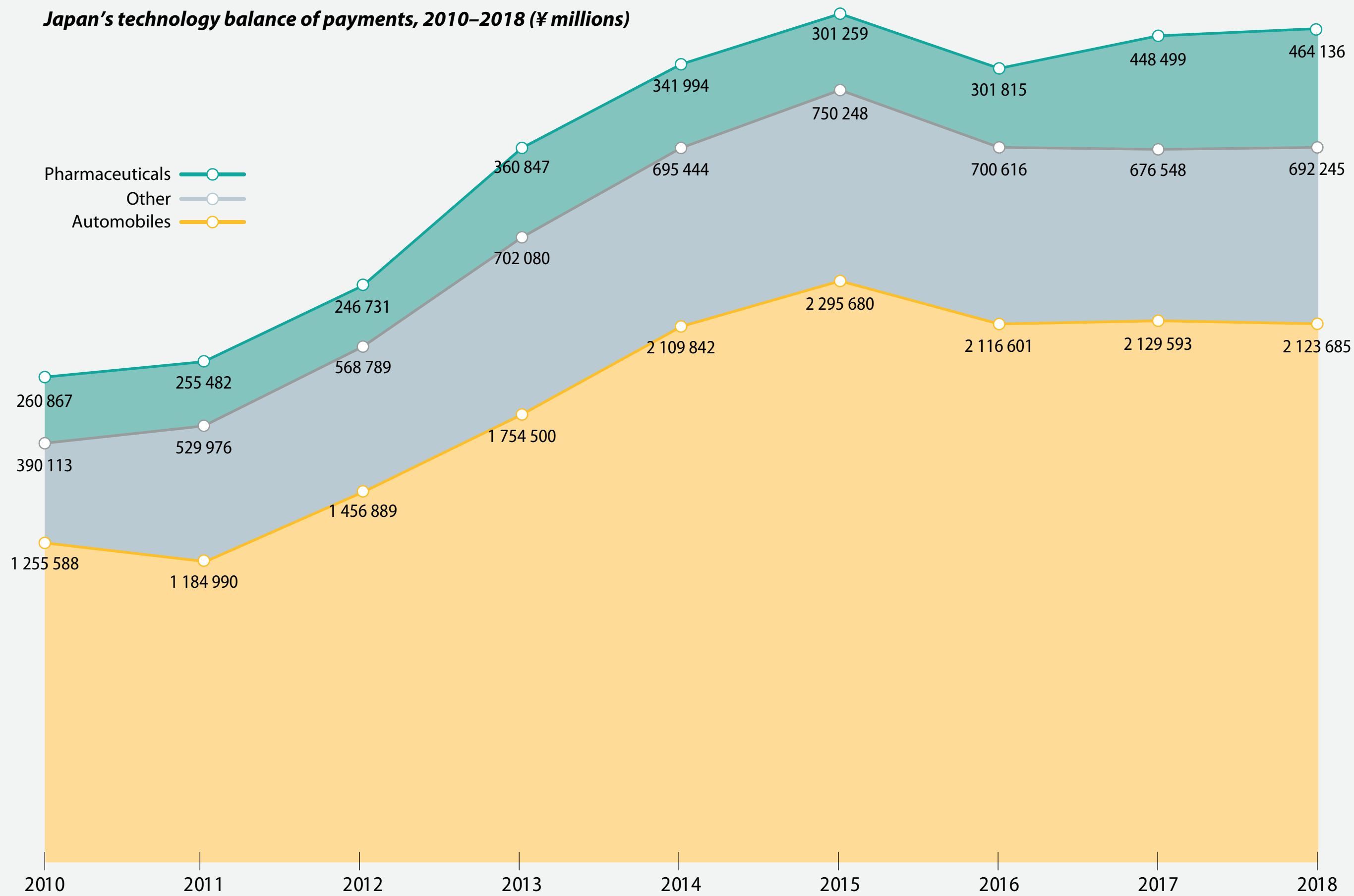
Source: WIPO (2019) *Technology Trends – Artificial Intelligence*

Twelve Japanese manufacturers rank in the Top 30 for AI patents, including Toyota and Mitsubishi which are developing autonomous cars.

¥ 3 347 187 million

Japan's technology balance of payments in 2015, a record high driven primarily by the automotive and pharmaceutical industries

Japan's technology balance of payments, 2010–2018 (¥ millions)



Source: MIAC (2019) *Report on the Survey of Research and Development.* Survey by Statistics Bureau of Japan. Ministry of Internal Affairs and Communications: Tokyo

Chapter 24

abroad. The number of Japanese studying abroad has stagnated, with 54 912 choosing to do so in 2014 and 55 969 in 2016, after plummeting from 82 975 in 2004. This trend can be partly explained by the difficulties Japanese graduates encounter in finding a job upon returning home.

Japan's education budget has also been a casualty of higher spending on social security to accommodate the ageing population and low fertility rate. Spending on higher education amounted to just 0.6% of GDP in 2016. Public expenditure on education as a whole – 3.2% of GDP in 2016 – has fallen beneath the OECD average of 4.4%, according to the OECD's Education at a Glance database in 2019.

Despite the drop in public funding and decline in the number of 18-year-olds between 2013 and 2018, the number of university students has risen modestly but steadily, pushing up the gross tertiary enrolment ratio to 52%. This ratio has remained stable since 2015 (Figure 24.6).

One challenge will be to train enough IT engineers to drive Society 5.0. CSTI estimates that Japan will have a shortage of approximately 50 000 advanced IT engineers and 300 000 general IT engineers by 2020 (Cabinet Office, 2018).

More foreign students, fewer foreign researchers

The growing number of foreigners choosing to study in Japan is one of the success stories of the ongoing university reform. Foreign students numbered 78 174 in 2013 and 94 973 in 2018.

The government intends to attract as many as 300 000 international students to Japan by 2020 to enhance the global competitiveness of Japanese universities.

This target was first enshrined in the five-year Global 30 (G30) initiative launched in 2009 before being pursued through the ten-year Super (Top) Global University Project launched in 2014, which aims to increase the ratio of both international students and faculty. From 2017 to 2019, MEXT selected seven universities with strong potential for world-class teaching and research to be known henceforward as designated national universities.[8]

The number of foreign researchers working in Japan has actually receded, however, from 9 645 (2013) to 8 888 (2018), according to the Ministry of Justice and the Bureau of Immigration, after peaking in 2001.

Paperwork up, productivity down

One unforeseen consequence of the university reform has been the lowering of research productivity of university faculties. Each is now required to submit a host of documents to MEXT: a six-year plan, its medium-term target and a plan for the coming fiscal year. In parallel, government subsidies to cover operating costs have continued to shrink by 1% per year since 2004. Although MEXT converted incremental funds amassed from these cuts to government subsidies into competitive funds, this has obliged national universities to devote an inordinate amount of time to filling out documents to secure funding for their own research proposals.

Between 2013 and 2017, the number of researchers (in head counts) rose by just 0.44% to 930 720 (Figure 24.7). This translated into an increase of 24% (to 676 292) over 2013 in full-time equivalents. This rise can be explained by the extension of the retirement age under Abenomics.

However, each researcher is spending less time on R&D. Each university faculty member counted as 0.329 full-time equivalent (FTE) researchers in 2018, compared to 0.456 in 2002, shortly before the reform was introduced (MEXT, 2019a). The average amount of time spent on research in academia dropped by 26% between 2008 (1 142 hours) and 2018 (844 hours), although the downward trend has slowed somewhat since 2013 (900).

Researchers would have more time to devote to teaching and research, if they did not have to fill out so many forms. The *Integrated Innovation Strategy* (CSTI, 2018) has recommended that each assistant professor devote more than 50% of their time to research, to improve productivity (Figure 24.7).

Distorted age and funding pyramids for research

The major indices of scientific papers, derived from the databases such as Web of Science, Elsevier's Scopus and the Nature Index, all show that Japan's scientific research is on the verge of stalling.

In addition to the impact of university reform on research productivity, Japan's waning international competitiveness in STI is also the result of a calamitous structural problem in the academic sector. We focus, hereafter, on this population, which made up one-third (35%) of Japanese researchers in 2018, compared to 60% employed in industry, according to a *Survey of Research and Development* by the Statistics Bureau in 2019. The university population is broadly divided into doctoral students, postdoctoral fellows, fixed-term researchers and tenured researchers.

The emphasis in Japan is on graduate schools but enrolment in master's and doctoral degree programmes has pursued its decline since the last edition of the *UNESCO Science Report* (Sato and Arimoto, 2015). Doctoral students see a limited career path for themselves after completing their degree. In parallel, the number of graduate students working full-time on top of studying has kept rising. More than four out of ten PhD students (42.2%) were working full-time by 2018 (Figure 24.6).

A 2017 MEXT *School Teachers Survey* found that 77% of university faculty were over the age of 40 by 2017, a record-high proportion. According to the Ministry of Finance, despite the fact that many top-level researchers tend to be younger than 40 years of age, the grants-in-aid scheme for scientific research called KAKENHI is strongly biased towards senior researchers.

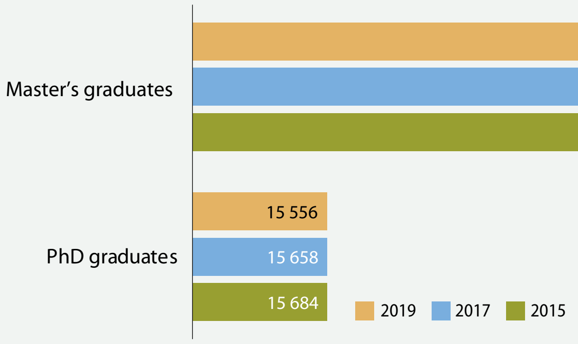
Still lowest ratio for women in OECD

Although the proportion of women researchers rose from 14.7% to 16.6% between 2014 and 2018 (Figure 24.7), Japan still has the lowest ratio among OECD countries. Boosting this ratio has been a priority of the *Third* (2006), *Fourth* (2011) and *Fifth* (2016) *Basic Plans for Science and Technology*.

The *Fourth* and *Fifth Basic Plans* sought to raise the proportion of women researchers to 25% of all researchers: 20% in science, 15% in engineering and 30% in agriculture,

Figure 24.6: **Trends in higher education in Japan**

Graduates in master's and PhD programmes in Japan, 2015, 2017 and 2019



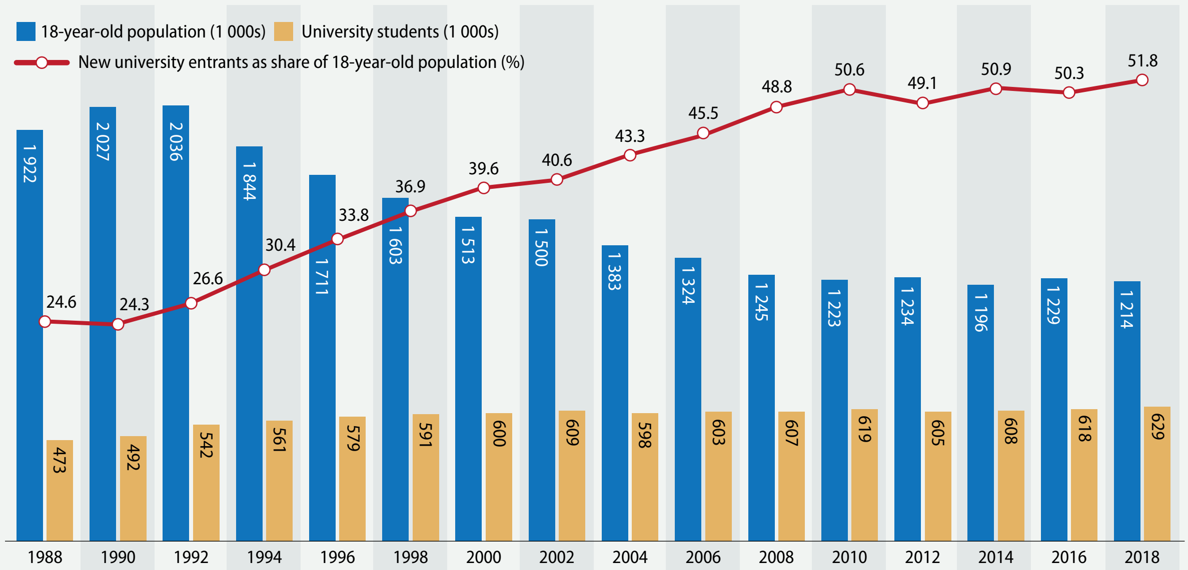
52%
Share of 18-year-olds enrolled at university in 2018

42%
Share of graduate students working full-time in 2018

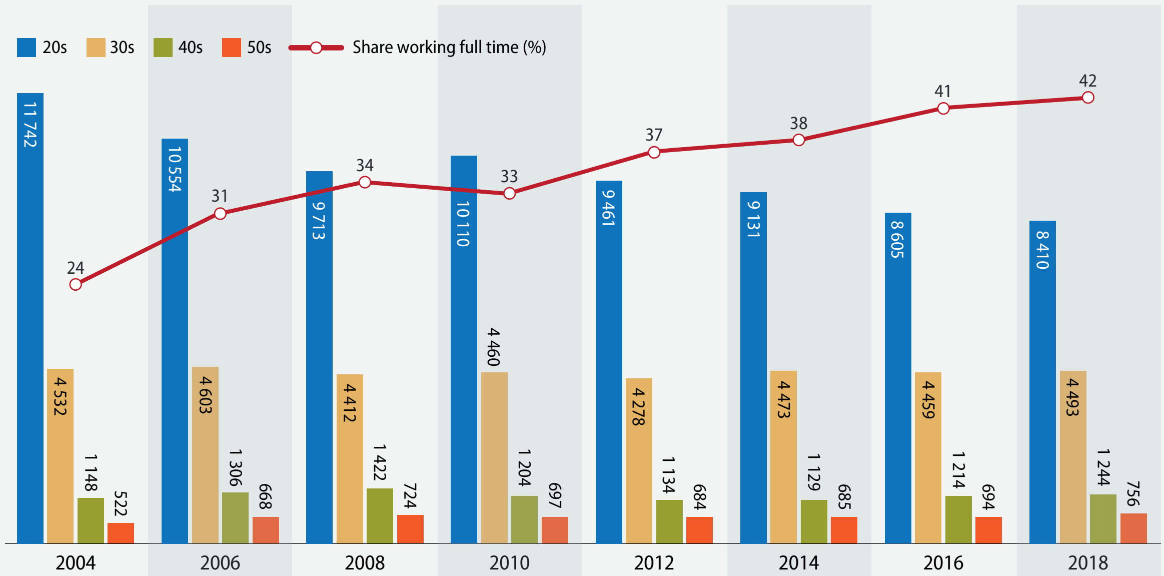
Note: The master's degree includes professional degree courses.

Grant-in-aid schemes for scientific research tend to favour senior researchers, nurturing a disaffection among doctoral students for a research career.

Number of university students in Japan, 1988–2018



Enrolment in Japanese graduate schools by age and percentage of those working full-time, 2004–2018



Source: MEXT (2019b); MEXT (2019c)

Figure 24.7: **Trends in human resources in Japan**

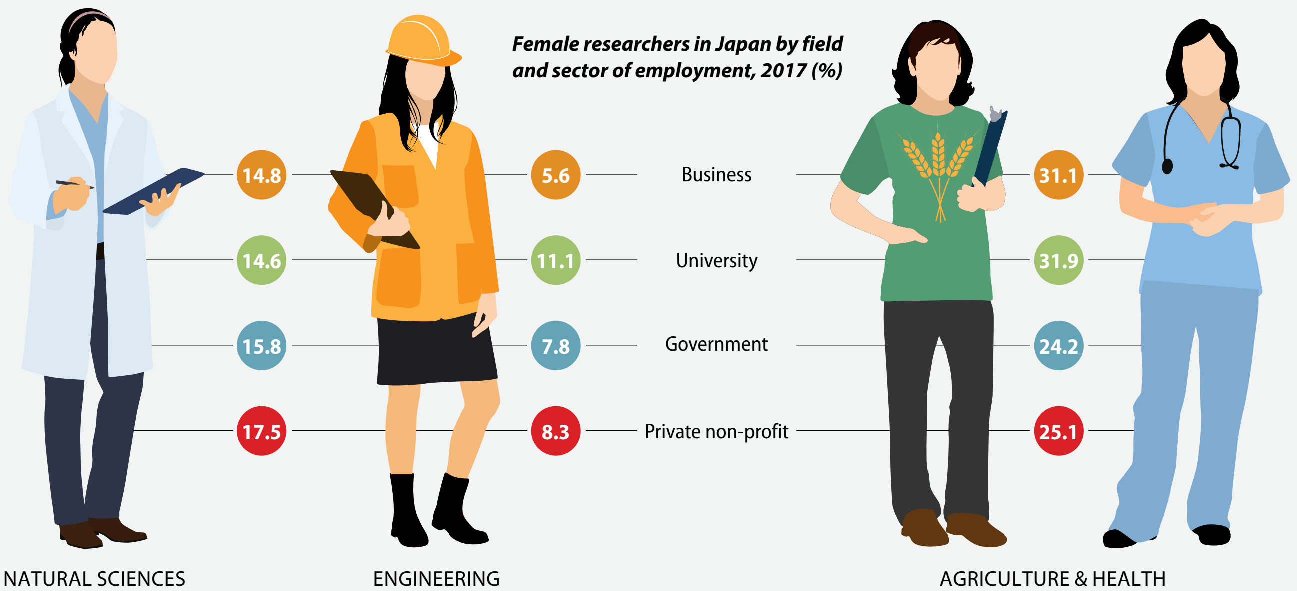
Number of Japanese researchers (HC), 2014 and 2018

	Total		Business		Private non-profit		Government		University	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
2014	790 465	136 206	514 888	45 578	9 108	1 459	28 326	5 741	238 143	83 428
2018	780 694	154 964	504 013	55 970	8 047	1 456	28 200	6 545	240 434	90 993

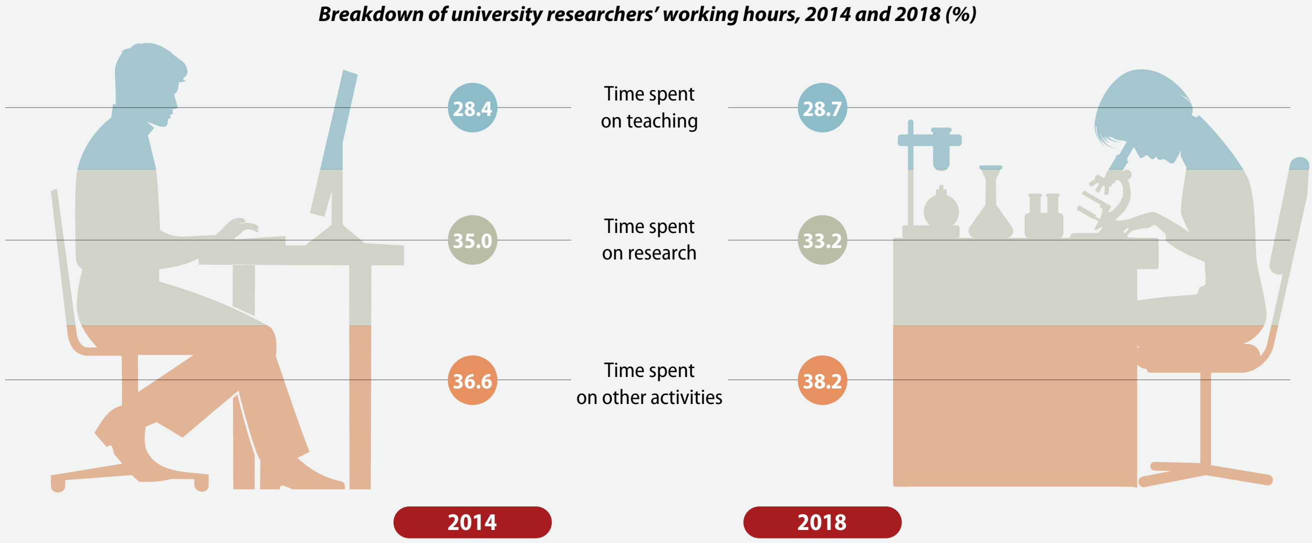
10%
Female researchers in the business sector, which employs 60% of researchers, 2017

27.5%
Female researchers in the academic sector, which employs 35% of researchers, 2017

Although the proportion of women researchers rose from 14.7% to 16.6% between 2014 and 2018, Japan still has the lowest ratio among OECD countries.



The Integrated Innovation Strategy of 2018 has recommended that each assistant professor devote more than 50% of their time to research, to improve productivity.



Source: MIAC (2019) *Report on the survey of research and development.* Survey by Statistics Bureau of Japan. Ministry of Internal Affairs and Communications: Tokyo medicine, dental and pharmaceutical research. These percentages were based on the share of doctoral students in these fields at the time.

Although Japan is still far from reaching these targets, it has made headway, judging from the current ratio of doctoral students in these fields. In 2018, one-third of doctoral students of agriculture, medicine, dental and pharmaceutical research were women (33.6%), as were almost one-fifth of doctoral students in science (18.8%) and engineering (17.1%) [MEXT, 2019c].

A grand design for higher education

To tackle the challenges outlined in the preceding sections, the Central Council for Education, which is affiliated with MEXT, released its *Grand Design for Higher Education: towards 2040* in November 2018. This document introduces sweeping changes that will necessitate a fundamental review of admission quota management, educational methods, facilities and equipment. Universities will be resized to ensure they can deliver a quality education and establishments that fail to reach their goals will undergo a strict assessment. Key changes include:

- *quality assurance and information disclosure:* visualization of learning outcomes and promotion of information disclosure;
- *size and location of universities*: in light of the declining 18-year-old population, establishment of campuses that will accept diverse students, including adult students and international students;
- *roles of individual universities:* increase of student mobility though enhanced partnerships among universities to provide more diversified career paths; and
- *investment in higher education*: assistance from the private sector in the form of investment and donations.

CONCLUSION

Companies buying time in a shrinking market

Monetary easing and fiscal stimulus from the Abenomics policy package have brought Japan its longest period of economic expansion since December 2012.

However, Abenomics is yet to deliver on other promises, even if artificial intelligence is shaping up as a potential economic growth engine. By actively introducing artificial intelligence into the workplace, the current phenomena of depopulation and ageing may even cease to be disadvantageous in a less labour-intensive economy.

Some of the shocks known collectively as the sextuple whammy have been absorbed but the stream of FDI and stocks flowing out of the country is turning into a torrent. As the population declines in response to a low fertility rate, the domestic market is shrinking.

Japanese companies have reacted to the shrinking market by purchasing overseas companies to 'buy time and labour'. As a result, investment is leaving Japan's shores, hollowing out the country's industrial base. To compound matters, foreign direct investment in Japan is not rising. These converging trends should be of grave concern. They suggest that the country's scientific and technological power is waning.

A new social model for an ageing society

Society 5.0 is the government's trump card to overcome these interconnected structural problems. In a distinct departure from the previous four *Basic Plans for Science and Technology*, the *Fifth Basic Plan* has achieved the feat of turning STI policy into a mainstream political agenda. It lays the foundations for a new social model which uses digital technologies to bring services to parts of the country that are rapidly ageing and becoming depopulated. The business community is fully on board. Japan is even intending to export its new social model to countries suffering from similar ills.

University reform failing young researchers

Japan's global share of scientific publications has been slipping since 1999. This crisis is not solely a product of lower university subsidies but also of more competitive budgets, with related paperwork leaving researchers little time to devote to research, even when they obtain the necessary funding. Should all types of academic research be subject to competitive funding, even curiosity-driven research with its unforeseeable outcomes? We are yet to find the answer to this question in Japan.

The decline in scientific publications is another sign that the country's scientific and technological power is dissipating. This is not simply a budgetary issue. The crux of the problem seems to lie in the incapacity of the university reform process to counter the side-effects of an ageing society.

The situation is especially critical for young researchers, who are expected to play a key role in the country's future. In an ageing society, the number of twenty-something students enrolling in graduate schools has dwindled. Universities do not recognize the young as a promising 'market' anymore, preferring to woo more mature students in their thirties, forties or fifties to their graduate programmes. Universities seem to overlook the fact that young researchers are much more mobile than their more senior colleagues. One would expect universities to encourage this mobility but, instead, young researchers find themselves trapped in a caste system based on fixed-term appointments. There may yet come a day when some 'young' researchers end their career with the status of postdoctoral fellows.

A promising new funding model for research

One ray of sunshine in this somewhat sombre tableau is the establishment of the Japan Agency for Medical Research and Development. It introduces a promising new funding model: a one-stop service for the allocation and management of government research expenditure, as opposed to the previous system in which research funds were distributed in silos by three different ministries (MEXT, METI and MHLW).

The rapid enactment of laws in the field of regenerative medicine is also a shining example of how well-conceived policies can link scientific output to the country's growth strategy.

KEY TARGETS FOR JAPAN

Japan plans to:

- achieve a primary balance surplus by 2025;
- raise the energy self-sufficiency rate to 25% to bolster energy security and reduce greenhouse gas emissions by 26% by 2030 over 2013 levels;
- triple industrial investment in the academic sector between 2014 and 2023;
- count 100 institutions among the world's top 50 for the citation of research papers in specific fields by 2025;
- attract 300 000 international students to Japan by 2020.

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ENDNOTES

1. The trade agreement has since been ratified by Brunei Darussalam, Chile, Malaysia and Peru.
2. This approach is based on Japan's Top Runner programme of 1998, which set mandatory efficiency standards for automobiles, home appliances and equipment. The top-runner approach has become a pillar of Japan's climate policy (Kimura, 2010).
3. This concept considers the greenhouse gas emissions, energy efficiency and industrial costs associated with a wide range of automotive fuels.
4. See: https://www8.cao.go.jp/cstp/english/moonshot1.pdf
5. J-PlatPat (English version available): www.j-platpat.inpit.go.jp/
6. Formally known as The Patent and Trademark Law Amendments Act, the Bayh-Dole Act of 1980 authorized US universities and businesses to commercialize their federally funded inventions. The Japanese version of this act was first codified in a specific act in 1999 then made permanent in the Industrial Technology Enhancement Act, amended in 2007. See Sato and Arimoto, 2015.
7. As of 2018, there were 86 national universities, 93 public universities and 607 private ones.
8. These are: Tohoku University, Kyoto University, Nagoya University, Osaka University, Hitotsubashi University, the University of Tokyo and Tokyo Institute of Technology.

AT A GLANCE

In July 2020, the Hyundai Motor Company shipped the first 10 units of the Hyundai XCIENT Fuel Cell, the world's first mass-produced fuel cell heavy-duty truck, to Switzerland. The company plans to roll out a total of 1 600 such trucks by 2025.

- Having achieved the world's second-highest research intensity, the Republic of Korea is now focusing on streamlining co-ordination of the national innovation system for efficiency gains.
- The government is promoting disruptive innovation and regional autonomy by establishing specialized national innovation clusters, relocating public institutes to the provinces and investing in regional R&D. Small and medium-sized enterprises are expected to play a growing role in these clusters.
- The country's Industry 4.0 blueprint is being operationalized through the I-Korea strategy and a special Presidential Committee set up in 2017 to oversee expanding investment in areas such as big data, artificial intelligence and robotics.
- The government is also prioritizing the development of hydrogen energy to compensate for the gradual phasing out of nuclear energy and place the country on track to reach its renewable energy targets to 2030.

25 · Republic of Korea

Deok Soon Yim and Jaewon Lee

INTRODUCTION

An innovative economy has paid dividends

The Republic of Korea has become one of the world's most innovative nations. According to the World Economic Forum, it ranks 13th for global competitiveness and tops the scoreboard for the adoption of information and communication technologies (ICTs), including mobile and fibre-optic Internet subscriptions per 100 people (WEF, 2019).

The country enjoys full employment – 4.1% of the population was unemployed in 2019 – and a high standard of living, with GDP per capita nearing PPP$ 37 000 in 2018 (Figure 25.1).

The Republic of Korea has tightened its embrace of science, technology and innovation (STI) to the point where it now has the second-highest research intensity in the world after Israel: domestic expenditure on research and development (GERD) climbed from 3.85% to 4.53% of GDP between 2012 and 2018 (Figure 25.2).

This commitment has paid generous dividends. According to a performance evaluation report, it is estimated that investment in research and development (R&D) contributed to about 40% of national GDP over the 2013–2017 period (MSIP and KISTEP, 2017).

A robust response to Covid-19

In February 2020, the Republic of Korea became one of the first countries after China to experience an outbreak of Covid-19. The confirmation of more than 220 domestic cases in February 2020 caused the Korean stock exchange, KOSPI, to slump by 20.16% in the first quarter. Within weeks, however, the epidemic seemed to be under control. Test kits developed by the private sector have been mass-deployed in more than 85 drive-through testing stations installed around the country.

The Republic of Korea has an infectious disease surveillance system. The Infectious Disease Control and Prevention Act (2009), which was last amended in 2015, allows the government to withhold critical information and publish anonymous travel logs of infected cases. The government and municipal authorities are using emergency text messaging services to disseminate information on newly discovered cases of infection to the general public.

Mobile phone applications have been rapidly developed to trace compliance with the two-week self-quarantine period.

As of mid-May 2020, the country is facing its second wave of Covid-19 infections. Personal data protection has become the subject of debate, after initial broad acceptance by the population of the need to use phone tracking apps in an emergency.

More inclusive growth a priority

On the domestic economic front, anxieties have coalesced around the high household debt and large income gap (Figure 25.1). Against this backdrop, the government has been pursuing two major growth policies since 2017: innovation-driven and income-led growth.

In part, the current approach to innovation-driven growth is a pursuit of previous government policy. As we saw in the last *UNESCO Science Report* (Yim and Lee, 2015), the Park Geun-hye government had sought to foster a creative economy by pioneering a cultural shift towards greater entrepreneurship. To this end, the government had bolstered support for start-ups and small and medium-sized enterprises (SMEs). The current government has built on this foundation by creating a Ministry for Small and Medium-sized Enterprises and Start-ups.

Income-led growth is another pillar of the current government's economic policy. It pledged to raise the legal minimum wage to KRW 10 000 (*ca* US$ 8.63) per hour by 2020. By 2019, the legal minimum wage had reached KRW 8 590, an increase of about 25% since 2017. Following an animated debate about whether this economic drive amounts to an inspired idea or wishful thinking, the government is forging ahead with plans to reduce the household debt burden and raise income to boost consumption and, thereby, economic growth.

An effort to reduce the gender gap

Among other key issues, the Republic of Korea still has the largest gender pay gap of any member of the Organisation for Economic Co-operation and Development (OECD), although this gap has shrunk somewhat since 2015 (Figure 25.1).

The *Fourth Basic Plan for Fostering and Supporting Women in Science, Engineering and Technology 2019–2023* is pursuing a policy of reducing the gender gap in the research profession. It has introduced a bonus point system for research grants to boost the representation of women-led teams (see chapter 3). In 2018, women formed 20% of the scientific workforce but only 10% of research managers. When it came to projects with over KRW 1 billion in funding, this proportion dropped to 6.6%. On average, each senior male researcher had access to twice as much expenditure (KRW 410 million) in 2017 as his female colleague (KRW 200 million) [WISET, 2019].

TRENDS IN SCIENCE GOVERNANCE

Revisiting the *Future Vision* for energy sources

President Park Geun-hye had realized her signature economic policy of a creative economy by enshrining it in the *Third Basic Plan for Science and Technology* covering the period 2013–2017 (Yim and Lee, 2015).

The Moon Jae-in government inherited[1] this plan after the presidential election of May 2017. It then had to wait until

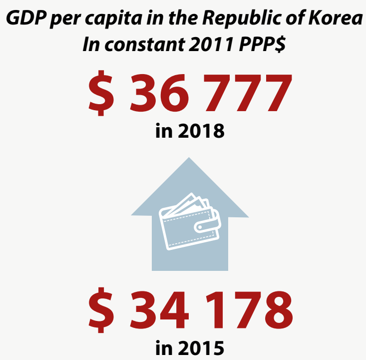
February 2018 to release its own *Fourth Basic Plan for Science and Technology* to 2022 (MSIT, 2018a).

The government used this opportunity to revisit the *Future Vision for Science and Technology: Towards 2040* (2010), which had been formulated by the Lee Myung-bak government (2008–2013), whose signature policy had been 'low carbon, green growth' (Lee, 2010). The revised *Future Vision* stresses quality of life, consumption based on social values and support for small and medium-sized enterprises (SMEs).

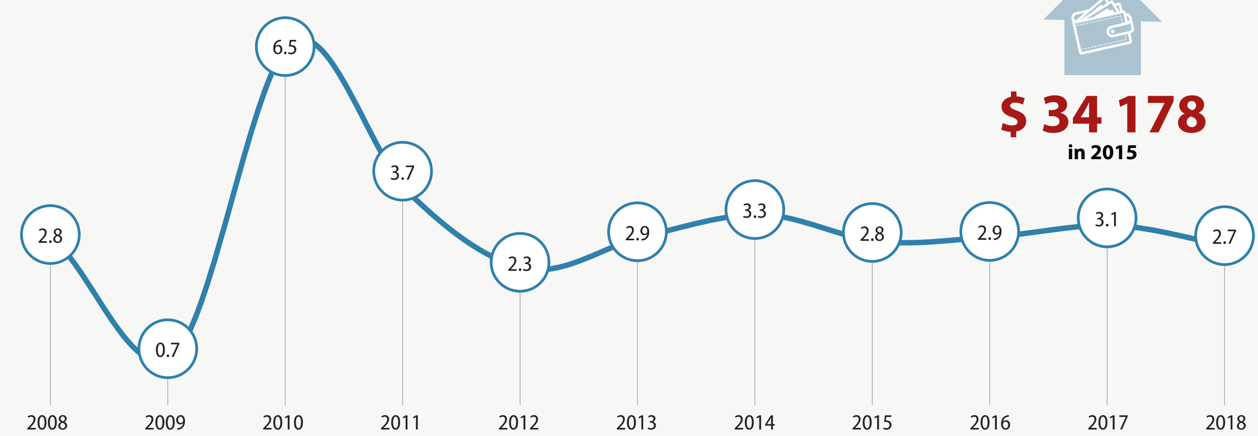
One major modification is the removal from the *Future Vision* of any mention of nuclear technology as a future energy source for the Republic of Korea. Upon taking office, Moon had confirmed his election pledge to make the country nuclear free, in a speech delivered on 19 June 2017 at the ceremony marking the permanent closure of Kori 1, the country's first commercial nuclear reactor, which had been in operation since 1978. However, the president has since accepted the Public Deliberation Committee's recommendation to pursue construction of Shin Kori nuclear reactors 5 and 6. The Republic of Korea currently has 24 nuclear power reactors in operation (Lim, 2019).

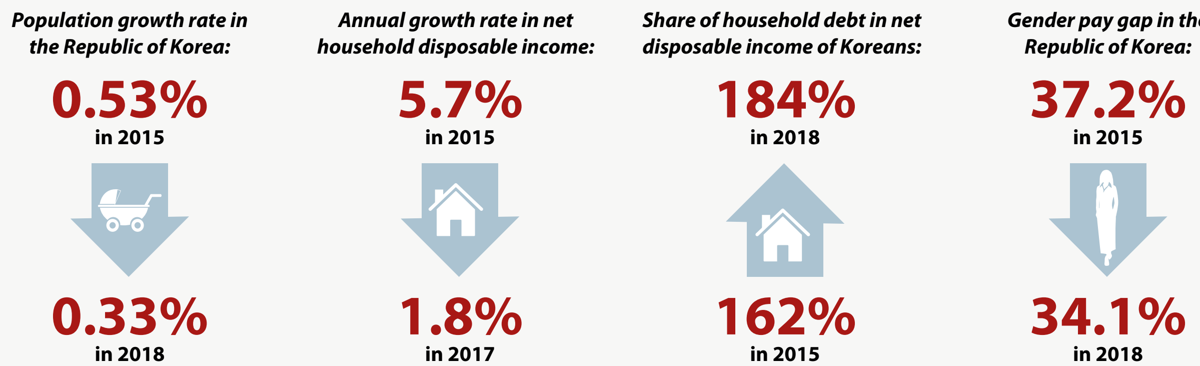
The Fukushima Daïchi Nuclear Power Plant disaster of 2011 in Japan (see chapter 24) has sown doubts about the safety of nuclear power (Lim, 2019). In parallel, there are concerns

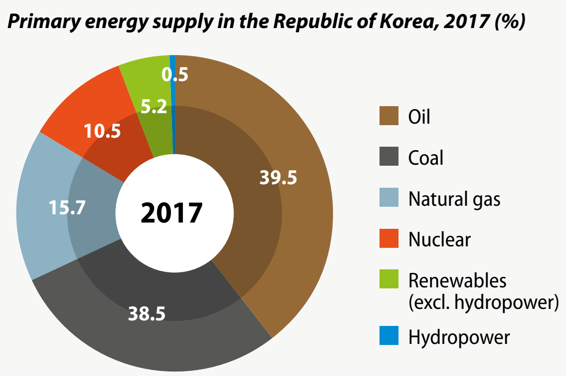
Figure 25.1: **Socio-economic trends in the Republic of Korea**



Rate of economic growth in the Republic of Korea, 2008–2018 (%)







Note: The unemployment rate is based on the modelled estimate from the International Labour Organization.

Source: World Bank's World Development Indicators, May 2020; for household disposable income, household debt, poverty and gender wage gap: OECD, May 2020; for energy, Korea Energy Economics Institute (2018) *Yearbook of Energy Statistics 2018* that the planned nuclear phase-out will erode the country's global competitiveness. The Republic of Korea is a leader for the manufacture of nuclear reactors. The export of four reactors to the United Arab Emirates generated US$ 173 million (NTI, 2015). The sudden policy reversal has jeopardized the country's leading manufacturer of nuclear reactors, Doosan Heavy Industries, which has suffered another blow with the Covid-19 outbreak. In 2020, it received a much-needed government bail-out.

The government is continuing to promote innovation by the country's tech giants, which have written much of the country's economic success story. For instance, the president visited Hyosung and Hyundai Motors in August 2019 to urge them to turn investment in R&D into groundbreaking innovation. Both companies vowed to invest in the development of a fuel-cell electric vehicle. Almost two months later, the president visited Samsung to show government support for this world-class tech giant.

The government is seeking to strengthen the effectiveness of the *Future Vision* as a long-term strategy and to link it to the five-year *Basic Plan for Science and Technology* to 2022. However, the *Future Vision* is not legally binding, unlike the five-year basic plans,[2] so its long-term survival in its current form will be dependent upon future political will. This said, since the five-year *Basic Plan* and the presidential term of office are no longer aligned, it is expected that the *Future Vision* will serve as a bridge between each administration and the *Basic Plan* they inherit.

Higher investment has not raised competitiveness

By the end of the *Third Basic Plan*, the outgoing government had reached several of its key targets, including that of raising the value of technology exports (Table 25.1). However, the country's global competitiveness has slipped since peaking in 2010, as has its scientific and technological competitiveness (Figure 25.2). Heightened investment in R&D has not led to demonstrably better outcomes.

Some point out that the growth ratio for government research expenditure is slowing down (Lee, 2018; Gwon, 2018). Individual researchers have also opined that funds for basic research remain insufficient, even though the share of basic research now accounts for 40% of total government research expenditure (Hwang *et al*., 2017). No additional increase is expected, unless an extensive reform is implemented.

Solution could lie in better budget allocation

For the government, this systemic failure calls for policy measures that go beyond financial assistance. The government's plan for meeting the Sustainable Development Goals (SDGs), discussed below, suggests maintaining the GERD/GDP ratio at the current high level. This may explain why the *Fourth Basic Plan* no longer fixes a specific target for this ratio. It does, however, propose doubling the level of government investment in basic research by 2022 (Table 25.2).

It has been suggested that a better allocation and management of the government research budget would overcome both the lack of a co-operative network among industry, academia and research institutes and the immaturity of the tech-financing market (Han and Kim, 2019). Consequently, the government has proposed measures to restructure the innovation ecosystem.

Research services being streamlined

As of 2017, 20 separate research bodies provided support services for projects ranging from research planning to performance management. To streamline the research budget management and provide the research community with an

Table 25.1: **Republic of Korea's progress towards its 2017 targets for R&D**

	Indicator	Unit of measure	Situation in 2012	Situation in 2017	Target to 2017 of *Third Basic Plan*
Research input	Share of industry-financed research expenditure	% of GERD	71.8^{-2}	76.2	–
	Share of basic research in government research budget	%	35.4^{+1}	40.2	40.0
	Share of support for SMEs in government research budget	%	16.9^{+1}	19.2^{-1}	18.0
	Government investment in quality of life	Share of government expenditure on R&D (%)	15.0	14.3^{-2}	20.0
	PhD-holders in science and engineering	% of total population	0.4^{-4}	0.6^{-2}	0.6
Research output	Number of patents with international co-applications	Per 1000 researchers	0.38^{-1}	0.70^{-3}	0.50
	Jobs in science and engineering	Total	6 050 000	–	6 690 000
	Contribution of R&D to economic growth	% of GDP	35.4*	40.0**	40.00
	Industrial value added per capita	US$	22 000	$24\,000^{-2}$	25 000
	Value of technology exports	US$ millions	5 311	$10\,408^{-2}$	8 000

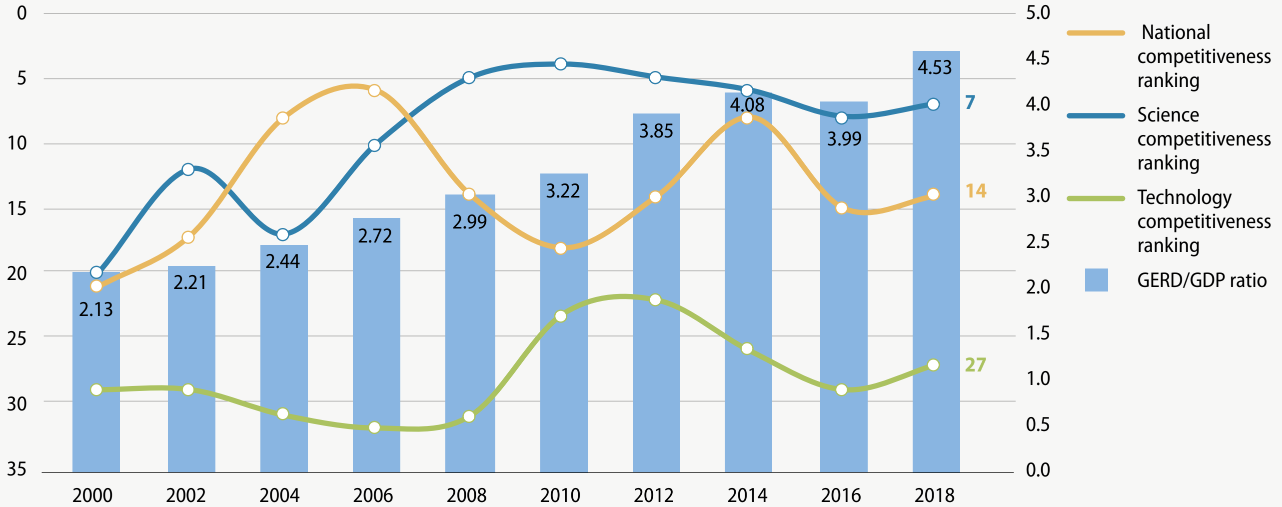
-n/+n: data refer to n years before or after reference year
*average contribution over 1981–2010
**average contribution over 2013–2017

Note: The Composite Science and Technology Innovation Index (COSTII) was developed by the Korean National Research Council of Science and Technology in 2005. It compares the innovation capacity of 30 OECD countries. Government budget consists of 'general accounts', 'special accounts' and 'funds'.

Source: UNESCO Institute for Statistics; MSIT (2019a); NTIS for COSTII index; MSIP; KISTEP (2017)

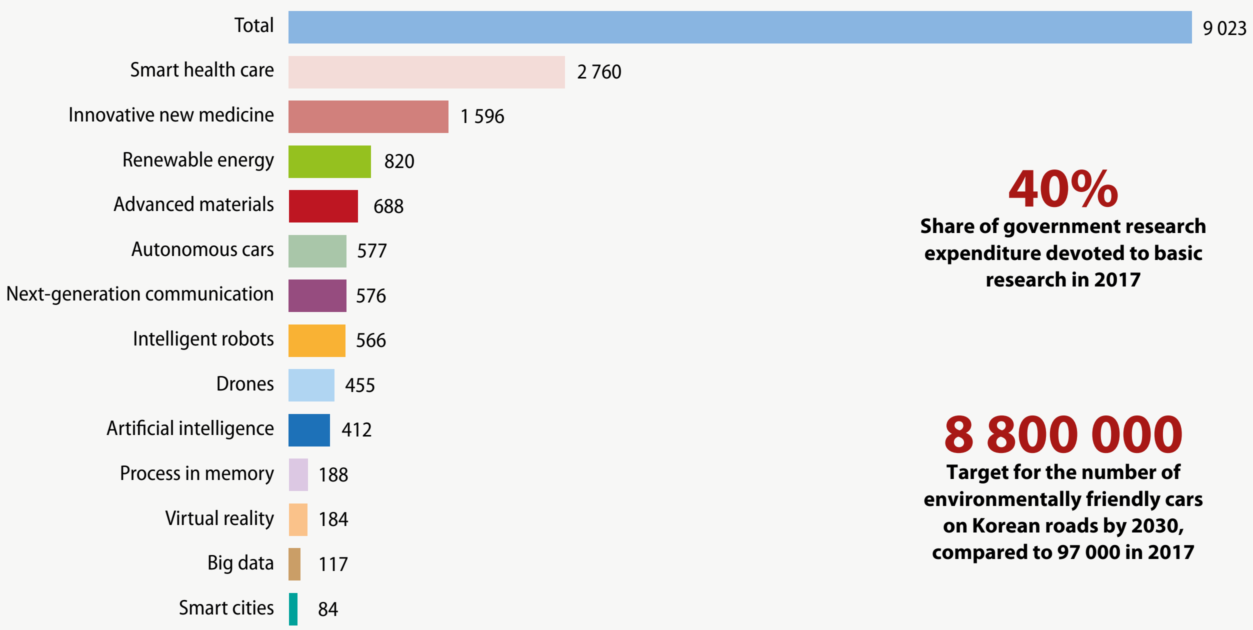
Figure 25.2: **Trends in research expenditure and innovation in the Republic of Korea**

GERD as a share of GDP and competitiveness rankings in the Republic of Korea, 2000–2018



Planned investment in innovation in the Republic of Korea, 2018–2022

In KRW billions



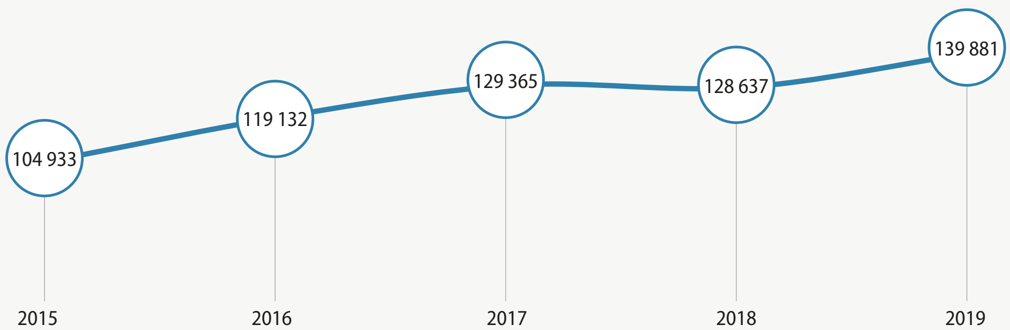
40%

Share of government research expenditure devoted to basic research in 2017

8 800 000

Target for the number of environmentally friendly cars on Korean roads by 2030, compared to 97 000 in 2017

Number of IP5 patents granted to the Republic of Korea, 2015–2019



Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China.

Source: for competitiveness rankings: IMD International (2019) *World Competitiveness Yearbook* © 1995–2021. IMD International: Switzerland. World Competitiveness Center. See: www.imd.org/wcc; for GERD: UNESCO Institute of Statistics; for planned investment in innovation: PACST (2018); patents prepared by Science-Metrix using PATSTAT data integrated information service, the government has begun merging 20 administrative online systems into one.

In parallel, it is clustering and merging the 17 online systems that manage research funds into just two systems that will each be accessible through an integrated portal (MSIT, 2019a). This project got under way in late 2018 and is expected to conclude by 2022, at a total cost of KRW 27 billion (*ca* US$ 23 million).

The government has also decided to standardize regulations and simplify documentation and processes in support of the new unified research management system. A system operated by MoSIT will integrate the management system of research funds for universities, research institutes and other bodies, whereas the other system operated by MoTIE will do the same for enterprises. Users will be able to access a single online portal providing them with all the services they need in terms of research funding applications, funds management and researcher information registration.

From performance- to research-centred management

The defining feature of the *Fourth Basic Plan* is the shift in focus of the government research ecosystem from short-term, performance-oriented management to research-centered management, in order to foster 'disruptive innovation' and regain lost ground in terms of global competitiveness. Disruptive innovation is the signature policy of the Moon government, in much the same way that the creative economy was the signature policy of the Park government.

To this end, the *Fourth Basic Plan* outlines four strategies: expanding capacity to tackle future challenges; creating an ecosystem that stimulates innovation; creating new industries and jobs led by science and technology; and using science and technology to build happier lives for all.

In order to increase the autonomy of researchers, projects in basic science are to be designed by researchers, rather than commissioned by the government (MSIT, 2018a).

The government also plans to rationalize the entire cycle of government research from the design to evaluation stages. For example, the format of calls for research proposals will be simplified. From now on, the evaluation of research will focus on process, rather than outcome, by staging mid-term evaluations to adjust the amount of funds provided or the objective of the research. The role of evaluations in deciding whether a basic research project has been a success or a failure will be eliminated.

Policy co-ordination at the highest level

Some observers have drawn attention to a lack of coordination among the various actors of the national innovation system, as well as to overlap in the investment strategy and missions entrusted to different government bodies. The government itself has recognized the limitations of short-term, performance-oriented investment in R&D.

Against this backdrop, the government established a Science, Technology and Innovation Office (STIO) under the Ministry of Science and Information and Communication Technology (MSIT) in 2017. The Vice-Minister serves as the head of STIO and as the country's chief innovation officer. STIO has a mandate to co-ordinate national policy in science, technology and innovation (STI), as well as to review, adjust and evaluate national research projects, with the aim of reshaping the national innovation system (MSIT, 2018b).

In 2018, the National Science and Technology Council (NSTC) was integrated into the Presidential Advisory Council on Science and Technology (PACST) to combine NSTC's mission of evaluation with PACST's advisory function.

Table 25.2: **Major targets to 2022 of the Republic of Korea's *Fourth Basic Plan for Science and Technology***

Strategy	Indicator	Unit of measure	Situation as of 2017	Target to 2022 of *Fourth Basic Plan*
Expanding capacity for future challenges	Government-funded basic research designed by researchers	KRW trillions (US$ billions)	12.60 (1.1)	25.20 (2.2)
	World's most influential scientific minds (Thomson Reuters)	Individuals	28	40
	Level of interest in science and technology (measured by OECD Programme for International Student Assessment)	Ranking	26^{-2}	24
Creation of ecosystem that stimulates innovation	Ratio of innovative start-ups to total start-ups	Percentage share	21^{-3}	30
	Joint patenting by industry, academia and research institutes	Cases per thousand researchers	2.3^{-3}	3.0
	S&T budget as share of total regional government budget	Percentage	1.07^{-1}	1.63
Creation of new industries and jobs led by science and technology	Jobs based on S&T and ICTs	Number	–	260 000
	Global software developers	Number	37^{-1}	100
Happier lives	Ratio of healthy population over 65 years old to total population over 65 years old	Percentage share	21.1^{-2}	25
	Technological level in safety from disaster	Percentage share of population	73.5^{-1}	80.0
	Average density of particulate matter (PM 2.5) in Seoul	µg m-3	26	18

-n: data refer to *n* years before reference year
Source: MSI (2018a)

Chapter 25

PACST is responsible for convening a joint committee. According to the Constitution, PACST is the highest-ranking policy body in the country. To reflect its status, the president serves as Chair of PACST and PACST designates an expert from the private sector to serve as vice-chair; the position is currently occupied by a professor at the Pohang University of Science and Technology (POSTECH).

Balancing national growth with SME-led innovation

As we saw in the previous edition of the *UNESCO Science Report* (Yim and Lee, 2015), fostering greater regional autonomy is a priority for the Republic of Korea, which is a highly centralized state.

The challenge will be to ensure that national growth benefits all regions, while decongesting the Seoul region. To this end, KRW 4 532 trillion (*ca* US$ 3.9 billion) was invested in regional R&D in 2017 under the *Fourth National Plan for the Regional Development of Science and Technology 2013–2017* (MSIT and KISTEP, 2018).

The main focus of this plan was to decentralize industrial specialization to each province to create clusters around regional priorities. The focus of each cluster was proposed by the regional government concerned to reflect the local socio-economic reality, before being shared by the Ministry of Trade, Industry and Energy with other branches of government.

Figure 25.3: **National innovation clusters in the Republic of Korea**

CITIES OF DAEJEON AND SEJONG

Specialization after *National Innovation Cluster* plan of 2018:
- ICT convergence.

Specialization as innovation city prior to reallocation in 2017:
- Policy research in the city of Sejong, a newly established government complex city.

CHUNGCHEONGNAM-DO

Specialization after *National Innovation Cluster* plan of 2018:
- Hydrogen energy.

Specialization as innovation city prior to reallocation in 2017:
- Chungcheongnam-do was not designated an innovation city, owing to its geographical proximity to Daejon and Sejong.

GANGWON

Specialization after *National Innovation Cluster* plan of 2018:
- Smart health care.

Specialization as innovation city prior to reallocation in 2017:
- Mining promotion;
- Health and life;
- Tourism.

GYEONSANGBUK-DO

Specialization after *National Innovation Cluster* plan of 2018:
- Automobiles of the future.

Specialization as innovation city prior to reallocation in 2017:
- Roads and traffic;
- Agricultural technology and innovation;
- Electrical power technology.

JEOLLABUK-DO

Specialization after *National Innovation Cluster* plan of 2018:
- Smart agricultural life science.

Specialization as innovation city prior to reallocation in 2017:
- Land development management;
- Agriculture and life;
- Food research.

CHUNGCHEONGBUK-DO

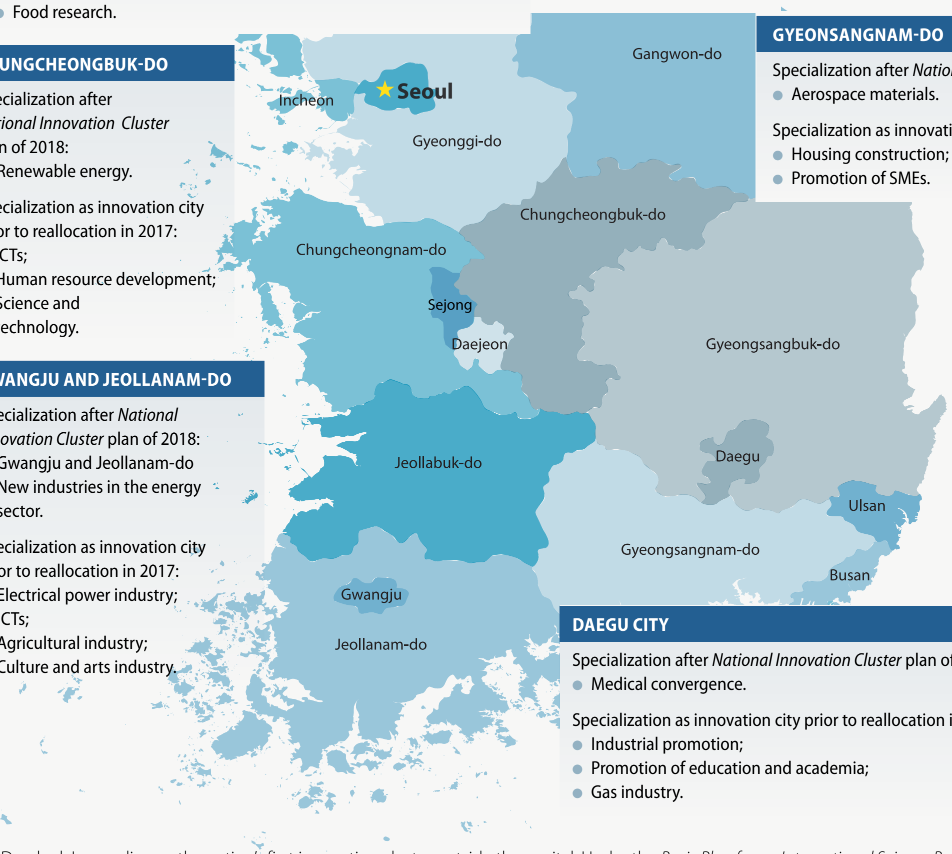
Specialization after *National Innovation Cluster* plan of 2018:
- Renewable energy.

Specialization as innovation city prior to reallocation in 2017:
- ICTs;
- Human resource development;
- Science and technology.

GWANGJU AND JEOLLANAM-DO

Specialization after *National Innovation Cluster* plan of 2018:
- Gwangju and Jeollanam-do New industries in the energy sector.

Specialization as innovation city prior to reallocation in 2017:
- Electrical power industry;
- ICTs;
- Agricultural industry;
- Culture and arts industry.



GYEONSANGNAM-DO

Specialization after *National Innovation Cluster* plan of 2018:
- Aerospace materials.

Specialization as innovation city prior to reallocation in 2017:
- Housing construction;
- Promotion of SMEs.

BUSAN CITY

Specialization after *National Innovation Cluster* plan of 2018:
- Smart city.

Specialization as innovation city prior to reallocation in 2017:
- Marine fisheries;
- Financial industry;
- Film industry.

ULSAN CITY

Specialization after *National Innovation Cluster* plan of 2018:
- Green mobility.

Specialization as innovation city prior to reallocation in 2017:
- Energy industry;
- Labour and welfare;
- Industrial safety.

DAEGU CITY

Specialization after *National Innovation Cluster* plan of 2018:
- Medical convergence.

Specialization as innovation city prior to reallocation in 2017:
- Industrial promotion;
- Promotion of education and academia;
- Gas industry.

Note: Daedeok Innopolis was the nation's first innovation cluster outside the capital. Under the *Basic Plan for an International Science Business Belt* (2011), Daedeok Innopolis is expanding into a vast complex, the International Science Business Belt (Yim and Lee, 2015). The 'Belt' took a step closer to realization in December 2019 with the first distribution of land for commercial purposes.

Source: for regional specialization, see MSIT and KISTEP (2018); for functional categorization before 2017, see: innocity.molit.go.kr

UN Disclaimer

The development of national innovation clusters has been supported by the relocation to the provinces of public institutions, including state-owned enterprises and government-supported research institutes, under the previous Park Geun-hye government. Today, these clusters are in need of stronger coordination, as regions are beginning to diverge from their original designated specialization (Figure 25.3). The approach has its limitations when it comes to fostering regional capabilities, since it remains a government-led plan. This means that the regions remain financially dependent on the central government.

The Ministry for Small and Medium-sized Enterprises and Start-ups is a strong supporter of the plan to operationalize national innovation clusters. It has also taken on the portfolio for the national programme for the Creative Economy Town and the Centre for the Creative Economy and Innovation (Yim and Lee, 2015), which used to come under the umbrella of the Ministry of Trade, Industry and Energy.

The Centre for the Creative Economy and Innovation is currently reforming its decision-making process to give regional authorities greater autonomy, by supporting mechanisms ranging from unilateral assistance from large companies to mutual co-operation among universities and medium-sized and venture companies (MSIT and KISTEP, 2018).

Thanks to the regional clusters and other measures fostering a creative economy under the *Third Basic Plan for Science and Technology 2013–2017* (Yim and Lee, 2015), SMEs are expected to play a greater role than before in national innovation. In connection with the *National Innovation Cluster* plan of 2018 (Figure 25.3), the *Medium-sized Enterprise Vision 2280* was announced in 2018; it sets out to cultivate 80 global champions with annual sales worth more than KRW 1 trillion (*ca* US$ 857 million) by 2022 and to increase the number of medium-sized companies to 5 500 by the same date (MSIT and KISTEP, 2018).

In 2018, the state-run Korea Development Bank announced plans to invest KRW 2.5 trillion (*ca* US$ 1.9 billion) in SMEs by 2022 in support of the *Medium-sized Enterprise Vision 2280* initiative (Kwak, 2018). These funds are being disbursed through the bank's new Global Challengers 200 programme. Under this programme, the bank is selecting 200 medium-sized enterprises on the basis of their potential for job creation in one of three areas: innovative, export-oriented or global reach. To qualify, companies should be at least seven years old with annual sales exceeding KRW 30 billion (*ca* US$ 26 million).

Missed targets for climate commitments

Some Sustainable Development Goals (SDGs) are proving to be a major challenge for the Republic of Korea including those for affordable and clean energy (SDG7), industry, innovation, and infrastructure (SDG9) and climate action (SDG13). In accordance with the Sustainable Development Act of 2011, the Ministry of the Environment publishes an annual monitoring report. It has also developed a new index called K-SDGs, in order to evaluate the impact of investment on the country's progress towards sustainable development. The index monitors progress towards a number of targets to 2030 (MoE, 2018a):

- reducing carbon dioxide (CO_2) emissions from 694 million metric tonnes (MMmt) in 2016 to between 574 and 608 MMmt per year (K-SDG13);
- increasing GERD by 0.01% every three years to maintain a ratio of around 4.3% of GDP (K-SDG9);
- increasing the share of renewable energy in total energy generation from 7% of installed capacity in 2017 to 20% (K-SDG13); and
- increasing the number of environmentally friendly cars from 97 000 in 2017 to 8 800 000 (K-SDGs 7 and 13).

In June 2019, Korea announced its *Third Energy Master Plan* for the years 2019–2040, which sets long-term goals of reducing energy production from nuclear and coal sources and raising the share of renewable energy in domestic power generation to between 30% and 35% by 2040. No specific goal is set for reductions in supply from nuclear and coal sources. In the mid-term, the *Plan* sets a target of 20% for the share of renewable energy in the primary supply by 2030 (K-SDG13). Considerable investment in infrastructure will be necessary to reach this target: renewables accounted for about 5% of the primary energy supply in 2017 (Figure 25.1). Energy consumption levels are also to drop 18.6% below the business as usual scenario for 2040.

The government plans to help farmers convert degraded farming areas, including reclaimed lands, into solar farms. It is incentivizing uptake through feed-in tariffs and schemes centred on local co-operatives and investment funds, which could earn dividends for participants. The government is encouraging regional governments to plan their own renewable energy projects and gain local support through further incentives for participation.

Details of other energy policies are to be revealed in sub-level plans, such as the *Ninth Basic Plan of Long-Term Electricity Supply and Demand*, which has been delayed from 2019 to 2020.

Green triangle has not lived up to expectations

The Republic of Korea's green growth policy is also reflected in its separate 'green' plan. Under the first *Five-Year Plan for Green Growth over 2009–2013*, the government had established a 'green triangle' combining strategy, capital and technology: the Global Green Growth Institute (strategy) was initially designed as a non-governmental institute but became an international body offering support to developing countries in 2012; the Green Climate Fund (capital), hosted by the Korean city of Incheon, was set up by the United Nations to help developing countries adapt to climate change; and the Green Technology Centre Korea (technology) had a specific mandate to 'green' the Korean economy.

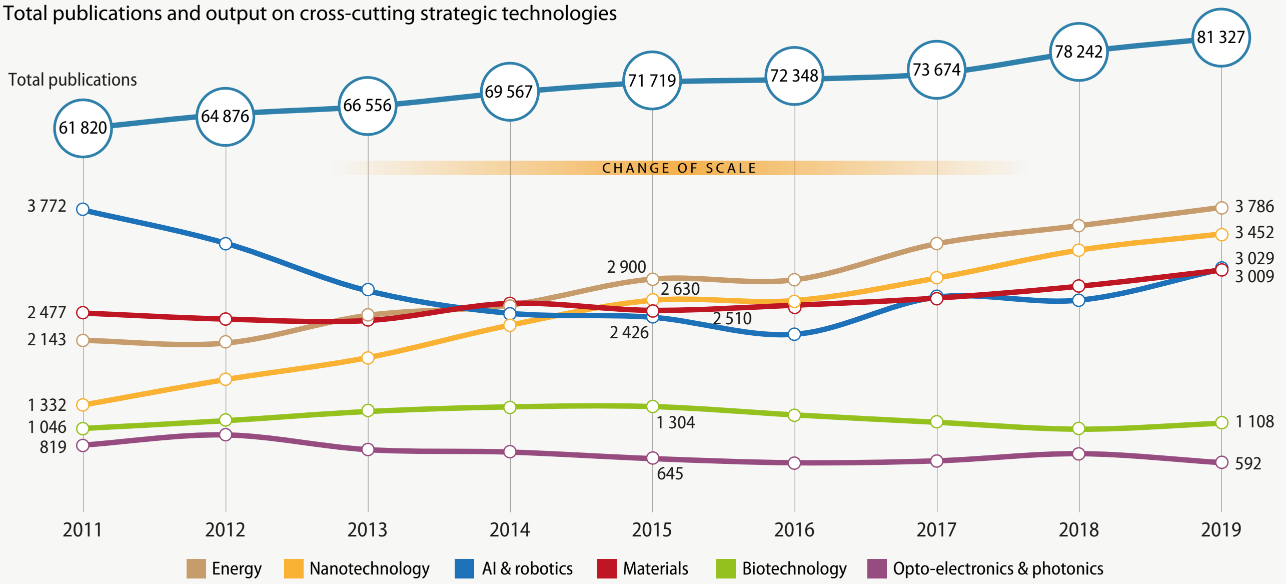
Air quality still leaves much to be desired. The World Health Organization recommends a threshold of 10 $\mu g\ m^{-3}$ for airborne particulate matter up to 2.5 microns in size (PM 2.5) but the ratio in 2018 was more than twice this limit, at 23 $\mu g\ m^{-3}$ (MoE, 2018b). The target for 2022 under the *Fourth Basic Plan* is 18 $\mu g\ m^{-3}$ (Table 25.2).

In addition, between 2008 and 2016, CO_2 emissions rose from 592.7 MMmt to 694.1 MMmt (OECD, 2019). The country's supply-centered energy policy has been charged with

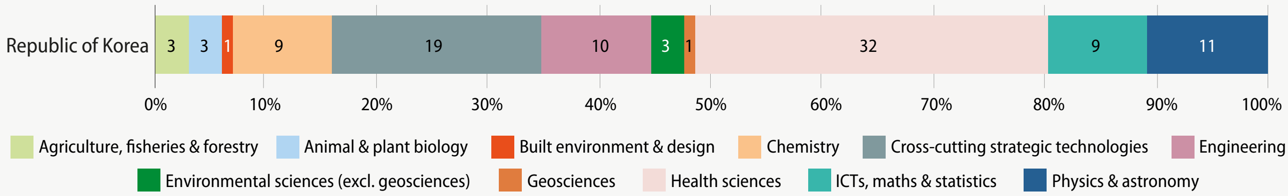
Figure 25.4: **Trends in scientific publishing in the Republic of Korea**

Volume of scientific publications in the Republic of Korea, 2011–2019

Total publications and output on cross-cutting strategic technologies



Scientific publications in the Republic of Korea by broad field of science, 2017–2019 (%)



Scientific publications per million inhabitants in the Republic of Korea, 2011, 2015 and 2019

0.99
Average of relative citations for Korean publications, 2014–2016; the OECD average is 1.11

28%
Share of Korean publications with foreign co-authors, 2016–2018; the OECD average is 34%

How has output on SDG-related topics evolved since 2012?

Scientists in the Republic of Korea are publishing more on the following topics than would be expected, relative to global averages: photovoltaics (2.5 times), greater battery efficiency (2.3 times), hydrogen energy (1.9 times), sustainable transportation (1.6 times), radioactive waste management and desalination (1.6 times each), regenerative medicine and carbon capture and storage (1.5 times each).

The number of publications on greater battery efficiency has grown by 50%, from 2 866 (2012–2015) to 4 164 (2016–2019). Conversely, output on photovoltaics has dropped from 4 311 (2012–2015) to 3 861 (2016–2019).

This eight-year period also witnessed strong growth in publications on sustainable transportation, from 1 406 (2012–2015) to 2 138 (2016–2019).

The issue of radioactive waste management, meanwhile, was the subject of 315 (2012–2015) and 402 (2016–2019) publications.

Among topics with at least 100 publications over the period under study, the impact on human health of soil, freshwater and air pollution recorded the fastest growth, from 401 (2012–2015) to 812 (2016–2019) publications.

For details, see chapter 2

Republic of Korea's top five partners for scientific co-authorship, 2017–2019 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Republic of Korea	USA (28 427)	China (12 467)	Japan (7 559)	India (6 676)	UK (5 605)

Source: Scopus (excluding Arts, Humanities and Social Sciences), data treatment by Science-Metrix failing to manage demand. Between 2008 and 2018, energy consumption progressed from 4.91 to 5.96 tonnes of oil equivalent (TOE) per capita (KEEI, 2019).

The *Second Plan for Green Growth over 2014–2018* was more successful. Greenhouse gas emissions rights were allocated to companies and the emissions trading market began operating through the Korea Exchange in January 2015. The volume of emissions trading climbed steadily from 5.73 MMmt in 2015 to 39.33 MMmt in 2018. As a result, the ratio of total greenhouse gas emissions to GDP decreased from 505 tonnes per billion KRW in 2013 to 460 tonnes per billion KRW in 2016. However, total emissions are still rising and the country still faces many challenges, including the lack of a framework to assess progress towards the country's reduction targets.

The dawn of I-Korea 4.0

In 2017, the government initiated the preparation of its grand strategy for participating in the Fourth Industrial Revolution, which it called *I-Korea 4*.0. Industry 4.0, as the Fourth Industrial Revolution is also known, is mainly driven by data (cloud services and big data), networks [Internet of Things and fifth generation (5G) networks] and artificial intelligence (machine learning and algorithms).

Under the Presidential Committee on the Fourth Industrial Revolution (PC4iR), established in 2017, which serves as the highest decision-making body, the Republic of Korea aims to expand investment in research and innovation to encompass artificial intelligence, big data, robotics, brain science, industrial mathematics, nanotechnology and materials science, among other topics. The country has embarked on installing a designated network for the Internet of Things and is commercializing a 10 GB Internet network and 5G mobile network.

In line with its innovation-driven economic policy, the government suggested a plan in 2017 to foster new growth engines in 13 areas, including artificial intelligence, next-generation communication technology, drones and autonomous cars (Figure 25.2). The government plans to invest KRW 9 023 billion (*ca* US$ 7.7 billion) between 2018 and 2022, although fiscal adjustments may modify this plan. Cross-cutting technologies like artificial intelligence and robotics already represent the second-largest category of scientific publications after health (Figure 25.4).

Although the Republic of Korea has world-class infrastructure for information and communication technologies (ICTs), it has been argued that deregulation is needed to permit analysis of big data (Kang, 2020). The commercial use of pseudonymized personal information had been prohibited by the Personal Information Protection Act (2017). In January 2020, this act was amended to authorize the use and analysis of personal information for commercial use, statistical analysis, scientific research and public record-keeping. A non-governmental organization, the People's Solidarity for Participatory Democracy, is advocating further studies to ensure that the future amendment provides concrete criteria for all uses of personal information (PSPD, 2020).

In addition to the proposed deregulation, the government introduced a 'regulatory sandbox' in 2019 which is helping to accelerate the commercialization of ICTs and FinTech by temporarily authorizing experimentation and verification in a non-regulatory environment, whenever existing regulations bar businesses from accessing new technologies and services.

In 2019, the government announced a national strategy to develop technologies related to the Fourth Industrial Revolution and register these research projects with the International Organization for Standardization. Doing so should not only guarantee high quality but also streamline acceptance of the products and processes by world markets. The strategy proposes 300 development projects, including 52 projects for electric and autonomous cars, 28 projects for hydrogen energy, 18 projects for intelligent robotics, 33 projects for non-memory semiconductors and 25 projects for drones and maritime structures (MoTIE, 2019b).

In particular, standards for hydrogen and fuel cell technologies have received a great deal of attention from the Moon government, as hydrogen energy is perceived as a means of compensating for the phasing out of nuclear energy. A performance evaluation for an autonomous navigational system is another targeted standard for the country's world-class shipbuilding industry (Box 25.1). The steady and strong patenting record reflects this ongoing push for innovation (Figure 25.2).

INTERNATIONAL CO-OPERATION

A growing network of research support centres

Launched in 2014, the Korea Innovation Centre is now a major government programme for international co-operation (Yim and Lee, 2015). It acts as a local hub for Korean SMEs seeking to expand their business into global markets, also offering them accelerator programmes such as 3–4-week training courses (MSIT, 2018b).

There is now a global network of regional Korea Innovation Centres. The European centre moved from Brussels (Belgium) to Berlin (Germany) in March 2017 and other regional offices have been established since 2013 in Washington, DC, and Silicon Valley (USA) as well as Beijing (China).

Other centres with a mandate for addressing global challenges, often pertaining to the SDGs, are operating in seven countries. These centres are located in Cambodia, Ethiopia, Indonesia, Lao People's Democratic Republic, Nepal, Tanzania and Viet Nam. The National Research Foundation is managing projects in these countries as part of the government's official development assistance.

The National Research Foundation is expected to finance projects for a total of KRW 25 billion (*ca* US$ 21.4 million) in 2020, with KRW 500 million (US$ 428 000) being allocated to each. A new centre is to be established in Myanmar focusing on ICTs between 2020 and 2024 (MSIT, 2019b).

Overtures to the northern neighbour

The Moon government's overtures to the Democratic People's Republic of Korea have led to growing expectations of bilateral co-operation between the two Koreas. A proposal to establish a co-operation centre in Pyongyang has regained traction after its implementation was suspended a decade ago (Lee *et al.,* 2018). In a speech delivered in August 2018, President Moon also proposed establishing an East Asian Railroad Community. The idea would be to reconnect the rail network between the two Koreas and extend it to China, Japan, Mongolia and the Russian Federation.

These ambitious proposals are yet to be realized.

Through the Pyongyang Joint Statement of 19 September 2018, the two Koreas agreed to strengthen cooperation in epidemiology, public health and medical care. This agreement covered emergency measures to prevent the entry and spread of contagious diseases. However, as of June 2020, the agreement had not yet been applied to the outbreak of Covid-19, despite the Republic of Korea having reached out to its northern neighbour.

CONCLUSION

Steps towards greater state intervention

With 4.5% of GDP being devoted to R&D, raising the country's quantitative investment in science and technology no longer seems as crucial as it once did.

At the same time, a lower economic growth rate, lower birthrate, ageing population and economic polarization are symptomatic of systemic weaknesses that demonstrate the need for greater and smarter government intervention in managing the national innovation system. The current government has taken up the challenge but it is too early to see the endgame of the ongoing transformation. The government has opted for a development model based on strong state intervention and extensive government-directed regulation and planning.

Expectations of greater regional autonomy

Since the government is expecting SMEs to play a greater role in driving the Fourth Industrial Revolution than in past technological revolutions, it has arrived at the conclusion that resources and capacity for research and innovation will need to be dispersed nationwide. Consequently, the government has elaborated a plan to empower regions to play a greater role in developing innovation clusters which, in turn, has prompted demands for greater regional autonomy in STI policy.

This regional dispersal will not mean a diminished role for the larger conglomerates, or chaebols. In fact, it seems inconceivable that the Republic Korea could regain its economic momentum without these tech giants.

In preparing for the Fourth Industrial Revolution, the Republic of Korea is building a framework for more entrepreneurial, innovative and autonomous talent. How the existing Asian developmental model will adapt to this future-oriented vision will be fascinating to observe.

Box 25.1: **Republic of Korea embracing autonomous ships**

The Republic of Korea's *Master Plan for Cultivating Marine Science and Technology* (2018–2022) focuses on strategic industries where private-sector engagement will be essential. The plan's goals include developing 50 innovative start-ups, generating 800 experts annually and raising the country's technical capacity in specific areas, such as marine forecasting and polar research, to over 80% that of the most advanced nation. Another goal is to expand the share of marine sources in new and renewable energy production to 5.2% by 2022.

Alongside smart shipping and ports, the Republic of Korea plans to foster autonomous ships to nurture new growth engines and create jobs. Although it may seem counterintuitive, reducing the human presence in navigation will create new jobs in the maritime industry, such as for port-side management, technicians and engineers.

A 2018 report suggests that career prospects for sailors remain positive over the next decade, which may help to alleviate seafarers' anxieties about job security (Johns and HSBA, 2018). Pilotless vehicles will not be 'fully automated', the highest level on the six-part scale for vehicle autonomy, whereby no human attention or interaction is needed. Most ships will be semi-autonomous and still need sailors.

Some aspects of maritime navigation have been automated for years, helping sailors and port authorities to reduce the margin for error and simplify the manoeuvres of massive ships and movement of cargo.

The Republic of Korea conducted a technology assessment on maritime autonomous surface ships under its Marine Science and Technology Cultivation Act (2017). Its efforts are in line with one of the International Maritime Organization's (IMO) seven strategic directions for 2018–2023, to integrate new and advanced technologies in the regulatory framework. In June 2018, IMO launched a Regulatory Scoping Exercise to determine the extent of adoption of autonomous surface ships.

Autonomous ships should ensure greater safety at sea for seafarers and reduce risks to the environment from spills, collisions and other disasters. This will be vital to cleaning up the shipping industry, which moves 90% of global trade and accounts for 3% of global CO_2 emissions. The industry's emissions are even projected to more than double by 2050, according to the IMO. Shipping also accounts for 18–30% of global nitrous oxides and over 10% of sulphur oxide emissions.

As of January 2020, IMO regulations demand that vessel fuel contain no more than 0.5% sulphur, a significant drop from the 3.5% average in 2018, which may prove difficult for some countries to achieve.

These changes come at a time when countries are actively updating their fleets to comply with the requirements of the *Ballast Water Management Convention*, adopted in 2004 and entering into force in 2017, which requires water treatment systems on all vessels to be retrofitted by 2024 (IMO, 2017).

By 2025, the IMO wishes all new ships to be 30% more energy-efficient than those built in 2014. For the Republic of Korea, autonomous ships are part of the answer.

Source: compiled by Tiffany Straza

KEY TARGETS FOR THE REPUBLIC OF KOREA

The Republic of Korea plans to:

- increase the share of renewable energy in domestic power generation to between 30 and 35% by 2040;
- cut CO2 emissions to between 574 and 608 MMmt per year by 2030;
- boost domestic expenditure on R&D by 0.01% each year to maintain a ratio of around 4.3% of GDP through to 2030;
- raise the share of renewable energy in total energy generation from 7% of installed capacity in 2017 to 20% by 2030;
- multiply the number of environmentally friendly cars to 8.8 million by 2030, up from 97 000 in 2017;
- ensure that 30% of start-ups are innovators by 2022;
- double government funding for basic science designed by researchers from KRW 12.6 trillion in 2017 to 25.2 trillion by 2022.

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ENDNOTES

1 Each Basic Plan is aligned with the expected five-year presidential term; the Park administration lasted four years.

2 Article VII of the Framework Act on Science and Technology (2001) states that 'the government shall set medium- and long-term policy objectives and directions relating to the development of science and technology, after deliberation by the Presidential Advisory Council on Science and Technology.'

AT A GLANCE

A helicopter drops water to quell the flames in Harrington, New South Wales, as bushfires blaze across the east coast of Australia in November 2019. With extensive areas of dryland agriculture and fire-prone forest, Australia is vulnerable to climate change. The government has allocated AU$ 4.5 billion over 15 years to a Climate Solutions Package. © Shane Chalker

- The signing of the landmark Regional Comprehensive Economic Partnership in November 2020 links 15 countries representing about 30% of the global population and GDP in one of the world's largest free-trade deals.
- Intraregional collaboration in scientific publishing has grown since 2015 when the Association of Southeast Asian Nations (ASEAN) Economic Community took effect; it seeks to foster intraregional mobility.
- There is a growing convergence in research intensity across the region, as research intensity has dipped in Australia and Singapore but risen in Malaysia, New Zealand, Thailand and Viet Nam.
- Countries are seeking to harness the Fourth Industrial Revolution, with a focus on upgrading industry, upskilling the workforce and fostering innovation.
- Many cities in Southeast Asia have smart ambitions, with young, digital-aware populations.
- The transition from fossil fuels to renewable energy presents a challenge for most countries. The Pacific Islands are embracing renewables to achieve energy independence.

26 · Southeast Asia and Oceania

Australia, Brunei Darussalam, Cambodia, Cook Islands, Fiji, Indonesia, Kiribati, Lao People's Democratic Republic, Federated States of Micronesia, Malaysia, Republic of the Marshall Islands, Myanmar, Nauru, New Zealand, Niue, Palau, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Thailand, Timor-Leste, Tonga, Tuvalu, Vanuatu, Viet Nam

Don Scott-Kemmis, Patarapong Intarakumnerd, Rajah Rasiah and Ranasinghe Amaradasa

INTRODUCTION

A sweeping trade agreement

Most of the countries in this diverse region achieved fairly robust economic growth over the five years to 2020, thanks primarily to commodity exports (Figure 26.1).

The November 2020 signing of one of the world's largest free-trade deals, the Regional Comprehensive Economic Partnership, is set to eliminate tariffs on about 65% of goods traded within the region by the ten members of the Association for Southeast Asian Nations (ASEAN), along with Australia, China, Japan, the Republic of Korea and New Zealand. These 15 countries represent about 30% of the global population and GDP. The USA and India have opted not to join this trade alliance.

The Regional Comprehensive Economic Partnership extends to trade in services. It makes no provision for unified labour and environmental standards, despite eight years of negotiation.

One common challenge will be to mobilize science, technology and innovation (STI) to raise productivity levels, add value to industry and develop new areas of specialization. Some long-term strategies are ambitious in this regard, including those of Indonesia, Malaysia, New Zealand, the Philippines, Thailand and Viet Nam, as we shall see later.

Human resources remain the priority area for investment among the region's less developed countries, where technical and vocational education plays an important role. This is notably the case for Cambodia, the Lao Peoples' Democratic Republic (Lao PDR), Myanmar and Timor-Leste.

The small Pacific Island nations face additional, existential challenges, namely, the need to raise returns on investment in resource-based industries such as fishing and agriculture while simultaneously improving health and building resilience to climate change.

ASEAN has adopted a Covid-19 exit strategy

At the time of writing in January 2021, the Covid-19 pandemic is testing the capacities of health systems and governments. Australia, Malaysia, New Zealand and Singapore have implemented strict lockdowns that appear to have contained the spread of the virus. By rapidly closing their borders, the Pacific Island countries managed to evade or stamp out infection altogether but this victory has come at a high economic cost to their vital tourism industry.

Adopted in November 2020, the *ASEAN Comprehensive Recovery Framework* has been touted as a consolidated exit strategy from the Covid-19 crisis that is aligned with regional priorities. The implementation plan makes no reference to any funding mechanism.

According to this framework, a *Regional Strategic Action Plan for ASEAN Vaccine Security and Self-Reliance* is to be implemented, with an initial focus on ensuring timely and equitable access to affordable and quality-assured Covid-19 vaccines. For example, the Covid-19 ASEAN Response Fund may be used to procure test kits, personal protective equipment and medical supplies. This fund was announced in June 2020. By the end of the year, at least US$ 15 million had been pledged, including by countries situated beyond the bloc such as China and Germany.

Over 2014–2018, a series of workshops were held in Thailand on building vaccine security and self-reliance in the region. These workshops were recalled in the *ASEAN Leaders' Declaration on ASEAN Vaccine Security and Self-Reliance* of November 2019. They endeavoured to strengthen co-operation among ASEAN members, particularly through information-sharing, training and other forms of capacity-building.

A communication and co-ordination plan entitled *ASEAN Vaccine Security and Self-reliance Initiatives* (2016) affirmed the long-term goal of seeing ASEAN countries adopt a comprehensive financial management plan for the purchase and/or manufacture of common vaccines, as well as innovative ones for emerging infectious diseases.

Potential for special economic zones to foster innovation

Special economic zones are common in ASEAN countries. As of early 2020, Cambodia is home to no fewer than 31 such zones, under the authority of the Cambodia Special Economic Zone Board. One area in particular has come into focus: the port city of Sihanoukville, touted as the 'next Shenzhen'. In 2014, the area was home to three economic zones. Since then, Sihanoukville has become a focal point for Chinese investment under the Belt and Road Initiative. Between 2017 and 2018, US$ 1.3 billion was invested in the city, of which US$ 1.1 billion came from China (Ellis-Petersen, 2018). The government announced in November 2019 that four more special economic zones would be established in Sihanoukville (Hui, 2020).

In Thailand, meanwhile, there are plans to develop an innovation hub within the country's flagship special economic zone, the Eastern Economic Corridor (Box 26.1).

In Indonesia, eight special economic zones are presently under development to support the expansion of infrastructure such as electricity, transport, trade and other logistics. These zones will add to the four already existing in Sei Mangkei, Tanjung Lesung, Palu and Mandalika. The objective is to improve access to finance for micro-enterprises and small and medium-sized enterprises (SMEs) [ADB, 2019b]. The favoured approach is to offer tax incentives but these can reward the continuation of activities, rather than catalyse innovation. There is a general lack of grant schemes to support innovation and technological development.

The Indonesian government has sought to alleviate the regulatory and licensing burdens on firms. Deregulation was a focus of the 'omnibus' law (Law on Job Creation), which came into effect in November 2020. The law has triggered concern from 35 global investors and others, including the International Monetary Fund, about the environmental cost of the new legislation. The new law weakens the participatory process for environmental impact assessments and shifts from an approval process based on permits to one in which developers declare their own compliance. It also weakens workers' protections. The government has justified the law by the need to attract FDI and stimulate economic growth to offset the impact of the Covid-19 pandemic (Jong, 2020; Mahy, 2021).[1]

Figure 26.1: **Socio-economic trends in Southeast Asia and Oceania**

Socio-economic indicators for Southeast Asia and Oceania, 2020 or closest year

	Population	Economy	Employment	Trade, remittances and foreign investment				Access to services			
	Population (thousands)	GDP growth (%)	Unemployment rate (%)	Exports of goods & services as a share of GDP (%)	High-tech exports as a share of manufactured exports (%)		FDI inflows as a share of GDP (%)	Internet access per 100 inhabitants	Share of population with electricity access (%)	Share of population with access to basic drinking water services (%)	Share of population with access to at least basic sanitation (%)
	2019	2015–2019	2020	2019	2015	2019	2019	2019	2018	2017	2017
ASEAN member states											
Brunei Darussalam	433	2.69	9.0	57.9	19.6	8.5	2.8	95.0	100.0	99.9	96.3[-2]
Cambodia	16 487	31.55	0.7	61.1	1.5	1.2	13.5	40.0	91.6	78.5	59.2
Indonesia	270 626	21.90	4.8	18.4	8.9	7.6	2.2	47.7	98.5	89.3	73.1
Lao PDR	7 169	27.20	0.6	–	35.2	20.6	3.1	25.5	97.9	82.1	74.5
Malaysia	31 950	20.78	3.4	65.2	48.5	51.8	2.1	84.2	100.0	96.7	99.6
Myanmar	54 045	23.59	1.7	30.4[-1]	0.5	2.8	3.0	30.7	66.3	81.8	64.3
Philippines	108 117	29.20	2.2	28.3	–	62.2	2.0	43.0	94.9	93.6	76.5
Singapore	5 704	12.24	4.4	173.5	52.4	52.1	28.4	88.9	100.0	100.0	100.0
Thailand	69 626	14.74	0.8	59.8	23.9	23.6	1.1	66.7	100.0	99.9	98.8
Viet Nam	96 462	30.00	2.0	106.8	36.4	40.4	6.4	68.7	100.0	94.7	83.5
Oceania											
Australia	25 364	10.57	5.3	24.1	19.8	21.5	2.9	86.5	100.0	100.0	100.0
Fiji	890	11.55	4.1	47.9[-1]	2.1	3.9[-1]	5.9	50.0	99.6	93.8	95.1
Kiribati	118	10.97	–	9.6[-1]	1.4		0.3	14.6	100.0	71.6	47.8
Marshall Islands	59	9.24	–	40.4[-1]	–		4.4-1	38.7	96.4	88.5	83.5
Micronesia	114	3.83	–	35.5[-1]	–		–	35.3	82.1	78.6	88.3
Nauru	13	3.57	–	20.0	–		0.0-1	57.0	99.8	99.5	65.6
New Zealand	4 917	13.39	4.0	28.0[-1]	10.2	9.9	1.9	90.8	100.0	100.0	100.0
Palau	18	-2.35	–	47.6[-1]	41.2	51.7[-1]	8.2	–	100.0	100.0	100.0
Papua New Guinea	8 776	15.34	2.5	–	–	–	1.4	11.2	59.0	41.3	12.9
Samoa	197	10.76	8.4	37.1	0.8	2.3	0.1	33.6	100.0	97.4	98.2
Solomon Islands	670	17.32	0.5	39.8[-4]	2.8	1.4[-1]	2.1	11.9	66.7	67.8	33.5
Timor-Leste	1 293	16.44	4.6	28.2	–	–	3.7	27.5	85.6	78.3	53.5
Tonga	104	11.25	1.2	21.1	6.0[-1]	–	0.3	41.2	98.9	99.9	93.4
Tuvalu	12	20.66	–	–	–	–	0.6	49.3	100.0	99.3	84.1
Vanuatu	300	14.80	4.4	–	–	–	4.4	25.7	61.9	91.3	34.1

Note: Data are unavailable for the Cook Islands (population of 20 200 in 2019) and Niue (1 719 in 2017).

Strategies to develop digital economies

There is a growing awareness in the region that the digital transformation inherent to the Fourth Industrial Revolution (also known as Industry 4.0) presents a deep challenge for business, government and society at large.

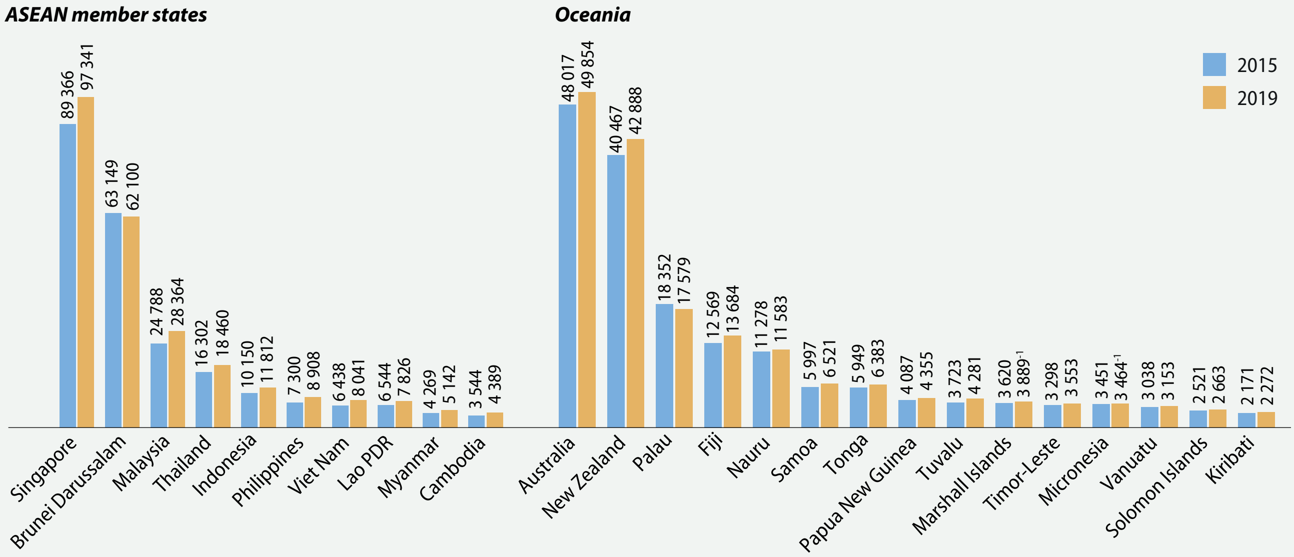
Australia established a Digital Technology Taskforce in 2019 with a mandate to turn the country into a leading digital economy by 2030. Related strategies focus on smart cities, digital skills and cybersecurity.

New Zealand's innovation agency, Callaghan Innovation, is now primarily focused on supporting the country's manufacturing firms in their digital transformation.

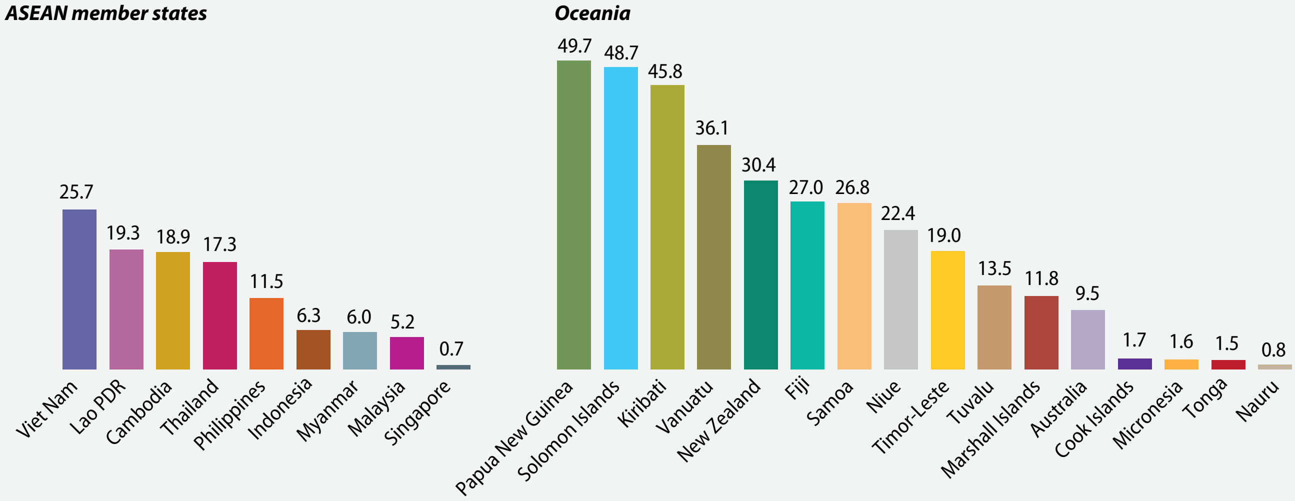
In 2016, ASEAN leaders adopted the *Master Plan on ASEAN Connectivity 2025*, which guides policy development in member countries. It targets digital innovation, logistics, sustainable infrastructure, regulatory harmonization and the mobility of persons.

The *Master Plan on ASEAN Connectivity 2025* has been designed to complement the *ICT Masterplan 2020* launched in November 2015. For instance, there is an ambition in

GDP per capita in Southeast Asia and Oceania, 2017 (%)
In constant 2017 PPP$



Share of modern renewables in final energy consumption in Southeast Asia and Oceania, 2017 (%)



-n: data refer to *n* years before reference year

Note: Data are unavailable for some countries. Modern renewables exclude traditional uses of bio-energy like wood burning. Brunei Darussalam and Palau are excluded, as the value for this indicator is nil or negligible.

Source: World Bank's World Development Indicators, December 2020; data for Cook Islands and Niue from Cook Islands Statistics Office and the Secretariat for the Pacific Community; unemployment rates are modelled on International Labour Organization estimates; for energy: International Renewable Energy Agency's Statistical Profiles, December 2020 the *ASEAN Connectivity* plan to establish an ASEAN Open Data Network. Whereas the *ICT Masterplan* had mainly targeted the private sector, such as by establishing a platform for information-sharing on big data management and analysis, the *ASEAN Connectivity* plan proposes an open data forum to allow ASEAN governments to share the results of related initiatives. The *ASEAN Connectivity* plan also proposes that a common set of data standards be established for member states, to ensure a coherent approach to data collection, coverage and storage.

More than eight in ten people have access to Internet in the region's high-income countries. Internet penetration is spreading rapidly in other economies but still eludes two-thirds of the population in some Pacific Islands, Lao PDR and Timor-Leste (Figure 26.1).

The *Pacific Regional ICT Strategic Action Plan* for 2016–2020 set the goals of achieving universal access to affordable information and communication technologies (ICTs) and using them to foster sustainable development.[2]

Technologies such as the Internet of Things, artificial intelligence (AI) and advanced robotics offer countries an opportunity to reduce the cost of education and improve the viability of remote learning. This is a particularly appealing prospect for the dispersed Pacific Island nations, which already rely on distance-learning technologies for higher education.

Australia, Malaysia, New Zealand, the Philippines, Singapore and Thailand have all developed comprehensive strategies and implementation mechanisms for their digital agenda. Countries are striving to develop e-governance to improve service delivery and to digitalize existing industries to achieve efficiency gains and consolidate linkages within domestic and international value chains. However, there are concerns that SMEs may struggle to remain competitive.

Malaysia has addressed this concern by launching an initiative which will select 500 SMEs on the basis of their readiness to adopt Industry 4.0 technologies for targeted support from the Ministry of International Trade and Industry (Govt of Malaysia, 2018).

Several countries are developing smart cities through public–private partnerships (Woetzel *et al*., 2018). One example is Beeline, an on-demand transit service in Singapore that was launched by the government as a pilot project in August 2015, before expanding its operations through

Box 26.1: **Innovation on the cards for Thailand's Eastern Economic Corridor**

The Eastern Economic Corridor (EEC) is Thailand's flagship special economic zone, covering three eastern provinces: Chachoengsao, Chonburi and Rayong. It was established in 2016 before becoming a legal entity in May 2018.

As of January 2021, the EEC hosts what is purportedly the world's eleventh-largest auto-exporting industry (EECOT, 2021).

It is also home to global suppliers of home appliances and hard disc drives, as well as a large petrochemical industry. It is envisaged as a logistics hub and gateway linking China, India and the ASEAN bloc.

A high-speed train route is presently under construction to link Bangkok's two airports with the EEC's own airport. In 2021 alone, THB 100 billion (*ca* US$ 3.3 billion) has been allocated for its construction. The total cost of the EEC development is estimated at THB 1.7 trillion (*ca* US$ 57 billion), with the private sector to cover 80% of the cost.

According to Dr Kanit Sangsubhan, Secretary-General of the EEC, the annual targets for private-sector contributions have been reached. For instance, half of the funding for the high-speed rail has been allocated by the government and half by a consortium of international investors led by Thailand's CP Group (EECOT, 2021).

Dr Sangsubhan anticipates that half of the EEC's current geographical area of 13 000 km will be covered by a 5G network by February 2021 (EECOT, 2021).

A corridor of innovation

Plans for the Eastern Economic Corridor of Innovation (EECi) were approved in May 2017 (BOI, 2017). Managed by the Ministry of Science and Technology, this innovation hub will be mandated to invest in application-oriented R&D; transfer technology to the ten sectors targeted by the *Thailand 4.0 strategy*; promote innovative and high-tech start-ups; and develop linkages between the actors of the national innovation system.

These goals are to be achieved through, *inter alia*, the establishment of public- and private-sector laboratories, testing and analysis centres, field laboratories and pilot and demonstration plants for new industrial technologies and processes.

Three categories of innovation have been prioritized for support from public research institutes and universities: life sciences and biotechnology; automation, robotics and intelligent systems; and space technology and geo-informatics.

The EECi is scheduled to become fully operational in June 2021. Convinced that biorefineries have the potential to kickstart an era of Thai leadership in bio-industry, the director plans to establish model biorefineries to transform agricultural produce and other outputs into biofuel and bioplastic palettes for use in various bioproducts (The Nation, 2020).

Biopolis, an innovation centre for biotechnology, is set to open in the EECi in 2021. It will work alongside the planned science park, Food Innopolis, and Airpolis, another park specializing in automation, robotics and intelligent systems. These centres plan to use smart-farming technology to turn the EEC into a hub for tropical fruit production. There are also plans to produce upstream products such as food additives and supplements (FEA, 2020).

Source: compiled by Patarapong Intarakumnerd and Jake Lewis partnerships with the private sector. Beeline's bus routes were computer generated, based on an analysis of historical travel patterns and online crowd-sourced suggestions (Yi, 2019).[3]

Digital financial services are spreading, even in ASEAN countries with limited Internet penetration. In late 2014, no Laotian institution offered branchless banking. Four years later, multiple banks had launched related initiatives. One example is the U-Money e-wallet service launched in 2018 as a joint venture between Lao PDR's largest mobile network operator, Unitel, and the Vietnamese multinational Viettel. By December 2020, U-Money had more than 500 000 customers and Unitel had signed agreements with half of Laotian districts to pay local public employees via the service (Vietnam News Agency, 2020).

In September 2018, Myanmar's largest private bank, KBZ Bank, launched the mobile wallet extension KBZPay. Over the first eight months of 2020, the bank reported processing US$ 5.7 billion worth of transactions across 6 million retail and merchant users, corresponding to one-fifth of the population (DigFin, 2020). In the interim, the government had released the *Myanmar Digital Economy Roadmap* in 2019 (see p. 699).

ASEAN members integrating Industry 4.0 in manufacturing

Most ASEAN countries have strong manufacturing sectors, with Indonesia, Thailand, Malaysia, Singapore and the Philippines leading for added-value manufacturing (measured in current US$). All but Brunei Darussalam[4] have shown growth for this indicator since 2015.

For instance, in Myanmar, the export value of manufactured garments surged from US$ 349 million to US$ 4.6 billion over 2010–2018. There is also an emerging automotive manufacturing industry, with several major companies operating local plants in Myanmar (OBG, 2020). It remains to be seen what effect the military coup of January 2021 will have on foreign direct investment (FDI) flows to this country. Cambodia's own garment manufacturing sector employs about 1 million people (ADB, 2019a).

Some countries have launched strategic initiatives to integrate Industry 4.0 technologies in manufacturing. In 2017, Enterprise Singapore and the Singapore Standards Council developed the Standards Mapping for Singapore Smart Industry Readiness Index, billed as the world's first standards mapping tool to help companies upgrade their Industry 4.0 capabilities. It defines good practices with regard to reliability, interoperability, safety and cybersecurity, in areas such as operations, supply, automation and talent readiness.

In October 2018, Singapore signed a memorandum of understanding with Indonesia to boost investment, knowledge-sharing and training in areas related to in Industry 4.0.

In January 2019, Indonesia launched its own Industry 4.0 Readiness Index, which assesses companies' performance against five indicators: technology; products and services; factory operations; management and organization; and people and culture (OBG, 2019).

The *Making Indonesia 4.0* strategy aims to ramp up performance in five strategic industries by transitioning to high-tech, high value-added and specialized production in: food and beverages; textiles and garments; automotive; electronics; and chemicals. These five industries already benefit from economies of scale through strong consumer demand and existing supply chains. They also reflect domestic advantages in terms of natural resources (OBG, 2019).

The Philippines' Department of Trade and Industry developed the *Inclusive Innovation Industrialization Strategy* (i³S) in 2017. It sets out to:

- build an innovation and entrepreneurship ecosystem;
- embrace Industry 4.0;
- improve the ease of doing business and the environment for investment;
- upskill or reskill the workforce;
- develop innovative SMEs and start-ups; and
- integrate production systems to deepen global and regional value chain participation.

The Philippines' strategy foresees a network of regional inclusive innovation centres to encourage market-oriented research. Four such centres have been piloted through a virtual platform connecting stakeholders in Cebu, Legazpi, Cagayan de Oro and Davao. Projects have been launched in advanced manufacturing in Cebu and in high-value crop development in the three other regions (DTI, 2019).

RESEARCH TRENDS

Greater convergence in research intensity

There is a growing convergence in research intensity across the region. Gross domestic expenditure on research and development (GERD) has dipped below the symbolic threshold of 2% of GDP in Australia and Singapore. Conversely, research intensity has progressed in each of Malaysia, New Zealand, Thailand and Viet Nam (Figure 26.2).

Researcher density, on the other hand, shows a growing divergence (Figure 26.2). Although the development of human resources remains a priority for less developed countries in the region, this is not reflected in levels of expenditure on education (Figure 26.3).

Economic gap limiting self-financing initiatives

One aim of the ASEAN Economic Community (est. 2015) has been to strengthen intraregional ties by facilitating mobility, including among the region's scientific communities (Turpin *et al*., 2015).

This goal is also reflected in the *ASEAN Plan of Action on Science, Technology and Innovation 2016–2025* (UNESCO, 2018). It seeks to enhance the mobility of scientists and researchers by developing a dedicated policy framework on this issue; establishing scholarship, fellowship and attachment programmes for students and research personnel; and expanding efforts to standardize certification and accreditation.

However, in practice, there have been few initiatives since 2015 to close the gap in STI capabilities among ASEAN member countries. ASEAN's operational budget is limited, so programme implementation depends largely upon funding provided by individual member nations.[5]

As a result, high-level plans have tended to remain normative political visions. The wide range of capabilities and economic resources among ASEAN countries remains an obstacle to developing more robust scientific co-operation. The same arrangements that have enabled ASEAN to engage these diverse economies – such as avoiding the creation of supranational institutions, decision-making through consensus and flexible co-ordination mechanisms – also limit its capacity to add value to national strategies and activities.

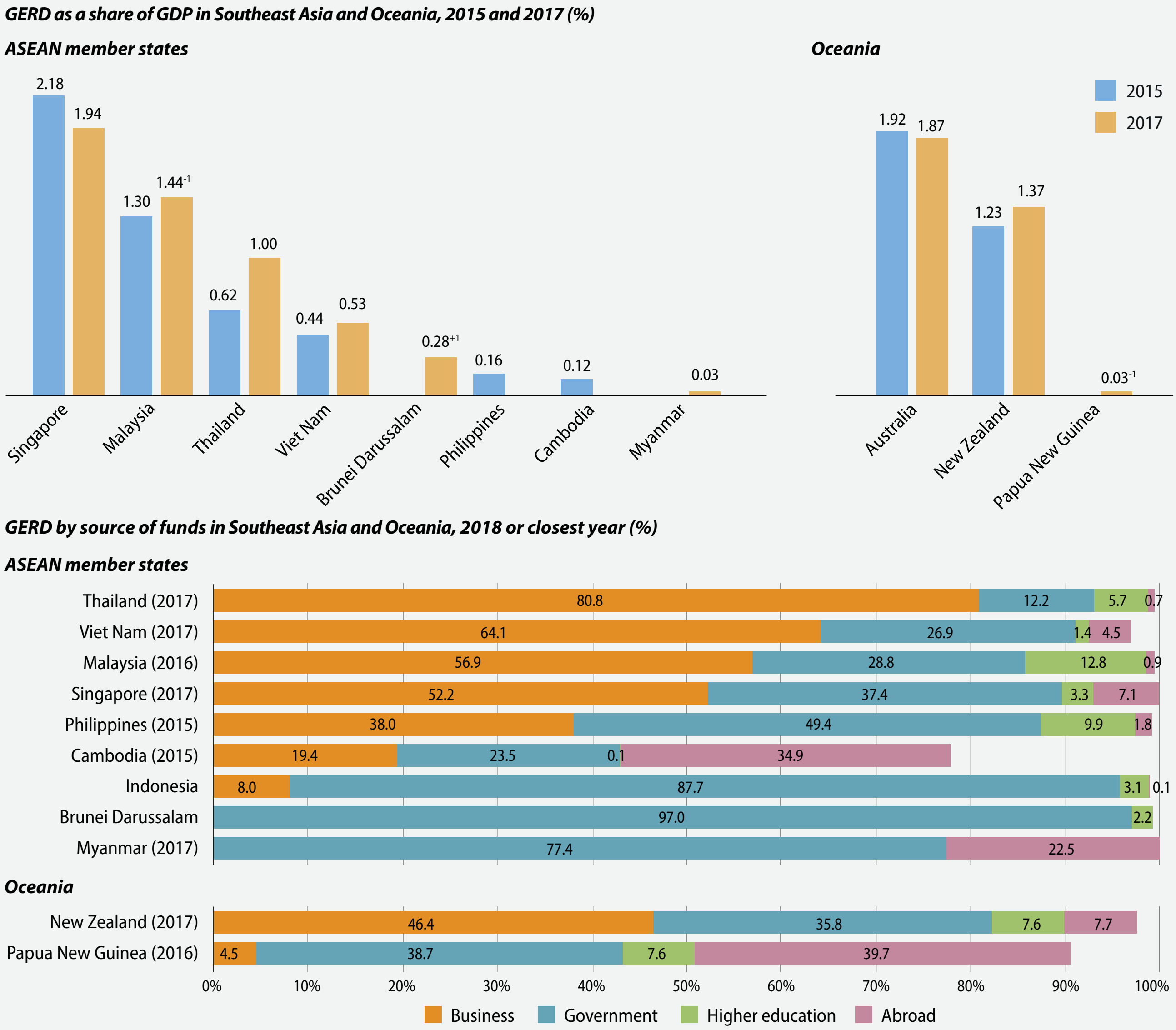
ASEAN governments may share ideas on strategic approaches to ascending global value chains – through R&D, vocational training and other forms of technical capacity-building – but they rarely share resources. The rising significance of China for ASEAN countries in trade, investment, security and, increasingly, STI is likely to challenge intraregional co-operation further. Over the 2017–2019 period, China was one of the top five partners for eight countries profiled in the present chapter (Figure 26.4), as also in 2014–2016.

There is no lack of bilateral co-operation agreements in STI between ASEAN and its ten 'dialogue partners' but these tend to involve the more advanced ASEAN economies that are in a position to provide substantial funding and train ASEAN personnel.[6]

Scientists forging closer intraregional ties

Scientific organizations within ASEAN countries have been developing stronger ties with their counterparts within the region, while maintaining ties with most of their 'dialogue partners'. Over 2014–2016, there were only five instances of an ASEAN member being a top collaborator for another ASEAN

Figure 26.2: **Trends in research expenditure and personnel in Southeast Asia and Oceania**



Note: Private non-profit organizations accounted for 22.1% of GERD in Cambodia (2015) and 2.5% of GERD in New Zealand (2017). Unspecified sources accounted for 8.8% of GERD in Papua New Guinea (2016) and 3.1% in Viet Nam (2017).

country.[7] Over 2017–2019, this increased to eight instances (Figure 26.4).

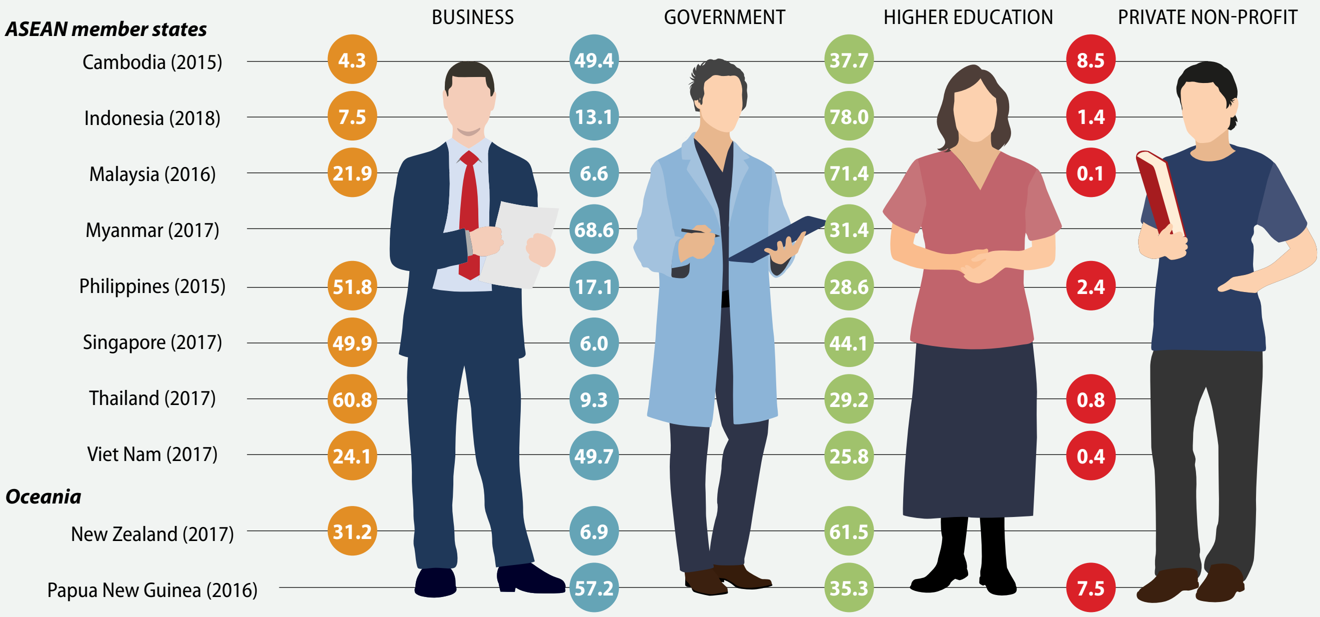
Change has been most visible in Lao PDR, where Thailand moved up from fifth to first position and the USA ceded its place to Viet Nam among the country's top five scientific partners over the dual 2014–2016 and 2017–2019 periods. Malaysian scientists now count Indian and Indonesian peers among their favoured partners, Iran and Japan having vacated the top five. Among Brunei Darussalam's top five partners, the USA has ceded its place to India.

Elsewhere, there has simply been some reshuffling. Malaysia and Japan have switched places as Indonesia's top partner. The only Asian country Australia counts among its top partners is China, which has moved up from third to second place. In the region, Australia is a top-five partner in scientific research for all but Myanmar and Tuvalu.

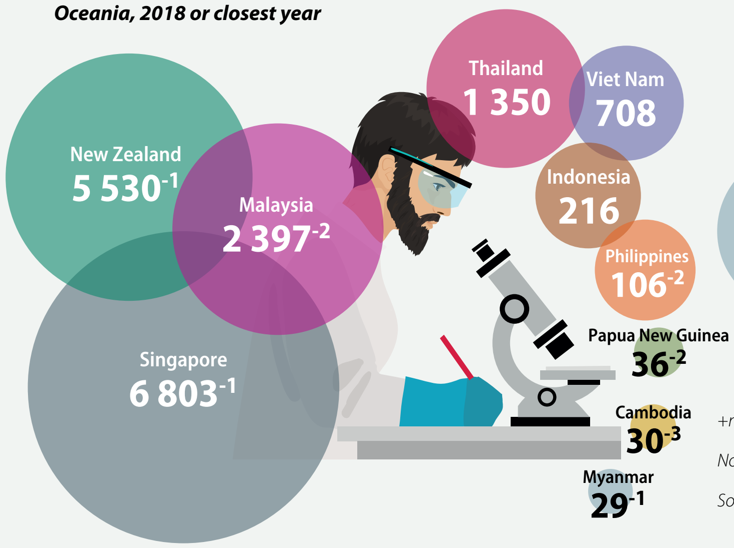
Most countries profiled in the present chapter demonstrate a high level of international scientific collaboration. This trend has even become more pronounced. For instance, at least two-thirds of publications by scientists from Australia, New Zealand and Singapore had foreign co-authors by 2019, double the average (36%) for members of the Organisation for Economic Co-operation and Development (OECD). In Malaysia, the ratio progressed from 39% to 44% of publications between 2015 and 2019.

Notable exceptions to the rule are Indonesia and the Philippines. Between 2015 and 2019, the rate of international collaboration involving Indonesian scientists plummeted from 40% to 17%. This drop may relate to the decision, in 2017, to link assessments of career research excellence for Indonesian scientists to their publication record in international, indexed journals. As Indonesian output has soared (Figure 26.4), the proportion of articles

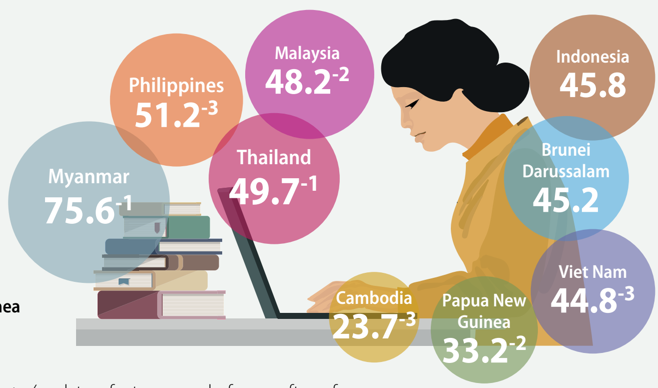
Researchers (FTE) by sector of employment in Southeast Asia and Oceania, 2018 or closest year (%)



Researchers (FTE) per million inhabitants in Southeast Asia and Oceania, 2018 or closest year



Share of female researchers (HC), 2018 or closest year (%)



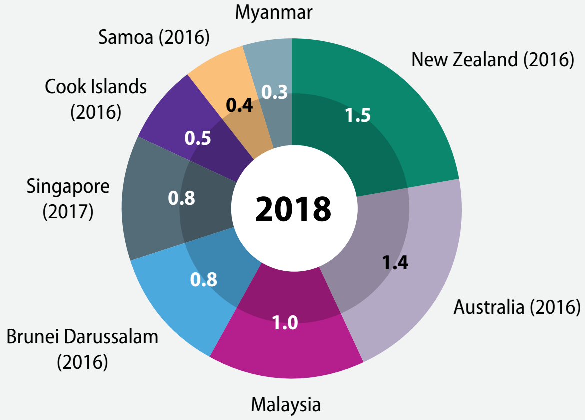
+n/-n: data refer to *n* years before or after reference year

Note: Data are unavailable for some countries.

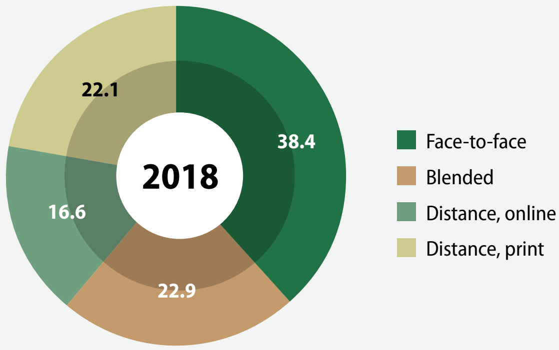
Source: UNESCO Institute for Statistics

Figure 26.3: **Trends in higher education in Southeast Asia and Oceania**

Public expenditure on higher education as a share of GDP in Southeast Asia and Oceania, 2018 or closest year (%)



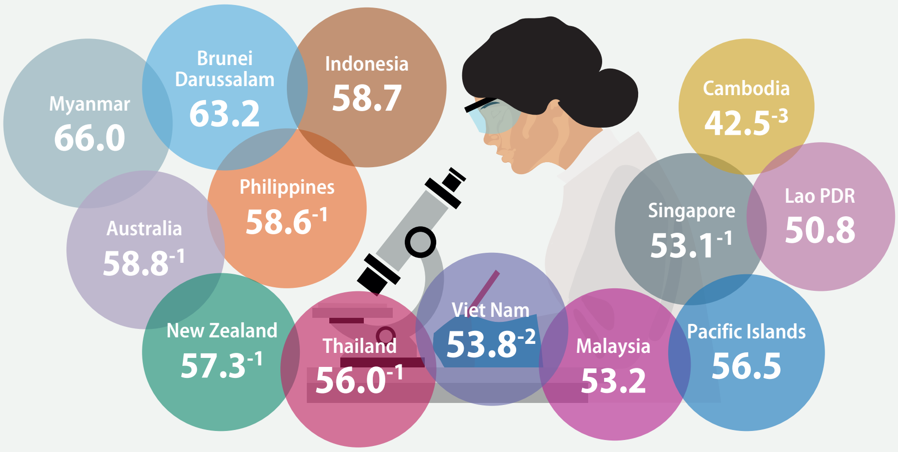
Enrolment by mode of study at the University of the South Pacific, 2018 (%)



Note: Print enrolment does not rely on Internet connectivity for coursework.

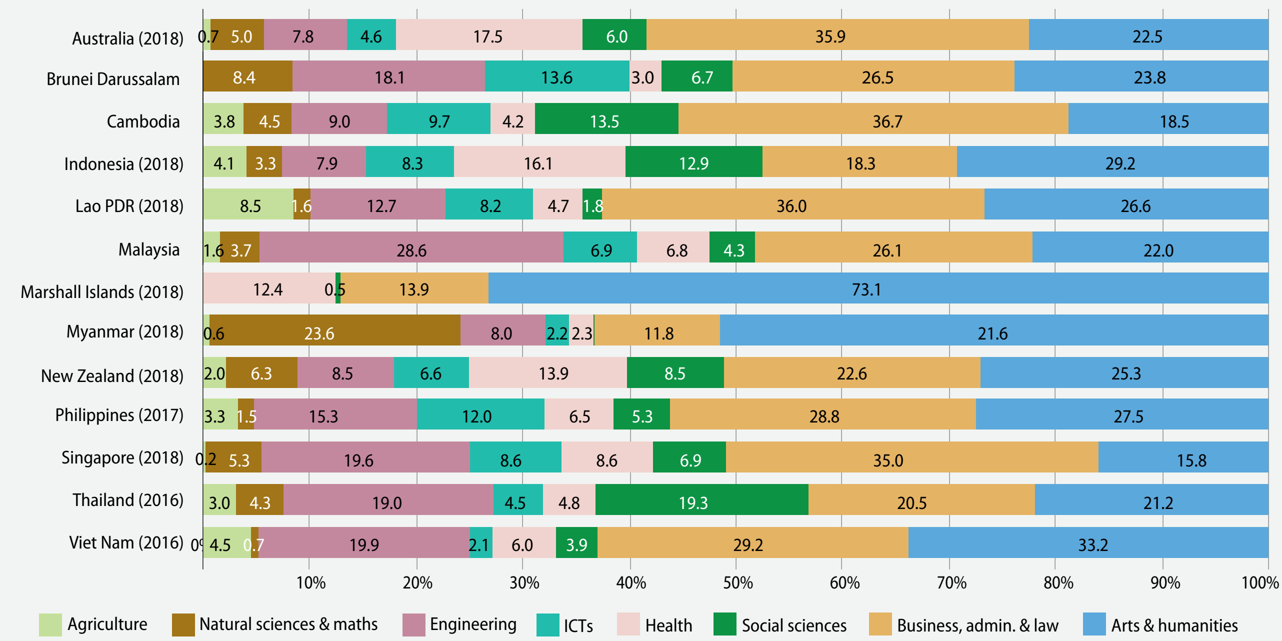
The ASEAN Plan of Action on Science, Technology and Innovation 2016–2025 proposes student exchanges and university twinning programmes with top educational institutions in ASEAN countries.

Share of female tertiary graduates in Southeast Asia and Oceania, 2018 or closest year (%)



Note: Data for the Pacific Islands represent enrolment at the regional University of the South Pacific.

Distribution of tertiary graduates in Southeast Asia and Oceania by programme, 2019 or closest year (%)



Note: The share of students in unspecified programmes amounted to 3.7% in New Zealand and 3.3% in Thailand.

+n/-n: data refer to *n* years before or after reference year

Note: Data are unavailable for some countries.

Source: UNESCO Institute for Statistics; for Pacific Islands: University of the South Pacific (2019) *Annual Report 2018* with foreign collaborators has shrunk, pursuing a precipitous decline from the 2012 peak of 55% for international co-authorship.

In the Philippines, the downward spiral has been visible since 2013 when two-thirds (64%) of scientific publications had foreign co-authors. The trend accelerated between 2018 and 2019, with the share of foreign-affiliated co-authorship shrinking from 49% to 41% within a year. Assuming that much of international scientific collaboration has been driven by ties with the diaspora, this phenomenon may be linked to the adoption of the Balik (Returning) Scientist Act (2018).[8] The Department of Science and Technology, which manages the programme, is looking to persuade 235 Balik scientists to return to the Philippines over the 2018–2022 period (Arayata, 2018).

Adding value to industry

As in other parts of the world, AI and robotics dominate academic publishing on strategic, cross-cutting technologies in Southeast Asia and Oceania, with one exception: Indonesian scientists published equally heavily on both AI and materials science between 2011 and 2019. Along with Brunei Darussalam, Indonesia has shown the greatest leap in publication intensity in materials science since 2012 (Figure 26.5).

The volume of Australia's output on nanotechnology grew by 86% over 2012–2019 and its share of global output from 2.2% to 3.8% between 2011 and 2019. In the region, only Viet Nam recorded a higher growth rate (91%), even if it maintained a 0.3% share of global output.

Viet Nam also recorded the fastest growth rate in biotechnology, with output doubling from 155 (2012–2015) to 313 (2016–2019) publications. In 2019, Vietnamese researchers contributed to 0.68% of global output on biotechnology, up from 0.17% in 2011.

Singapore's output on both biotechnology and bioinformatics receded slightly over the same period. Its share of global output in bioinformatics constricted from 2.0% in 2011 to 0.8% in 2019.

When it comes to adding value to industry, most countries have shown progress, judging from the patent record (Figure 26.6). However, research institutions and businesses have evolved along separate paths over the years. This makes it urgent for countries to improve links and knowledge flows among the different actors in the innovation system.

SUSTAINABLE DEVELOPMENT AGENDA

Moves to close data gaps to improve monitoring

The 2030 Agenda for Sustainable Development is increasingly driving policy-making. The region is vulnerable to the impact of climate change on health, the environment and on natural resource-based industries. This has prompted policy-makers to acknowledge the need to develop capacities in renewable energy. It is also reflected in patterns of relative specialization in scientific publishing (Figure 26.7; see also Chapter 2).

For the larger ASEAN economies, reducing their high level of dependence on fossil fuel remains a daunting challenge. For the Pacific Island countries, solar and wind energy offer the tantalizing promise of greater energy independence and lesser reliance on costly fuel imports.

Ensuring the environmental and economic sustainability of natural resource-based industries is a priority for most countries. This emphasis is particularly acute in countries where much of the population depends on these industries, such as in the case of fisheries in the Pacific Islands and agriculture in Timor-Leste.

In most countries, climate change is stimulating substantial internal debate over how best to respond to the opportunities offered by climate change mitigation and adaptation; there is global demand for technologies and products that can serve these ends. Developing 'green industries' is an explicit objective in Indonesia and the Philippines.

Most countries have developed a strategic plan or performance monitoring framework in relation to the Sustainable Development Goals (SDGs), although few have been able to provide a comprehensive report on their progress. In 2019, available data allowed for an assessment of progress against fewer than half of the SDG indicators (ESCAP, 2020). Reports by the Asia–Pacific SDG Partnership indicate that information is particularly poor for SDGs 9, 12, 13, 14, 15, 16 and 17.

Most of the larger economies are developing strategies to address the SDGs but few have systematically incorporated these goals into their strategic planning for STI. As we have seen, research intensity has dropped among the region's leading countries for this indicator, Australia and Singapore, even as researcher density has surged (Figure 26.2). This equation should logically translate into less available funding per researcher.

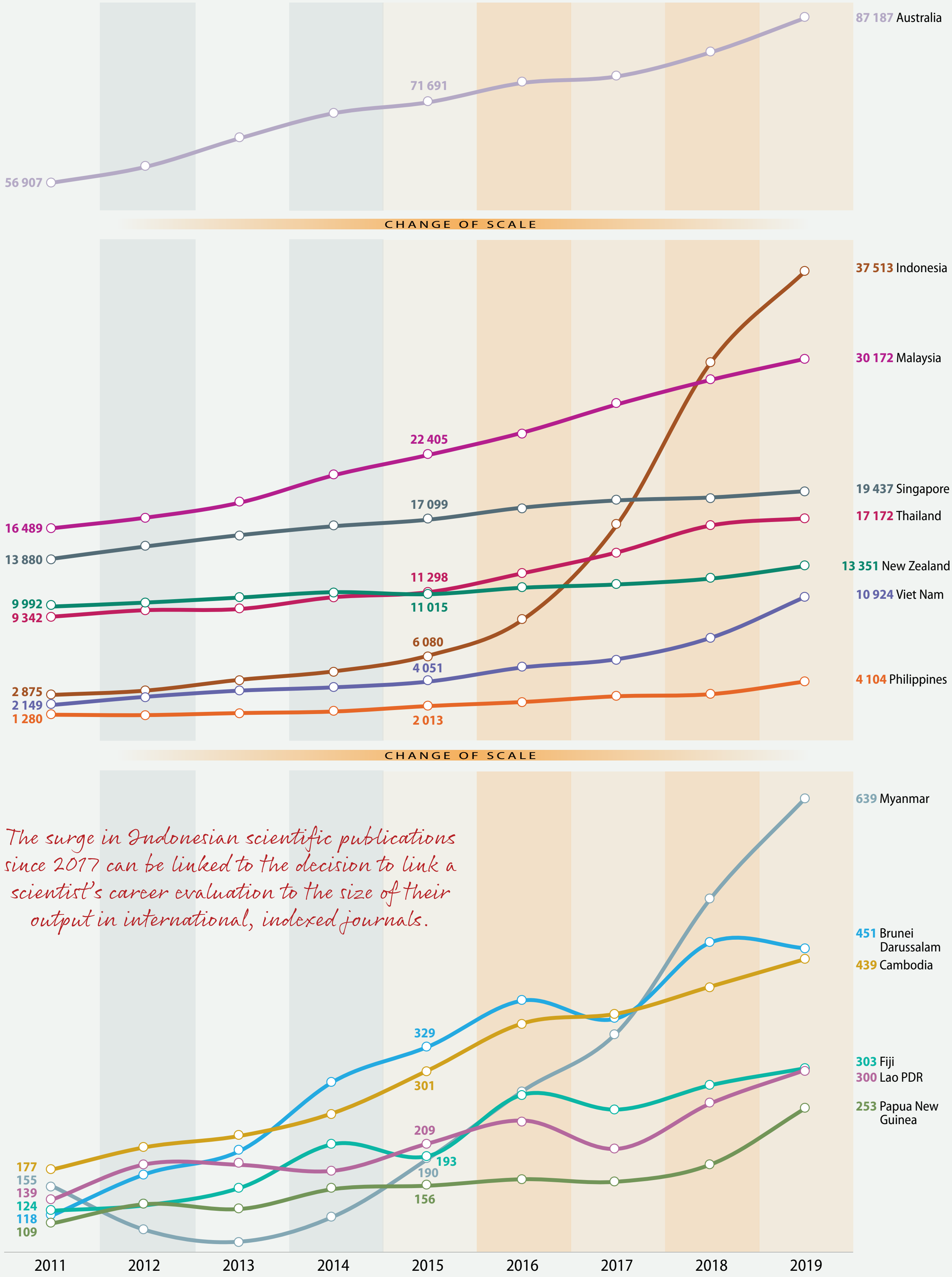
Australia is supporting several initiatives to close data gaps for specific SDGs by strengthening regional and national measuring capacities. For example, Australia provided AU$ 12 million over 2015–2020 to support the *Ten-Year Pacific Statistics Strategy* (2009).

The Australian Bureau of Statistics is also supporting regional statistical capacity development through five ongoing long-term partnerships with national statistics offices in Indonesia, Timor-Leste and Papua New Guinea. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) of Australia has developed a comprehensive set of indicators for Asia and the Pacific, to track national policy efforts towards achieving the SDGs. Australia, itself, would benefit from publishing internationally comparable statistics on domestic human and financial investment in research on a regular basis.

The desire to ensure sustainability is also driving an ambition to shift to knowledge- and skill-intensive products and production processes. This presents a challenge to local education and research systems. New Zealand has been active in promoting the interests of the Pacific Island countries and in promoting the integration of the SDGs into national planning.

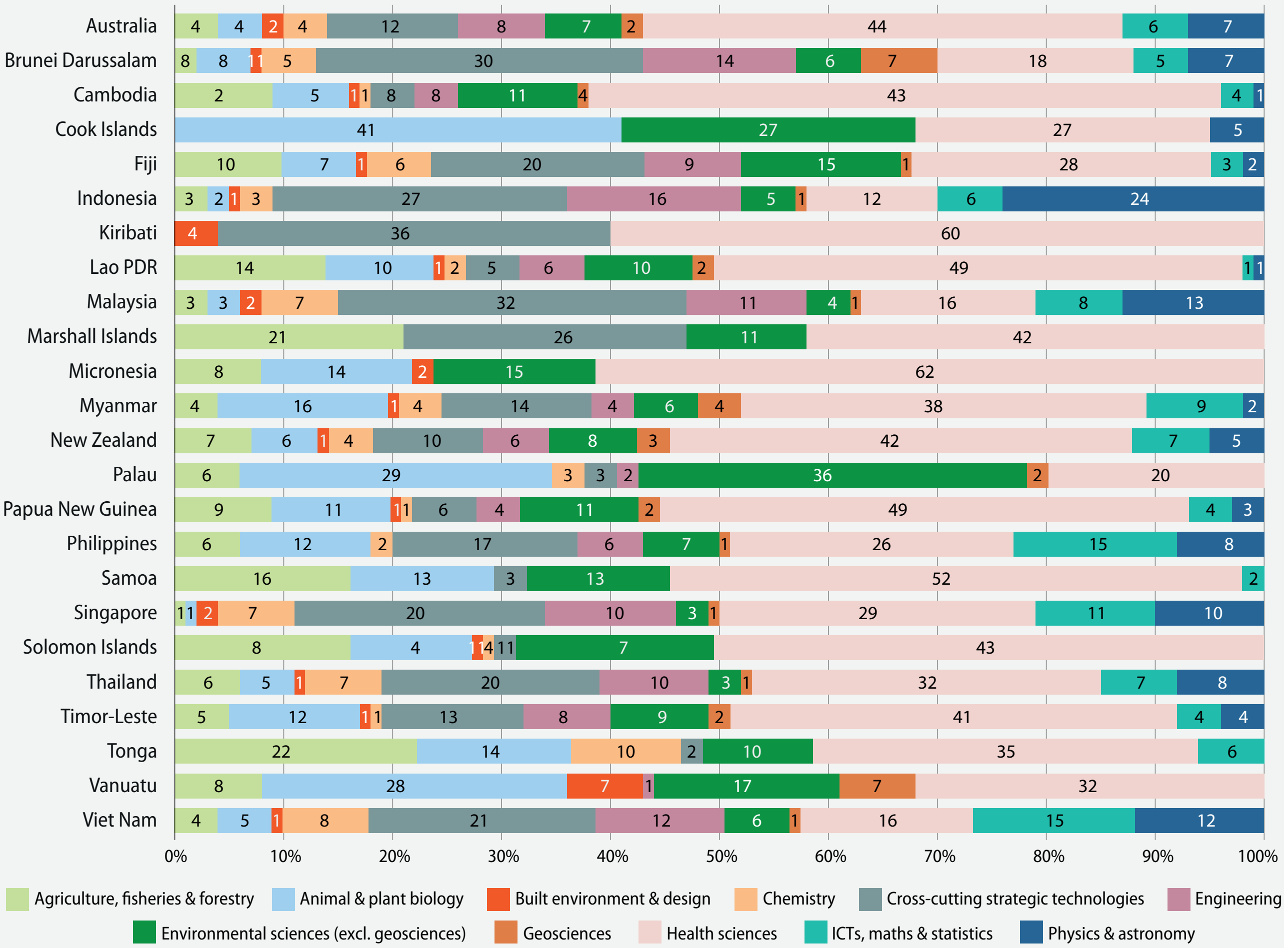
Figure 26.4: **Trends in scientific publishing in Southeast Asia and Oceania**

Volume of scientific publications in Southeast Asia and Oceania, 2011–2019



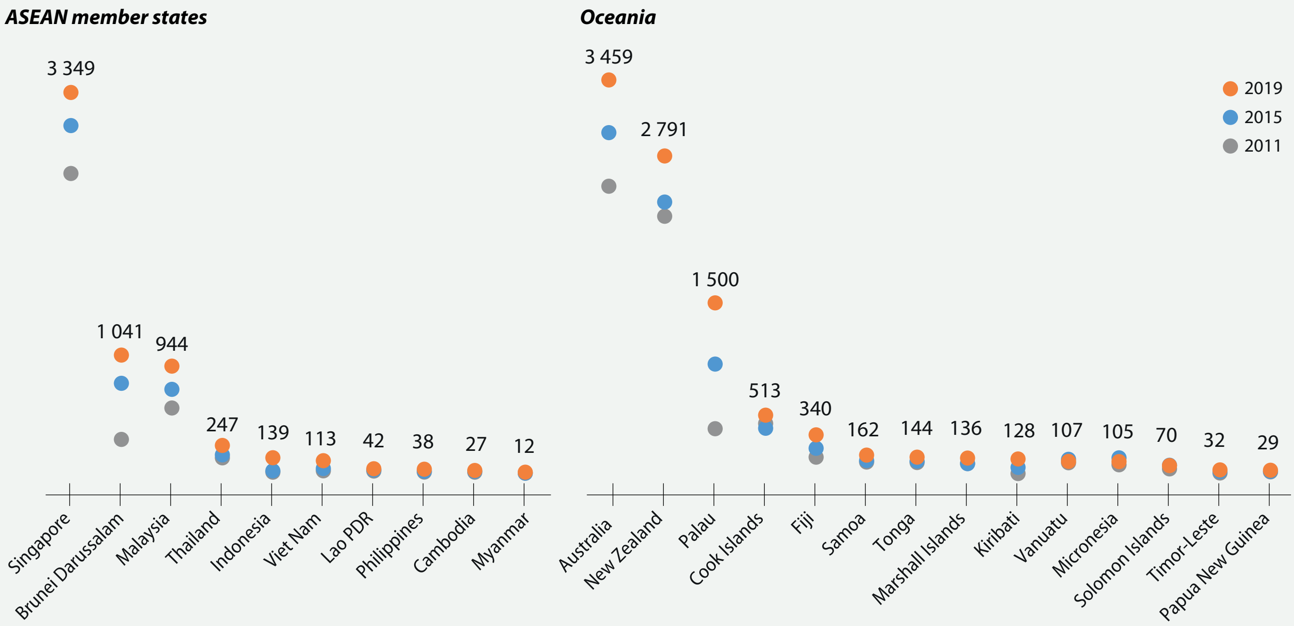
Note: Nauru (14), Niue (10), the Marshall Islands (19) and Tuvalu (19) are not shown, having produced fewer than 20 publications during the period under study. For complete data for all countries, see the statistical annex.

Share of scientific publications in Southeast Asia and Oceania by broad field of science, 2017–2019 (%)



Note: Nauru, Niue and Tuvalu do not feature here, having produced fewer than 25 publications over 2017–2019.

Scientific publications per million inhabitants in Southeast Asia and Oceania, 2011, 2015 and 2019
Data labels are for 2019



Note: Nauru, Niue and Tuvalu do not feature here, having produced fewer than 20 publications over 2011–2019.

Chapter 26

Figure 26.4: **Trends in scientific publishing in Southeast Asia and Oceania…** ***continued***

The average of relative citations during 2014–2016 fell below the G20 average of 1.02 for six countries: Thailand, Malaysia, Indonesia, Vanuatu, Timor-Leste and Samoa.

Seven out of ten publications during 2017–2019 involved international co-authorship for 19 countries. Only Indonesia (18%) recorded international collaboration below the G20 average of 25%.

How has output on SDG-related topics evolved since 2012?

SDGs

Traditional topics in the fields of agriculture and tropical diseases remain priorities but research related to climate, pollution and ecosystems is growing in the region. The Predator-Free 2050 New Zealand initiative is backed by research on invasive alien species that amounts to nearly seven times the average publication intensity. Australia, Fiji, Indonesia, the Philippines and Viet Nam all publish over four times as much as would be expected on the local impact of climate-related hazards and disasters. Pacific Small Island Developing States (SIDS) are conspicuous by their absence from these topics.

Brunei Darussalam, Fiji, Malaysia, Thailand and Singapore are specializing in sustainable energy topics such as photovoltaics, wind or hydrogen energy and smart-grid technologies, with rapid growth observed in other countries, including Viet Nam.

Researchers in Indonesia, Malaysia, the Philippines and Thailand are now publishing 5–9 times more than would be expected on sustainable alternatives to plastic, with Indonesia's output swelling from 6 (2012–2015) to 155 (2016–2019) publications.

As host of the regional University of the South Pacific, Fiji dominates the research output of Pacific SIDS. Despite low numbers, Pacific publishing reflects the national priorities of sustainable use of terrestrial ecosystems and tropical communicable diseases, with signs of growing attention being paid to sustainable agriculture in Papua New Guinea and Vanuatu.

For details, see chapter 2

Top five partners for scientific co-authorship in Southeast Asia and Oceania, 2017–2019 (number of papers)

	1st collaborator(s)	2nd collaborator(s)	3rd collaborator(s)	4th collaborator(s)	5th collaborator(s)
Australia	USA (40 958)	China (36 750)	UK (30 121)	Germany (15 730)	Canada (13 185)
Brunei Darussalam	Malaysia (220)	China (160)	UK (152)	Australia (142)	Indonesia (111)
Cambodia	USA (345)	France/Thailand (248)		UK (246)	Australia (222)
Cook Islands	New Zealand (16)	USA (13)	France (11)	Australia (9)	UK (6)
Fiji	Australia (329)	USA (150)	UK (111)	India (82)	New Zealand (74)
Indonesia	Malaysia (3 633)	Japan (3 548)	Australia (1 805)	USA (1 743)	UK (1 395)
Kiribati	Fiji (10)	USA (8)	Australia (7)	UK (6)	Switzerland (4)
Lao PDR	Thailand (240)	UK (163)	USA (160)	Australia (145)	Viet Nam (124)
Malaysia	UK (4 807)	India (3 851)	Australia (3 741)	USA (3 716)	Indonesia (3 633)
Marshall Islands	USA (6)	Micronesia (5)	Australia/Japan/Palau (3)		
Micronesia	USA (54)	Australia (32)	UK (26)	Canada/France/Germany/India/Japan/Rep. Korea/Saudi Arabia/Spain/Sweden (22)	
Myanmar	Japan (321)	China (291)	Thailand/USA (236)		UK (169)
New Zealand	USA (7 149)	Australia (7 087)	UK (5 605)	China (3 643)	Germany (3 017)
Niue	Australia (6)	Samoa/Vanuatu (4)		Solomon Islands/UK (3)	
Palau	USA (40)	Australia (13)	Japan/UK (12)		New Zealand (7)
Papua New Guinea	Australia (313)	USA (157)	UK (96)	France (70)	India (54)
Philippines	USA (1 503)	Japan (961)	China (723)	UK (693)	Australia (658)
Samoa	Australia (45)	USA (32)	New Zealand (24)	Fiji (17)	UK (11)
Singapore	China (15 327)	USA (10 129)	UK (5 486)	Australia (4 257)	Germany (2 578)
Solomon Islands	Australia (108)	UK (41)	USA (39)	Fiji (19)	France (17)
Thailand	USA (5 742)	Japan (3 704)	UK (3 149)	China (2 577)	Australia (1 980)
Timor-Leste	Australia (59)	Indonesia (19)	Portugal (17)	UK (16)	USA (13)
Tonga	Australia (27)	New Zealand (21)	Fiji (12)	USA (11)	France (8)
Tuvalu	France/USA (4)		Brazil/Fiji/Tonga/UK (3)		
Vanuatu	USA (34)	Australia (33)	France (21)	Canada (16)	Japan/UK (11)
Viet Nam	USA (2 462)	Japan (2 327)	Korea, Rep. (2 302)	Australia (1 881)	China (1 841)

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

AUSTRALIA

No more business innovation than necessary

Australia faces systemic challenges. The country's high dependence on commodity exports, such as minerals and gas, and on a narrow range of markets topped by China lays it open to economic shocks.

A crisis can bring about real policy change. The Covid-19 pandemic has heightened awareness of the risks inherent to Australia's dependence on global value chains for critical resources, prompting renewed debate on the need to redevelop manufacturing industries.

Entrepreneurship will be vital to create new industrial strengths. The past few years have witnessed an influx of venture capital and a growing number of start-ups in the cities of Sydney and Melbourne, in particular, in finance, agriculture, education, food and medical technologies.

There is a strong uptake of mobile Internet, high-speed broadband and cloud technology in Australia but applications of data analytics and AI are still in the early stages. Improving cybersecurity remains a challenge for many firms. According to a 2018 survey, Australian business executives were the least confident in the world about their firms' readiness for the challenges of Industry 4.0 but also the least concerned about impending skill shortages (Deloitte, 2018). Few established Australian firms see technology as a key differentiator or source of competitive advantage.

Demand for knowledge is strong among large mining and agricultural firms and in some segments of industry, such as medical instruments, but they remain the exception, rather than the rule. Without greater demand for new knowledge from businesses, government policies to raise levels of collaboration will most likely have little impact.

A *Performance Review of the Australian Innovation, Science and Research System* (2016) by Innovation and Science Australia (ISA)[9] concluded that Australia's relatively poor performance in knowledge transfer and application 'may be partially explained by Australia's low rates of collaboration and mobility among research institutions and businesses compared to the best innovation nations.'

This would suggest that businesses are engaging in no more innovation than is necessary to remain viable. Universities and research organizations do have strategies in place to foster collaboration with business and they have earned more income over the past decade from consultancies, contracts and collaboration. However, there has been no increase in income from active licenses, options and assignments (Office of the Chief Economist, 2018).

A focus on adapting existing technologies

With a number of world-class universities and medical research institutes, not to mention the flagship CSIRO, Australia has developed a high-performing research system. However, compared to the size of the economy, Australia records a relatively modest level of international patenting and high-tech exports, suggesting that more needs to be done to promote innovation and commercialization (Figure 26.6).

Business funded about 4% of academic R&D in Australia in 2018, slightly below the OECD average (5.8%). Few Australian firms active in innovation collaborate with research organizations: at 2.9% over 2014–2015, this was the lowest level in the OECD. About one-fifth collaborate with other innovation-active Australian firms, particularly through customers and suppliers (ABS, 2018).

As the Australian economy is open to international competition, amplified by Internet-based trade, a growing share of firms (currently about half) are innovators. Most of this innovation involves adapting existing technologies, rather than developing new ones. Over 2017–2019, innovation-active firms outgrew other types of enterprise for sales, value-added output, employment and revenue, particularly when they collaborated as part of the innovation process.[10]

A commercial focus stand-in for long-term strategy

Between 2007 and 2020, there were ten successive federal ministers with titular responsibility for science. With no long-term strategic plan nor bipartisan support, science-related policies and programmes have changed frequently. The top representative bodies – the Australian Academy of Science, Universities Australia and Science and Technology Australia – have all deplored this lack of a strategy and the limited support for research.

In December 2015, the government announced a *National Innovation and Science Agenda* (NISA) to foster a whole-of-government approach to science and research priorities. It outlines initiatives worth AU$ 1.1 billion, to be implemented over four years, in four areas: culture and capital, collaboration, talent and skills and government as an exemplar (Table 26.1).

The ISA review suggested that Australia had missed out on opportunities to innovate. NISA aligns with its findings, insofar as it seeks to catalyse a 'cultural shift' to encourage innovation and support risk-taking.

In 2017, the government expressed its intent, in a National Science Statement, to develop a holistic and strategic approach to science, innovation and entrepreneurship. No such approach has since been developed, perhaps owing to a change in leadership.

Following extensive consultations, ISA proposed a strategic plan for innovation in 2017, entitled *Australia 2030: Prosperity through Innovation*.

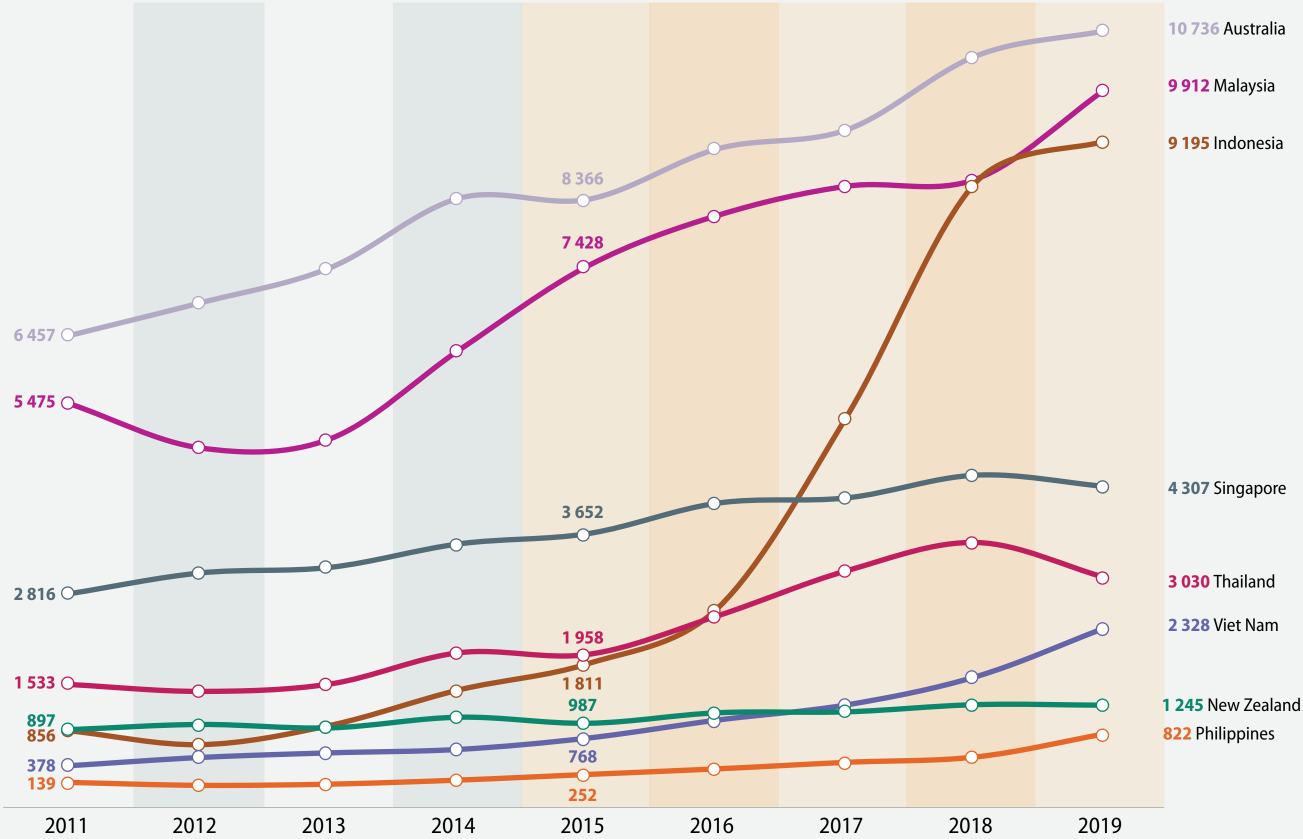
In its official response, the government signalled its support for a number of the plan's recommendations, such as that of benchmarking the effectiveness of applications of digital technologies in service delivery and establishing protocols, including data rights protections, to maintain 'healthy' competition in knowledge-intensive industries (Govt of Australia, 2018).

The government did not, however, support the recommendation to undertake a review of vocational education and training with a focus on its responsiveness to automation, innovation and new technologies. In its response, the government expressed willingness to review the impact of reforms introduced over 2016–2018 in the vocational

Figure 26.5: Trends in scientific publishing on cross-cutting strategic technologies in Southeast Asia and Oceania

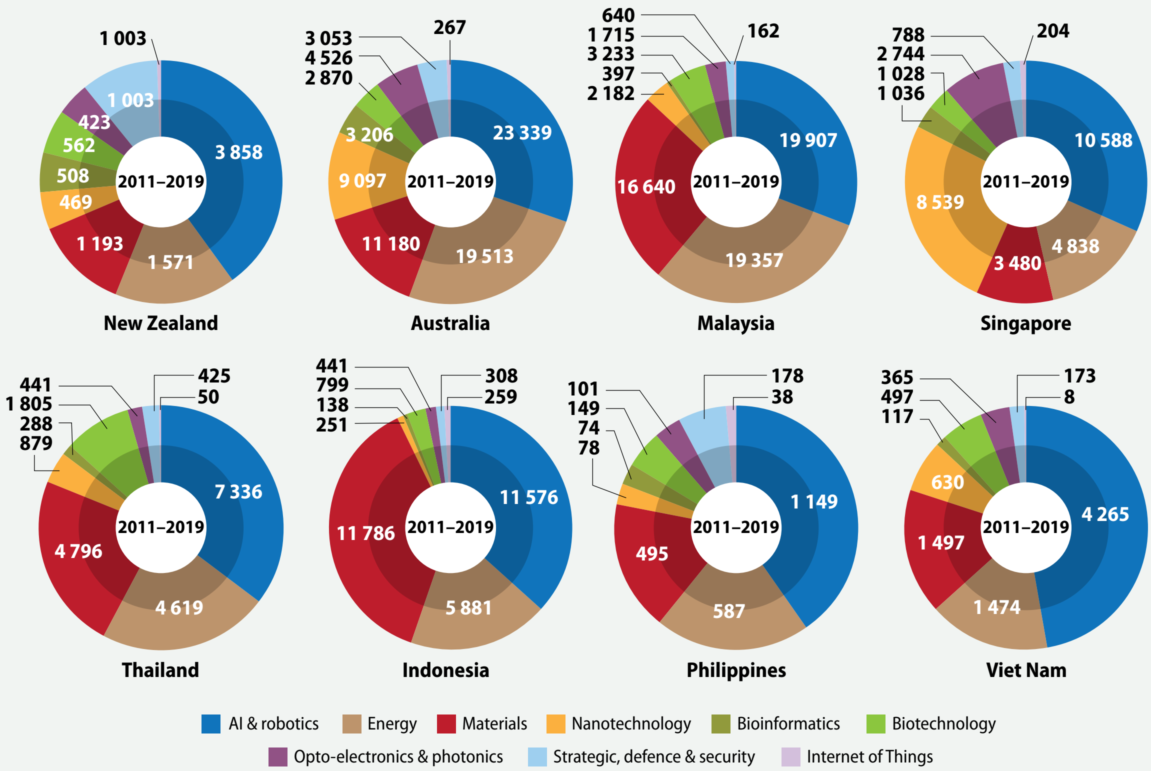
Volume of scientific publications on cross-cutting technologies by top performers in Southeast Asia and Oceania, 2011–2019

Among countries with at least 1 000 publications in this broad field



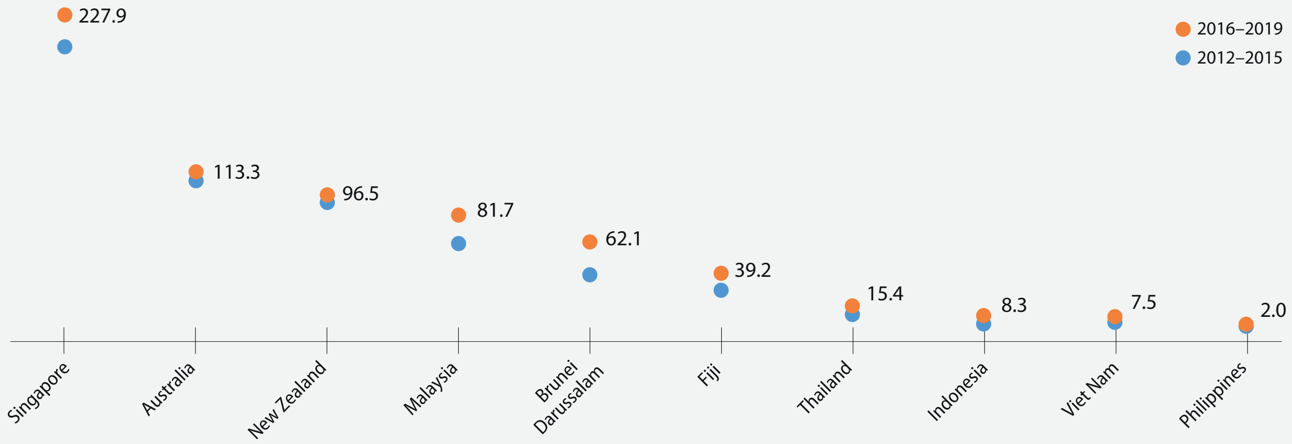
Scientific publications on cross-cutting strategic technologies by topic in Southeast Asia and Oceania, 2011–2019

Among countries with at least 1 000 publications

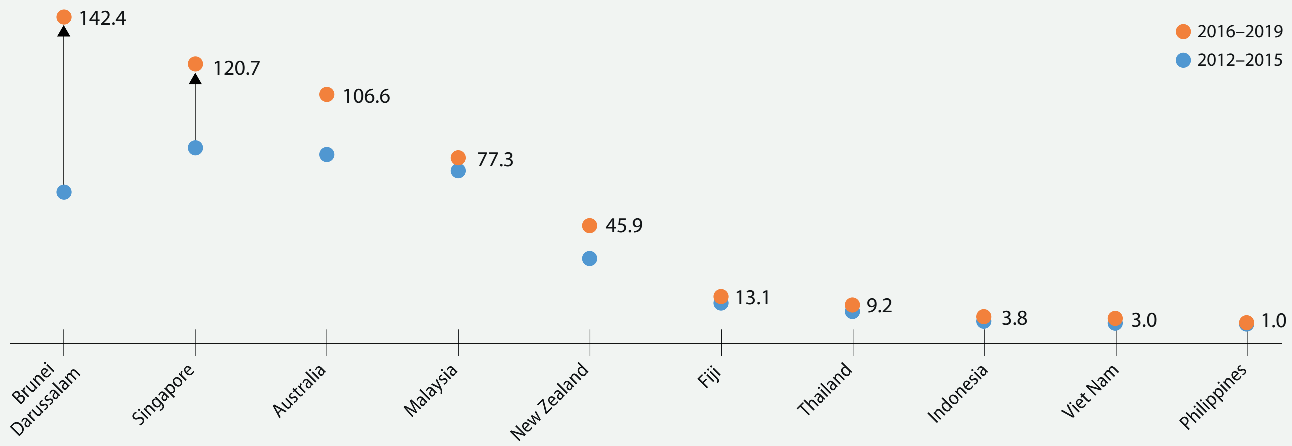


Note: Blockchain technology is excluded due to the emergence of this topic in 2018.

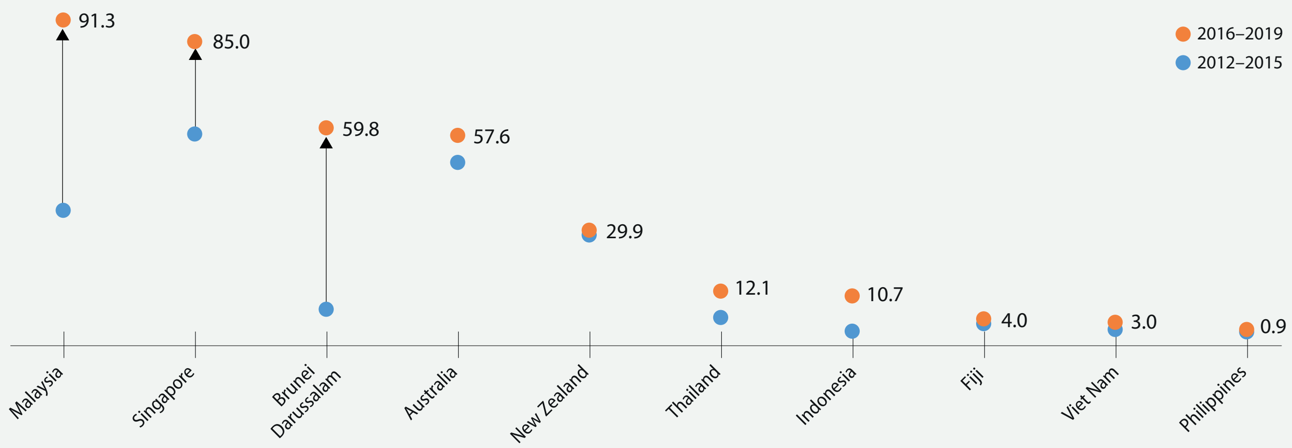
Top 10 countries in Southeast Asia and Oceania by publication intensity on AI & robotics, 2012–2015 and 2016–2019
Among countries with at least 10 publications on this topic over the period under study
Data labels are for 2016–2019



Top 10 countries in Southeast Asia and Oceania by publication intensity on energy, 2012–2015 and 2016–2019
Among countries with at least 10 publications on this topic over the period under study
Data labels are for 2016–2019



Top 10 countries in Southeast Asia and Oceania by publication intensity on materials science, 2012–2015 and 2016–2019
Among countries with at least 10 publications on this topic over the period under study
Data labels are for 2016–2019



Note: The broad field of cross-cutting strategic technologies encompasses AI and robotics, bioinformatics, biotechnology, blockchain technology, energy, Internet of Things, materials, nanoscience and nanotechnology, opto-electronics and photonics and strategic, defence and security studies. The growth rate was calculated as the number of publications over 2016–2019 divided by the number of publications over 2012–2015 to buffer the variability among individual years. See the statistical annex for complete data for all countries, freely available from the *UNESCO Science Report* web portal.

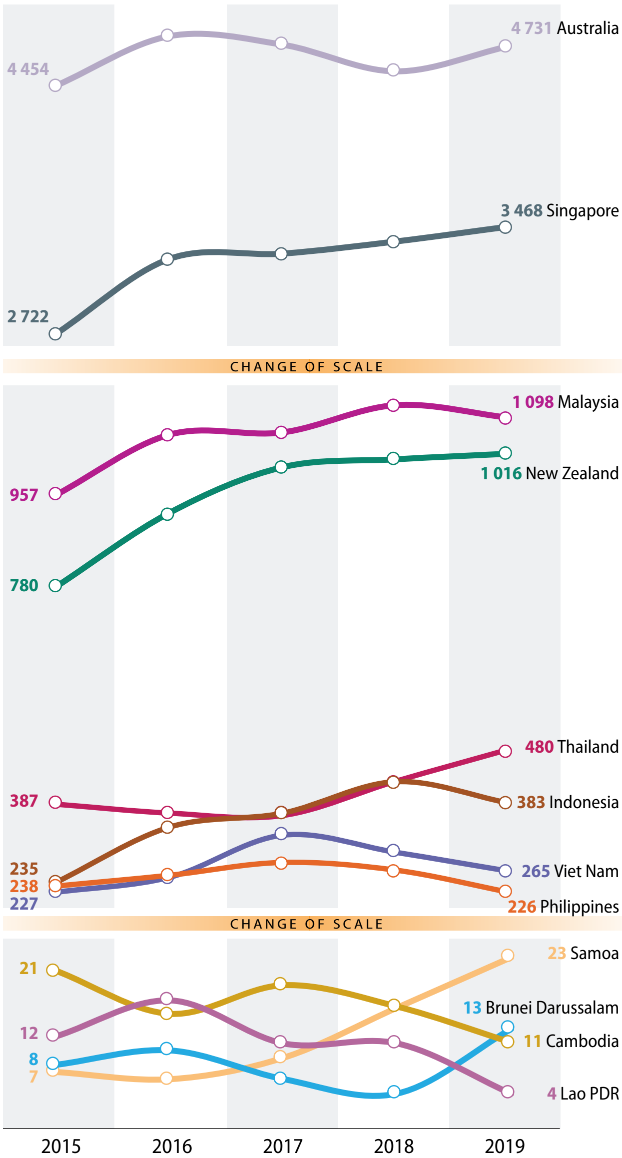
Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

Chapter 26

education and training sector, when the government (Govt of Australia, 2018):

- commissioned a review of the National Vocational and Education Training Regulator Act (2011);
- established a Skilling Australians Fund to support apprentices and trainees; and
- launched the Vocational Education and Training Student Loans programme in January 2017, which offers loans to trainees in areas with skills shortages, in particular.

Figure 26.6: **Number of IP5 patents granted to inventors from Southeast Asia and Oceania, 2015–2019**



Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China. Micronesia, Myanmar, Nauru, Niue, Timor-Leste, Tonga and Tuvalu received no IP5 patents during the period under study. Palau and the Solomon Islands received one patent each during the period under study, in 2017 and 2015, respectively. For other countries not featured here, the numbers were: Marshall Islands (21), Kiribati (9), Cook Islands (6), Fiji (7) and Vanuatu (4).

Source: PATSTAT, data treatment by Science-Metrix

The mechanisms through which institutions can provide advice to government have changed since 2015. A National Science and Technology Council was announced in 2018 to replace the Commonwealth Science Council, formed in 2014, which itself had supplanted the Prime Minister's Science, Engineering and Innovation Council. As a result, ISA's own mandate has become unclear.

The most consistent aspect of policies over the past few years has been to emphasize the role of markets as the key tool for allocating resources. This is demonstrated by the near-total reliance on tax concessions to stimulate business R&D, consistent support for the commercialization of public-sector knowledge and the priority given to 'mission-oriented', as opposed to curiosity-led, research.

Science publishing outperforming investment

The combined research output of 39 universities and the CSIRO has enabled Australia to maintain a strong share of global scientific publications (3.3% in 2019) that are also highly cited (Figure 26.4). This is, in part, the result of a policy drive to monitor and reward research performance at the department and university level (ARC, 2019). Australia ranks sixth in the OECD for its publication intensity.

However, overall, research expenditure has declined over the past few years to well below the OECD average of 2.37% in 2017. The mining and manufacturing sectors are spending less on R&D and there has been little or no growth in public research expenditure. Over 2017–2018, industrial R&D accounted for just over half of GERD, about 30% of which concerned the services sector. Government research expenditure has increasingly targeted the university sector, which accounted for about 30% of GERD by 2017–2018 (ABS, 2019).

The 2019 research budget was consistent with earlier years, boosting funding for medical research but providing little or no increase for most other research fields, or for the CSIRO. New funding has been directed towards the Medical Research Future Fund (MRFF, est. 2015), which is being used to implement major initiatives identified in the *National Health and Medical Industry Growth Plan* (2018). In July 2020, the MRFF achieved its AU$ 20 billion target for reaching maturity.

Unlike most research funding schemes, the government decides on the MRFF's funding allocations on the basis of advice from the Australian Medical Research Advisory Board and the priorities of the *Australian Medical Research and Innovation Strategy 2016–2021*, as well as the *Australian Medical Research and Innovation Priorities 2018–2020*.

New priority: a National Space Agency

A renewed *National Research Infrastructure Investment Plan* was announced in 2018 with AU$ 1.9 billion for a 12-year period. However, part of these funds was transferred to other programmes in 2019.

Other budgets have seen significant cuts since 2015. The Education Investment Fund (est. 2008), which had financed strategic infrastructure development in the higher education sector, was discontinued in 2019. About AU$ 3.9 billion was reallocated to the new Emergency Response Fund, which focuses on national disaster relief. In December 2017, the government announced cuts of AU$ 2.2 billion from projected funding for universities through a two-year freeze in commonwealth grants funding.

One sector to have benefited from a spending boost is the space industry. In 2018, the government established a National Space Agency endowed with AU$ 260 million. The last two annual government budgets have provided additional funding for the agency.

The *Australian Civil Space Strategy 2019–2028,* meanwhile, aims *to* stimulate private-sector initiatives, such as in telecommunications.

Energy habits inhibiting climate action

Australia's progress towards the SDGs lags behind most other advanced economies, particularly with regard to climate action (ESCAP, 2020).[11] Australia's high use and export of fossil fuels is the major factor. Although climate-related issues are included in the set of Australia's science and research priorities, these priorities have not been updated since 2015.

With large areas of dryland agriculture vulnerable to lower rainfall and extensive areas of fire-prone forest, the cost of inaction is likely to be dire in Australia. Most of the country has been in a severe drought since 2017. In 2019, wildfires blanketed Sydney in toxic fumes for months (see photo, p. 674).

The government has consistently rejected proposals for taxing carbon emissions as a means to achieving Australia's 26% emissions reduction target under the *Paris Agreement* (2015). Instead, it has developed a form of 'direct action' and allocated modest funding (AU$ 4.5 billion over 15 years) to a Climate Solutions Package.

Part of this package is a *National Electric Vehicle Strategy* designed to co-ordinate government, industry and community action in diffusing this technology. The strategy is expected to be financed by grants from the Australian Renewable Energy Agency and the Clean Energy Finance Corporation.

These two funding bodies are also to provide funding of AU$ 370 million to support initiatives under the *National Hydrogen Strategy* announced in 2019. One of the most significant initiatives is 'Snowy 2.0', a large project to build a pumped hydropower storage facility under the existing Snowy Mountains Hydro-electric Scheme. This is expected to add 2 000 MW of energy generation capacity and serve as a battery back-up for the National Electricity Market, enabling greater use of solar and wind electricity.

In 2016, the Australian government announced plans to establish the Clean Energy Innovation Fund (Turpin, 2017). According to its *2019–2020 Annual Report,* the Clean Energy Finance Corporation, which manages the fund, had committed AU$ 85.7 million to financing early-stage clean-tech companies by June 2020.[12] It made its first investment in the same month, co-funding the start-up Goterra, which combines robotics with fly larvae to tackle food waste.

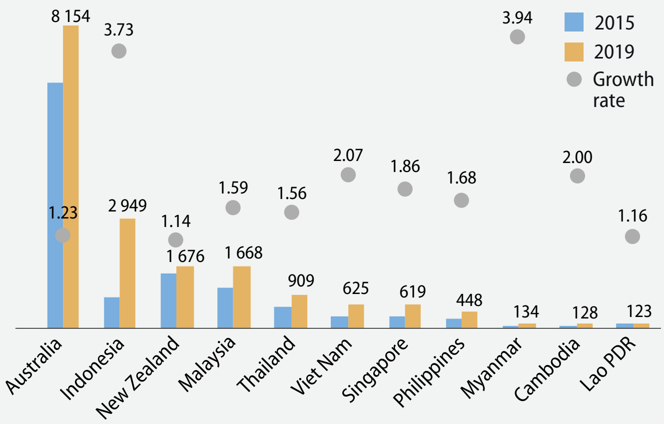
State and federal policies with regard to climate and energy policy tend to diverge. In 2017, the government of the State of South Australia commissioned Tesla to build the world's largest lithium ion battery to store renewable energy. The battery is paired with a wind farm. This project placed South Australia at odds with the federal minister of energy, who was in favour of a single national target. However, South Australia and other states have argued that the federal government's targets are not sufficiently ambitious (Turpin, 2017).

Figure 26.7: **Trends in publishing on SDG-related topics in Southeast Asia and Oceania**

Top ten topics by number of countries in Southeast Asia and Oceania with an increase in output of at least 50% over 2012–2019
Among topics with at least 100 publications over 2011–2019

Number of countries	Research topic
10	Sustainable use of terrestrial ecosystems
9	Status of terrestrial biodiversity
7	Sustainable transportation
6	Agro-ecology
6	Biofuels & biomass
6	Eco-industrial waste management
6	Human resistance to antibiotics
6	Impact on health of soil, freshwater and air pollution
6	Smart-grid technologies
6	Wastewater treatment, recycling and re-use

Growth in scientific publishing on the sustainable use of terrestrial ecosystems in Southeast Asia and Oceania, 2012–2019
Among countries with at least 200 publications on this topic over 2011–2019; data labels are for 2019



Note: The growth rate is calculated as the number of publications from 2016–2019 divided by the number of publications from 2012–2015. For details, see Annex 4.

Source: Scopus (including Arts, Humanities and Social Sciences); data treatment by Science-Metrix

In 2017, the Chief Scientist, Dr Alan Finkel, recommended developing 'a whole-of-economy emissions reduction strategy for 2050' to be agreed upon by the Australian state and territorial governments, in preference to extending the existing renewable energy target beyond 2020 (Finkel, 2017).

Taskforce for international Industry 4.0 collaboration

In 2016, the government released its *Smart Cities Plan*, recognizing that Australia's future prosperity depended on the capacity of its cities to attract, retain and nurture increasingly mobile talent and organizations to foster innovation and growth. A Cities Reference Group was established in 2017 to provide a forum for the government to consult with stakeholders from academia, industry, the research community and non-government groups.

The Department of Industry, Innovation and Science has developed a strategy for transitioning to Industry 4.0, entitled *Australia's Tech Future* (2018). Some industry commentators have suggested that it merely repackages existing programmes. The strategy covers seven broad themes: skills, inclusion, digital government, digital infrastructure, data, cybersecurity and regulation. It proposes establishing 'testlabs' at five universities, to help businesses transition to 'smart' factories. It also creates an apprenticeship development programme with funding from the Skilling Australia Fund and the Australian Industry Group.

The government has set up a working group to pilot the transition to Industry 4.0. Led by leaders of industry, the Prime Minister's Industry 4.0 Taskforce (est. 2016) promotes collaboration with industry groups in Germany and the USA. This taskforce followed on the heels of the announcement of a collaboration between the German Plattform Industrie 4.0 group and US Industrial Internet Consortium to set global standards for the Internet of Things.

The Digital Transformation Agency (est. 2015) is using digital technologies to improve government services.[13]

Table 26.1: **Status of implementation of Australia's *National Innovation and Science Agenda***
Selected initiatives

Measure	Status of implementation
Tax incentives for angel investors	• Tax Laws Amendment Bill (2016) includes a 20% tax offset for investment in qualifying early-stage companies
New arrangements for venture capital investment	• new measures in place since 1 July 2016 include doubling the maximum fund size of Early Stage Venture Capital Limited Partnerships to AU$ 200 million and removing restrictions on foreign venture capital
Establish CSIRO Innovation Fund worth AU$ 200 million to co-invest in new spin-off companies and existing start-ups	• launched in December 2016 and attracted AU$ 232 million in its first year, when the fund made nine investments
Establish Biomedical Translation Fund to co-invest, with the private sector, AU$ 250 million to increase capital available for commercializing medical research	• launched in August 2016; active as of early 2021
Innovation Connections to connect SMEs to researchers	• Active as of early 2021; enables businesses in five priority growth sectors to apply for a service report to understand research needs and for a grant to undertake research projects. • the priority sectors are: advanced manufacturing; cybersecurity; food and agribusiness; medical technologies and pharmaceuticals; and mining equipment, technology and services
Cyber Security Growth Centre to create business opportunities in cybersecurity	• AustCyber launched in 2017, one of six government Industry Growth Centres • AustCyber has developed the Cyber Security Sector Competitiveness Plan 2020 and the first national skills-based cybersecurity qualifications
Developing STEM skills among youth	• funding allocated to 15 STEM-focused initiatives, such as the Digital Technologies Massive Open Online Courses • evaluation submitted to the Department of Education in January 2020 found that most initiatives had achieved their objectives*
Establish: • Innovation and Science Australia statutory board, to improve policy focus on innovation • Digital Transformation Office to improve tech procurement by SMEs • Digital Marketplace to support government agencies and digital experts in doing business	• Innovation and Science Australia is active; developed Driving Effective Government Investment in Innovation, Science and Research in January 2021 • Digital Transformation Office launched in January 2015, replaced by Digital Transformation Agency in October 2016 • Digital Marketplace launched in August 2016; by January 2021, AU$ 2.894 billion had been contracted through the platform
Launch Data61	• launched in July 2016 • conducted research on computer modelling of Covid-19 in 2020; supported development of an AI-based alert and intelligence system to help the Indonesian government tackle the coronavirus pandemic

* See: https://tinyurl.com/eval-aus-schools-initiatives

Note: The Department of Industry, Innovation and Science is responsible for the formal monitoring and evaluation of NISA.

Source: Department of Industry, Science, Energy and Resources, see: https://tinyurl.com/Aus-boosting-innov-science; CSIRO (2018) Investment in CSIRO innovation fund boost jobs and innovation. Commonwealth Scientific and Industrial Research Organisation, 12 September

The Australian Data and Digital Council (est. 2018) has been entrusted with co-ordinating the introduction of digital services and standards across the central and state governments. In response to calls from industry bodies for a strategic approach to the digital transformation, the prime minister set up a Digital Technology Taskforce in 2019 to ensure that Australia is a leading digital economy by 2030.

The *JobMaker Digital Business Plan* (2020) includes initiatives to reduce regulation, encourage technology uptake and improve digital skills, supported by the AU$ 1.5 billion *JobTrainer* fund. Australia's *Cyber Security Strategy* (2016) has a particular focus on training cybersecurity professionals, with funding of AU$ 230 million over four years.

In 2018, the government established a Small Business Digital Taskforce in 2018, with funding of AU$ 3 million, to advise small businesses on digital best practices, since the transformation to Industry 4.0 will be particularly challenging for them.[14]

The Australian Council of Learned Academies has, meanwhile, received funding from the Australian Research Council to assess the potential socio-economic, environmental, ethical and cultural impact of AI and the Internet of Things.

BRUNEI DARUSSALAM

Expanding non-oil sectors on the agenda

The economy wavered between recession and low growth between 2015 and 2018. Unplanned maintenance and repairs in the oil and gas sector in 2018 saw exports fall, even as oil prices rose (ADB, 2019d). The oil and gas sector remains central to the economy, although its share of GDP did decline from 62.7% to 55.7% over 2014–2019 (Govt of Brunei Darussalam, 2020).

The long-term *Wawasan Brunei 2035* (2007) outlined plans to diversify the economy, upskill the labour force, reduce unemployment – and expand production of oil and gas up to 650 000 barrels of oil equivalent per day.[15]

A cornerstone of the diversification agenda is the Bio-Innovation Corridor, formerly known as the Brunei Agro-Technology Park. Launched in 2014, this industrial park specializes in halal food manufacturing. It was intended for the park to provide 28 000 employment opportunities but, in early 2020, the sultan and prime minister indicated that the project had missed its targets, owing to the failings of planners (Abu Bakar, 2020).

Little visibility on future for renewables

Another goal of *Wawasan Brunei 2035* is to raise the share of renewables in total power generation. The government committed to a 30% share by 2035 in its *Nationally Determined Contribution 2020* to the United Nations Framework Convention on Climate Change (UNFCCC). There is little evidence of progress on this front; as of 2019, Brunei Darussalam had a single solar energy plant, the 1.2-MW Tenaga Suria Brunei plant, commissioned in 2010. A study found that this plant had saved the government US$ 1.7 million and reduced carbon dioxide emissions by 8 000 tonnes over 2011–2017. The *Energy White Paper* was published in 2014 but neither a regulatory framework, nor a formal policy has since been developed for renewable energy (ADB, 2019d).

Renewables are not mentioned in the *Eleventh National Development Plan (2018–2023)*, the primary objective of which is to expand the non-oil economy. It identifies five priority areas for development: halal products and services; innovative technologies and creative industries, including digital media, the Internet of Things and biotechnology; business services; tourism; and downstream industries of oil and gas. A total of BND 3.5 billion (*ca* US$ 2.6 billion) is to be invested over five years for the plan's implementation. The document states that projects to build infrastructure have been launched but does not provide details.

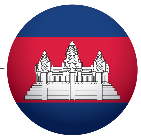
Brunei Darussalam's Research and Development Fund gives priority to research activities with high commercial value. The *Eleventh National Development Plan* allocated roughly 1% of the budget to science, technology, research and innovation.

Plans for a 'smart nation'

The Digital Economy Council dates from mid-2019. It released its *Digital Economy Masterplan 2025* in June 2020. The masterplan defines a 'smart nation' as being characterized by a vibrant, diversified competitive economy in which citizens enjoy a high quality of life and environmental sustainability is assured.

The mission of the *Digital Economy Masterplan* is to create a 'smart nation' by digitalizing industry and government services, expanding the digital economy and supporting human resources development, such as by updating curricula. The document outlines plans to conduct an assessment of industrial readiness for Industry 4.0 and to launch a pilot projects showcasing Industry 4.0 technologies. There are also plans to develop a 'digital identity ecosystem' in government, strengthen cybersecurity and launch a digital data policy.

CAMBODIA



Measures to close skills gaps and boost SMEs

Since 2015, Cambodia has maintained a growth rate above 7%. Between 2012 and 2018, the proportion of those living below the National Poverty Line dropped from 19% to 13% (ADB, 2020). The Cambodian economy is attracting the second-highest level of FDI in the region after Singapore (Figure 26.1). However, more than one-third of these inflows go to the banking sector, contributing to disproportionate levels of investment in construction and real estate (ADB, 2019a).

In 2021, Cambodia is expected to lose free trade access to the markets of the European Union (EU) and USA. This will impact revenue from garment exports, in particular. In an effort to reduce dependence on this sector, the government has been developing industries such as electronics and automotive component assembly.

Key barriers to diversifying the economy include inadequate infrastructure and a poor business enabling environment. Relatively high prices for electricity have held back SME growth.[16] Little progress has been made in implementing the *Industrial Development Policy 2015–2025*, which sets a number of targets for electrification (Govt of Cambodia, 2019).

In March 2019, the prime minister presented 17 reforms to improve competitiveness, support SMEs and attract FDI. The proposed measures include lower logistics costs and electricity tariffs, stronger labour laws and better access to finance for SMEs.

Another barrier to diversifying the economy is the skills gap emerging in most sectors. In 2016, three-quarters of respondents to a survey of 21 enterprises working in information technology (IT) and related areas reported difficulties in hiring competent staff, particularly project managers and software engineers (Markova and Wray, 2016).

A Skills Development Fund was established in 2018. It targets five priority sectors: manufacturing, ICTs, electronics, tourism and construction. It is funded by a 1% levy on company payrolls, which a firm can then claim back by invoicing the government (ADB, 2018). As of May 2020, the Skills Development Fund had received nearly US$ 10 million from the Asian Development Bank (ADB) for its operational activities.[17]

In 2019, the ADB approved a loan of US$ 60 million for skills training through to 2024. The government is using the Entrepreneurship Development Fund (est. 2019), an SME Bank (est. 2020) and tax incentives to encourage local content and SME development in the priority sectors.

The uptake of Industry 4.0 technologies in Cambodia will require that education and training incorporate programming, cognitive and machine learning skills and other disciplines.

Research intensity among lowest in region

Cambodia's first *Science and Technology Master Plan 2014–2020* outlines an ambition to upskill the workforce through technical and vocational education and training, so as to steer the economy towards value-added activities (Turpin *et al*., 2015). This ambition has not been reflected in the gross enrolment ratio, which remained stable between 2015 and 2017.

The government approved its *National Science, Technology and Innovation Policy 2020–2030* in December 2019. The policy sets out to lay the foundations for an innovation ecosystem that is conducive to sustainable, inclusive development.

Cambodia's research intensity is among the lowest in the region (Figure 26.2). The largest share of expenditure (35%) comes from abroad, followed by the private non-profit sector (22%), an unusually high share for any country. This reflects the fact that foreign donors, such as the World Bank and Asian Development Bank, are key financiers of R&D. The main recipients of funds are the Cambodian Agricultural Research and the Development Institute of the Ministry of Agriculture, Forestry and Fisheries.

Significant progress in Internet penetration

The *Cambodian ICT Masterplan 2020* (2014) sought to create an 'ICTopia' in Cambodia. Although it is unlikely to reach its target of expanding Internet access to 70% of Cambodians by 2020, progress has been quite remarkable since 2015, when about 6% had access to Internet (Figure 26.1).

Increasing Internet penetration will be essential to realize Cambodia's *ICTopia 2020* goal of 'building an intelligent nation' by ensuring that digital development is inclusive. Pilot projects launched under this initiative have targeted the development of capacity in cybersecurity, through the National Computer Emergency Response Team for Cambodia; better e-governance; the promotion of e-commerce; and the launch of educational programmes to teach digital skills.

A lack of funding, combined with technical constraints, has impeded implementation of *ICTopia 2020*. Cambodia's *ICT Policy 2017–2020*, which was funded by the Swedish International Development Agency, cited these same barriers to implementation.

Challenge to raise funds for strategic plans

The *Cambodian SDGs Framework 2016–2030 (CSDGs)* has added an 18^{th} national goal on the clearance of landmines and unexploded ordinance to the 17 standard goals of *The 2030 Agenda for Sustainable Development*. This nationally adapted development framework fixes 88 national targets and sets indicators to measure the performance of ministries and agencies.

These targets and indicators provide the basis for the *National Strategic Development Plan 2019–2024*. The central goal of this plan is to accelerate reforms addressing human resources development, economic diversification and greater public-sector participation in the economy. The government has estimated the cost of implementation at US$ 57.7 billion, one-quarter of which is to be provided by the government and the remainder by the private sector. As of May 2020, little progress had been made in raising these funds.

The other key planning document is the *Rectangular Strategy Phase IV* (2018), the final phase of a strategy initiated in 1998. *Phase IV* has four policy prongs: development of human resources; economic diversification; private sector and market development; and sustainable and inclusive development.

Target of 1% achieved for climate expenditure

The National Council for Sustainable Development co-ordinates implementation of the *Cambodia Climate Change Strategic Plan 2014–2023*. The plan focuses on climate adaptation, mitigation of greenhouse gas emissions and low-carbon development in the prioritized sectors of agriculture, forestry, human health, coastal zones and water resources. Progress is being hampered by a lack of data and technologies and limited access to finance for firms wishing to make climate-smart investments (Govt of Cambodia, 2019).

In 2017, Cambodia achieved its target of devoting 1% of public expenditure to addressing climate change (Govt of Cambodia, 2019). A new Environment and Natural Resources Code is being drafted to guide efforts to conserve and protect the environment.

Hydropower expansion put on hold until 2030

Hydropower accounted for 61% of total energy consumption in 2018, with 67% of electricity users primarily reliant on clean fuels (Govt of Cambodia, 2019).

These results will be boosted by the new 400-MW Lower Sesan II hydropower dam in the Stun Treng province, which produced electricity for the first time in December 2018. The

Ministry of Mines and Energy has estimated that the dam could boost domestic electricity generation by 20%. The dam was constructed over a four-year period at a cost of just under US$ 800 million. It was financed by China's Hydrolancang International Energy, Cambodia's Royal Group and Viet Nam's EVN International. After 40 years, ownership is to be handed over to the government (Bangkok Post, 2018).

The benefits of hydropower expansion in Cambodia must be weighed against serious environmental and social concerns. One study found that the Lower Sesan II dam could lead to a 9.3% drop in fish stocks across the whole river basin (Ziv *et al.*, 2012).

A separate proposal for the Sambor Hydropower Dam proved to be especially controversial: a report by the US-based National Heritage Foundation, commissioned by the Cambodian government, found that the dam would be 'devastating for the migratory fish stocks' and could even 'devastate Cambodia's economy and food security' (NHI, 2017). In April 2020, the government announced that all hydropower development would be halted until 2030 (Kijewski, 2020).

INDONESIA

Making Indonesia 4.0

Upstream and midstream industries are underdeveloped in Indonesia, with 74% of basic materials being imported in 2018, including those that are critical to the electronics and automotive industries. The majority of workers (62%) are employed by small and micro-enterprises, where productivity tends to be low.

The government is developing eight special economic zones to make it easier to do business in Indonesia and support the development of infrastructure such as electricity, transport and other logistics.

In 2018, the government adopted *Making Indonesia 4.0*, its strategy for the Fourth Industrial Revolution. Key targets to 2030 include becoming a top-10 global economy; raising the industry net export rate to 10% of GDP; achieving labour productivity that is twice the value of labour costs; and allocating 2% of GDP to R&D, technology and innovation.

This strategic framework defined ten key national priorities to reap the benefits of Industry 4.0:

- improve upstream production;
- redesign industrial zones by building a unifying roadmap for industry zoning;
- take advantage of opportunities in green and sustainability sectors;
- empower 3.7 million SMEs through the adoption of technologies, such as to foster e-commerce;
- advance networks and digital platforms by upgrading from 4G to 5G, increasing fibre-optic speed to 1 GB/s and by establishing data centres as well as cloud facilities;
- engage top global manufacturers and accelerate technology transfer;
- redesign curricula in light of Industry 4.0 and create professional talent mobility programmes;
- improve government, private sector and university research centres;
- introduce tax exemptions and subsidies for firms that promote technology adoption; and
- build coherent policies across government ministries.

To incentivize R&D in the business sector, the government introduced a 300% tax reduction on research expenditure for firms in 2019.

Implementation of *Making Indonesia 4.0* will require effective action by government agencies and leadership by key firms. The large degree of fragmentation among agencies may hinder effective cross-agency co-ordination. In 2019, the portfolio for higher education was separated from the Ministry of Research and Technology and returned to the Ministry of Education and Culture.

Co-ordination also poses a challenge for the 329 institutions conducting R&D in Indonesia, since these are attached to different ministries and government agencies.

To boost interministerial co-ordination, the Law on the National System of Science and Technology was enacted in August 2019. It establishes the National Agency for Research and Innovation as a co-ordinating body between various research institutions and researchers (Jakarta Post, 2019).

Eight priority areas for research

Indonesia's *Master Plan of National Research 2017–2045* identified eight broad research priority areas: food; energy; health; transportation; engineering products; defence and security; maritime; and socio-humanity studies. The specific focus within each of these priority areas is to be evaluated every five years.

The new *Science–Technology and Innovation Development Framework 2020–2024* prioritizes similar fields to *Making Indonesia 4.0*, such as modern biotechnology for high-yield rice seeds, suggesting that STI policy is becoming better aligned with the country's overall industrial development policy. This framework set a target to 2024 of devoting 0.42% of GDP to R&D.

Indonesia is attempting to integrate the SDGs into this framework. They are already integrated in the *National Medium-Term Development Plan 2015–2019*, which has been translated into the *Government Work Plan* with its associated budget.

Publish or perish?

In early 2017, the government introduced a Science and Technology Index system to rank scientists according to the volume of their publications in Scopus-indexed journals. This system is part of a wider set of assessment criteria that influence the award of grants, promotions and financial incentives.[18] Critics have argued that the system is undermined by its failure to account for different publishing trends among fields and its reliance on a single database. By the end of 2018, 15 Indonesian scientists had been sanctioned for inflating their 'S-score', which is derived from the number of articles and citations (Singh Chawla, 2018). The introduction of a direct link between an academic researcher's salary and their publication output in international journals has stimulated a surge in the number of Indonesian publications in the international indexed literature (Figure 26.4).

In 2019, the Ministry of Research, Technology and Higher Education launched a capacity-building programme in scientific publishing that included training sessions and financial incentives to publish in international journals (MoRTHE, 2019).

LAO PEOPLE'S DEMOCRATIC REPUBLIC

Emerging digital economy

Lao PDR has enjoyed strong economic growth since 2015 (Figure 26.1). The large services and mining sectors – accounting for 41.6% and 24.1% of GDP, respectively – have both attracted FDI. Joint ventures between Lao PDR and foreign firms may help to foster technology transfer in the initial stages but will need to be carefully monitored (ASEAN–Japan Centre, 2019).

Internet connectivity is rising but the cost of Internet is relatively high for the region and rural communities are underserved (Figure 26.1).[19] The quality of this connectivity was ranked lowest in the region in 2018, alongside Myanmar (Tae *et al*., 2018).

One barrier is the relatively low level of regulatory capacity and expertise in telecommunications. To rectify the situation, the government established the Lao Telecommunication Regulatory Authority in March 2017. According to the World Bank (2018), further regulations are needed to address infrastructure sharing, consumer protection, roaming and the quality of service. A law on electronic transactions was passed in 2012 but, by 2018, had not been fully implemented (World Bank, 2018).

Launched in 2017, the national e-commerce website Plaosme.com is financed by the Asian Development Bank and operated by the Lao National Chamber of Commerce. By late 2020, the platform was hosting 600 businesses offering 1 700 products for sale, with an option for online payment and delivery. A law is under preparation to regulate e-commerce and protect online buyers and sellers (Molakhasouk, 2020).

During the Covid-19 pandemic, some digital marketplaces have seen their customer base expand. Online delivery services Go Teddy and Food Panda saw their average daily online orders grow tenfold to up to 2 000 between January and February 2020, for instance. In January, the two companies employed fewer than 100 people; by mid-April, this figure had risen to 2 000 (Homsombath, 2020).

Promoting collaboration in the national innovation system

The Eighth *Five-Year National Socio-economic Development Plan (2016–2020)* prioritizes developing a strong technical workforce while ensuring a social safety net; promoting research and applications of science and technology; positioning international co-operation as a means of mobilizing support for domestic skills development; and strengthening institutes offering technical and vocational education and training, among other things (UNESCO, 2018). The plan advocates using innovation to add value across all economic sectors, with emphasis on the agribusiness, tourism, renewable energy and natural resource-based sectors.

International co-operation with European countries has increased since 2010 with regard to the transfer of processing technology to Lao PDR. However, Laotian companies find it a challenge to meet the certification standards of the International Organization for Standardization (ERIA, 2019). Consequently, the range of goods produced in the agroprocessing sector remains limited to canned corn and processed coffee products, for instance. Co-operation with ASEAN countries has primarily increased in the digital sector and in banking.

Guided by the *Five-Year National Socio-economic Development Plan (2016–2020)*, the government has promoted national and international networking (including with the diaspora) to support public laboratories, universities and the manufacturing sector. Much of the focus is on fostering collaboration between Laotian organizations and ministries. Efforts to develop human capital have targeted personnel in the hydropower, renewable energy, ICTs, agriculture and health sectors (UNESCO, 2018).

Stronger government action is needed to accelerate the transition to a high value-added economy. Further incentives and grants are needed to support research activities, especially in the mining sector, dominated by copper and gold, and in the agroprocessing sector.

Aiming to expand hydropower capacity

Although the electricity grid draws on hydroelectric resources for almost all of its output and Lao PDR is a net exporter of energy (UNESCO, 2018), the relatively low share of modern renewables in final energy consumption is a sign of the population's continued reliance on bio-energy (Figure 26.1).

The *Renewable Energy Development Strategy in Lao PDR* (2011) set a target to 2025 of 30% for the share of renewables in total energy consumption (Figure 26.1) [ADB, 2019c].

The government is planning to expand national hydropower capacity, with the ambition of exporting electricity not only to Thailand and Viet Nam but also to Myanmar and China.

The government has also sought to boost the domestic production of biofuels through incentives for farmers and both domestic and foreign investors, while at the same time acknowledging the need to monitor the sector's development and mitigate any negative impact.

There is progress to be made in various areas of Lao PDR's sustainable development agenda. For example, flooding is a serious risk. The *National Forestry Strategy 2020* (2005) sought to increase forest cover to a total of 70% of land area by 2020, which could have the advantage of stabilizing soils while capturing carbon. Data from the National Forest Inventory (2018) found that forest cover had fallen from 61% to 58% between 2000 and 2015. Deforestation has been driven largely by the expansion of agriculture and clearing for hydropower projects, mining sites and other infrastructure development, according to the European Union's REDD Facility.[20]

MALAYSIA

Ambitious target for research intensity within reach

In Malaysia, exports account for about 66% of GDP, the third-highest share in the region after Singapore and Viet Nam (Figure 26.1).

The government has continued to advocate research-enabled development in the *Eleventh Malaysia Plan 2016–2020* (2016), the last in a series of development plans for realizing *Vision 2020* (1991). This eleventh plan highlights the need to translate innovation into wealth and foster linkages among the actors of the national innovation system. The latest data suggest that Malaysia may be on track to reach its 2% target to 2020 for the GERD/GDP ratio (Table 26.2).

The *National Transformation Policy 2050* (2017) assigns a greater role to science and technology in all sectors and mandates a shift towards the use of 'green' energy, such as solar, biomass and wind, to drive the country's economic transformation to 2050.

To deliver this agenda, the government developed an action plan for science, technology, engineering, mathematics (STEM) and medicine as part of its 2018 budget. The new administration has acted on its predecessor's recommendations to raise the number of students enrolled in STEM courses and foster uptake of Industry 4.0 technologies like nanotechnology. Over 2016–2019, the direct contribution of nanotechnology to the economy was estimated at MYR 3.5 billion (*ca* US$ 800 million) [Dardak and Rahman, 2020].

The volume of scientific publications on nanotechnology rose by 14% over the 2012–2019 period. Malaysia contributed 0.64% of global output in this field in 2011 and 0.67% in 2019.

Large-scale solar projects launched

Formed in 2018, the coalition government was committed to meeting Malaysia's commitments under the *Paris Agreement* (2015) on climate action and took steps to shift energy consumption towards renewable energy sources. The government also committed to reviewing the construction of all new dams, especially in sites prone to landslides and where indigenous people rely on forestry. In 2018, it began a campaign to eliminate the use of plastics and actively support the recycling of biowaste.

Over 2018–2020, the government launched four large-scale solar projects with capacity of 500–1 228 MW, two of which are presently operational. Contractors hired as part of all three projects must include at least one national player. In 2019, the Sustainability Energy Development Authority began to implement the MySuria programme, which aims to install 3-kW solar photovoltaic systems in 1 620 households belonging to the bottom-40% income group.

Malaysia's high-tech exports were buoyed by a relocation of solar panel firms into the country from China following the start of the USA–China trade dispute in 2018.

By 2019, the new government was advancing towards the target to 2025 of 20% for the share of renewable energy in domestic energy consumption (IEEFA, 2019).

Since the government lost its majority in parliament in early 2020, the longer-term ramifications of these policies are not yet clear.

Initiatives to support SMEs in Industry 4.0

The *Industry4WRD: National Policy on Industry 4.0,* published in 2018 by the Ministry of International Trade and Industry, focuses on transforming Malaysia's manufacturing sector and related service industries through digitalization. One goal is to adopt smart manufacturing. Targets include raising labour productivity by 30% over 2016–2025; raising the value of the manufacturing sector from about US$ 58 billion to US$ 90 billion; and expanding the share of highly skilled workers in the manufacturing workforce from 18% to 35%.[21]

One notable initiative is the Smart Manufacturing Experience Centre, announced in mid-2020 by the Standard

Table 26.2: **Progress towards Malaysia's targets for science and technology**

Selected targets as of 2015	Latest available data	Revised targets
Attain high-income economic status by 2020 (PPP$ 15 000, in constant 2010 PPP$)	GNI per capita of PPP$ 12 156 (2019, in constant 2010 PPP$)	Target for high-income economic status shifted to 2030
Raise the GERD/GDP ratio to 1.9% by 2020	1.44% (2016)	No new target defined
Raise the participation rate in higher education from 40% to 50% by 2020	45.3% (2018)	Target of 50% shifted to 2030
Raise the number of PhD-holders to 60 000 by 2023	23 000 (2016)	Target of 60 000 shifted to 2030
Raise the share of science, technology and mathematics tertiary students to 60% by 2020	44% (2018)	No new target defined
Develop 87 international primary and secondary schools with a roll of 75 000 pupils by 2020	153 primary and secondary schools with enrolment of 153 000 (2019)	No new target defined
Increase the number of international university students to 200 000 by 2020 to make Malaysia the world's sixth-largest destination	30 341 tertiary students; overall total: 183 341 (2018)	No new target defined
Reduce carbon emissions by 45% by 2030 over 2005 levels	33% reduction in carbon emissions per unit of GDP (2005–2019)	Target to 2030 remains unchanged

Source: compiled by Rajah Rasiah; for 2020 targets: Rasiah and Chandran (2015) and Industrial Research Institute of Malaysia. Due to be launched in 2021, the centre will support SMEs in developing their strategies and capacities for Industry 4.0, by providing access to existing platforms and technologies. In this way, it should provide a 'test bed' for companies to trial their innovations. The centre will also train institutes of higher learning, as well as the private sector, in applications of Industry 4.0 technologies (ITA, 2020).

Malaysia's 2020 budget introduces instruments to boost e-commerce, such as an e-wallet and cashless payment system (Govt of Malaysia, 2019b). A strategy on AI is reportedly under development.[22]

In July 2020, the Malaysia Digital Economy Corporation launched the Smart Automation Grant to help firms digitalize their business processes. This matching grant targets firms in the services sector, including wholesale and retail, which pay at least half of the total cost of their digitalization project. In February 2021, 66 SMEs and mid-tier firms in traditional sectors such as tourism, real estate, education and health care were awarded the Smart Automation Grant as part of the government's National Economic Recovery Plan (Penjana) in response to the Covid-19 pandemic (Bernama, 2021).

Higher education sector still driving R&D

About 44% of tertiary students were enrolled in STEM courses in 2018, falling short of the 60% target. Cheong and Selvaratnam (2019) suggest that this ratio could even decline on account of poor teaching and facilities at universities.

Malaysia's higher education sector funds and performs a greater share of R&D than any other country in the region with available data (Figure 26.2). Most researchers also work in this sector (Figure 26.2). Universities are conducting relatively little commercial R&D. As a result, multinational corporations with a presence in Malaysia, which have research needs, limit their local activities to 'supportive' research. Science and technology parks have thus far had little impact on the national innovation system (Rasiah and Chandran, 2015).

The government has sought to strengthen Malaysia's industrial zones and science parks by developing the surrounding ecosystems in Malaysia's five economic corridors.[23] A total of RYM 1.1 billion (*ca* US$ 270 million) was allocated in the 2020 budget to the five corridors to support projects such as the Chuping Valley Industrial Area and Kuantan Port (Rasiah and Gopi, 2020; NST, 2019).

Although GERD increased over 2015–2016 (Figure 26.2), the government has since trimmed or eliminated several funding schemes, including the Long Term Research Grant Scheme, the Transcendental Research Grant Scheme and the Fundamental Research Grant Scheme for universities.

In February 2021, the Ministry of Science, Technology and Innovation [24] launched the Malaysia Grand Challenge to encourage disruptive innovation and reduce reliance on foreign technologies. This body will allocate funds to start-ups and SMEs through the following five new mechanisms to help them commercialize their products and services: the Strategic Research Fund, Technology Development Funds 1 and 2 (TeD 1 and TeD 2), a Bridging Fund and an Applied Innovation Fund (Yunus).[25]

Most of Malaysia's STI targets to 2020 have not been met (Table 26.2). Credit is due for the high GERD/GDP ratio but the innovation system remains held back by the lack of a systematic mechanism for appraisal and monitoring (Rasiah and Chandran, 2015). Stringent performance standards and requirements for universities to collaborate with industry could support the commercialization of STI outputs and boost innovation performance.

MYANMAR

Living standards on the rise

Myanmar is in the early stages of integrating the global economy. Despite facing trade sanctions from the USA, the economy grew by 6–7% annually over 2015–2019, one of the region's highest growth rates (Figure 26.1).

This reflects the country's progress since beginning a process of economic and democratic reform in 2011 (Turpin *et al.*, 2015). Living standards, international trade and personal incomes have significantly improved since and transport and logistics networks have expanded (OBG, 2020; Figure 26.1). The outlook for the country has been thrown into doubt, however, since the military took control of the levers of power on 31 January 2021 (OHCHR, 2021).

Major infrastructure projects in the pipeline

In 2018, Myanmar ranked poorly on the World Bank's logistics Performance Index (152nd out of 160 countries) but there were major infrastructure projects in the pipeline. In September 2019, these were valued at a total of US$ 14 billion, with about 63% of developments targeting the transport sector (OBG, 2020).

Work is set to begin on upgrading the Yangon-Pyay railway, funded for US$ 200 million by the Asian Development Bank and European Investment Bank.

In 2018, an upgrade got underway to the Yangon Circular Railway, financed for US$ 2.5 billion via a loan from the Japan International Cooperation Agency.

There are also a number of initiatives to upgrade Myanmar's roads, with the government aiming to provide 80% of villages with all-weather roads by 2030 (OBG, 2020; MMT, 2018).

Innovation hubs emerging

In 2018, the government published the *Myanmar Sustainable Development Plan* to 2030, which rests on three pillars: peace and stability; prosperity and partnership; and people and planet. To promote prosperity, the government aims to foster private sector-led growth and job creation. This is particularly relevant for Myanmar, where state-owned enterprises, overseen by the Ministry of Industry, remain prominent in the economy. These accounted for about 12% of GDP in 2018. Yet, by the government's own estimates, only four out of 57 factories controlled by the Ministry of Industry are profitable (OBG, 2020; Mya Htwe, 2019).

The lion's share (90%) of firms in Myanmar are micro-enterprises or SMEs. A 2017 survey by the Ministry of Planning and Finance found that few had integrated the formal economy; only 3.5% had registered with the national licensing body, the Directorate of Investment and Company Information (OBG, 2020).

Innovation hubs are appearing. The Yangon Innovation Centre, established in 2019, is the city's largest innovation hub. Managed by the Yangon Regional Government and built by the Switzerland-based Seedstars Academy, it offers programmes on investor readiness, some of which target young innovators. In 2020, the IT company Ooredoo Myanmar and the United Nations Development Programme Myanmar launched the Innovation Hub – Supporting the Sustainable Development Goals, which specializes in developing and marketing 'green' products.

Ambition to build a digital economy

The government established the Digital Economy Development Committee in June 2018, comprising representatives of various ministries as well as private-sector actors. This committee released the *Myanmar Digital Economy Roadmap* in 2019. Among the nine priority sectors identified are education, health care, manufacturing, SMEs and financial services. It sets the goal of producing 10 000 qualified tech graduates annually by 2025, with 300 000 citizens to be employed in the digital economy by the same year.

Improving cybersecurity in Myanmar will be a prerequisite for building a digital economy. At present, legal frameworks are ill-equipped to ensure safe online communications and transactions, as reflected in Myanmar's poor ranking in the Global Cybersecurity Index 2018 (128th out of 175 countries). A law is reportedly in development to cover all of e-government, e-commerce and cybersecurity, although the Myanmar Centre for Responsible Business has warned that the scope of a single law could be too broad (OBG, 2020).

According to Speedtest Intelligence, Myanmar saw the world's second-largest improvement in mobile download speeds in 2018, with a 122% rise. Myanmar's market for mobile Internet has also become one of the world's most affordable, with 1-GB Internet plans widely available for about US$ 1 (McKetta, 2018; OBG, 2020).

Moves to protect intellectual property

Myanmar enacted its Science, Technology and Innovation Law in 2018. The Department of Research and Innovation under the Ministry of Education is leading the process to create an STI policy with the support of the United Nations Economic and Social Commission for Asia.

Provisions for STI do feature, however, in the *Myanmar Sustainable Development Plan (2018–2030)*, which sets the ambition of strengthening the enabling environment for a diverse and productive economy with reduced poverty (Thazin, 2019). The aim is to promote innovation and entrepreneurship through a strengthened legal and regulatory framework and the development of a national innovation policy.

The *Myanmar Sustainable Development Plan (2018–2030)* advocates strengthening links between academia, research institutions and the private sector and improving access to research funding but does not specify particular measures.

The private sector is yet to participate in R&D. In 2017, the government employed nearly 70% of researchers and the academic sector the remainder (Figure 26.2).

Myanmar passed four laws pertaining to intellectual property in 2019 to align with the Agreement on Trade-Related Aspects of Intellectual Property Rights, an agreement among members of the World Trade Organization.[26] Among these is the Patent Law, which makes provision for establishing a Myanmar Intellectual Property Office under the Ministry of Commerce. By early 2020, this law had not come into force.

Low expenditure for higher education sector

Myanmar's tertiary education sector receives one of the lowest levels of funding in the region, at 0.3% of GDP. Over 96% of educational expenditure was allocated to basic (85.5%) and higher education (10.8%) in 2018, with 2.0% set aside for technical and vocational education and training as well as research and innovation.

The 2014 National Education Law was amended in 2015 to emphasize the need for quality assurance at all levels of education. According to the foreword by State Counsellor Aung San Suu Kyi to the *National Education Strategic Plan 2016–2021* (2016), 'the national education system [...] needs to undergo a major transformation over the next five years, if it is to meet the life-long-learning and career aspiration of our students, youth and adults'. The strategy proposes strengthening the legislative and policy framework for technical and vocational education and training and observes that higher education institutions need to strengthen their research capacity.

NEW ZEALAND

Productivity lagging compared to peers

New Zealand's geographical isolation, small domestic market and relatively high dependence on agriculture continue to frame its policy challenges for science and industry. New Zealand remains an exporter of primary, largely agricultural, products. It has strong economic ties to countries in the Asia–Pacific region, with more than half of exports going to markets in Asia. Although New Zealand has ties to the other island nations of the South Pacific, the government has been expanding its international partnerships in a number of policy areas since 2015, including as a means of addressing the SDGs.

New Zealand tends to benchmark its scientific and innovative performance against the other members of the group of Small Advanced Economies, namely Denmark, Finland, Ireland, Israel, Singapore and Switzerland (Turpin *et al*., 2015). Compared with these countries, New Zealand has a higher level of specialization in agriculture and lower levels of trade as a share of GDP. The business enterprise sector also spends less on R&D and is less innovative, the country is less economically complex and there are fewer start-ups relative to the population. For both the OECD and the Treasury, low rates of innovation and investment in R&D appear to be determining factors behind New Zealand's low economic productivity (OECD, 2019).

Sustainable intergenerational well-being

In early 2020, New Zealand's *whanau* or 'extended family' concept inspired the government's rallying cry to the 'team of five million' that is credited with uniting the country behind the goal of eradicating Covid-19 in the early days of the global pandemic.

Prior to the adoption of *The 2030 Agenda for Sustainable Development* in 2015, the New Zealand Treasury had developed a *Living Standards Framework* as a novel means of assessing well-being, based on the OECD's *How's Life* document. This New Zealand framework stretches beyond the mainstream focus on income and GDP as measures of well-being; it elevates 'sustainable intergenerational well-being' to the status of key objective of policy-making and natural resource management.

New Zealand's approach to the SDGs reflects three pervasive themes inherent to its approach to science and technology, as well as other areas of policy:[27]

Social inclusion: the title of New Zealand's Voluntary National Review (2019), *He waka eke noa*, is a Māori proverb that translates to 'we are all in this together.' It reflects the special status of the Māori indigenous peoples in New Zealand. The review incorporates the Māori concept of *kaitiakitanga,* or guardianship, of the natural environment.

International networking: as noted in the previous *UNESCO Science Report*, New Zealand has been active in fostering and supporting international co-operation in science as a way of achieving global policy influence (Turpin *et al*., 2015). The 2020–2021 Budget allocates NZ$ 35 million to the Catalyst Fund, which supports international research relationships. New Zealand is also involved in the Global Research Alliance on Agricultural Greenhouse Gases. Two-thirds (64% in 2019) of scientific publications have foreign co-authors, almost double the OECD average (34% in 2019). Moreover, this ratio has risen since 2015 (59%).

Pacific Island allegiance: in 2018, New Zealand increased its Official Development Assistance in response to the financing needs of developing countries to meet *The 2030 Agenda for Sustainable Development*. The additional NZ$ 714 million allocated over four years represents a 30% increase in the budget; 60% of New Zealand's Official Development Assistance goes to the Pacific region.

More than 80% of electricity generation in New Zealand comes from renewable sources (hydropower, wind and geothermal) but the transport sector is a major user of fossil fuels and contributor to emissions. The uptake of electric vehicles is expected to improve the share of renewable energy in total final energy consumption. A Hydrogen Strategy is currently under development to assess the potential for using hydrogen as a fuel in the transport and electricity sectors.

Intensive lamb and beef production is also causing pervasive water pollution and contributing to greenhouse gas emissions. This has prompted the government to require all producers to develop an environmental plan.

Entrepreneurial ecosystem taking shape

Greater expenditure on R&D by large firms was the major driver of the 24% growth in research expenditure observed over 2016–2018 to NZ$ 3.9 billion. Although the manufacturing sector leads the table for the performance of R&D, the health sector has been spending more on R&D since 2016 (MBIE, 2018).

New Zealand's publication output per dollar of research expenditure and per researcher is double the OECD average for countries with a similar share of researchers in the workforce. New Zealand research is of a relatively high quality. Domestic academic–business collaboration remains relatively low, however, as reflected in the 1.5% share of publications having academic–business co-authorship (MBIE, 2018).

New Zealand's entrepreneurial ecosystem is developing, with start-ups being formed notably in the software and AgTech industries. According to *Startup Genome*, over 40 AgTech startups were founded from 2013 to 2020, representing 20% of the seed activity by deal value and making New Zealand a 'top 10 global ecosystem for Agtech & New Food'.

New Zealand has also developed a strong space industry; the start-up RocketLab is one successful example. Revenue from the space economy over 2018–2019 was estimated at NZ$ 1.75 billion, representing 0.27% of global revenue from the space economy and supporting an estimated 5 000 full-time equivalent roles (Deloitte, 2019).

Draft STI strategy proposes sectoral priority-setting

A draft Research, Science and Innovation Strategy was released in 2019 further to statements on industrial policy. The strategy included a range of ambitious objectives. For instance, it stated that, by 2027, New Zealand will be 'a global innovation hub, a world-class generator of new ideas for a productive, sustainable and inclusive future' (Govt of New Zealand, 2019).

The draft strategy proposes raising gross domestic research expenditure to 2% of GDP by 2027 and transitioning the economy to zero-carbon emissions by 2050. To help achieve this goal, the government introduced the Taxation (Research and Development Tax Credits) Bill in October 2018, which offered a 15% tax credit on qualifying research activity for the 2019/2020 fiscal year.

One key aspect of the strategy, which has attracted some criticism, is its proposal for priority-setting at the sectoral level. The draft strategy does not identify these priority sectors; rather, the goal is to identify areas in which New Zealand can establish a 'sustainable competitive advantage on the world stage' or where there are unique domestic challenges or needs.

The strategy recognizes the importance of strengthening linkages within the national innovation system, particularly between researchers and users of research output, both domestically and internationally. The draft strategy does not propose specific policy mechanisms or instruments to achieve its ends.

The draft seeks to boost the commercialization of public-sector research through start-ups and industrial R&D, which may be stimulated through a new R&D tax concession.

Four sectors identified for industrial focus

In 2019, the New Zealand Ministry of Business, Innovation and Employment published a major statement on industrial policy with the aim of boosting productivity, innovation and entrepreneurship. It is entitled *From the Knowledge Wave to the Digital Age: Growing Innovative Industries in New Zealand.*

The new industrial policy maps the challenges and opportunities faced by New Zealand's digital technologies sector. It identifies four priority sectors for developing plans for industrial transformation, based on their potential to develop and apply digital technologies: the agtech, food and beverage, forestry and wood-processing sectors.

The agtech plan was launched in July 2020. *Growing Innovative Industries in New Zealand* outlines plans for a Horticultural Robotics Institute and a specialist agtech venture capital fund, among various other initiatives, many of which involve public–private collaboration.

Other sectoral plans are under development but are expected to focus on public–private collaboration and joint investment and governance; expanding exports and the level of value-addition; evolving strategic planning; and the application of digital technologies.

Recommendation for AI strategy

As it enters its second decade, the NZ Tech Alliance has come to represent over 20 associations and more than 1 000 organizations. These include the Internet of Things Alliance (2017), Artificial Intelligence Forum of New Zealand (AI Forum, est. 2017) and AgriTech New Zealand (2018). The government has indicated its intention to work with the Internet of Things Alliance and AI Forum to drive the uptake of digital technologies.

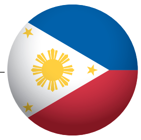
The AI Forum (2018) reported that New Zealand had more than 140 organizations already working with or investing in AI but that there was a gap in co-ordination and strategic intent among businesses and at the national level. It therefore recommended developing a national AI strategy to address ethical issues, the development of human resources and promotion of AI applications.

From the Knowledge Wave to the Digital Wave also highlights the implementation of the Industry 4.0 Demonstration Network programme to increase uptake of Industry 4.0 technologies across manufacturing sectors. A National Digital Infrastructure Model will support the development of 'digital twins' for major infrastructure projects.[28] Agreements on data standardization and sharing will be essential to support the development of digital twins and the growth of domestic firms specializing in digital technology.

In 2020, the government launched the Digital Council for Aotearoa New Zealand with a three-year work programme, in order to identify mechanisms for linking technology to societal benefit. Working through the Digital Skills Forum, a coalition of industry and government, the government aims to ensure that the digital technology sector, and the industries that rely on digital technology workers, can access the tech talent they need to grow. Based on its 2019 charter, the forum takes a largely co-ordinating role.

New Zealand's innovation agency, Callaghan Innovation, has re-oriented its primary focus towards supporting the digital transformation of New Zealand's manufacturing firms.[29] It employs over 200 researchers and categorizes itself as an innovation, rather than research, agency. Partnering with enterprises of all sizes, it provides technical solutions, skills and capability development, as well as co-funding.

PHILIPPINES



Preparing for Industry 4.0

To prepare national industries for the Fourth Industrial Revolution, the Department of Trade and Industry developed the *Inclusive Innovation Industrialization Strategy* (i^{3}S) in 2017. It identifies a range of priority sectors, counted among which are electrical and electronic goods; automotive and parts; metal products, machinery and equipment; aerospace parts and maintenance; IT and business process management and e-commerce; chemicals and pharmaceutical products; agribusiness; and shipbuilding and ship repair.

Future-oriented skills development

Anticipating the impact of Industry 4.0 on the local labour force, the National Technical Education and Skills Development Authority (TESDA) plans to revise its curricula to ensure that students are equipped for the new economy.

The *National Technical Education and Skills Development Authority Plan 2018–2022* focuses on developing requisite skills for occupations in seven sectors: tourism; construction; information technology and business process management; transport, communication and storage; agriculture, fisheries, and forestry (including agroprocessing); manufacturing (including food and electronics manufacturing); and health, wellness and social services.

TESDA's programmes are included in curricula at the secondary level of education.

It is planning for future careers in areas that include software development, mobile app development, agricrop processing, farm machinery technical management and engineering.

Attracting expat Filipino scientists

Two significant pieces of legislation were enacted over 2018–2019 to develop human resources.[30] The *Balik (Returning) Scientist Act* (2018) builds upon the Balik Science programme, which was first launched in 1975 and implemented at intervals. The programme funds the repatriation of Filipino volunteer personnel living abroad who work in science and engineering fields. Since the programme's inception, 533 Balik Scientists have been involved in 670 short-, medium- and long-term engagements (Guevara, 2020). The Department of Science and Technology (DOST), which manages the programme, has set itself the goal of attracting 235 more Balik Scientists over 2018–2022 (Arayata, 2018).

The Act Strengthening the Magna Carta for Scientists, Engineers, Researchers and Other Science and Technology Personnel in the Government (2019) expands the coverage of benefits available to this category of personnel beyond DOST to the whole of government. It also allows for the rehiring of STI personnel who have retired or the extension of service of those facing compulsory retirement.

Research programmes launched despite funding shortages

The *Harmonized R&D Agenda 2017–2022* (2017) builds on the earlier *Agenda 2013–2020* and the *National Science and Technology Plan 2002–2020*.

The Philippines' *National Integrated Basic Research Agenda* (2017) addresses water security, food and nutrition security, health sufficiency, clean energy, sustainable communities, and inclusive nation-building. It complements the *Harmonized R&D Agenda 2017–2022*, which defines four other priority areas for research:

- health;
- agriculture, aquatic and natural resources;
- industry, energy and emerging technology; and
- disaster risk reduction and climate change adaptation.

Expenditure on R&D is low in the Philippines (Figure 26.2).[31] Despite funding challenges, DOST has launched several notable programmes since 2015 (Table 26.3).

The government has also made some STI-related investments in infrastructure. The Philippine Earth Data Resource and Observation Center is a ground station for satellites, launched alongside the Philippines' first microsatellite, Diwata-1, in 2016. In 2019, nanotechnology laboratories were set up at the Industrial Technology Development Institute (est. 2015) and at Central Luzon State University (Manila Times, 2019).

Legislating to nurture start-up ecosystem

Two bills were passed in 2019 to boost the creation of start-ups. The Philippine Innovation Act (2019)[32] established the National Innovation Council with a mandate to define a strategic vision for innovation, as well as develop and implement programmes. The Council was established with an initial revolving fund of PHP 1 billion (*ca* US$ 19.7 million); it will also receive an annual needs-based budget. The same act also created an innovation development credit and finance programme to help meet innovators' financial needs.

The Innovative Start-up Act[33] (2019) created the Philippine Start-up Development Programme, which provides services and incentives to start-ups, such as by accompanying them in business registration and providing expedited intellectual property registration and protection, as well as financial support to enable them to participate in local or international start-up events. The law also creates new start-up visas for prospective or current foreign owners of start-ups.

Private sector supporting smart cities

In 2018, the Philippine government revealed its plans for New Clark City, which is being developed in Tarlac, in partnership with the Japanese government (Tokyo Grand Renovation, 2018). Driverless electric vehicles and bus and railway networks are envisaged to support a highly mobile population.

Buildings are being designed with a focus on efficient consumption of water and energy. The government is partnering with the Asian Development Bank to secure public–private partnerships to build a water and wastewater system, transport network, ICT infrastructure and power distribution network.

The Philippine Institute of Volcanology and Seismology considers New Clark City development to be a strategic disaster-resilient metropolis. Ecosystem-based adaptation principles have been incorporated into planning for the city. For instance, it is located at a distance from geological fault

Table 26.3: **Selected STI-related programmes in the Philippines**

Programme and year of launch	Function
Niche Centers in the Regions (2016) and Research and Development Leadership Programme (RDLead) [2016]	complementary programmes that support tertiary and research institutions in building centres for R&D; promotes development according to regional needs
Collaborative Research and Development to Leverage the Philippine Economy Program (2016)	spurs industry–university collaboration; under this programme, a tertiary or research institution forms a partnership with at least one enterprise, with the government funding up to a maximum of PHP 5 million (*ca* US$ 100 000) and the partner company providing 20% of the required funds for collaborative R&D
Business Innovation through S&T for Industry Program (2016)	helps Filipino companies acquire relevant technologies to conduct R&D; Dept of Science and Industry (DOST) provides loans of up to 70% of eligible expenses with zero interest
OneSTore.ph (2018)	an e-commerce platform managed by DOST that enables micro-enterprises and SMEs under the Small Enterprise Technology Upgrading Program (SETUP) to showcase and sell their products
SETUP 4.0 (2020)	builds on SETUP, offering micro-enterprises and SMEs loans of up to PHP 5 million (*ca* US$ 100 000) to innovate in Industry 4.0-related areas, providing also equipment and training; it planned to support 800 companies in 2020 (Arayata, 2020)

Source: compiled by Patarapong Intarakumnerd lines, at a higher elevation and farther inland than Manila, to reduce the risk of flooding. It will also have wide drainage systems and no-build zones, to reduce the impact of floods when they do occur (Messling, 2019).

Other cities have 'smart' ambitions. Makati City was the sole representative of the Philippines in the 2019 World Smart Cities Awards. It was selected for its use of technology to improve disaster preparedness and communication. With the Makatizen App, developed by the company Neo-Converge ICT Solutions in collaboration with the Makati City government, residents may call for assistance or report emergency incidents directly to the city office.

Private-sector firms like SAP Philippines are offering their services to local governments to support the development of smarter cities. For its part, the government-owned company, the Development Academy of the Philippines, offers smart city management and administration courses and seminars to interested government officials and staff.

SINGAPORE

Standards mapping for Industry 4.0

Since 2015, Singapore's economy has grown steadily. Inflows of FDI remain staggeringly high, at 28% of GDP in 2019 (Figure 26.1). The prime development organ, the Economic Development Board (EDB), has been instrumental in stimulating technological development in Singapore.

A year after the launch of the Standards Mapping for Singapore Smart Industry Index in 2017, the EDB launched the Index Partners Network. This network brings together partners specializing in technology, financing, talent development and training, in order to help manufacturers execute their ideas for Industry 4.0. For instance, McKinsey and Siemens figure among the partners in the technology, solution and strategy category.

Singapore's Smart Nation Initiative (2014) has applied a high-tech focus to health, urban living, transport, digital government services, start-ups, more mature businesses and strategic national projects. For instance. the government plans to roll out driverless buses in 2022 in Ponggol, Jurong and Tengah. With regard to urban living, about 80% of Singaporean households live in public housing. Smart homes and towns equipped with Housing and Development Board technologies and sensors are helping to provide efficient services and reduce waste.

Business sector active in R&D

Singapore has become a hub for incremental innovation activity in Southeast Asia, enabled by its basic infrastructure, integration in global markets and strong co-ordination between firms and research institutions. The business sector is, thus, responsible for more than half of research funding and performance (Figure 26.2). The Agency for Science, Technology and Research (A*STAR) is a key driver of scientific research in the country, identifying potential and matching funding opportunities.

Laboratories at the National University and Nanyang University are also supporting firms in the shipbuilding industry. Given its small size, Singapore largely focuses on dock repair and outsources its ship manufacturing activities to suppliers in Southeast Asia.

Specializing in biopharmaceuticals

Singapore has redirected its industrial focus towards areas with a competitive advantage. The EDB has been key to this transformation, identifying the limits of existing industries and changing the grants orientation for research to favour higher value-added activities, through an astute use of incentives and promotional mechanisms. Consequently, science parks in Singapore have experienced a rapid increase in biopharmaceutical incubators, with biopharma inching ahead of electronics in priority since 2015 (Rasiah, 2020).

The National University of Singapore and Nanyang University, in particular, have worked with incubators and firms in science parks to establish Singapore as a world-class research hub for biopharma.

In 2018, a consortium agreement worth about US$ 24 million was signed establishing the Pharma Innovation Programme Singapore. The consortium consists of A*STAR, local universities and three leading pharmaceutical companies, GlaxoSmithKline, MSD International and Pfizer (Hawksfo-rd, 2019). The programme aims to raise the bar for pharmaceutical manufacturing, resulting in more sustainable processes and quicker production of active pharmaceutical ingredients.

Laboratories at the National University of Singapore have also become hubs for petrochemical innovation, supporting over 100 firms in Singapore (ASMI, 2019).

Closing the gap in intellectual property trade balance

The Research, Innovation and Enterprise Secretariat published its *Research Innovation Enterprise 2020 Plan* (*RIE 2020*) in 2016. *RIE 2020* allocates funds across four sectors and four cross-cutting programmes (Figure 26.8). It outlines a plan to invest US$ 19 billion over 2016–2020 under four strategic thrusts:

- promoting multidisciplinary and multistakeholder co-operation for strategic, goal-oriented research and investment;
- steering competitive funding towards areas of national priority, including in four fields of strategic technology: advanced manufacturing and engineering; health and biomedical sciences; urban solutions and sustainability; and services and the digital economy;
- prioritizing value creation and 'Smart Nation' initiatives (Turpin *et al.*, 2015); and
- developing and sustaining a highly skilled and knowledgeable workforce in both the private and public sectors to drive research and innovation.

The commitment in the *RIE 2020* to elevate R&D expenditure is not yet reflected in the GERD/GDP ratio (Figure 26.2). This investment, combined with the *RIE 2020*'s focus on sectors with potential for strong commercialization and social benefit, has, nevertheless, raised royalties from exports of intellectual property.

The intellectual property trade balance improved from -0.38 to -0.27 over 2015–2018,[34] closing the gap with the Republic of Korea (Rasiah, 2020). Singapore has established a strong, commerce-oriented research base.

Introduction of a carbon tax

Under the *Paris Agreement* (2015), Singapore has committed to reducing carbon emissions by 36% over 2005 levels by 2030. However, Singapore's 2020 updated target for its *Nationally Determined Contribution* is now an absolute emissions cap, considered insufficient to meet the goals of the *Paris Agreement*.

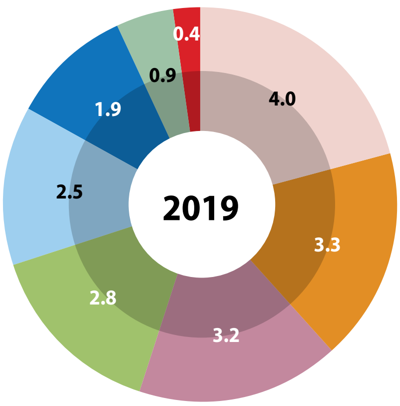
The government is, nonetheless, taking an innovative approach to ensure that industrial facilities are accountable for their emissions (Rep. Singapore, 2020). The government introduced a carbon tax of S$ 5 (*ca* US$ 3.50) per tonne of greenhouse gas emissions in 2019, which will apply until 2023 when the rate will be reviewed.[35]

The government has already indicated that it plans to raise the carbon tax to S$ 10–15 (*ca* US$ 7–11) per tonne by 2030. The tax is expected to discourage high-emission commercial activities, with company revenue being re-oriented towards funding green technologies. Any industrial facility meeting the set emissions thresholds must self-register and report.

To widen the deployment of green practices, the government has launched the *Public Sector Sustainability Plan 2017–2020* to stimulate sustainable practices and green procurement. The plan proposes upgrades to infrastructure, such as cooling systems, in 1 000 public sector facilities. Seeking to expand the development of green walls, it sets a target of multiplying the rooftop acreage of gardens threefold by 2030, from 72 hectares in 2017.

Figure 26.8: **Singapore's *Research Innovation Enterprise 2020 Plan*, 2016–2020**

Allocated funding, in SGD billions



Note: Singapore sets aside 'white space' funding for unanticipated needs and opportunities. An example is cybersecurity, which arose as an emerging sector during the 2011–2015 funding cycle. As of January 2021, SGD 1 billion corresponds to about US$ 750 million.

Source: Singapore's *Research Innovation Enterprise 2020 Plan* for 2016–2020

'Whole of nation' approach

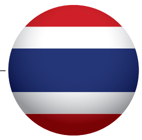
Singapore's 'whole of nation' approach has proved a boon both to national data collection and collaborative efforts to meet the SDGs (Rep. Singapore, 2020). Infrastructure development is intended to have both social and environmental benefits, such as the deep tunnel wastewater system that will shrink the land occupied by wastewater infrastructure by half and facilitate efficient, large-scale water recycling.

As Singapore expects the share of non-domestic water use to rise to 70% by 2060, the government has also recognized the need to work across sectors to reduce consumption.

However, Singapore is still struggling to meet some SDG milestones. For example, Singapore only managed to raise the share of renewable energy in total consumption from 0.62% to 0.71% over 2014–2017. The government is scaling up deployment of solar energy, aggregating demand across sectors and testing floating solar panels in the Straits of Johore and the country's reservoirs.

These and other effective interventions will be necessary to make Singapore a sustainable Smart Nation.

THAILAND



A Sufficiency Economy Philosophy

In 2017, Thailand approved the *National Strategy (2018–2037)*, the country's first long-term national strategy. It set the goal of becoming a 'developed country with security, prosperity and sustainability in accordance with the Sufficiency Economy Philosophy,' an approach to development based on moderation, prudence and a form of social immunity. Although the *National Strategy* is not explicitly aligned with *The 2030 Agenda for Sustainable Development*, the sufficiency economy approach has much in common with the SDGs.

Several of the *National Strategy*'s targets directly concern STI. To boost competitiveness, the strategy focuses on developing value-added agriculture through, for instance, biological and smart farming. It identifies sectors considered to be of future strategic importance. These include biology; integrated medicine; digital-, big data- and AI-driven industries; transport and logistics; and security. The *National Strategy* looks to build a modern, entrepreneurship-based economy (NESDB, 2017).

The *National Strategy* has fixed a target of devoting 2% of GDP to GERD by 2036 (Theparat, 2018). In 2017, the government reported a 1% GERD/GDP ratio (Figure 26.2).

To promote industrial R&D, the Cabinet approved tax incentives in May 2017 for companies that form clusters to raise their investment in five priority areas, namely: food, agriculture and biotechnology; public health, health care and biomedical technology; robotics and smart devices; digital technology such as the Internet of Things and AI; and the creative economy, culture and lifestyle. Firms are entitled to a 300% tax rebate on their research expenditure (Theparat, 2018).

In 2019, the Cabinet approved the *National Policy and Strategy on Higher Education, Science, Research and Innovation (2020–2027)*. Targets include creating 1 000 innovation-driven enterprises with annual sales worth around US$ 30 million; improving the ease of doing business in an innovative manner; and developing an Economic Zone of Innovation with tax incentives to promote innovative firms. The number of start-ups in Thailand has increased, although few employ sophisticated technologies.

Structural shake-up of national innovation system

The governance of Thailand's innovation system received a structural shake-up in 2019 with the establishment of the Ministry of Higher Education, Science, Research and Innovation, formed by merging the Ministry of Science and Technology, Office of the Higher Education Commission, National Research Council and the Thailand Research Fund. STI is governed at four 'levels' (Figure 26.9).

These structural reforms could serve to eliminate bargaining and rivalry among agencies, which may have previously compromised reforms. Although responsibilities have been divided among the various institutions and ministries, in practice, some agencies are still attempting to work beyond their mandates. A certain level of distrust among the agencies is also preventing them from working as a collective (Table 26.4).

Thailand 4.0

The objective of the *Thailand 4.0* (2016) strategy is to seize the opportunities offered by the Fourth Industrial Revolution to steer the economy towards high value-added sectors, upgrade existing industries and promote the emergence of new industries.

The strategy targets ten strategic sectors for integrating high technology and developing human resources: new-generation automobiles (electric vehicles in various forms); smart electronics; high-income, medical and wellness tourism; agriculture, biotechnology and food; robotics for industry; logistics and aviation; biofuels and biochemicals; digital medical services; education; and defence.

Innovation districts target the demand side

The National Innovation Agency is establishing 'innovation districts' in Thailand's cities in a bid to make them 'smart'. Working with enterprises, universities, hospitals, start-ups, local experts and residents, the agency has begun developing ten such districts in Bangkok and the surrounding provinces.

In innovation districts, the National Innovation Agency provides financial and other support to test smart technologies, with a view to identifying those that suit local needs. Once the relevant technologies have been selected, they are to be implemented in a wider urban area.

Thai policies tend to address the supply side of innovation, such as financial support and incubation. The concept of innovation district focuses on the demand side, by allowing start-ups to test their unproven ideas and technologies. In this model, producers of innovative products or services benefit from their proximity to business and consumers in the same districts. For instance, within the Yothi Medical District in Bangkok, there are several leading hospitals.

TIMOR-LESTE

Challenge to diversify the economy

Since emerging as a sovereign state in 2002, Timor-Leste has faced the daunting task of rebuilding public infrastructure and creating its own institutional frameworks.

Timor-Leste is one of the world's most oil-dependent countries. In 2017, oil and gas contributed 91% of government

Figure 26.9: **Structure of Thailand's national innovation system, 2019**

	Level 1	Level 2	Level 3	Level 4
Entity	National Higher Education, Science, Research and Innovation Policy Council (est. 2019)	Thailand Science Research and Innovation Fund (est. 2019)	National Innovation Agency (est. 2003; for start-ups); National Research Council (est. 1959; for social sciences and humanities); Agricultural Research Development Agency (est. 2003; for agriculture and food); Health Systems Research Institute (est. 1992; for public health)	Universities, public research institutes and STI service providers
Role	undertakes policy formulation, chaired by the prime minister	responsible for policy deployment and budget allocations; assigns budgets to funding agencies (Level 3) as well as to public research institutes and universities for basic research and institutional capacity-building; managed by the Thailand Science, Research and Innovation Agency, formerly known as the Thailand Research Fund	funding agencies responsible for different academic disciplines and business/social groups; the annual budget for each agency depends on the National Higher Education, Science, Research, and Innovation Policy Council and the Budget Bureau	these entities undertake human resource development and research as well as STI service creation and implementation

Source: compiled by Patarapong Intarakumnerd revenue (World Bank, 2019). Oil revenue is declining sharply, due to a combination of low oil prices and declining production from existing fields. A central development challenge will, therefore, be to diversify the economy and, in so doing, create employment opportunities for the rapidly growing population;[36] the capital-intensive petroleum industry provides very few local jobs in production, processing or supply.

The strong economic growth observed in the previous edition of the *UNESCO Science Report* (Turpin *et al*., 2015) has not been maintained. Government policy has been to invest in the pillars of infrastructure, education and health (Bovensiepen, 2018). However, the limited funds available and low skills base have constrained development. Corruption and crime have hindered the growth of the private sector (World Bank, 2019; ADB, 2015).

The weak regulatory framework for trade and investment is another barrier. Uncertainty around property rights and the slow development of land law and cadastral mapping often preclude land from being used as collateral for development loans.

In 2018, a permanent maritime boundary between Australia and Timor-Leste was agreed, along with a resource-sharing agreement for the Greater Sunrise oil and gas fields. However, finance to develop these fields remains uncertain, especially since the government wishes to ensure high local involvement. Moreover, questions have been raised over the development value and probity of public investment in major petroleum-related infrastructure projects, which have absorbed a large share of the national budget.

Science and technology not yet a priority

In the *Strategic Development Plan 2011–2030*, as in more recent annual government programmes, science and technology are not addressed, other than as aspects of development strategies for telecommunications, agriculture or higher education.

The focus of the National Institute of Science and Technology is on planning and capacity development. Together with the Timor Lorosa'e National University and the Polytechnic Institute of Betano, it falls under the responsibility of the Ministry of Higher Education, Science and Culture. Top priority has been accorded to developing higher education, as well as technical and vocational education and training. Research capacity remains low (Monteir, 2017).

In May 2017, the government launched Timor-Leste's *Roadmap for the Implementation of The 2030 Agenda and the SDGs*. The *Roadmap* outlines how the global goals align with the country's *Strategic Development Plan.* For instance, it lays particular emphasis on the eradication of poverty (SDG1) and working towards a peaceful, just and inclusive society (SDG16). The *Roadmap* notes the role of the National Programme of Adaptation to Climate Change.

Although most of the population has access to a 3G network, only about 1% have access to fixed-broadband services – and both are considered unaffordable. Close to 80% of the population has a mobile phone and access to electricity – more than double the level a decade ago – but only about 25% use Internet. The country's commitment to inclusion has made investment in telecommunications and in related skills a high priority (OECD, 2018; ESCAP, 2019).

Educational spending and attendance rates have both risen, with the number of students in higher education doubling from 27 009 in 2011 to 57 436 in 2016 but basic literacy and completion rates remain unsatisfactory, particularly among young women (Govt of Timor-Leste, 2019).

VIET NAM

A sustainable development agenda

Viet Nam maintained a high rate of economic growth over 2016–2019 (Figure 26.1). In 2019, 18.9 million people worked in agriculture, aquaculture and forestry, meaning that about 5.7 million workers have left this sector since 2015 (ILO, 2020). This is indicative of a pervasive trend towards industrialization.

The principles of sustainable development have been mainstreamed in the *Social and Economic Development Strategy for 2011–2020* and the Social and Economic Development Plan for 2016–2020.[37]

The policy focus on inclusion is reflected in the drive to give more households access to Internet, safe water and electricity (Figure 26.1).

There have also been improvements in environmental management, as demonstrated by the increase in forest cover to 41.5% in 2017. The Ministry of Science and Technology issued a *Circular on Equipment Importation* in 2015 which was revised in 2017 to emphasize energy-saving and protection against environmentally damaging technologies.

Institute of Science, Technology and Innovation established

The Master STI Strategy for 2021–2030 is due to be approved in 2021.

Over 2016–2020, government policy centred on boosting the autonomy of public research institutions and the commercialization of their research results through legislative amendments and flexibility in budgeting, combined with more stringent monitoring and inspection of projects involving science and technology.

Resources were concentrated in the following focal areas: ICTs; biotechnologies; new materials; automation; environmental technology in agriculture, industry, health care and medicine; transportation; construction; energy; marine science; natural resources management and use; and space.

The Viet Nam Institute of Science, Technology and Innovation was established in 2018 to conduct STI policy research and foresight, provide policy advice to the government and offer master's, PhD programmes and training in STI policy. In 2020, 9 PhD holders were employed by this institute.

In 2016, a network of centres for intellectual property and technology transfer was established to link universities, public research institutes and enterprises in technology development, patent protection and commercialization. By December 2019, approximately 60 universities and institutes had joined the network (IP Viet Nam, 2020).

In 2017, the Viet Nam–Korea Institute of Science and Technology was established to conduct near-market research.

Since 2015, several large local firms have established research institutes (MOST, 2019). For instance, the Vin

High-tech Institute was set up in 2018 by the Vingroup, a Vietnamese conglomerate with subsidiaries in the retail, services, real estate and health care industries. The Vingroup has signed memoranda of understanding with over 50 universities to support scientific research, exchanges of researchers and students, teaching and job offers. Another example is the FPT Technology Research Institute set up by the group of the same name, formerly the Corporation for Financing and Promoting Technology, Viet Nam's largest IT services company. The FPT Group is positioning itself in Viet Nam as a key player in Industry 4.0 by offering enterprises and organizations 'digital transformation services' (FPT, 2019).

Meanwhile, both foreign and local firms have been setting up accelerators for start-ups. In 2015, Microsoft Vietnam and the Startup Accelerator Fund established the CLAS–Expara Vietnam Accelerator.[38] Since 2017, Expara Vietnam has been working with the Saigon Innovation Hub to launch a series of accelerator programmes; 30 start-ups were selected for the second batch in August 2020.

Industry 4.0 initiatives in their infancy

Policy on Industry 4.0 falls under the remit of the Ministry of Information and Communication, the Ministry of Science and Technology and the Ministry of Industry and Trade. These three ministries conducted technical studies of Industry 4.0-related issues which recommended integrating scattered Industry 4.0-related technologies into standardized IT infrastructure and utilizing them to develop smart cities.

Subsequently, the prime minister signed a directive on *Capacity Building for Industry 4.0* in May 2017 which prioritized support for innovative start-ups and university autonomy; forging linkages between domestic and foreign scientific communities; and a curricular focus on STEM, foreign languages and IT in schools.

In the same month, the prime minister approved the establishment of a 'digital Vietnamese knowledge system',[39] an open database housing information made public by businesses, organizations, government ministries and individuals. The database is expected to help start-ups working in Industry 4.0-related areas, such as big data, the Internet of Things and AI, to develop a range of applications (Nhân Dân, 2018). However, as of May 2020, the deeper layers of this database remain inaccessible.

In January 2021, the government approved the *National Strategy on AI Research, Development and Application* to 2030. The central goal is for Viet Nam to become a hub for AI solutions and applications at the regional and global levels by 2030. There are plans to establish three national centres on big data and high-performance computing and three national innovative centres on AI, as well as to boost international co-operation in the field.

In April 2019, the Ministry of Science and Technology inaugurated an Internet of Things Innovation Hub at the Hoa Lac High-tech Park in Hanoi.

Lacking common standards for smart cities

Smart city projects are the responsibility of local governments. About 30 cities and provinces nationwide have implemented smart urban construction projects. However, there are no common legislative regulations or standards for smart cities, which could give rise to technical issues when integrating local smart city systems with the national system. Vietnamese ministries are presently conducting research to establish construction guidelines and policies for smart cities (Dharmaraj, 2019).

Some localities have started deploying basic applications and services for smart cities. Large cities such as Hanoi, Ho Chi Minh, Danang and Halong are applying ICTs to transportation, tourism and public health management and encouraging digital business transactions. It is, as yet, too early to systematically evaluate the results of the smart city projects.

Local manufacture and export of ventilator parts

The Ministry of Science and Technology approved research projects on the new coronavirus from the beginning of February and a diagnosis kit for SARS-CoV-2 was successfully developed in March. In April, the Vietnamese diagnosis kit was approved for use in Europe (MOST, 2020) and Vingroup announced plans to manufacture ventilators to treat Covid-19. In August, the corporation signed a contract to supply 50 000 ventilator parts to Medtronic, a medical device company active in more than 140 countries (Crotti, 2020).

In April 2020, the entrepreneur Nguyen Manh Hung launched a free rice dispenser, referred to as a 'rice ATM', to support poor communities struggling in the wake of Covid-19. At launch, the dispenser had ten tonnes of rice to distribute, with each person entitled to 3 kg per day (Minh, 2020).

PACIFIC ISLAND COUNTRIES

Distance learning tradition an asset during pandemic

At the time of writing in January 2021, many Pacific Islands have eradicated the local transmission of Covid-19, judging from the World Health Organization's Covid-19 situation reports. Lacking the local capacity to run tests, Pacific Islands have relied on border closures, which have devastated the tourism industry.

The Covid-19 pandemic has also disrupted efforts to eradicate other critical diseases in the region like malaria and highlighted gaps in water and sanitation infrastructure (SPREP, 2021).

One sector that has proven resilient to the pandemic is higher education. Constrained by their geographical isolation, universities in the region have been trail-blazers in distance learning, initially relying on the postal service to share coursework and now, increasingly, on Internet (Figure 26.3).

Otherwise, there has been limited change in the higher education sector over the past decade, apart from scholarship schemes implemented by countries that include Fiji, Tonga, Vanuatu, the Solomon Islands and Nauru to boost student enrolment. Statistics on graduates are not readily available, although the University of the South Pacific and the Fiji Higher Education Commission are introducing annual reporting of increasingly standardized indicators.

Pacific Island economies are dominated by resource-based industries such as fisheries and agribusiness. They host only a handful of medium- and high-tech industrial factories.

The 2017 closure of the Yazaki automotive parts factory, thus, dealt the Samoan economy a severe blow. Yazaki had been the largest private employer in Samoa. Parts produced by the factory's staff of more than 700 used to generate 60% of national export earnings (ILO, 2017).

Growing advocacy on climate risk

In 2016, five Pacific Island nations ranked among the top 20 countries in the world for disaster risk. The effective loss to Pacific nations from natural disasters translated into 14% of GDP, on average (UNU-EHS, 2016; Lee *et al*., 2018).[40]

Single events have been devastating. For instance, post-disaster needs assessments have indicated losses amounting to as much as 30% of national GDP for Fiji (Cyclone Winston in 2016) or even 64% for Vanuatu (Cyclone Pam in 2015). Cyclone Harold in 2020 was the most severe category 5 cyclone on record in the South Pacific; it left nearly one-third of the Vanuatu population homeless. Despite these blows, Vanuatu became the sixth country in the world to graduate from least developed country status in December 2020.

In recognition of their vulnerability and strong dependence on fisheries, tourism and agriculture for their livelihood, the Pacific Island countries have embraced the SDGs and related multilateral agreements like the *Paris Agreement*, building on their own regional approach. One example within the region is the *Framework for Resilient Development in the Pacific 2017–2030*. In some cases, voluntary action has surpassed requirements; for example, the Pacific Islands have exceeded the 17% target set under the global Convention on Biological Diversity for area-based protection of marine spaces by 2020 (SPREP, 2021).

Pacific Island leaders are engaging in international advocacy to combat climate change. Fiji held the presidency of the 23rd Conference of the Parties to the United Nations Framework Convention on Climate Change in 2017, the first of the Small Island Developing States (SIDS) to do so.

In 2020, the Regional Pacific Nationally Determined Contributions Hub Office in Fiji was launched to support climate change mitigation and adaptation (GGGI, 2020). Pacific authors on the frontlines of climate change remain underrepresented in the scientific literature on the impact of disasters and on climate resilience strategies (see chapter 2).

Regional approach to science and technology

Both the largest and smallest Pacific nations acknowledge that taking a regional approach to science and technology offers them greater opportunities for institutional development.

This approach is encapsulated in the *Framework for Pacific Regionalism* (2014). All 14 nations have mandated the agencies attached to the Council of Regional Organizations of the Pacific (CROP) to conduct technical backstopping.[41]

CROP agencies partially fulfill the role that a science council might play in other regions. As noted in the previous edition of the *UNESCO Science Report*, none of these agencies has a specific mandate or policy for science and technology (Turpin *et al*., 2015).

The Ministers of Education from Pacific Island countries signed a *Ministerial communiqué on Pacific Science, Technology and Innovation* in 2017, in which they committed to developing regional and national STI policies and roadmaps. However, no policy or roadmap has since been published for want of resources.

The 2014 *Small Island Developing States (SIDS) Accelerated Modalities of Action Pathway* (*Samoa Pathway*) identified science and technology as being critical to SIDS' sustainable development. In the Pacific, new institutions for science and technology seem to be lower on the list of priorities than critical areas such as climate change and renewable energy. For example, several years ago, it was proposed to establish a National Research Council in Fiji but this council has not materialized.

About half of Pacific Island countries do not have legal guidelines in place for research.[42] A regional project supporting the implementation of the *Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization* was launched in 2017. Under this project, countries have been advancing national frameworks for research and building the capacity of national negotiators to influence the design of research projects undertaken in their country. In 2018, Vanuatu passed a bill to protect traditional knowledge associated with genetic resources (Govt of Vanuatu, 2018).

In the absence of a dedicated national strategy or science advisory committee, the need for research is increasingly being recognized by national sectoral policies. For instance, Vanuatu's *National Ocean Policy* (2016) specifically calls for the development of a strategy for marine scientific research and proposes establishing a national ocean council to serve as an advisory body.

The need for research is also being recognized at the regional level. The Pacific Community Centre for Ocean Science was established in New Caledonia in 2015. It is hosted by the Secretariat of the Pacific Community.

A Pacific Climate Change Centre

The Seventh Pacific Islands Leaders Meeting with Japan in 2015 pledged to establish a Pacific Climate Change Centre. Construction of the centre was completed in Apia, Samoa, in 2019.

A shared regional asset, the centre has four mutually reinforcing functions: knowledge brokerage; applied research; capacity-building; and innovation to promote climate change adaptation and mitigation. The government of Samoa, the Pacific Regional Environment Programme and the Japan International Cooperation Agency are all collaborating to deliver 12 courses for trainees from all Pacific Island countries and territories by 2022.

The centre also houses a research node of Australia's University of Newcastle in partnership with the Pacific Regional Environment Programme; it has offered PhD scholarships since 2018 and hosts an 'innovation incubator'. Research undertaken at the centre aligns with the four priority areas defined by the Pacific leaders, namely: climate change resilience; ecosystems and biodiversity protection; waste management; and environmental governance.

Plugging into the Digital Revolution

Mobile Internet penetration was the lowest (18%) of any region in the world in 2018 but this figure is expected to double by 2023 (GSMA, 2019). In this remote region, high-speed Internet access comes from laying an expensive undersea cable. Recent links have been created for Papua New Guinea (2020), the Solomon Islands (2020) and Tonga (2018).[43]

Pacific countries are reshaping their social and economic environments to meet digital demands. To benefit from modern digital and other technological tools, regulatory bodies have adopted social media platforms and messaging systems in official protocols to disseminate disaster warnings in Samoa, Tonga, Fiji and Niue, as well as weather forecasts and information on climate change (SPREP, 2016).

In the *Boe Declaration on Regional Security*, produced during the 2018 Pacific Islands Forum, Pacific leaders expanded the concept of security to include cybersecurity. Efforts are under way to assess cybersecurity capacity in Polynesia, Melanesia and Micronesia, in tandem with the United Nations International Telecommunications Union and other partners. Samoa has been the first to develop a *National Cyber Security Strategy 2016–2021*.

In 2015, the Pacific Islands Forum Leaders established an ICT Working Group made up of CROP agencies that is co-ordinated by the University of the South Pacific. However, no regional mechanism has since emerged in this area.[44]

In 2018, the Marshall Islands took the groundbreaking step of introducing a digital currency act. The Marshallese sovereign may yet become the first digital-only national currency and one of few state-backed digital currencies in circulation.

Start-up cost of energy transition a barrier

Energy consumes the lion's share of government expenditure. On top of domestic spending, the Pacific energy sector received US$ 847 million in aid between 2015 and 2018.[45]

Countries spend almost 10% of their GDP, on average, on imported petroleum products, the main source of energy for both rural and urban populations (Turpin *et al.*, 2015). Fossil fuel burning is also beginning to pique concerns over air quality, although precise data are unavailable for most countries. In Suva, Fiji, the level of black carbon in airborne particulate matter up to 2.5 microns in size (PM 2.5) is similar to that found in large urban centres (Isley *et al.,* 2017).

As part of their *Nationally Determined Contributions* under the *Paris Agreement*, the Pacific Island countries are building national renewable energy systems. All 14 countries now have energy strategies, although some extend only to 2020. Nearly all place a strong emphasis on electricity generation using renewable resources (Table 26.4).

Although the levelized cost of electricity is significantly cheaper from renewable sources than from diesel generation, the start-up cost of the energy transition remains a barrier. Financing was the weakest link identified by the readiness assessments for 20 SIDS (IRENA, 2017). It will require a joint effort by governments, the private sector and development partners to accelerate the pace of the energy transition in the islands.

The Pacific Centre for Renewable Energy and Energy Efficiency was established in Tonga in 2016 to advise the private sector on related policy matters, provide capacity-building and promote business investment. The centre

Table 26.4: **Progress towards targets for renewable electricity generation in Pacific Island countries, 2018**

	Share of electricity generated from renewable sources, 2018 (%)	Target for share of renewables in electricity generation (%)	Timeline for target	Policy framework
Papua New Guinea	62.0	100	2030	*National Energy Policy 2016–2020*
Fiji	60.0	100	2036	in preparation; see *National Energy Policy 2013–2020*
Samoa	42.0	100	2017	*Energy Sector Plan 2017–2022*
Cook Islands	26.0	100	2020	*Renewable Electricity Chart 2011–2020*
Tuvalu	23.0	100	2020	*Master Plan for Renewable Electricity and Energy Efficiency, 2012–2020*
Vanuatu	22.0	100	2030	*National Energy Road Map 2016–2030*
Niue	14.0	80	2025	*Strategic Energy Road Map 2015–2025*
Tonga	10.0	50	2020	*Energy Road Map 2010–2020*
Nauru	2.0	50	2020	*Energy Road Map 2018–2020*
Palau	2.0	45	2025	*National Energy Policy 2010–2020*
Kiribati	17.0	40	2025	*Integrated Energy Roadmap 2017–2025*
Micronesia	5.0	30	2020	*Energy Master Plans (2018)*
Solomon Islands	6.0	20	2020	*National Energy Policy (2014)*
Marshall Islands	2.0	20	2020	*Electricity Roadmap (2018)*

Note: Data for Kiribati's share of electricity generated from renewable sources in 2018 cover solar energy in South Tarawa only.

Source: compiled from SPREP (2021)

facilitates a financial mechanism offering competitive grants for start-ups to spur the adoption of renewable energy by the business sector.[46]

To equip its *National Energy Road Map 2016–2030,* Vanuatu approved the National Green Energy Fund in 2016 with the goal of mobilizing US$ 20 million to provide all households with access to electricity (primarily through individual solar systems) and to improve energy efficiency by 2030. In off-grid areas, households' access to electricity increased from 9% in 2015 to 64.4% in 2017. The increase was attributed to investments in imported, plug-in solar home systems, supported by the Vanuatu Rural Electrification Project in 2016. However, the share of renewable energy in electricity generation declined from 29% to 18% over the same period, owing in part to a reduction in the use of biofuels in Vanuatu's largest electricity concession in Port Vila (PCREE, 2019).

The Fiji Rural Electrification Fund will bring affordable solar power and battery storage to 300 rural communities that rely on diesel generators or are without electricity access. Initiated in 2018 and lasting ten years, this fund is a public–private partnership.[47]

From 2013 to 2017, the European Union funded the Renewable Energy in Pacific Island Countries Developing Skills and Capacity programme (EPIC). EPIC developed two master's programmes in renewable energy management, one at the University of Papua New Guinea and the other at the University of Fiji, both accredited in 2016. In Fiji, 45 students have enrolled for the master's degree since the launch of the programme and a further 21 students have undertaken a related diploma programme introduced in 2019.

Transboundary pollution a growing concern

Transboundary pollution is a growing concern in the region, which receives substantial waste via wind and ocean currents. As of 2020, 11 of the 14 Pacific Island countries have legislated bans or levies on single-use plastics (SPREP, 2021). In 2018, Vanuatu became the first country in the world to ban plastic straws.

Growing technology consumption also contributes to pollution around the world. The toxic metal mercury is notoriously mobile over long distances. Mercury bio-accumulates, building up in the bodies of top-level predators such as tuna. The presence of high body loads of mercury is linked with heavy consumption of tuna (Bell, 2017). Seven Pacific Island countries have become parties to the *Minamata Convention on Mercury*, which entered into force in 2017. National assessments of mercury sources and management capacity have been completed in Papua New Guinea and Samoa and are under way in eight other countries with the assistance of the Pacific Regional Environment Programme and United Nations Environment Programme.

CONCLUSION

Development must be sustainable

Spanning a vast region, the economies of Southeast Asia and Oceania are increasingly interwoven through trade. In 2015, the Economic Community of the Association of Southeast Asian Nations (ASEAN) came into being with the goal of fostering freedom of movement in capital, goods, services and people. In November 2020, one of the world's biggest free-trade deals was signed, the Regional Comprehensive Economic Partnership. It encompasses countries that produce about 30% of the world's GDP. It has the potential to link more closely the economies of the ASEAN members with Australia, China, Japan, the Republic of Korea and New Zealand. These five countries are longstanding ASEAN 'dialogue partners' and scientific partners.

Over the same period, the *ASEAN Plan of Action on Science, Technology and Innovation 2016–2025* has sought to foster intraregional mobility among scientists and researchers. In practice, though, there have been few initiatives since 2015 to close the gap in STI capabilities among ASEAN member states. ASEAN's operational budget is limited and, although governments may agree on strategic approaches to research and vocational training, they rarely share resources.

Over the past five years, countries have made steady progress with two of their long-standing priorities: integrating science, technology and human resources in development plans; and improving the socio-economic sustainability of such development.

In the less developed economies, raising the technical and managerial capability of the workforce remains a requirement for mastering technology and an investment focus. Levels of public expenditure on higher education are not always commensurate with this imperative, however.

The more developed countries are tackling the challenge of effectively applying science and technology to add value to manufacturing and nurture new industries. Initiatives include generous tax concessions for R&D (Indonesia), special economic zones to attract FDI (Cambodia) and innovation districts (Thailand) to strengthen linkages between research, industry and users, along with 'mission-oriented' research and innovation programmes targeting specific industrial objectives.

There is a need to ensure that development initiatives are sustainable. Special economic zones are proliferating in several countries. These can provide a fertile terrain for the development of innovation hubs, as in Thailand. However, in the rush to improve the ease of doing business, governments must take care to preserve a regulatory framework that is protective of the environment and workforce.

Although only a handful of countries, including Cambodia and Indonesia, have explicitly integrated the SDGs in their national development strategy, most share the same objectives. Thailand, with its agricultural resources and biotechnology capabilities, sees great opportunities in biomass-based energy and chemical production. Other countries are prioritizing 'green tech' development. In many countries, funding and capability gaps have limited progress towards achieving sustainability goals, despite these gaps being a focus for international aid and research collaboration.

This is the case in Timor Leste and the Pacific Island nations, for instance.

For development policies to be coherent, they must all point in the same strategic direction. Implicit STI policies for industrial development, energy, environmental protection and agriculture should complement rather than undermine one another. This is a key policy challenge not only for Southeast Asia and Oceania but for the entire world. In this connection, the decision by the Cambodian government to suspend hydropower development until 2030, following a report on the threat to fish stocks of a proposed dam, adheres to this integrated approach to development.

Three waves of change

Over the coming decade, three waves of change will test the progress made over the past decade. The first of these waves is Industry 4.0. All of the countries in the region are engaging in the early phase of digital transformation through initiatives such as smart cities, support to accelerate the digitalization of firms and the provision of greater Internet access. Some countries have opted for ambitious, comprehensive strategies, as in Singapore and Thailand and, to a lesser extent, Australia, Indonesia, Viet Nam and Cambodia.

Most countries recognize that Industry 4.0 technologies offer an opportunity to boost efficiency in the use of capital, energy, material and labour. Whether foreign investors will consider that the availability of skilled labour compensates for higher labour costs remains to be seen.

The second wave consists in the growing impact of climate change and its repercussions in terms of market adjustments and international regulation. Global action to mitigate and adjust to climate change will bring opportunities for some countries, such as for Thailand's bio-based industries.

The cost of inaction could be dire for many countries in the region. In Australia, proposals for a tax on carbon emissions have been rejected in preference to the allocation of modest funding to a Climate Solutions Package. Singapore introduced a carbon tax in 2019 but updated its *Nationally Determined Contribution* the following year to an absolute emissions cap, deemed inadequate to meet the goals of the *Paris Agreement*.

The third wave brings uncertainty to the region. Industrial and trade strategies in the USA and China, coupled with evolving geopolitical realignments, are likely to have a major impact on trade and investment, in addition to the repercussions of the Regional Comprehensive Economic Partnership, which the USA has opted not to join. Several countries are likely to attract foreign investment that might otherwise have gone to China or, as in the case of solar panel production in Malaysia, that has been relocated from China.

These waves of change will often reinforce each other, increasing the level of unpredictability and potential impact. The capabilities of the workforce, of firms and of all levels of government to take up the challenge and work collaboratively with each other and with local communities will shape the effectiveness of innovation and scientific endeavour. These levels of uncertainty mean that policy will be unavoidably experimental, underscoring the need for monitoring, evaluation and openness to policy learning and change.

KEY TARGETS FOR SOUTHEAST ASIA AND OCEANIA

- Australia is aiming to become a leading digital economy by 2030;
- Brunei Darussalam and Lao PDR are planning to increase the share of renewables in total energy consumption to 10% by 2035 and 30% by 2025, respectively;
- Cambodia intends to provide 90% of households with access to the electricity grid by 2030;
- Indonesia plans to allot 0.42% of GDP to research by 2024 and 2% by 2030;
- Malaysia plans to devote 2% of GDP to R&D by 2020;
- New Zealand's draft Research, Science and Innovation Strategy proposes a 2% target to 2027 for the GERD/GDP ratio;
- The Philippines aims to attract 235 Balik Scientists by 2022;
- Thailand's *National Strategy* fixes a target of 2% for research intensity, to be achieved by 2036;
- Nine of the Pacific Island countries plan to produce 50% or more of their electricity from renewable sources by 2036 or earlier;
- Singapore has committed to reducing carbon emissions by 36% over 2005 levels by 2030;
- Viet Nam aims to become a global and regional hub for artificial intelligence solutions and applications by 2030.

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ENDNOTES

1 The Law on Job Creation creates a new framework for business licensing and amends 77 existing national laws covering, *inter alia*, environmental protection, spatial planning, special economic zones, SMEs, land rights, taxation and the transport, energy, agriculture and fisheries sectors. The law also makes changes to existing labour and social security laws, reducing existing worker protections in many cases (Mahy 2021).

2 The Pacific Regional ICT Strategic Action Plan was developed by the ICT Working Group of the Council of Regional Organisations of the Pacific. A review of implementation was planned for 2018 but was unavailable to the present authors at the time of writing in January 2021.

3 Beeline's services came to an end in January 2020 (Yi, 2019).

4 Value-added manufacturing (in current US$) declined slightly in Brunei Darussalam over 2015–2019, from US$ 1.9 to 1.8 billion.

5 Like ASEAN, the Asia–Pacific Economic Community (APEC) lacks operating funds. APEC's Policy Partnership for Science, Technology and Innovation, formerly the Industrial Science and Technology Working Group, aims to 'support the development of science and technology co-operation, as well as effective science, technology and innovation policy recommendations in APEC through collaboration between government, academia, the private sector and other APEC fora' (APEC, 2015). APEC is largely a forum for communication.

6 ASEAN's ten dialogue partners are Australia, Canada, China, India, Japan, Republic of Korea, New Zealand, the Russian Federation, USA and European Union.

7 These five instances comprised: Malaysia as first collaborator for Brunei Darussalam; Thailand as second collaborator for Cambodia; Malaysia as second collaborator for Indonesia; Thailand as first collaborator for Lao PDR; and Thailand as third collaborator for Myanmar.

8 Two significant pieces of legislation were enacted in the Philippines over 2018–2019 to develop human resources. The Balik (Returning) Scientist Act (2018) builds upon the Balik Science programme, which was first launched in 1975 and implemented in intervals. The programme funds the return of Filipino STI personnel living abroad work in the Philippines. Since its inception, 533 Balik Scientists have been involved in 670 short-, medium- and long-term engagements (Guevara, 2020; Arayata, 2018).

9 Innovation and Science Australia was established in 2015 as an independent advisory board to the government. See its review of the Australian science system: https://tinyurl.com/1pytitmv

10 See: https://tinyurl.com/aus-innov-system-monitor

11 The 2020 Climate Change Performance Index, which assesses national climate action across greenhouse gas emissions, renewable energy, energy use and policy, ranked Australia sixth to last among 57 countries.

12 See: https://tinyurl.com/rv6ufzvo

13 See the Digital Transformation Strategy Dashboard: https://www.dta.gov.au/digital-transformation-strategy

14 Many existing organizations have become increasingly orientated towards Industry 4.0 objectives, such as the Advanced Manufacturing Growth Centre and the Innovative Manufacturing Cooperative Research Centre. See: https://www.amgc.org.au/projects/ and https://www.imcrc.org/

15 In 2010, Brunei Darussalam produced 400 000 barrels of oil equivalent per day.

16 At an average cost of US$ 0.15 per kWh, the cost of electricity for Cambodian households is above the global average of US$ 0.14 per kWh, according to GlobalPetrolPrices.com

17 This information was obtained by the present authors via a personal communication with Kum Kim, Senior Marketing Expert at the Embassy of the Republic of Korea.

18 See: https://sinta.ristekbrin.go.id/

19 A 2017 survey by BDRC Continental ranked Lao PDR 192nd out of 196 countries for broadband pricing, with an average broadband package price of US$ 231 per month. Cambodia (US$ 53), Viet Nam (US$ 63) and Myanmar (US$ 77) all fared significantly better (World Bank, 2018).

20 These data are cited by the European Union's Reducing emissions from Deforestation and Forest Degradation initiative. See: https://www.euredd.efi.int/laos

21 The National Policy on Industry 4.0 was launched in 2018 but the report used 2016 as the baseline year to estimate growth targets.

22 According to one prominent industry representative, barriers to Industry 4.0 remain, including a shortage of professionals with STEM skills; a traditional mindset, which has impeded government efforts to promote technical and vocational education and training; and tight controls on certain industries (Lee, 2020).

23 These five economic corridors are Iskandar Malaysia, the Northern Corridor Economic Region, the Eastern Corridor Economic Region, the Sabah Development Corridor and the Sarawak Corridor of Renewable Energy. They were established by the Ninth Malaysian Plan (2007) and cover nearly 70% of the country's landmass. The largest corridor, Iskandar Malaysia, focuses on electronics, petrochemicals, oil and gas, food and agro-processing, logistics, tourism, health care, education, finance, insurance, real estate and business services.

24 After gaining three ministerial portfolios, the Ministry of Science, Technology and Innovation was renamed the Ministry of Energy, Science, Technology, Environment and Climate Change in 2018. Two years later, this move was reversed when the Ministry of Science, Technology and Innovation was reinstated.

25 These five funds fall under the Program Dana Pemacu Teknologi Strategik, also known as PEMACU (Yunus, 2021).

26 These are: the Trademark Law and Industrial Design Law (passed by parliament on 30 January 2019); the Patent Law (passed on 11 March 2019); and the Copyright Law (passed on 24 May 2019).

27 New Zealand's performance towards the SDGs is visualized on the website www.SDG.org.nz. SDG.org.nz is run by the Victoria University of Wellington's School of Government.

28 A digital twin is a data-based replica that enables virtual experimentation and, thereby, assists with the planning and management of infrastructure assets.

29 See: https://www.callaghaninnovation.govt.nz/industry-4

30 These acts are officially entitled the Implementing Rules and Regulations of Republic Act (RA) No. 11035 and Republic Act No. 11312, which amends the original Republic Act No. 8439.

31 The government reportedly raised R&D spending to PHP 13.7 billion (*ca* US$ 270 million) in 2017 (Guevara, 2018).

32 Formally documented as Republic Act # 11293.

33 Formally passed as Republic Act # 11337.

34 This value is calculated by weighing income from intellectual property exports and the cost of intellectual property imports against the total value of intellectual property trade.

35 The policy instrument to impose carbon taxes is based on estimation of the carbon intensity of emissions. Given that there is little information on the composition of energy used in imports, it can be reasonably assumed that imports will not be subject to carbon taxes.

36 Half of Timor-Leste's 1.2 million citizens are under 20 years of age.

37 The principles of sustainable development are also being integrated in the draft Social and Economic Development Strategy for 2021–2030 and draft Social and Economic Development Plan for 2021–2025.

38 The Startup Accelerator Fund was established with support from the FPT Group, the Dragon Capital Group, the Korean conglomerate Hanwha and Vietnam Securities Company of the Bank for Investment and Development.

39 This digital knowledge system was approved under Decision 677/QD-TTg.

40 These are Vanuatu, Tonga, the Solomon Islands, Papua New Guinea and Fiji.

41 These agencies include the Pacific Islands Forum, Pacific Community, Pacific Islands Forum Fisheries Agency, Pacific Regional Environment Programme and the University of the South Pacific.

42 This information was obtained by the authors via a personal communication with Ofa Kaisamy, Legal Adviser to the project on Ratification and Implementation of the Nagoya Protocol in the countries of the Pacific, executed by the Secretariat of the Pacific Regional Environment Programme.

43 See: https://www.submarinecablemap.com/

44 The University of the South Pacific and the University of Fiji have re-designed their educational programmes to include courses such as cybersecurity and cloud computing. However, these programmes may not focus on the frontier of knowledge generation.

45 For instance, the World Bank's Regional Sustainable Energy Industry Development Project, running over 2015–2022, is funded for US$ 5.6 million and operates in ten Pacific Island countries. See the Lowy Institute Pacific Aid Map: https://pacificaidmap.lowyinstitute.org/

46 The centre is part of the Global Network of Regional Sustainable Energy Centres and SIDS DOCK framework designed to attract international investment in the renewable energy sector. See: http://www.se4allnetwork.org/ and https://sidsdock.org/

47 The partners supporting the Fiji Rural Electrification Fund are Sunergise (Fiji) Ltd, the Fiji Locally Managed Marine Area Network, UK government, Leonardo DiCaprio Foundation and Electricity Fiji Limited.

Annexes

1. Composition of regions and sub-regions
2. Broad fields of science
3. Glossary & acronyms
4. Background information on the bibliometric study of research trends on selected topics related to *The 2030 Agenda for Sustainable Development*
5. Technical and methodological note on the statistical annex

Annex 1: Composition of regions and subregions

Groupings mentioned in chapter 1

COUNTRIES BY INCOME LEVELS[1]

High-income economies
Antigua and Barbuda; Australia; Austria; Bahamas; Bahrain; Barbados; Belgium; Brunei Darussalam; Canada; Chile; China, Hong Kong SAR; China, Macao SAR; Croatia; Cyprus; Czech Rep.; Denmark; Equatorial Guinea; Estonia; Finland; France; Germany; Greece; Iceland; Ireland; Israel; Italy; Japan; Korea, Rep.; Kuwait; Latvia; Liechtenstein; Lithuania; Luxembourg; Malta; Netherlands; New Zealand; Norway; Oman; Poland; Portugal; Qatar; Russian Federation; St Kitts and Nevis; Saudi Arabia; Singapore; Slovakia; Slovenia; Spain; Sweden; Switzerland; Trinidad and Tobago; United Arab Emirates; United Kingdom; United States of America; Uruguay

Upper middle-income economies
Albania; Algeria; Angola; Argentina; Azerbaijan; Belarus; Belize; Bosnia and Herzegovina; Botswana; Brazil; Bulgaria; China; Colombia; Costa Rica; Cuba; Dominica; Dominican Rep.; Ecuador; Fiji; Gabon; Grenada; Hungary; Iran, Islamic Rep.; Iraq; Jamaica; Jordan; Kazakhstan; Lebanon; Libya; Malaysia; Maldives; Marshall Islands; Mauritius; Mexico; Montenegro; Namibia; North Macedonia; Palau; Panama; Peru; Romania; Serbia; Seychelles; South Africa; St Lucia; St Vincent and the Grenadines; Suriname; Thailand; Tonga; Tunisia; Turkey; Turkmenistan; Tuvalu; Venezuela

Lower middle-income economies
Armenia; Bhutan; Bolivia; Cabo Verde; Cambodia: Cameroon; Congo; Côte d'Ivoire; Djibouti; Egypt; El Salvador; Eswatini; Georgia; Ghana; Guatemala; Guyana; Honduras; India; Indonesia; Kiribati; Kyrgyzstan; Lao PDR; Lesotho; Mauritania; Micronesia; Moldova, Rep.; Mongolia; Morocco; Nicaragua; Nigeria; Pakistan; Palestine; Papua New Guinea; Paraguay; Philippines; Samoa; Sao Tome and Principe; Senegal; Solomon Islands; South Sudan; Sri Lanka; Sudan; Syrian Arab Rep.; Timor-Leste; Ukraine; Uzbekistan; Vanuatu; Viet Nam; Yemen; Zambia

Low-income economies
Afghanistan; Bangladesh; Benin; Burkina Faso; Burundi; Central African Rep.; Chad; Comoros; Congo, Dem. Rep.; Eritrea; Ethiopia; Gambia; Guinea; Guinea-Bissau; Haiti; Kenya; Korea, DPR; Liberia; Madagascar; Malawi; Mali; Mozambique; Myanmar; Nepal; Niger; Rwanda; Sierra Leone; Somalia; Tajikistan; Togo; Uganda; Tanzania; Zimbabwe

REGIONAL GROUPINGS IN THE REPORT[2]

North America
Canada; United States of America

Latin America
Argentina; Belize; Bolivia; Brazil; Chile; Colombia; Costa Rica; Ecuador; El Salvador; Guatemala; Guyana; Honduras; Mexico; Nicaragua; Panama; Paraguay; Peru; Suriname; Uruguay; Venezuela

Caribbean
Antigua and Barbuda; Bahamas; Barbados; Cuba; Dominica; Dominican Rep.; Grenada; Haiti; Jamaica; St Kitts and Nevis; St Lucia; St Vincent and the Grenadines; Trinidad and Tobago

European Union
Austria; Belgium; Bulgaria; Croatia; Cyprus; Czech Rep.; Denmark; Estonia; Finland; France; Germany; Greece; Hungary; Ireland; Italy; Latvia; Lithuania; Luxembourg; Malta; Netherlands; Poland; Portugal; Romania; Slovakia; Slovenia; Spain; Sweden; United Kingdom[3]

Southeast Europe
Albania; Bosnia and Herzegovina; Montenegro; Serbia; North Macedonia

European Free Trade Association
Iceland; Liechtenstein; Norway; Switzerland

Eastern Europe & West Asia
Armenia; Azerbaijan; Belarus; Georgia; Iran, Islamic Rep.; Israel; Moldova, Rep.; Russian Federation; Turkey; Ukraine

Sub-Saharan Africa
Angola; Benin; Botswana; Burkina Faso; Burundi; Cameroon; Cabo Verde; Central African Rep.; Chad; Comoros; Congo; Côte d'Ivoire; Congo, Dem. Rep.; Djibouti; Equatorial Guinea; Eritrea; Ethiopia; Gabon; Gambia; Ghana; Guinea; Guinea-Bissau; Kenya; Lesotho; Liberia; Madagascar; Malawi; Mali; Mauritius; Mozambique; Namibia; Niger; Nigeria; Rwanda; Sao Tome and Principe; Senegal; Seychelles; Sierra Leone; Somalia; South Africa; South Sudan; Swaziland; Togo; Uganda; Tanzania; Zambia; Zimbabwe

Arab States in Africa
Algeria; Egypt; Libya; Mauritania; Morocco; Sudan; Tunisia

Central Asia
Kazakhstan; Kyrgyzstan; Mongolia; Tajikistan; Turkmenistan; Uzbekistan

Arab States in Asia
Bahrain; Iraq; Jordan; Kuwait; Lebanon; Oman; Palestine; Qatar; Saudi Arabia; Syrian Arab Rep.; United Arab Emirates; Yemen

South Asia
Afghanistan; Bangladesh; Bhutan; India; Maldives; Nepal; Pakistan; Sri Lanka

Southeast Asia
Brunei Darussalam; Cambodia; People's Republic of China; Indonesia; Japan; Korea, Dem. People's Rep.; Korea, Rep.; Lao PDR; Malaysia; Myanmar; Philippines; Singapore; Thailand; Timor-Leste; Viet Nam

Oceania
Australia; Brunei Darussalam; Cook Islands; Fiji; Kiribati; Marshall Islands; Micronesia; Nauru; New Zealand; Niue; Palau; Papua New Guinea; Samoa; Solomon Islands; Timor-Leste; Tonga; Tuvalu; Vanuatu

OTHER GROUPINGS

Least developed countries [4]
Afghanistan; Angola; Bangladesh; Benin; Bhutan; Burkina Faso; Burundi; Cambodia; Central African Rep.; Chad; Comoros; Congo, Dem. Rep.; Djibouti; Equatorial Guinea; Eritrea; Ethiopia; Gambia; Guinea; Guinea-Bissau; Haiti; Kiribati; Lao PDR; Lesotho; Liberia; Madagascar; Malawi; Mali; Mauritania; Mozambique; Myanmar; Nepal; Niger; Rwanda; Sao Tome and Principe; Senegal; Sierra Leone; Solomon Islands; Somalia; South Sudan; Sudan; Timor-Leste; Togo; Tuvalu; Uganda; Tanzania; Vanuatu; Yemen; Zambia

G20
Argentina; Australia; Brazil; Canada; China; France; Germany; India; Indonesia; Italy; Japan; Korea, Rep.; Mexico; Russian Federation; Saudi Arabia; South Africa; Turkey; United Kingdom; United States of America; European Union

INTERGOVERNMENTAL ORGANIZATIONS

Association of Southeast Asian Nations (ASEAN)
Brunei Darussalam; Cambodia; Indonesia; Lao PDR; Malaysia; Myanmar; Philippines; Singapore; Thailand; Viet Nam

Caribbean Community (Caricom)
Antigua and Barbuda; Bahamas; Barbados; Belize; Dominica; Grenada; Guyana; Haiti; Jamaica; Montserrat; St Kitts and Nevis; St Lucia; St Vincent and the Grenadines; Suriname; Trinidad and Tobago

Central African Economic and Monetary Community (CEMAC)
Cameroon; Central African Rep.; Chad; Congo; Equatorial Guinea; Gabon

Common Market for Eastern and Southern Africa (COMESA)
Burundi; Comoros; Congo, Dem. Rep.; Djibouti; Egypt; Eritrea; Eswatini; Ethiopia; Kenya; Libya; Madagascar; Malawi; Mauritius; Rwanda; Seychelles; Somalia; Sudan; Tunisia; Uganda; Zambia; Zimbabwe

Community of Latin American and Caribbean States (CELAC)
Antigua and Barbuda; Argentina; Bahamas; Barbados; Belize; Bolivia; Brazil; Chile; Colombia; Costa Rica; Cuba; Dominica; Ecuador; El Salvador; Granada; Guatemala; Guyana; Honduras; Jamaica; Mexico; Nicaragua; Panama; Paraguay; Peru; Dominican Rep.; St Kitts and Nevis; St Vincent and Grenadines; Trinidad and Tobago; Uruguay; Venezuela

East African Community (EAC)
Burundi; Kenya; Rwanda; South Sudan; Tanzania; Uganda

Economic Community of Central African States (ECCAS)
Angola; Burundi; Cameroon; Central African Rep.; Chad; Congo; Congo, Dem. Rep.; Equatorial Guinea; Gabon; Rwanda; Sao Tomé and Principe

Economic Community of West African States (ECOWAS)
Benin; Burkina Faso; Cabo Verde; Côte d'Ivoire; Gambia; Ghana; Guinea; Guinea-Bissau; Liberia; Mali; Niger; Nigeria; Senegal; Sierra Leone; Togo

Eurasian Economic Union (EAEU)
Armenia; Belarus; Kazakhstan; Kyrgyzstan; Russian Federation

Forum for the Progress and Development of South America (PROSUR)
Argentina; Brazil; Colombia; Chile; Ecuador; Guyana; Paragua; Peru

Intergovernmental Authority on Development (IGAD)
Djibouti; Eritrea; Ethiopia; Kenya; Somalia; South Sudan; Sudan; Uganda

Mercado Común del Sur (MERCOSUR)
Argentina; Brazil; Paraguay; Uruguay; Venezuela (suspended since 2016)

North Atlantic Treaty Organization (NATO)
Albania; Belgium; Bulgaria; Canada; Croatia; Czech Rep.; Denmark; Estonia; France; Germany; Greece; Hungary; Iceland; Italy; Latvia; Lithuania; Luxembourg; Montenegro; Netherlands; North Macedonia; Norway; Poland; Portugal; Romania; Slovakia; Slovenia; Spain; Turkey; UK; USA

Organization of the Black Sea Economic Cooperation (BSEC)
Albania; Armenia; Azerbaijan; Bulgaria; Georgia; Greece; North Macedonia; Moldova, Rep.; Romania; Russian Federation; Serbia; Turkey; Ukraine

Organization for Economic Co-operation and Development (OECD)
Australia; Austria; Belgium; Canada; Chile; Czech Rep.; Denmark; Estonia; Finland; France; Germany; Greece; Hungary; Iceland; Ireland; Israel; Italy; Japan; Korea, Rep.; Luxembourg; Mexico; Netherlands; New Zealand; Norway; Poland; Portugal; Slovakia; Slovenia; Spain; Sweden; Switzerland; Turkey; United Kingdom; United States of America

Organization of Ibero-American States (OEI)
Andorra; Argentina; Bolivia; Brazil; Colombia; Costa Rica; Cuba; Chile; Dominican Rep.; Ecuador; El Salvador; Equatorial Guinea; Guatemala; Honduras; Mexico; Nicaragua; Panama; Paraguay; Peru; Portugal; Spain; Uruguay; Venezuela

Organization of Islamic Co-operation (OIC)
Afghanistan; Albania; Algeria; Azerbaijan; Bahrain; Bangladesh; Benin; Brunei Darussalam; Burkina Faso; Cameroon; Chad; Comoros; Côte d'Ivoire; Djibouti; Egypt; Gabon; Gambia; Guinea; Guinea Bissau; Guyana; Indonesia; Iran; Iraq; Jordan; Kuwait; Kazakhstan; Kyrgyzstan; Lebanon; Libya; Maldives; Malaysia; Mali; Mauritania; Morocco; Mozambique; Niger; Nigeria; Oman; Palestine; Pakistan; Qatar; Saudi Arabia; Senegal; Sierra Leone; Somalia; Sudan; Suriname; Syrian Arab Rep.; Tajikistan; Togo; Turkey; Turkmenistan; Tunisia; Uganda; United Arab Emirates; Uzbekistan; Yemen

Pacific Islands Forum (PIF)
Australia; Cook Islands; Federated States of Micronesia; Fiji; French Polynesia; Kiribati; Nauru; New Caledonia; New Zealand; Niue; Palau; Papua New Guinea; Marshall Islands; Samoa; Solomon Islands; Tonga; Tuvalu; Vanuatu

Shanghai Cooperation Organisation (SCO)
China; India; Kazakhstan; Kyrgyzstan; Pakistan; Russian Federation; Tajikistan; Uzbekistan

South Asian Association for Regional Cooperation (SAARC)
Afghanistan; Bangladesh; Bhutan; India; Maldives; Nepal; Pakistan; Sri Lanka

Southern African Development Community (SADC)
Angola; Botswana; Comoros; Congo, Dem. Rep.; Eswatini; Lesotho; Madagascar; Malawi; Mauritius; Mozambique; Namibia; Seychelles; South Africa; Tanzania; Zambia; Zimbabwe

Union of South American Nations (UNASUR)
Argentina; Bolivia; Brazil; Chile; Colombia; Ecuador; Guyana; Paraguay; Peru; Suriname; Uruguay; Venezuela

World Trade Organization (WTO)
Afghanistan; Albania; Angola; Antigua and Barbuda; Argentina; Armenia; Australia; Austria; Bahrain; Bangladesh; Barbados; Belgium; Belize; Benin; Bolivia; Botswana; Brazil; Brunei Darussalam; Bulgaria; Burkina Faso; Burundi; Cabo Verde; Cameroon; Canada; Cambodia; Central African Rep.; Chad; Chile; China; Colombia; Congo; Costa Rica; Côte d'Ivoire; Croatia; Cuba; Cyprus; Czech Rep.; Congo, Dem. Rep.; Denmark; Djibouti; Dominica; Dominican Rep.; Ecuador; Egypt; El Salvador; Estonia; Eswatini; European Union; Fiji; Finland; France; Gabon; The Gambia; Georgia; Germany; Ghana; Greece; Grenada; Guatemala; Guinea; Guinea-Bissau; Guyana; Haiti; Honduras; China, Hong Kong SAR; Hungary; Iceland; India; Indonesia; Ireland; Israel; Italy; Jamaica; Japan; Jordan; Kazakhstan; Kenya; Korea, Rep.; Kuwait; Kyrgyzstan; Lao People's Democratic Rep.; Latvia; Lesotho; Liberia; Liechtenstein; Lithuania; Luxembourg; China, Macao SAR; Madagascar; Malawi; Malaysia; Maldives; Mali; Malta; Mauritania; Mauritius; Mexico; Moldova , Rep.; Mongolia; Montenegro; Morocco; Mozambique; Myanmar; Namibia; Nepal; Netherlands; New Zealand; Nicaragua; Niger; Nigeria; North Macedonia; Norway; Oman; Pakistan; Panama; Papua New Guinea; Paraguay; Peru; Philippines; Poland; Portugal; Qatar; Romania; Russian Federation; Rwanda; St Kitts and Nevis; St Lucia; St Vincent and the Grenadines; Samoa; Saudi Arabia; Senegal; Seychelles; Sierra Leone; Singapore; Slovakia; Slovenia; Solomon Islands; South Africa; Spain; Sri Lanka; Suriname; Sweden; Switzerland; China, Taiwan Prov.; Tajikistan; United Rep. of Tanzania; Thailand; Togo; Tonga; Trinidad and Tobago; Tunisia; Turkey; Uganda; Ukraine; United Arab Emirates; United Kingdom; United States of America; Uruguay; Vanuatu; Venezuela; Viet Nam; Yemen; Zambia; Zimbabwe

ENDNOTES

1 Groupings by income level are based on 2013 gross national income per capita, calculated using the World Bank Atlas method, as of May 2015. This classification was used to consider the middle of the period under study in the bibliometric analyses. Changes in classification in 2020 for individual countries are not reflected in the lists here, as the data collected by income group cover earlier years.

2 The regional groupings in the *UNESCO Science Report* are valid only for this series of reports. Regional groupings reflect the geographical scope of individual chapters, rather than any official United Nations grouping.

3 The United Kingdom (UK) left the European Union in January 2020. For the period under study, the UK was a member and is included in EU regional totals for the accompanying datasets unless otherwise specified.

4 Based on the standard classification of the United Nations Statistics Division: http://unstats.un.org/unsd/methods/m49/m49regin.htm Equatorial Guinea graduated from LDC status in 2017 and Vanuatu graduated in 2020 but these countries are included in the LDC group for the publication analyses, which cover the 2011–2019 period.

Annex 2: Broad fields of science

Adapted from the Science-Metrix Classification of Scientific Journals (v. 1.06)*

In order to generate statistics on scientific publications by broad field of science, the existing Science-Metrix classification of 174 subfields was regrouped in the 11 broad fields listed on the following page.

Some 38 of Science-Metrix's subfields were discarded from the full bibliometric study conducted by Science-Metrix because they classified papers from social sciences and the humanities that included fields such as linguistics, law or business. These papers were not covered by the *UNESCO Science Report*, in order to ensure greater homogeneity within fields and, thereby, facilitate comparisons between countries.

The broad field of cross-cutting technologies has been split into 10 subcategories. The three categories of artificial intelligence and robotics, blockchain technology and the Internet of Things did not align with the existing subfields* based on journal-level classification, so were created by manually assembling lists of journals principally covering those themes using a keyword-based approach. Journals identified as being mainly focused on one of these themes were removed from their original subfield to ensure that all broad fields were mutually exclusive.

It is important to note that all of these subfields are defined at the journal level. For example, this means that an article on robotics published in a more general journal on information and communication technologies would not be counted towards the AI and robotics dataset. The only exceptions are generalist journals, such as *Nature* or *Science*, which cannot be accurately assigned to a single subfield. Articles from such journals were instead assigned a subfield at the article level by using a machine-learning algorithm.

In graphics within chapters, percentage shares of broad fields of science have been rounded. This means that values of 0.5% and over have been rounded up to 1% and those accounting for less than 0.5% of total output have been excluded.

The composition of each broad field of science by subfield can be found on the following page.

For additional details of the bibliometric research, please see the methodological note at the end of Table E1.

* Available at:
https://www.science-metrix.com/?q=en/classification

See also: Archambault, É.; Beauchesne, O. H. and J. Caruso (2011) Towards a multilingual, comprehensive and open scientific journal ontology. In: E. Noyons, P. Ngulube and J. Leta (eds) *Proceedings of ISSI 2011 – the 13th International Conference of the International Society for Scientometrics and Informetrics*. ISSI, Leiden University and University of Auckland: https://tinyurl.com/y2wkn4xv

** Topics related to social sciences were eliminated from this category.

Composition of each broad field of science by subfield

Broad field	Subfield
Agricultural sciences	Agronomy and agriculture
	Dairy and animal science
	Fisheries
	Food science
	Forestry
	Horticulture
	Veterinary sciences
Biological sciences	Entomology
	Evolutionary biology
	Marine biology and hydrobiology
	Ornithology
	Plant biology and botany
	Zoology
Built environment and design	Architecture
	Building and construction
	Design practice and management
	Urban and regional planning
Chemistry	Analytical chemistry
	General chemistry
	Inorganic and nuclear chemistry
	Medicinal and biomolecular chemistry
	Organic chemistry
	Physical chemistry
	Polymers
Cross-cutting strategic technologies	Artificial intelligence and robotics
	Bioinformatics
	Biotechnology
	Blockchain technology
	Energy
	Internet of Things
	Materials
	Nanoscience and nanotechnology
	Optoelectronics and photonics
	Strategic, defence and security studies**
Engineering	Aerospace and aeronautics
	Automobile design and engineering
	Biomedical engineering
	Chemical engineering
	Civil engineering
	Electrical and electronic engineering
	Environmental engineering
	Geological and geomatics engineering
	Industrial engineering and automation
	Mechanical engineering and transport
	Mining and metallurgy
	Operations research
Environmental sciences (excl. geosciences)	Ecology
	Hydrology (excluding hydrobiology and hydrogeology)
	Meteorology and atmospheric sciences
	Oceanography
Geosciences	Geology
	Geochemistry and geophysics
	Hydrogeology
	Palaeontology
Health sciences	Allergy
	Anatomy and morphology
	Anaesthesiology
	Arthritis and rheumatology
	Behavioural science and comparative psychology
	Biochemistry and molecular biology
	Biophysics
	Cardiovascular system and haematology
	Clinical psychology
	Complementary and alternative medicine
	Dentistry
	Dermatology and venereal diseases
	Developmental and child psychology
	Developmental biology
	Emergency and critical care medicine
	Endocrinology and metabolism
	Environmental and occupational health
	Epidemiology
	Experimental psychology
	Gastroenterology and hepatology
	General and internal medicine
	General clinical medicine
	General psychology and cognitive sciences
	Genetics and heredity
	Geriatrics
	Gerontology
	Health policy and services
	Human factors
	Immunology
	Legal and forensic medicine
	Microbiology
	Microscopy
	Mycology and parasitology
	Neurology and neurosurgery
	Nuclear medicine and medical imaging
	Nursing
	Nutrition and dietetics
	Obstetrics and reproductive medicine
	Oncology and carcinogenesis
	Ophthalmology and optometry
	Orthopaedics
	Otorhinolaryngology
	Pathology
	Paediatrics
	Pharmacology and pharmacy
	Physiology
	Psychiatry
	Psychoanalysis
	Public health
	Rehabilitation
	Respiratory system
Health sciences *(continued)*	Social psychology
	Speech-language pathology and audiology
	Sport sciences
	Substance abuse
	Surgery
	Toxicology
	Tropical medicine
	Urology and nephrology
	Virology
ICTs, maths and statistics	Applied mathematics
	Computation theory and mathematics
	Computer hardware and architecture
	Distributed computing
	General mathematics
	Image processing
	Information systems
	Medical informatics
	Networking and telecommunications
	Numerical and computational mathematics
	Statistics and probability
Physics and astronomy	Acoustics
	Applied physics
	Astronomy and astrophysics
	Chemical physics
	Fluids and plasmas
	General physics
	Mathematical physics
	Nuclear and particle physics
	Optics

Annex 3: Glossary

Additive manufacturing
This is the process of manufacturing a three-dimensional (3D) object from digital design data, usually layer upon layer; also known as 3D printing.

Big data
This is a volume of data that is large in volume, variety and velocity of generation and processing and difficult to process using traditional methods, requiring approaches such as parallel computing; big data are collected by organizations and can be 'mined' for analytical applications.

Blue economy
Building on the green economy concept, the blue economy aims to improve human well-being and social equity while significantly reducing environmental risks and ecological scarcities. The term has come to be associated with ocean resources. Most working definitions refer to economic activities based on the use of marine resources that actively benefit marine ecosystem sustainability, such as 'ridge-to-reef' approaches linking land and ocean management.

Business accelerator
This model provides start-ups with training, facilities, mentorship and partners. Accelerators invest in their start-ups, unlike incubators (see next entry).

Business incubator
This model provides start-ups with training, facilities, mentorship and partners. Unlike accelerators (see previous entry), incubators do not invest in their start-ups.

Business enterprise sector (for research data)
This sector comprises both public and private firms; it includes all resident corporations, regardless of the residence of their shareholders, as well as all other types of quasi-corporations and all resident non-profit institutions that are market producers of goods or services or serve business. The unincorporated branches of non-resident enterprises are deemed to be resident because they are engaged in production on the economic territory on a long-term basis.

Capital expenditure
This is the annual gross amount paid for the acquisition of fixed assets that are used repeatedly or continuously in the performance of R&D for more than one year. The payments should be reported in full for the period when they took place, whether acquired or developed in house, and should not be registered as an element of depreciation.

Circular economy
This type of economy promotes the elimination of waste and continual, sustainable use of natural resources. Taking a lifecycle perspective, circular approaches strive to maintain high value for materials at all stages of a process chain. This approach boosts efficiency and promotes remanufacturing, re-use and reduced pressure on primary resources. See: **Linear economy**.

Current R&D expenditure
This is composed of labour costs and other current costs (including for external research personnel) used in research. Services and items (including equipment) used and consumed within one year are current expenditure. Annual fees or rents for the use of fixed assets should be included in current expenditure.

Digital twins
This is a dynamic software model, or digital representation, of a physical object or system. The twin is a mathematical model that simulates the real-world original in digital space and can receive input from sensors on its real-world counterpart. Digital twins can support monitoring, testing and experimentation.

Digitization vs digitalization
Digitization is the conversion of analog to digital, whereas digitalization is the use of digital technologies and digitized data to impact how work gets done, transform how customers and companies engage and interact and create new (digital) revenue streams.

Disruptive innovation
Dynamic start-ups which may be working on innovation with potential to create new markets and disrupt the business model of their more established competitors, including large corporations. Increasingly, corporations are opting to support these start-ups through business accelerators and incubators (see above), as this approach can be more cost-effective than the acquisition of the new technology. They also stand to gain insights into the future of their market and defuse disruptive innovation. Examples of corporations which have invested in disruptive innovation incubators and accelerators are Allianz, Google, LinkedIn, Microsoft, Samsung, Starbucks, Telefonica and Turner.

Dutch disease
This economic term describes the cause and effect relationship between a resource boom and a decline in manufacturing; the term was coined in 1977 by *The Economist* to describe the decline of the manufacturing sector in the Netherlands after the discovery of a large natural gas field in 1959. A resource boom increases demand for labour, which causes production to shift towards the booming sector, such

as hydrocarbons or minerals. A secondary effect is the rise in demand for labour in the services sector. In both cases, manufacturing suffers.

Energy consumption

Total final energy use is the sum of consumption by end-use sectors and for non-energy use. Final consumption reflects, for the most part, deliveries to consumers. The term excludes energy used for transformation processes and for self-use by energy-producing industries.

Ex post evaluation

This type of assessment focuses on the relevance, effectiveness, impact and sustainability of a completed project on the basis of international criteria.

External imbalance

In this situation, the amount of money a country earns from its exports is significantly higher or lower than the money it spends on imports.

Fabless company

This type of company develops and patents innovative products but outsources the fabrication (fab) of the components that make up these products; this practice is particularly common for hardware devices and semiconductor chips.

Field of study

The UNESCO Institute for Statistics defines these on the basis of the *International Standard Classification of Education: Fields of Education and Training 2013*, with the exception of arts and humanities, which combines the broad fields of arts and humanities, education and services (see Annex 5). The field classification of publications differs from the fields of study (see Annex 2 for the broad fields of science used to prepare publication statistics at the level of scientific disciplines).

Fiscal consolidation

This refers to government policy designed to reduce deficits and the accumulation of debt.

Fiscal deficit vs fiscal debt

Fiscal deficit is the difference between the government's total revenue and total expenditure. Fiscal debt is the accumulation of fiscal deficits over time and represents the total amount owed by the government to creditors.

Fiscal flexibility (Fiscal space)

This refers to the flexibility that a government can exercise in its spending choices.

Full-time equivalent (FTE)

This is calculated as the ratio of working hours spent on research during a specific reference period (usually a calendar year) divided by the total number of hours conventionally worked over the same period by an individual or by a group. One FTE may be thought as one person-year. A person who normally spends 30% of their time on R&D and the rest on other activities, such as teaching, university administration and student counselling, should be considered as 0.3 FTE. Similarly, if a full-time research worker is employed at a research unit for only six months, this results in an FTE of 0.5.

Gender parity

This is equivalent to female representation of between 45% and 55% of a given population.

Gini index

This measures the extent to which the distribution of income (or, in some cases, consumption expenditure) among individuals or households within an economy deviates from a perfectly equal distribution. A Gini index of zero represents perfect equality and a score of 100 represents perfect inequality.

Global Competitive Index

This ranks countries according to three types of attribute: '*basic requirements*' encompass institutions, infrastructure, macro-economic stability, health and primary education; '*efficiency enhancers*' include higher education and training, labour market efficiency, financial market sophistication, market size and technological readiness; '*innovation and sophistication*' factors cover business sophistication and innovation.

Great Recession

This term refers to a period of economic decline following the global financial crisis of 2007–2008, in which negative GDP growth persisted in many countries for the longest amount of time since the Great Depression of the 1930s. The impact of the Great Recession was felt worldwide but particularly affected North America and Europe. According to World Bank estimates, the Great Recession saw the global economy contract by 2.1% in 2009; it officially lasted in the USA from December 2007 to June 2009.

Greenfield investment

This refers to investment in a factory, airport, power plant, steel mill or other physical, commerce-related structure where no facilities existed previously. A parent company may construct new facilities in the same country or a foreign country; governments may offer prospective companies incentives to set up a greenfield investment (tax breaks, subsidies, etc), as most parent companies tend to create jobs in the foreign country, in addition to infrastructure.

Green Climate Fund

This is a financial mechanism of the United Nations Framework Convention on Climate Change that was established in 2010 to support developing countries by funding low-emission, resilient responses to climate change; the fund launched its first resource mobilization in 2014.

Gross enrolment ratio

This refers to total enrolment at a specific level of education, regardless of age, expressed as a percentage of the eligible official school-age population corresponding to the same level of education in a given school year.

Gross fixed capital formation
This consists of investment in improvements to land (fences, ditches, drains, etc); plant, machinery and equipment purchases; and the construction of roads, railways and the like, including commercial and industrial buildings, offices, schools, hospitals and private residences.

Headcount (HC) of research personnel
This refers to the total number of individuals contributing to R&D over a specific reference period that usually corresponds to a calendar year. Thus, it reflects the total number of persons who are mainly or partially employed in R&D, encompassing both full-time and part-time staff. These data allow links to be made with other data series, such as education and employment data, or the results of population censuses. These data also serve as the basis for calculating indicators analysing the characteristics of the R&D workforce, with respect to age, gender or national origin.

Higher education
Also known as tertiary education, this level of education leads to the award of a post-secondary diploma, bachelor's degree, master's degree or PhD. The higher education sector comprises all universities, colleges of technology and other institutions providing formal tertiary education programmes, whatever their source of finance or legal status; and research institutes, centres, experimental stations and clinics with research activities under the direct control of, or administered by, institutions offering tertiary education.

High-tech goods
These products require the use of advanced technology for their manufacture and repair; examples are pharmaceuticals, computers and electrical machinery. This classification is based on the size of research expenditure relative to the gross output and value added of different types of industry that produce goods for export. See also **Low-tech goods** and **Medium-tech goods**.

Innovation Union Scoreboard
This tool is used annually by the European Union (EU) to monitor the performance of member states and European countries with pre-accession status, via 25 indicators; countries are classified into four categories: innovation leaders (well above the EU average); innovation followers (above or close to the EU average); moderate innovators (below the EU average) and modest innovators (well below the EU average).

Intramural R&D expenditure
This refers to all research expenditure performed within a statistical unit or sector of the economy over a specific period, whatever the source of funds.

Knowledge Economy Index
This is a composite set of indicators reflecting: the incentives offered by the economic and institutional sectors to make efficient use of existing and new knowledge and nurture entrepreneurship; the population's level of education and skills; an efficient innovation ecosystem comprised of firms, research centres, universities and other organizations; information and communication technologies.

Knowledge Index
This is a composite of indicators reflecting: the population's level of education and skills; the efficiency of the innovation ecosystem comprised of firms, research centres, universities and other organizations; and extent of use of information and communication technologies.

Linear economy
A linear economy proceeds from extraction to production then from the use of the product to the end of the product's life.

Low-tech goods
This type of product requires simple technology for its manufacture, often using traditional or non-mechanical methods in a short processing chain. Typical examples include food and beverage products, apparel and textiles, furnishings and wood or paper products.

Medium-tech goods
This type of product requires an intermediate level of technological input and longer processing chain; examples are manufactured and fabricated metals, plastics, machinery and repair tools, chemical products and refined petroleum products.

Modern renewables
This refers to renewable energy derived from solar, wind, ocean, hydropower, biomass, geothermal resources and biofuels and hydrogen derived from renewable resources. Excluded are traditional uses of biomass, such as the primary reliance on fuelwood, charcoal and organic waste for cooking.

Patent and non-patent citations
This refers to the references provided in the search report that are used to assess an invention's patentability and help to define the legitimacy of the claims of a new patent application. As they refer to the prior art, they indicate what knowledge preceded the invention and may also be cited to show the lack of novelty of the citing invention. However, citations also indicate the legal boundaries on the claims of the patent in question. They, therefore, serve an important legal function since they delimit the scope of the property rights awarded by the patent.

Patent Co-operation Treaty
This international treaty adopted by 140 countries allows inventors to file one international patent application, rather than several national applications. The treaty is administered by the World Intellectual Property Organization.

Patent family
This is a set of patents obtained in various countries to protect a single invention. An inventor seeking protection tends to file a first application (priority) in their country of residence.

The inventor then has a 12-month legal period during which they may choose to file for protection of the original invention in other countries. Patent families, as opposed to patents, are provided with the intention of improving international comparability: the home advantage is suppressed and the values of patents are homogeneous across countries.

Purchasing power parity
This conversion is used to facilitate international comparisons: a given sum of money, when converted into US dollars at this rate (PPP$), will buy the same basket of goods and services in all countries.

Regenerative medicine
This field of tissue engineering and molecular biology sets out to regenerate, engineer or replace human cells, tissues or organs, in order to restore function.

Research and experimental development (R&D)
This term comprises creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge. The term covers three types of activity: basic research, applied research and experimental development. This extends to both formal R&D undertaken by research units and informal or occasional R&D undertaken elsewhere.

Research personnel
This refers to all persons engaged directly in R&D, as well as those providing direct services for the conduct of R&D, such as R&D managers, administrators, technicians and clerical staff. Persons providing indirect support and ancillary services, such as canteen, maintenance, administrative and security staff, are excluded. Research personnel are classified according to their function: researcher, technician and other support staff.

Researchers
Researchers are professionals engaged in the design or creation of new knowledge. They conduct research and improve or develop concepts, theories, models, techniques instrumentation, software or operational methods.

Rule of law
This measures the extent to which a population has confidence in, and abides by, the rules of society. It includes the incidence of violent and non-violent crime, the effectiveness and predictability of the judiciary and the enforceability of contracts.

Scientific and technological services
These are research activities contributing to the generation, dissemination and application of scientific and technical knowledge.

Specialization Index
This is measured as the proportion of output by a given country on a given topic, divided by the proportion observed at the global level; for example, a country which devotes 2% of its output to a research topic that represents 1% of all research output worldwide on the same topic would score 2.00, having twice as much output as expected, relative to the global average.

Sustainability science
This is generally perceived as referring to the use of multiple disciplines drawn from the natural and social and human sciences to address common themes related to sustainable development, including support for the transition to more sustainable production and consumption models.

Total primary energy supply
This is defined as energy production plus energy imports but minus energy exports and international bunkers then plus or minus stock changes. The national energy supply is distinct from the national production of energy or electricity, such as the production of electricity using coal or solar photovoltaic systems.

Vertical disintegration
This situation is typical of relatively small companies operating in a niche market, wherein the company is dependent on other businesses for parts of the supply chain, making it more subject to fluctuations in external price volatility than companies which are less dependent on other businesses for parts of the supply chain. See next entry.

Vertical integration
This refers to the integration of multiple components of the supply chain (commodities, manufacturing, distribution, retail) within a single company. See previous entry.

Annex 4: Background information on the bibliometric study of research trends on selected topics related to *The 2030 Agenda for Sustainable Development*

OVERVIEW

In 2020, UNESCO commissioned a study from Science-Metrix of the volume of scientific publications advancing the sustainable development agenda at the global, regional and national levels between 2011 and 2019. The study was not designed to be exhaustive. Rather, it focused on 56 sample research topics identified by UNESCO that were of particular relevance to eight of the Sustainable Development Goals (SDGs).

The aim of the study was three-fold:

- **to assess the volume of articles published** by each country in the world between 2011 and 2019 on key topics of relevance to the SDGs;
- **to identify the degree of specialization on each topic**, by assessing the number of publications produced by a given country over the 2012–2019 period as a proportion of that country's total scientific output. This level of specialization was then compared with the global average to give the **specialization index**. For example, a country which produced 2% of its output on a specific topic accounting for 1% of all research on that same topic at the global level would score 2.00 on the specialization index for this indicator because it produced twice as many publications as would be expected on this topic (for further details of this analysis, see Annex 5); and
- **to identify the growth rate of each topic**, in order to monitor change in the priority accorded to these topics since the adoption of *Agenda 2030 for Sustainable Development* in 2015. In order to avoid annual fluctuations, the study compared scientific output between two periods: 2012—2015 and 2016—2019.

This bibliometric study was undertaken in June 2020. Science-Metrix identified publications on each topic through searches for keywords across the complete Scopus (Elsevier) database, including as concerns the Arts, Humanities and Social Sciences. The section that follows describes the scope of each topic. The specific keywords used for each topic are available on the open access *UNESCO Science Report* portal as an online supplement.

The selected topics are grouped by Sustainable Development Goal. In some cases, an individual topic may be relevant to more than one goal, such as that on traditional knowledge. Moreover, as the key words are not mutually exclusive, there may be occasions when the same article has been counted under more than one topic; for instance, an article on the impact of radiation on human health (SDG3) may also be referenced under the topic on radioactive waste management (SDG9).

The complete datasets for this bibliometric study are available from the *UNESCO Science Report* portal. A summary of the key findings for individual countries and regions may be found in chapters 4–26 and a global summary in chapter 2 of the present report.

SCOPE OF THE STUDY

Topics relating to SDG2: Zero hunger

The data are presented in Table F1 of the statistical annex, available online, along with the full dataset.

Pest-resistant crops

This dataset includes articles on technology to activate or enhance plant resistance to pathogens. Articles on the genetic engineering of plants to resist pests, essentially *Bacillus thuringiensis* (*Bt*) crops, constitute a large share of the dataset.

Help for smallholder food producers

This dataset covers efforts to increase the agricultural productivity and income of smallholder food producers, including through value addition. The dataset includes articles on the productivity, sustainability, profitability and security of small-scale agriculture and farming, such as community agriculture/farming, family agriculture/farming, subsidence agriculture/farming and smallholders.

Precision agriculture

This dataset includes articles on precision agriculture, precision farming and other synonymous expressions. It also includes articles on data-monitoring technologies whenever articles also mention terms such as crops. Specific precision agriculture aspects such as precision irrigation, seed metering, variable-rate application, soil sensing, yield mapping, precision planting, site-specific management and the like have also been targeted.

Agro-ecology

This dataset focuses on agri-environmental practices and the impact of those practices, including environmentally promising agricultural practices such as reduced tillage, agroforestry, cover crops, crop rotation, low-input agriculture, conservation agriculture, silvopastures, alley cropping, integrated crop-livestock and more. Publications measuring and comparing the environmental impact of conventional agriculture are included. The topic includes alternatives to chemical pesticides.

Maintain genetic diversity of food crops
This dataset includes articles on maintaining the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species. Articles discussing the genetic diversity and use of wild or heirloom varieties are also included. All studies related to landraces, plant genetic resources, crop varieties, wild relative and germplasm conservation have been included, provided that they refer to agricultural plants or animals.

Traditional knowledge
This dataset includes articles relating to the recording of knowledge from traditional, indigenous or local populations or derived technologies. This topic is grouped under SDG2 but extends to other SDGs. Ethno-disciplines such as ethno-agriculture, ethnomedicine, ethnobotany and ethnomycology are part of the dataset. About 700 indigenous population names from every continent were used to help build this dataset, combined with terms related to traditional knowledge. The keyword 'local knowledge' was used only in combination with 'indigenous'. Ancestral knowledge from very large populations is voluntarily excluded; for instance, traditional Chinese medicine is excluded.

Topics relating to SDG3: Good health and well-being

The data are presented in Table F2 of the statistical annex, available online, along with the full dataset.

Reproductive health and neonatology
This dataset includes articles on reproductive health, neonatology and maternal health. It covers women's sexual health, in general. It does not extensively cover research on sexually transmitted diseases and excludes the human immunodeficiency virus, which is analysed as a separate topic.

Human immunodeficiency virus (HIV)
This dataset includes all articles on research into HIV and acquired immune deficiency syndrome (AIDS). For example, this includes articles on the epidemiology, treatment and prevention of the disease and/or its social impact.

Tropical communicable diseases
This dataset covers those diseases that figure in the list of neglected tropical diseases established by the World Health Organization, namely: Buruli ulcer; Chagas disease; dengue and chikungunya; dracunculiasis (Guinea-worm disease); echinococcosis; food-borne trematodiases; human African trypanosomiasis (sleeping sickness); leishmaniasis; leprosy (Hansen's disease); lymphatic filariasis; mycetoma; chromoblastomycosis and other deep mycoses; onchocerciasis (river blindness); rabies; scabies and other ectoparasites; schistosomiasis; soil-transmitted helminthiases; snakebite envenoming; taeniasis/cysticercosis; trachoma; and yaws (endemic treponematoses). Malaria and water-borne diseases such as coliform-caused illness, giardiasis, cholera and norovirus are also included.

Human resistance to antibiotics
This dataset covers all aspects of human resistance to antibiotics, with the exception of papers related to environmental aspects that were more difficult to identify.

Regenerative medicine
This dataset covers articles on stem cell research, as well as on regenerative technologies and therapies such as tissue engineering, biomaterials and nanoscaffolds.

Impact on health of soil, freshwater and air pollution
This dataset contains articles related to the assessment and mitigation of the impact of air, soil and freshwater pollution on the environmental health of humans. Topics covered include pollution monitoring, the assessment and effects of exposure to heavy metals, plastics, particulate matter, radiation and other pollutants.

Medicines and vaccines for tuberculosis
This dataset includes all articles on tuberculosis, except bovine tuberculosis.

New or re-emerging viruses that can infect humans
This dataset covers research on human resistance to new or re-emerging viruses that can infect humans. For example, this dataset includes articles on epidemiology, treatment, prevention and transmission vectors of emerging viruses such as Influenza A subtype H1N1, SARS-CoV, Ebola and hantiviruses. This topic excludes articles on HIV, which is treated separately. Also excluded are articles on SARS-CoV-2 (Covid-19), as it had not yet been identified in 2019.

Type 2 diabetes
This dataset covers research on prevention, effects, treatment and epidemiology of type 2 diabetes, also known as non-insulin-dependent diabetes mellitus or adult-onset diabetes. Efforts were made to include articles which study the impact of socio-economic factors on the development of the disease, such as obesity, malnutrition, lack of education and a sedentary lifestyle. Articles about insulin resistance, prediabetes and maturity onset diabetes of the young were also included. Studies of the genetic factors that play a role in development of the disease were also included. Some articles on other health conditions for which diabetes may be an aggravating condition are included but are not the focus of this dataset. Articles about heart disease were removed, unless they contained diabetes-related terms in their title, as were papers which mentioned diabetes in the abstract when the topic was then found to be peripheral to the dataset. Articles that only addressed type I diabetes or were

ambiguous about the type of diabetes studied were excluded. Articles were included, on the other hand, if the particular type of diabetes was not indicated in the title, keywords or abstract but the publication mentioned risk factors like obesity that are more specific to type 2.

Topics relating to SDG6: Clean water and sanitation

The data are presented in Table F3 of the statistical annex, which is available online, along with the full dataset.

Sustainable withdrawal and supply of freshwater

This dataset includes all articles pertaining to the sustainable governance, management and policy of withdrawal, supply and use of freshwater. Freshwater sources include groundwater, lakes and rivers.

Water harvesting

This dataset includes articles on techniques for harvesting precipitation, stormwater, runoff and fog. It also includes articles on rainfed agriculture and irrigation.

Desalination

This dataset includes articles related to desalination technologies, such as osmosis, membrane distillation, solar distillation and micro- and nanofiltration.

Wastewater treatment, recycling and re-use

This dataset includes articles on the management and treatment of wastewater, sewage water, polluted water and greywater, as well as re-use and recycling techniques.

National integrated water resource management

This dataset includes articles pertaining to the management of water resources and their allocation for domestic, agricultural and industrial use. It includes articles on policies and laws pertaining to water use and allocation (e.g. reservoir management), as well as system modelling (e.g. water use, reservoir or water quality) to enable strategic decision-making and the optimization of processes. Articles about management of water distribution networks or the smart water grid are also part of the dataset. Some articles may analyse the situation at local level, since the use of the key word 'national level' served, above all, to exclude articles on transboundary water resource management, as this topic is treated separately.

Transboundary water resource management

This dataset includes articles on governance, management, co-operation, law, allocation and sharing of transboundary and international freshwater resources, as well as related conflicts and disputes. Water resources analysed encompass aquifers, groundwater, lakes and rivers.

Topics relating to SDG7: Affordable and clean energy

The data are presented in Table F4 of the statistical annex, which is available online, along with the full dataset.

Cleaner fossil fuel technology

This dataset includes articles on clean coal technology, integrated carbon capture and storage technology, carbon dioxide (CO_2) capture from fossil fuel power plants, desulfurization of flue gases, the clean production of synthetic fuel, refinery processes to limit contaminants emitted, the clean synthesis of methanol and the conversion of CO_2 to hydrocarbons or fuel.

Photovoltaics

This dataset includes articles relating to stationary hosts, namely, solar cells, solar panels and photovoltaic cells. It also includes larger-scale projects, such as solar farms. Articles about developing materials specifically for solar cells are included.

Hydropower

This dataset includes articles relating to both large and small hydropower projects. It includes articles on the different types of dams but also on other hydropower methods (e.g. tidal and wave energy) and the development of specific hydropower station parts like hydroturbines.

Biofuels and biomass

This dataset includes articles on the main biofuels, such as bioethanol, biomethane, biobutanol and biocrude, as well as their production in biorefineries. Articles on the processing of biomass to create biofuels are also included. Little content was found on the hydraulic head of such processes.

Wind turbine technologies

This dataset includes articles about wind turbines and wind farms, with a focus on both their conception and their use. All main types of wind turbines are included, such as horizontal-axis, vertical-axis, offshore and floating wind turbines. Articles about the main types of generator used in the turbines are also part of this dataset, examples being doubly fed induction and Savonius.

Nuclear fusion

This dataset includes articles relating to studies of nuclear fusion for energy purposes, as well as articles relating to the development of materials, parts and methods to build nuclear fusion reactors. It voluntarily excludes articles focused on nuclear fusion reactions in stars because those are mostly unrelated to energy production on Earth.

Geothermal energy

This dataset contains articles on geothermal energy, the generation of electricity from geothermal energy and different techniques for harnessing this energy, most notably, enhanced geothermal systems and hydraulic stimulation. A small number of articles about the safe digging of wells to access this energy is also included.

Hydrogen energy

This dataset contains articles on most aspects of hydrogen energy harnessing. Machines and systems designed to have hydrogen as their source of power, the industrial production and storage of hydrogen and hydrogen-based fuel cells (i.e. most fuel cells) are all included.

Smart-grid technology

This dataset contains articles on smart grid technology and techniques and protocols to enable smarter, more reliable electrical networks. Articles are included on new devices such as smart power meters and grid-friendly appliances, as well as on protocols related to distributed grids and microgrids, such as islanding detection. Articles relating to the cybersecurity of smart grids are also included in the dataset. Furthermore, articles related to new challenges for the grid, such as electric vehicle (EV) charging on a national scale, are included because many of those articles advocate 'vehicle-to-grid' energy transfers and real-time pricing when mentioning EV charging. An effort was made to exclude papers specific to EVs that do not address the electrical grid. Some articles about renewable energy sources are part of the dataset but they only concern the integration of these new power sources in the grid.

Topics relating to SDG9: Infrastructure, industrialization and innovation

The data are presented in Table F5 of the statistical annex, which is available online, along with the full dataset.

Carbon pricing

This dataset includes articles related to all aspects of the taxation and trading of carbon and other greenhouse gas emissions (also known as cap and trade): the carbon market, carbon allowance, carbon credits, carbon trading, carbon pricing and carbon taxation.

Eco-industrial waste management

This dataset includes articles on the safe treatment and disposal of waste chemicals and other industrial wastes, such as those from the construction, pharmaceutical and electronic industries, reactive waste and wastewater treatment. Articles are also included on the minimization of waste production, such as zero-waste manufacturing and waste-to-energy processes. Articles about remediation techniques for soils contaminated with industrial wastes (heavy metals, petroleum, etc.) are included but these exclude nuclear waste, since it is treated separately.

Radioactive waste management

This dataset contains articles about radioactive waste management, storage and disposal. Articles about methods such as safe geological disposal, transmutation and vitrification of nuclear waste are included.

Eco-alternatives to plastics

This dataset includes articles studying the synthesis, effects and potential applications of ecologically friendly alternatives to traditional fossil fuel-derived plastics. Articles on biodegradable plastics or alternatives based on cellulose, starch or banana fibres are included. Any articles containing terms such as 'sustainable alternative to plastics' or 'environmentally degradable plastics' are also included.

Eco-construction materials

This dataset includes articles relating to 'eco-building', 'green building', 'sustainable construction', 'ecological housing', 'sustainable architecture' and other permutations of those terms. There is also a focus on low-energy and zero-energy buildings, sustainable building certifications (e.g. Leadership in Energy and Environmental Design [LEED] or Passivhaus) and environmentally friendly materials, sustainable materials and recycled materials. Articles on retrofitting buildings and infrastructure are included. The dataset is primarily focused on passive construction practices and materials, rather than active methods such as photovoltaic panels or wind generator integration, covered in other datasets (see Table F4). Sustainability here is almost always defined from an environmental standpoint but some articles are also focused on economic or social sustainability of buildings or infrastructure. For example, an article might tackle the health implications of using sustainable alternatives to traditional materials or designs for the occupants, or buildings that can better withstand the extreme conditions found in poorer countries or anticipated conditions relating to climate change.

Greater battery efficiency

This dataset contains articles on battery efficiency, new battery technologies and battery design and optimization. Since most articles are written to report improvements on batteries, most rechargeable battery types were included as keywords in the dataset, with the greatest contributions coming from more recent battery types such as Li-ion. Articles concerning the recycling of spent batteries and battery integration in the electrical grid are also part of the dataset.

Sustainable transportation

This database focuses on the development and use of sustainable means of transportation, including electric vehicles, solar vehicles, plug-in hybrid vehicles and hydrogen vehicles. Most articles indexed focus on cars but planes, boats, trains and trucks are all included. The dataset includes articles on self-driving cars and associated technologies, such as autonomous intersection management, lane detection and advanced driver assistance. This is because self-driving cars would achieve better fuel economy (or energy economy, if electric) and have the potential to reduce the number of road accidents. Articles are included on other methods of sustainable transportation and policies, such as carsharing, public bicycles, car-free cities and congestion pricing. 'Sustainable transport' is used as a keyword but, with the exception of publications using the terms 'solar boat' and 'electric boat', shipping is not explicitly included in this dataset.

Topics relating to SDG13: Climate action

The data are presented in Table F6 of the statistical annex, which is available online, along with the full dataset.

National and urban greenhouse gas emissions

This dataset includes articles on the measurement, assessment and estimation of greenhouse gas emissions at the national and urban levels. It includes articles on national and urban emission sources, such as agricultural, industrial and urban sources, including transportation.

Carbon capture and storage

This dataset includes articles on carbon capture techniques, such as pre-, post- and oxyfuel combustion, direct air capture and carbon sequestration, which is the capture and storage of carbon through natural (biological, chemical and physical) processes that include photosynthesis, oceanic and geological capture. The publications refer to both natural sequestration and human attempts to enhance sequestration. This dataset is restricted to gaseous carbon; it excludes solid-state carbon, namely particulate matter.

Local impact of climate-related hazards and disasters

This dataset focuses on articles assessing climate hazards and climate-related disasters and the impact of these on small and vulnerable communities. Examples are coastal erosion, sea level rise, droughts, floods and extreme weather events.

New technologies to protect from climate-related hazards

This dataset focuses on any technology, innovation or tool that has the potential to mitigate the impact of climate change or climate-related disasters on communities. This includes publications on ways of building more resilient infrastructure, as well as those on better modelling tools to predict the risk of occurrence and consequences of catastrophic events, enabling better preparedness.

Local disaster risk reduction strategies

This dataset focuses on planning processes and techniques that help to reduce the risk faced by local and vulnerable communities with respect to climate change and related disasters, such as drought, flooding, extreme storms and wildfires. The publications included consider communities' strategies, preparation and mitigation efforts as well as their capacity to recover and be resilient.

Climate-ready crops

This dataset includes articles related to agriculture and crops that are tolerant of and resilient to salinity, flooding, drought and other climate-related stressors.

Topics relating to SDG14: Life below water

The data are presented in Table F7 of the statistical annex, which is available online, along with the full dataset.

Coastal eutrophication

This dataset includes all articles on coastal eutrophication, phosphorus removal and pollution, algal blooms, water nutrient dynamics and specific harmful algal species.

Floating plastic debris in the ocean

This dataset includes articles related to plastic debris and plastic pollution in the ocean. Search terms cover plastic and plastic types in aquatic environments, plastic consumption by marine wildlife, as well as the identification of plastics and byproducts in marine and coastal environments and food chains.

Ocean acidification

This dataset includes all articles on ocean acidification and seawater acidification, including those assessing the impact on species.

Sustainably manage marine tourism

This dataset includes articles on tourism management and the effects of tourism on oceanic or coastal zones. Articles often focus on the environmental impact but the socio-economic impact is also covered. Whenever there was a focus on sustainability, cruises, diving, recreational fishing and sea animal tourism (watching, swimming and diving) were all specifically included as search terms.

Sustainably manage fisheries and aquaculture

This dataset includes articles on fish farming and aquaculture, as well as commercial fishing as it relates to sustainable resource management. The dataset was constructed using key terms related to sustainable fisheries and aquaculture, as well as species and techniques commonly associated with these practices. When aquatic species names were used, this was done in conjunction with terms related to sustainability, to limit the dataset to the topic as much as possible.

Ecosystem-based approaches in marine environments

This dataset contains articles relating to management of coastal zones using an ecosystem-based approach, meaning the ecosystem and its interactions are considered as a whole in management processes. The dataset includes articles on concepts like integrated coastal zone management, which is closely linked to ecosystem-based approaches. When the dataset was verified, no articles focusing on ecosystems in international waters were found.

Topics relating to SDG15: Life on land

The data are presented in Table F8 of the statistical annex, which is available online, along with the full dataset.

Sustainable use of terrestrial ecosystems

This broad dataset includes all papers on the conservation, preservation, restoration and sustainable use of terrestrial ecosystems: forest, habitat, land, wildlife, pond, freshwater, drylands, etc. It includes research on species richness, biodiversity, etc. It also includes articles on ecosystem services.

Status of terrestrial biodiversity

This dataset includes articles on species with a defined conservation status, as well as more fundamental research needed to monitor, predict and protect those species. For example, articles on causes of species endangerment, such as habitat loss, are included.

Minimize poaching and trafficking of protected species

This dataset includes articles on the Convention on the International Trade of Endangered Species (CITES), wildlife trade, poaching, illegal fishing, illegal harvesting, wildlife forensics, etc.

Tackle invasive alien species

This dataset includes all articles related to biological invasions, alien species, invasive plants, etc. Basic research on invasive potential has also been included.

Use of ecosystem-based approaches in protected areas on land

This dataset includes articles on ecosystem-based management of public and private land. An effort was made to exclude marine and freshwater ecosystems, to avoid overlap with other selected topics.

Extent of water-related ecosystems

This dataset includes articles measuring the extent of water-related ecosystems (excluding oceans) such as wetlands, rivers, estuaries, lakes, aquifers, swamps, fens, peatlands, marshes, mangroves and artificial water bodies. It involves articles either measuring or improving delineation protocols of such systems, as well as estimating the water quantity involved. Articles on disappearing systems are included, as well as articles on the inventory of water-based ecosystems. Some articles on ecosystems related to either the water quality or quantity found in ecosystems such as forests and mountains are also included when these are directly related to water.

Socio-ecological impact of terrestrial protected areas

This dataset covers conservation planning, reserve selection and reserve design, as well as the prioritization of protected areas and the future habitat suitability under climate change. The negative and positive impact of protected areas on humans, such as human–wildlife conflict or valuation of ecosystem services, are also targeted.

Annex 5: Technical and methodological note on the Statistical annex

METHODOLOGICAL NOTE

Bibliometric data

Publication data have been compiled for UNESCO by Science-Metrix from the Scopus (Elsevier) database, excluding Arts, Humanities and Social Sciences.

Publications listed under the People's Republic of China do not include those for its Special Administrative Regions of Hong Kong and Macao, or the Taiwan Province of China.

Economic data

Data on economic indicators, such as gross domestic product (GDP) and purchasing power parity (PPP), are based on the World Bank's economic data release of July 2020: http://data.worldbank.org/products/wdi (see the note on the cut-off date).

It should be noted that, since 2014, the UNESCO Institute for Statistics has used data on total general government expenditure (all sectors) from the International Monetary Fund's World Economic Outlook database as the denominator for its indicator, expenditure on education as a percentage of total government expenditure. For more information about the change in methodology, please visit: www.uis.unesco.org/education

Education data

The UNESCO Institute for Statistics (UIS) compiles education statistics, from official administrative sources at the national level, through its annual Survey of Formal Education. The objective of this survey is to provide internationally comparable data on key aspects of education systems, such as access, participation, progression and completion, as well as the associated human and financial resources dedicated to them.

In addition to this survey, these data are also collected through a joint data collection mechanism involving UIS, the Organisation for Economic Co-operation and Development (OECD) and the Eurostat. The data collected are used to monitor and report on international development goals related to education, including the education goal of *The 2030 Agenda for Sustainable Development*.

For more information on the UIS Survey of Formal Education, please visit: http://uis.unesco.org/en/uis-questionnaires

GERD

R&D expenditure in US dollars at the purchasing power parity (PPP$) rate is presented in Table B1 using constant 2005 prices.

Innovation data

The UNESCO Institute for Statistics collected data on innovation within the manufacturing industry every two years up to 2017 through its innovation data collection. In addition, the institute obtained innovation data directly from Eurostat and the African Science, Technology and Innovation Indicators (ASTII) Initiative of the African Union/NEPAD Planning and Coordinating Agency for countries which participate in the data collections of these organizations. With a few exceptions, innovation data refer to a three-year reference period that varies from one country to another. The data collected are featured in the institute's international database at: http://data.uis.unesco.org

Population data

Population data were obtained from the World Bank's World Development Indicators (accessed September 2020). For Eritrea, data were available only for 2011 and this value was used for all years, which could lead to a slight overestimation of the number of publications per million inhabitants for later years. Population data for the Cook Islands and Niue were obtained directly from the national statistical service. Niue provided data for only 2011 and 2017; the remaining years were estimated based on the growth between 2011 and 2017.

Research and experimental development (R&D) data

The UNESCO Institute for Statistics collects data on resources devoted to research and experimental development through its R&D statistics survey. In addition, it obtains data directly from the OECD, Eurostat, the Ibero-American and Inter-American Network on Science and Technology Indicators (RICYT) and the African Science, Technology and Innovation Indicators (ASTII) Initiative of the African Union/NEPAD Planning and Coordinating Agency for countries which participate in the data collections of these organizations. The data collected can be found at: http://data.uis.unesco.org

Data obtained from the OECD are based on the OECD's Research and Development Statistics database released in April 2020. Data obtained from Eurostat are based on the Eurostat Science and Technology database, as of April 2020. Data received from RICYT are as of July 2020. Data obtained from ASTII are based on the African Innovation Outlook III (2019).

Cut-off date for data in the statistical annex and chapters

R&D and economic data presented in the regional/individual country chapters may not always correspond to the data given in the statistical annex or in Chapter 1. The reason for this is that the underlying economic data used to calculate R&D indicators are based on the World Bank's economic data release of July 2020 for the annex and Chapter 1, whereas data in the other chapters might come from a different release of economic data by the World Bank.

TECHNICAL NOTE

Bibliographic data

Number of papers: this is the number of peer-reviewed scientific publications (e.g. articles, reviews and notes only) indexed in the Scopus database. Publications are assigned to countries according to the author affiliation address on the publications. Double counting is avoided at both the national and regional levels. For instance, a paper co-authored by two researchers from Italy and one author from France is counted only once for France and once for Italy but also once for Europe and once for the world.

The regions were defined using a blend of geographic and economic groupings based on status in 2019. For example, the United Kingdom was included in the European Union region due to its membership in the period under study (2011 to 2019). The total for the People's Republic of China excludes its Special Administrative Regions of Hong Kong and Macao and the Taiwan Province of China.

Number of international collaborations: this is the number of publications involving authors from at least two different countries, counted once for each entity. For instance, if 13 authors from one organization collaborate with 1 author from another, that article counts as a co-publication, counting once for each organization. For the computation of international collaboration, territories were considered to be part of their respective mainland countries. Thus, collaboration between Guadeloupe and France would not be considered as international co-authorship. The international collaboration rate of a country is simply a measure of how many articles are co-published with international partners as a proportion of the given country's total output.

Average of relative citations: this is an indicator of the scientific impact of papers produced by a given entity (the world, a country, an institution) relative to the world average (i.e. the expected number of citations, set as 1). Citation scores for conference papers are not included in the citation analysis because citation patterns associated with them tend to distort impact measurements.

Field classification of publications: see Annex 2 for the broad fields of science used to prepare statistics at the level of scientific disciplines: agriculture, fisheries and forestry; animal and plant biology; built environment and design; chemistry; cross-cutting strategic technologies; engineering; environmental sciences; geosciences; health sciences; ICTs, mathematics and statistics; and physics and astronomy.

Education data

The fields of study are defined as per the International Standard Classification of Education: *Fields of Education and Training* (ISCED-F 2013). Agriculture (includes agriculture, forestry, fisheries and veterinary); natural sciences (includes biological, environmental, geological and physical sciences), mathematics and statistics; engineering (includes engineering, manufacturing and construction); ICTs (information and communication technologies); health (health and welfare); social sciences and journalism; business, administration and law; and arts and humanities (contains the ISCED-F 2013 broad fields of arts and humanities, education and services).

Table 1: **Levels of tertiary education**

UNESCO Science Report term	ISCED 2011 equivalent
Short cycle	ISCED level 5 – short-cycle tertiary education
Bachelor's or equivalent	ISCED level 6 – bachelor's or equivalent level
Master's or equivalent	ISCED level 7 – master's or equivalent level
PhD or equivalent	ISCED level 8 – doctoral or equivalent level

International classifications for the type of degree received follow the International Standard Classification of Education (ISCED 2011) of level of education (Table 1).

Data on internationally mobile students that are collected by the UNESCO Institute for Statistics (UIS), OECD and Eurostat encompass students who are pursuing a tertiary degree and thus exclude students on exchange programmes. Data on inbound internationally mobile students reported by host countries are used by the UIS to estimate the number of outbound internationally mobile students from a given country. As not all host countries report disaggregated data on internationally mobile students by country of origin, the number of outbound students from a given country may thus be underestimated.

R&D data

The definitions and classifications used to collect R&D data are based on the *Frascati Manual: Proposed Standard Practice for Surveys on Research and Experimental Development* (OECD). Some of the key definitions related to R&D data are presented in the glossary of the present report.

Two types of R&D indicator are usually compiled: data on R&D personnel measure researchers, technicians & equivalent staff directly involved in R&D, as well as other support staff; data on R&D expenditure measure the total cost of carrying out the R&D activity concerned, including indirect support.

Global and regional estimates for R&D expenditure and researchers presented in Chapter 1 are calculated based on country-level data obtained from the UNESCO Institute for Statistics, accessed in August 2020.

Patent data

Number of granted patents: this is the number of granted patents indexed in the PATSTAT database for five patent offices, namely the US Patent and Trademark Office (USPTO), European Patent Office (EPO), Japanese Patent Office (JPO), Korean Intellectual Property Office (KIPO) and State Intellectual Property Office of the People's Republic of China (CNIPA). Patents are assigned to countries according to the country of the inventors on the applications. Double counting is avoided at both the national and regional levels. For instance, a patent application submitted by two inventors from Italy and one inventor from France is counted only once for France and once for Italy but also once for Europe and once for the world. Therefore, the sum across countries/regions is higher than the world total because of co-inventorship. The IP5 total is the sum across all five offices; therefore, some inventions are counted more than once because patents to protect them may have been granted in more than one market.

Data quality is high for the USPTO and EPO but information related to the country affiliation of inventors is often missing in PATSTAT for CNIPA, JPO and KIPO. To prevent underestimating output levels for countries with intensive patenting activity at these offices, methods based on patent families were implemented to reduce the number of unknown affiliations to a minimum (i.e., only a few percentage points). Caution is nonetheless advised because these methods do not make it possible to correct the data perfectly.

TECHNICAL NOTE FOR THE BIBLIOMETRIC STUDY PERTAINING TO THE SUSTAINABLE DEVELOPMENT GOALS

Bibliometric data

Publication data were compiled for UNESCO by Science-Metrix using keyword searches of the complete Scopus (Elsevier) database, including Arts, Humanities and Social Sciences, for publications released from 2011 to 2019. In selected cases, a complementary search was conducted to include all of the content of selected relevant journals. For the list of specific keywords, see the *UNESCO Science Report* web portal.

Countries and regions

As above, publications were assigned to countries according to the author affiliations listed on the publications. The regions were defined using a blend of geographic and economic groupings based on status in 2019. For example, the United Kingdom was included in the European Union region due to its membership in the period under study (2011 to 2019).

The total for the People's Republic of China excludes its Special Administrative Regions of Hong Kong and Macao and the Taiwan Province of China.

How publications are counted

As above, publication counts of articles, reviews and conference papers are based on the full-counting method. Using this method, each country or research organization that has a researcher on the list of authors for a given paper gets a full count (1 publication) for that paper. Therefore, the sum across countries/regions is higher than the world total because of co-authorship. Different topics are not necessarily mutually exclusive and do not cover the entirety of science; therefore, the sum across topics is not expected to be equal to the total reported in Scopus.

Specialization Index

The specialization index (SI) indicates how much output an entity produces in an area of research, adjusted for the entity's overall number of papers and relativized to the global average. Because countries or regions cannot be specialized in all areas of research by definition, fractional counting of publications is used instead of full counting. This avoids the overestimation of specialization in broad fields with high levels of international co-authorship, as the full counting method could lead to all countries being specialized in a given area simply because of these higher levels of collaboration. Fractional counting divides publications based on the proportion of authors from a country contributing to an article. For instance, if a paper lists two authors with addresses from the United Kingdom, one from Spain and one from Latvia, the publication is divided into four parts, with the United Kingdom receiving two of these parts (0.5 publication), Spain receiving one (0.25 publication) and Latvia receiving the fourth part (0.25 publication).

METHODOLOGICAL NOTE FOR THE BIBLIOMETRIC STUDY PERTAINING TO THE SUSTAINABLE DEVELOPMENT GOALS

Comprehensiveness

The initial dataset for the SDG-related publications is global, including all publications indexed in the Scopus database with publication dates from 2011 to 2019.

The data cannot be considered comprehensive for all the Sustainable Development Goals or for an entire relevant body of research. Due to the indivisibility of the SDGs, there are many overlapping areas of importance. The topics are grouped by SDG in Tables F1 to F8 but the keyword searches were conducted using the full database and the findings may be relevant across multiple SDGs.

The document types included in the Scopus analysis are articles, reviews, short surveys and conference proceedings. An empirical approach has been developed by Science-Metrix to filter documents based on the source types and document types (Table 2) and to maximize the recall of peer-reviewed papers while minimizing the inclusion of non-peer-reviewed documents.

Science-Metrix used a systematic approach to remove low-quality journals from the analysis, primarily by excluding the list of journals removed by Elsevier from the Scopus database, as well as the excluded journals list from the Directory of Open Access Journals.

Data analysis

The **specialization index** is measured as the proportion of output of a given country on a given topic, divided by the proportion observed at the world level. For example, a country with 2% of its output in a topic that represents 1% of all research at the world level would score 2.00 for this indicator because it has twice as much output as expected for this topic.

The **growth ratio** is calculated as the number of publications in 2012–2015 divided by the number of publications over 2016–2019.

Table 2: **Combinations of source types and document types used for the production of bibliometric indicators**

Source type	Documant type
Book series	Article, conference paper, review, short survey
Conference proceeding	Article, review, conference paper
Joural	Article, conference paper, review, short survey

Source: Prepared by Science-Metrix