

2 · Are we using science for smarter development?

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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

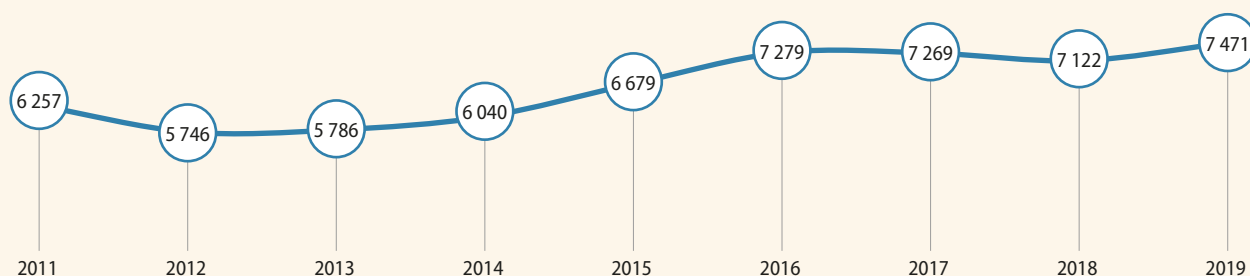
USA, Brazil and France. In January 2021, the French government announced the launch of the world's first research institution specializing in this field (see essay, p. 9).

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.’

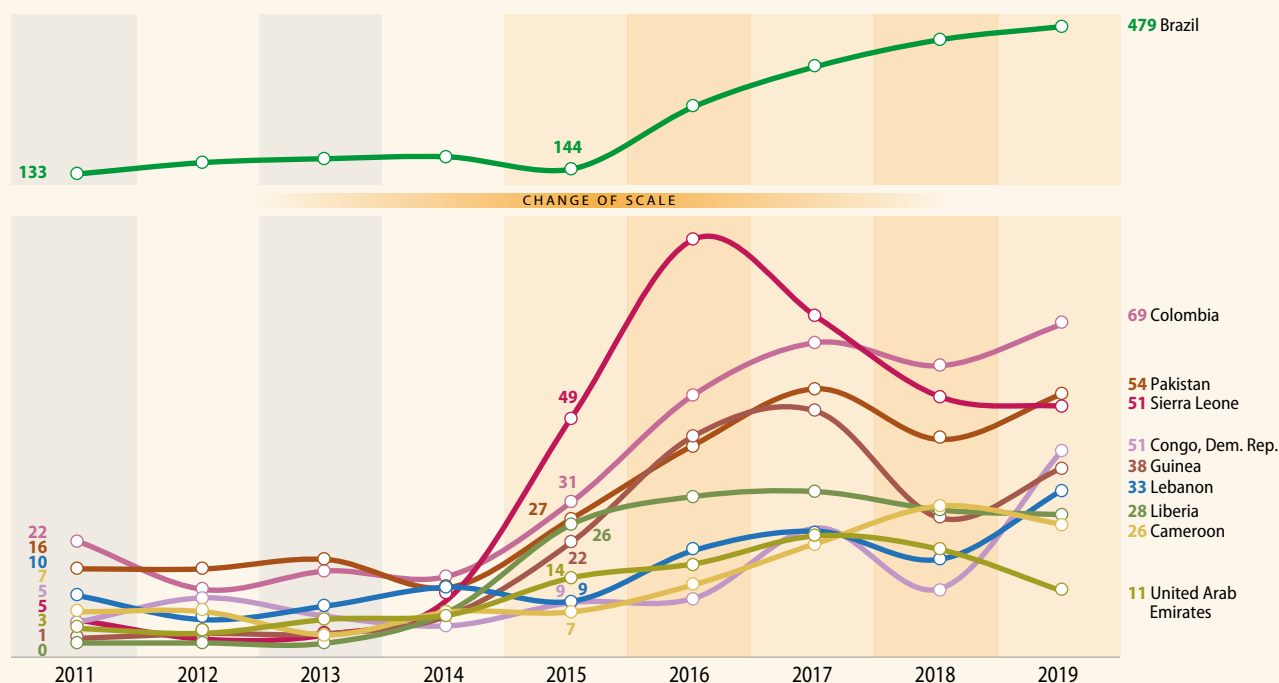
As the report recalls, the risk of a pandemic can be significantly lowered by reducing the human activities that drive the loss of biodiversity, such as agricultural expansion and intensification, the unsustainable exploitation of biodiversity-rich regions and unsustainable production and consumption 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



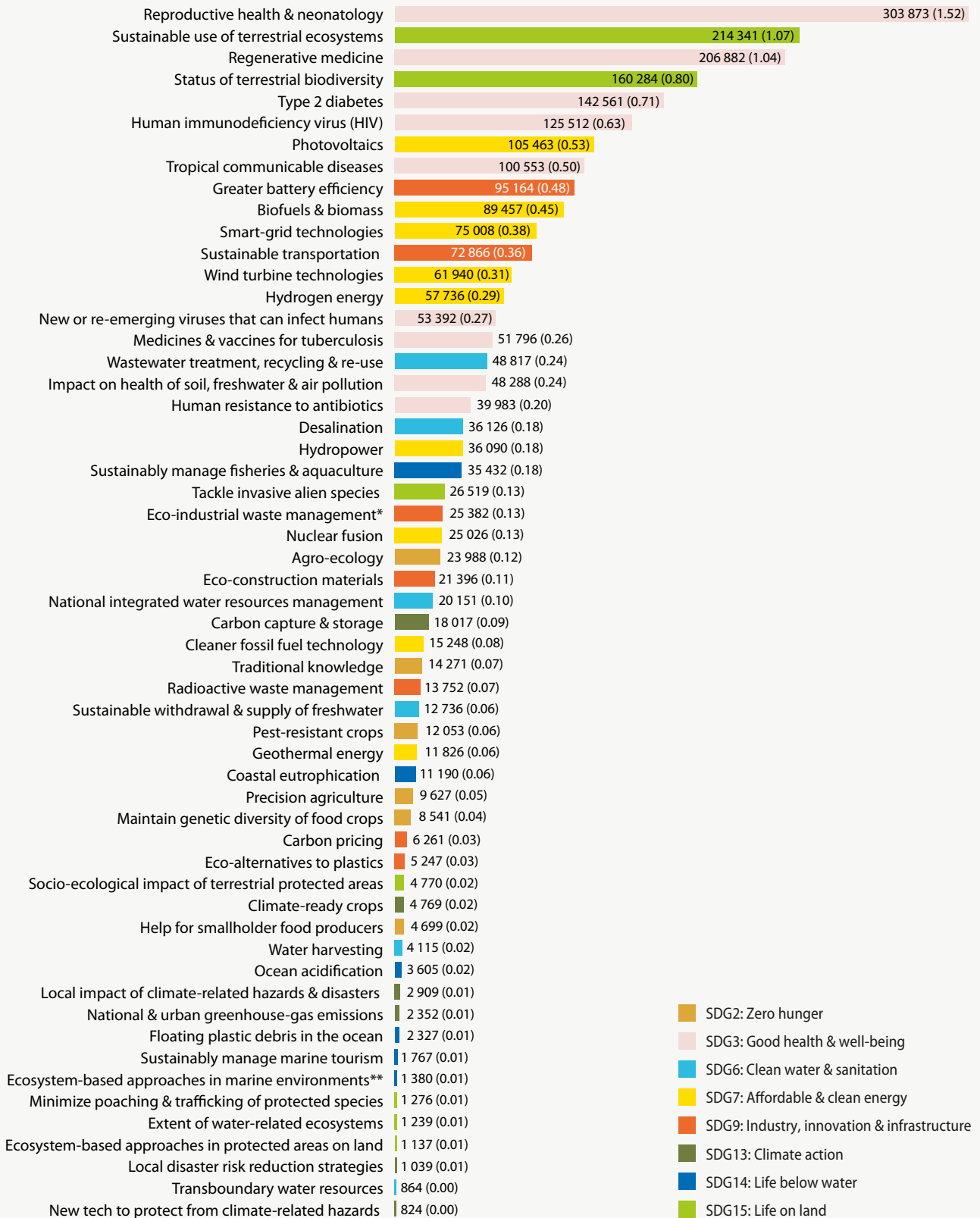
Note: These data exclude HIV, the subject of a separate research topic, and SARS-CoV-2 (Covid-19) which was unknown in 2019. The growth rate is calculated as the number of publications from 2016–2019 divided by the number of publications from 2012–2015. The degree of specialization is calculated by assessing 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 high³ 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).

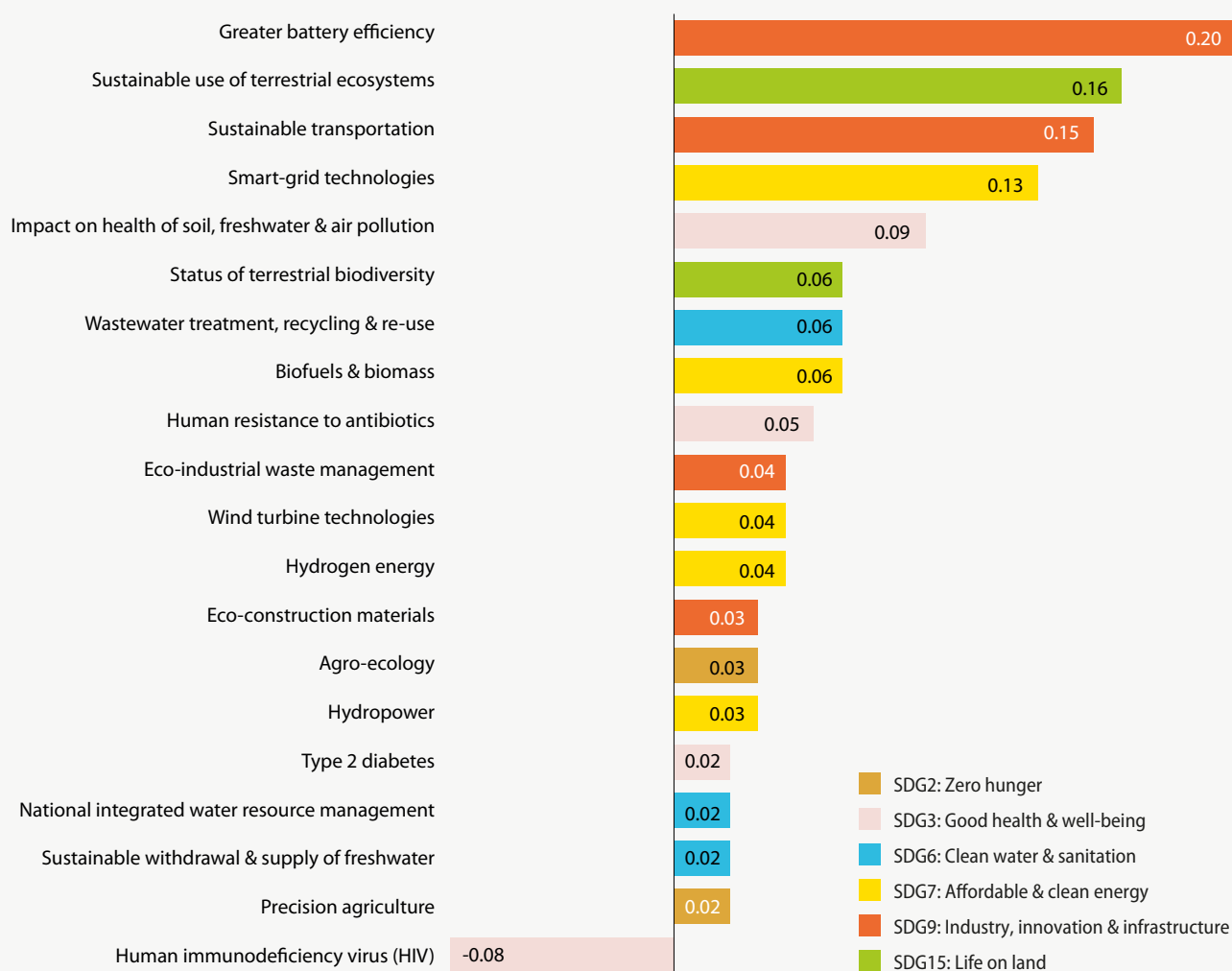
How can we distinguish volatile from flexible research?

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 $\pm 0.02\%$

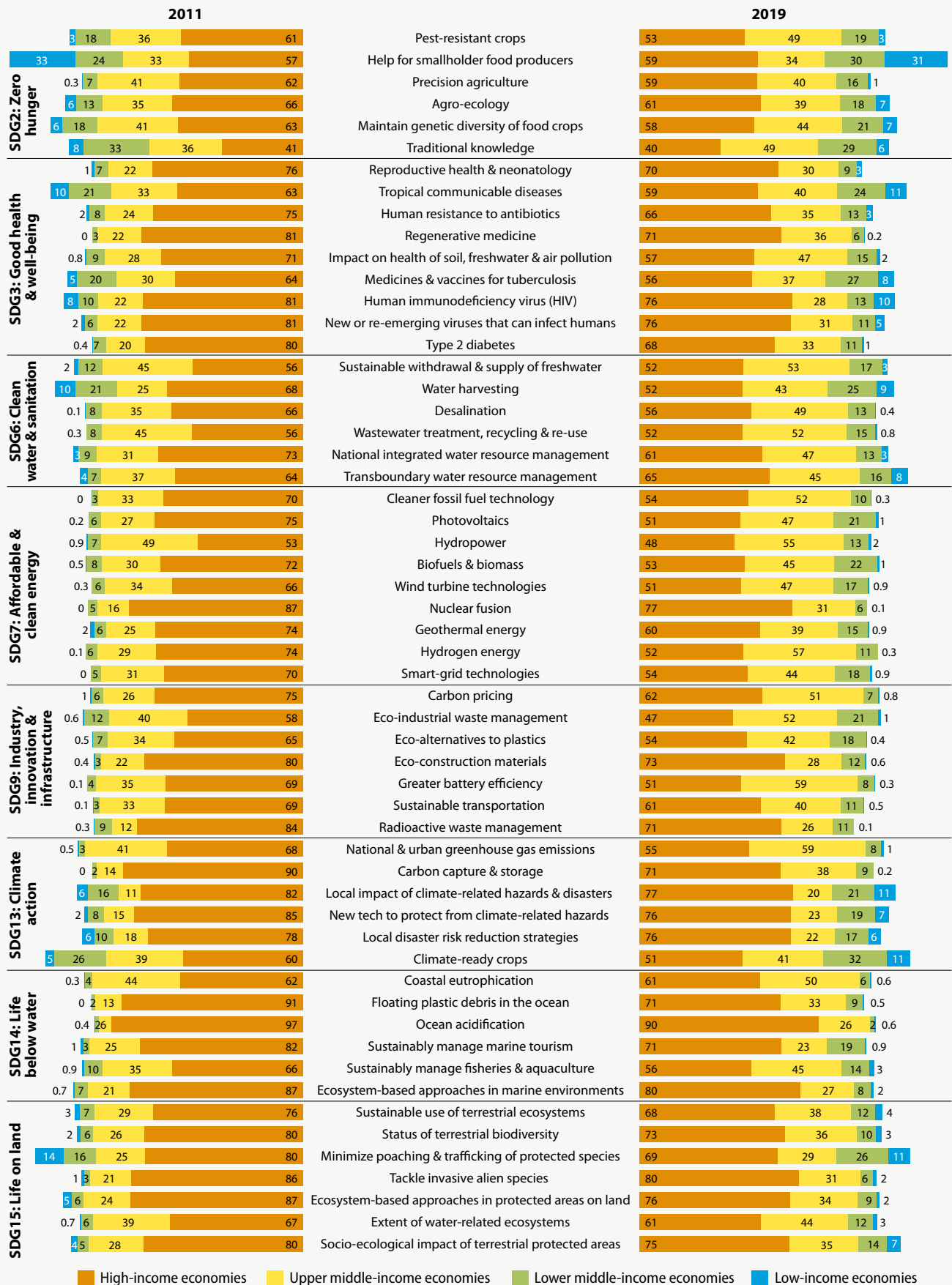


Note: The topic of floating plastic debris in the ocean has been excluded from this figure, owing to the low volume of publications on this topic.

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).

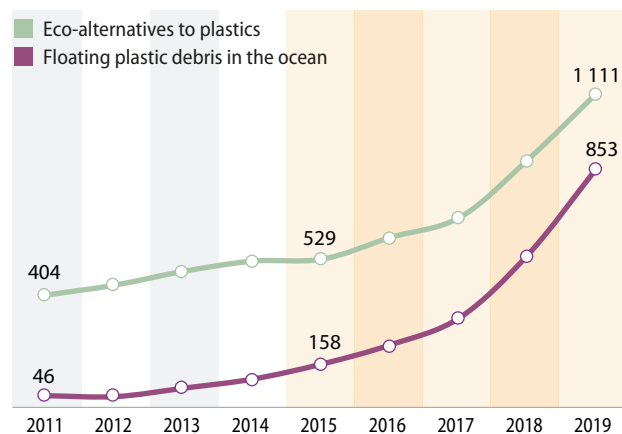
Plastics have been found not only in animals but also in fruit and vegetables, such as apples and carrots (Conti *et al.*, 2020). At the present rate, plastic particles could outweigh fish in the ocean by 2050 (WEF, 2016); experts estimate that plastic pollution will triple by 2040 (Lau *et al.*, 2020). 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).

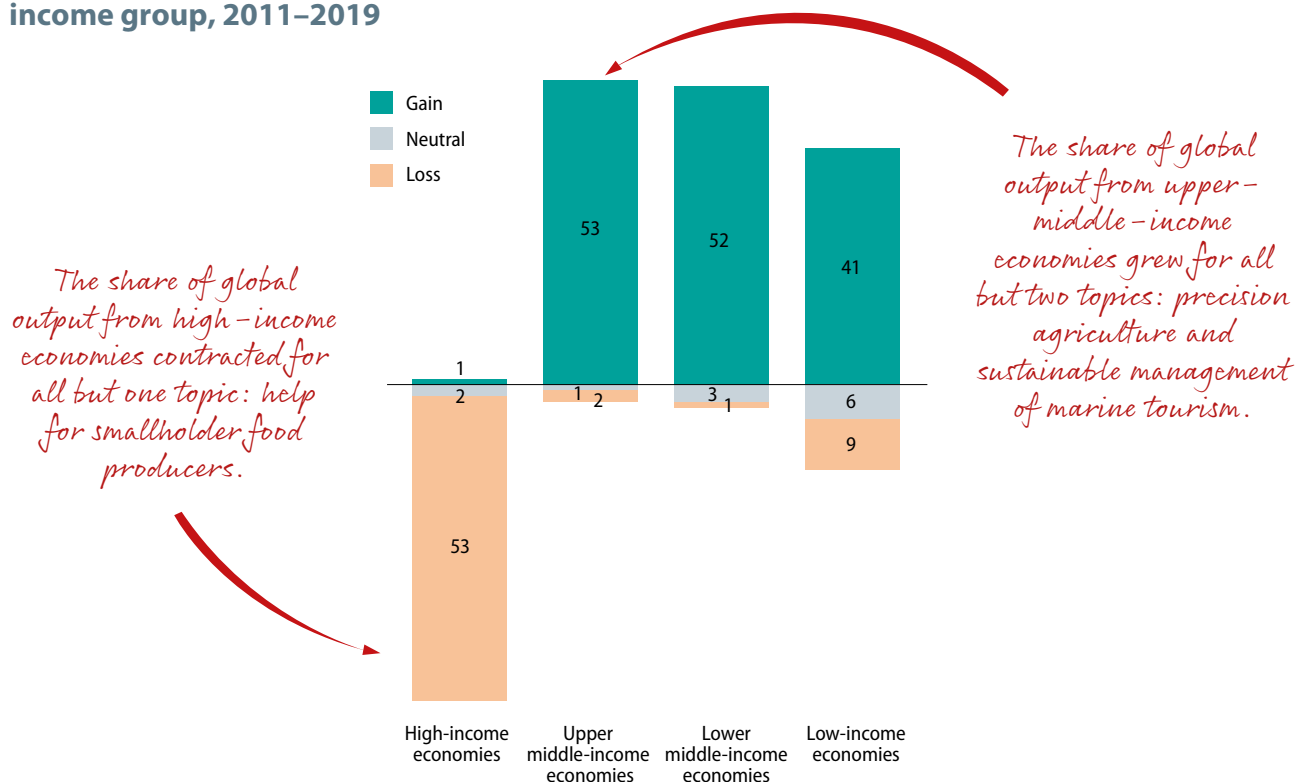
Figure 2.7: Volume of global publications on plastics, 2011–2019



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).

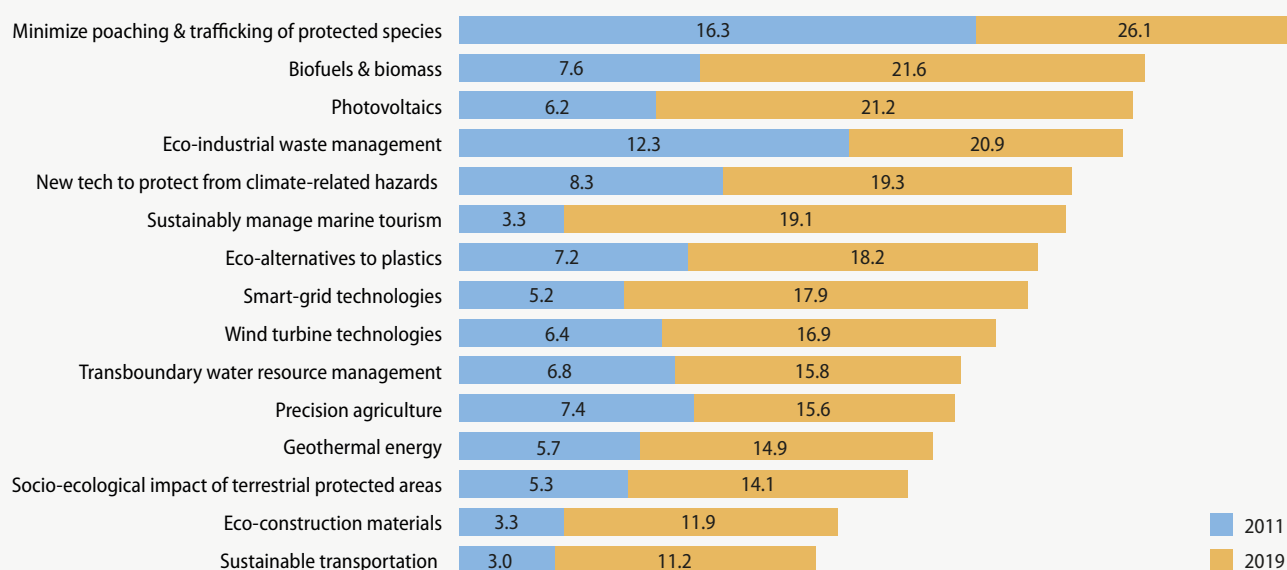
Globally, research still focuses more on understanding the **local impact of climate-related hazards and disasters** than on mitigating such hazards (Figure 2.9).

Climate-related disasters have focused attention on rebuilding more resilient infrastructure capable of

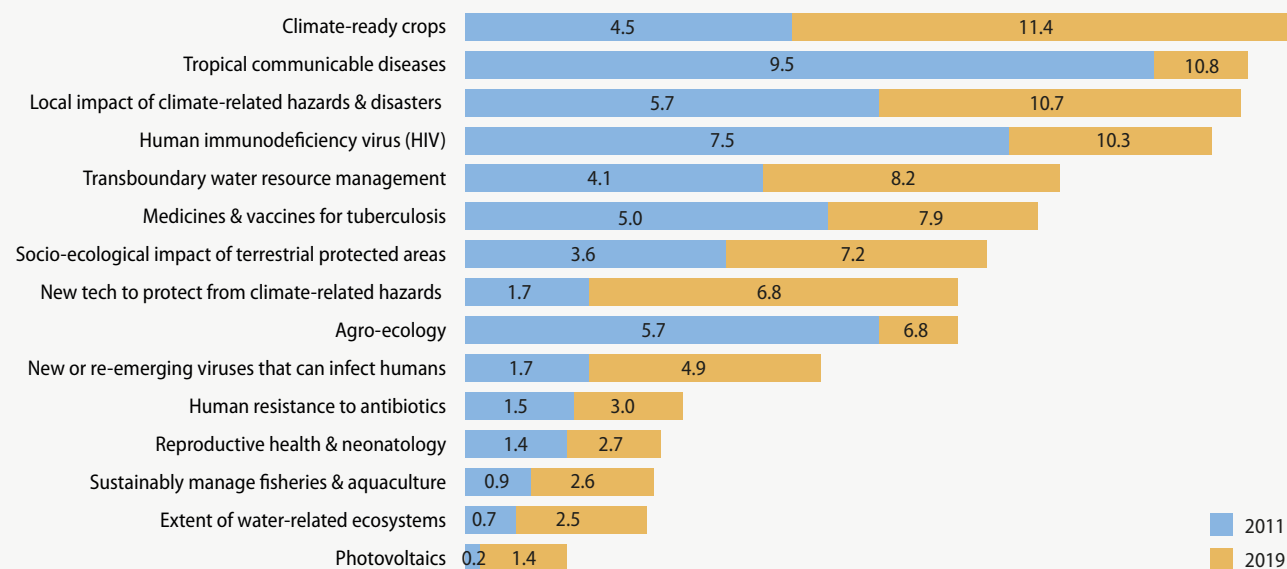


Figure 2.8: Top 15 research topics for lower middle-income and low-income countries by increase in their share of global output, 2011–2019

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 (CO₂) 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).

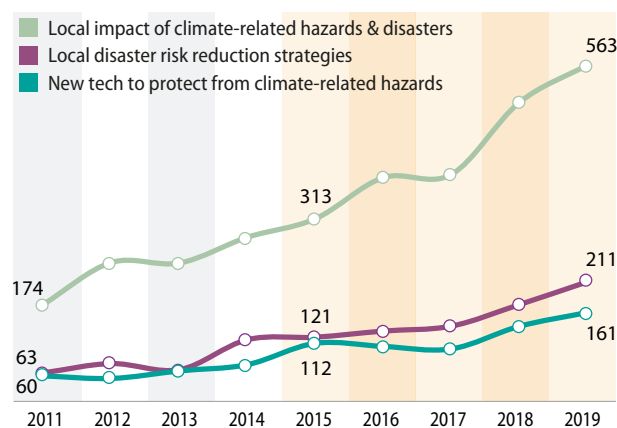
This new industrial sector is still in its infancy. Only a minute quantity of CO₂ is being stored artificially at the global level: 35 million tonnes in 2019, a drop in the ocean compared to global carbon emissions of 40 gigatonnes. The International Energy Agency's clean technology scenario forecasts a cumulative storage capacity of 107 gigatonnes of CO₂ 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



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)

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)

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)

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)

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)

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)

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)

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)

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)

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)

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)

* 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-Matrix

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.

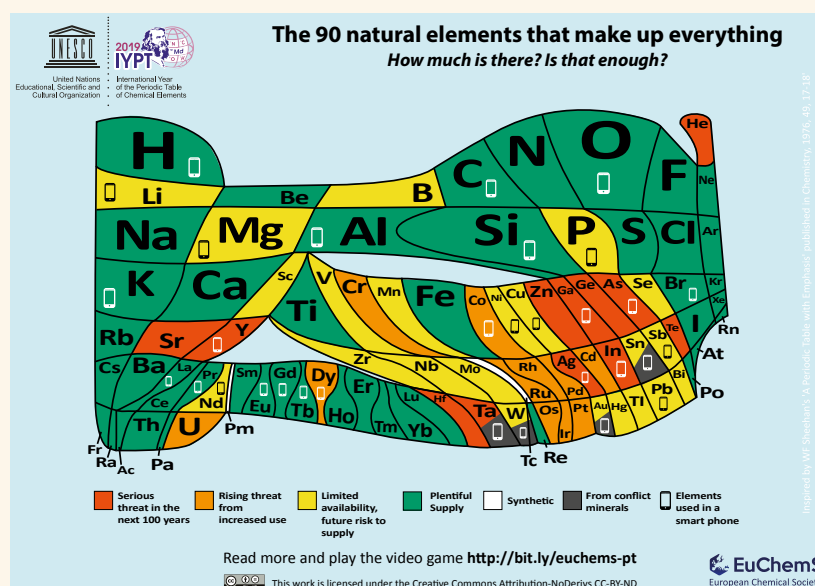
UNESCO is supporting the efforts of countries to identify and manage

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 others⁹ 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

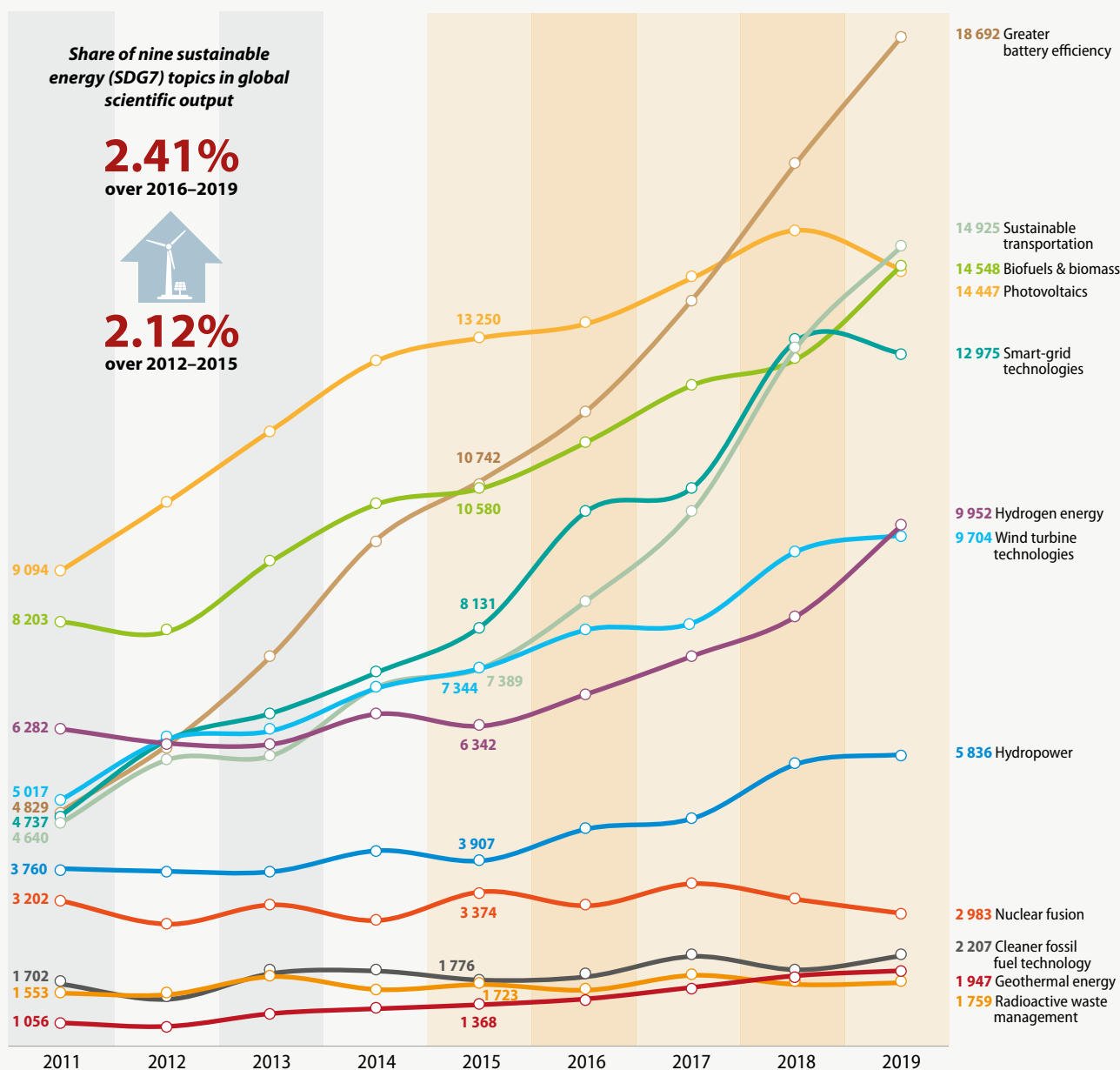
There are concerns that technological solutionism may become an excuse not to address the climate crisis, such as by investing in geo-engineering techniques to the detriment of transitioning to sustainable forms of energy, or by assuming that problems caused by new technology will be solved by technologies 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.

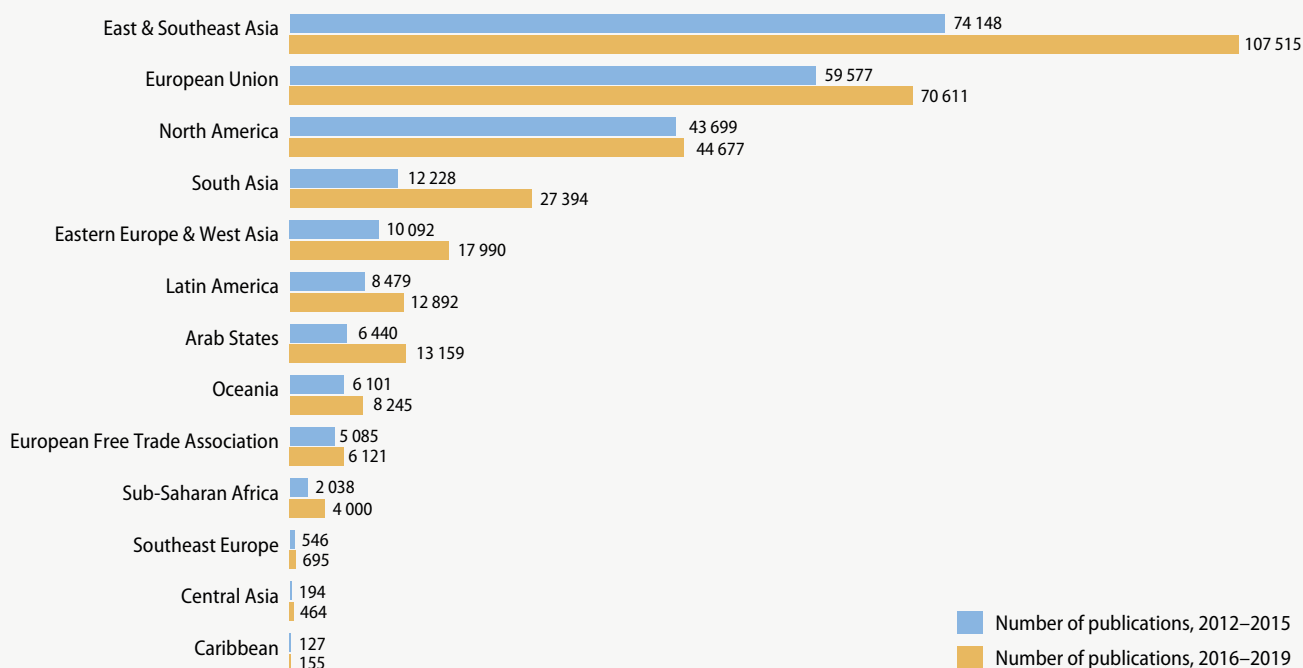
More generally, the management of waste generated by technology poses a major challenge for sustainability. Some solutions will be technological but just as important will be our capacity to adopt sustainable production and consumption patterns. Governments are increasingly adopting policies to reduce 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

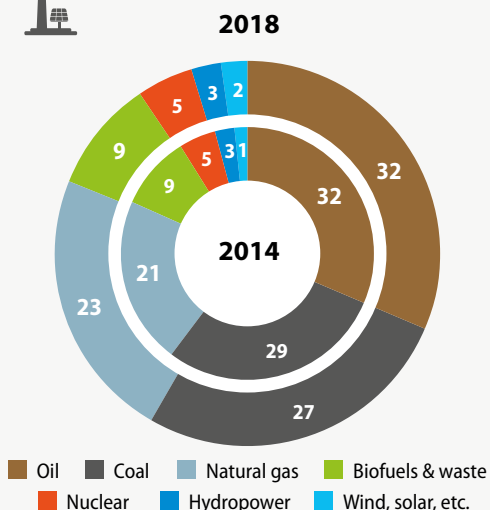
Volume of scientific publications on nine SDG7 renewable energy topics by selected region, 2012–2015 and 2016–2019



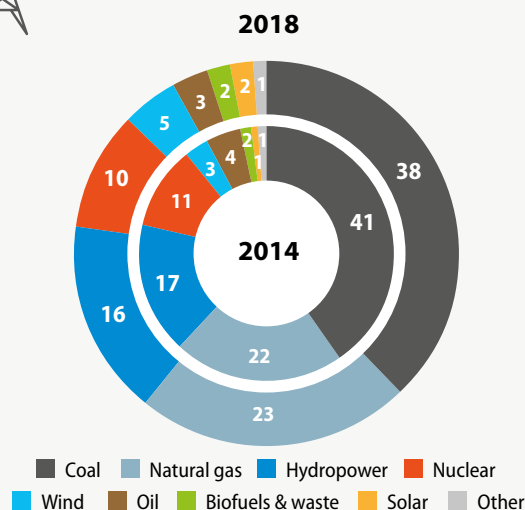
Note: The values for the regions are the number of unique publications and may differ from the sum of the sub-regions owing to potential co-authorship.



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 countries¹¹ 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 CO₂ 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'.

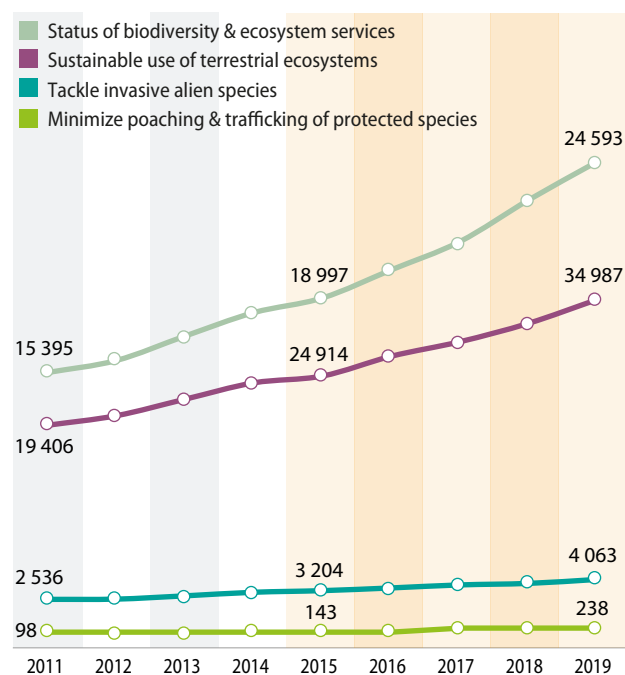
Poaching, trafficking and invasive species growing research fields

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 times¹⁴ 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 countries¹⁵ 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 policies 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 CO₂ 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 trematodiasis, 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 helminthiasis, 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.



ESISTIA

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.