UNESCO SCIENCE REPORT

The race against time for smarter development

EXECUTIVE SUMMARY

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

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

AT A GLANCE

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

1 · The race against time for smarter development

Susan Schneegans, Jake Lewis and Tiffany Straza

INTRODUCTION

Countries pairing their digital and green transition

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

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

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

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

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

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

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

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

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

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

SCIENCE AND THE PANDEMIC

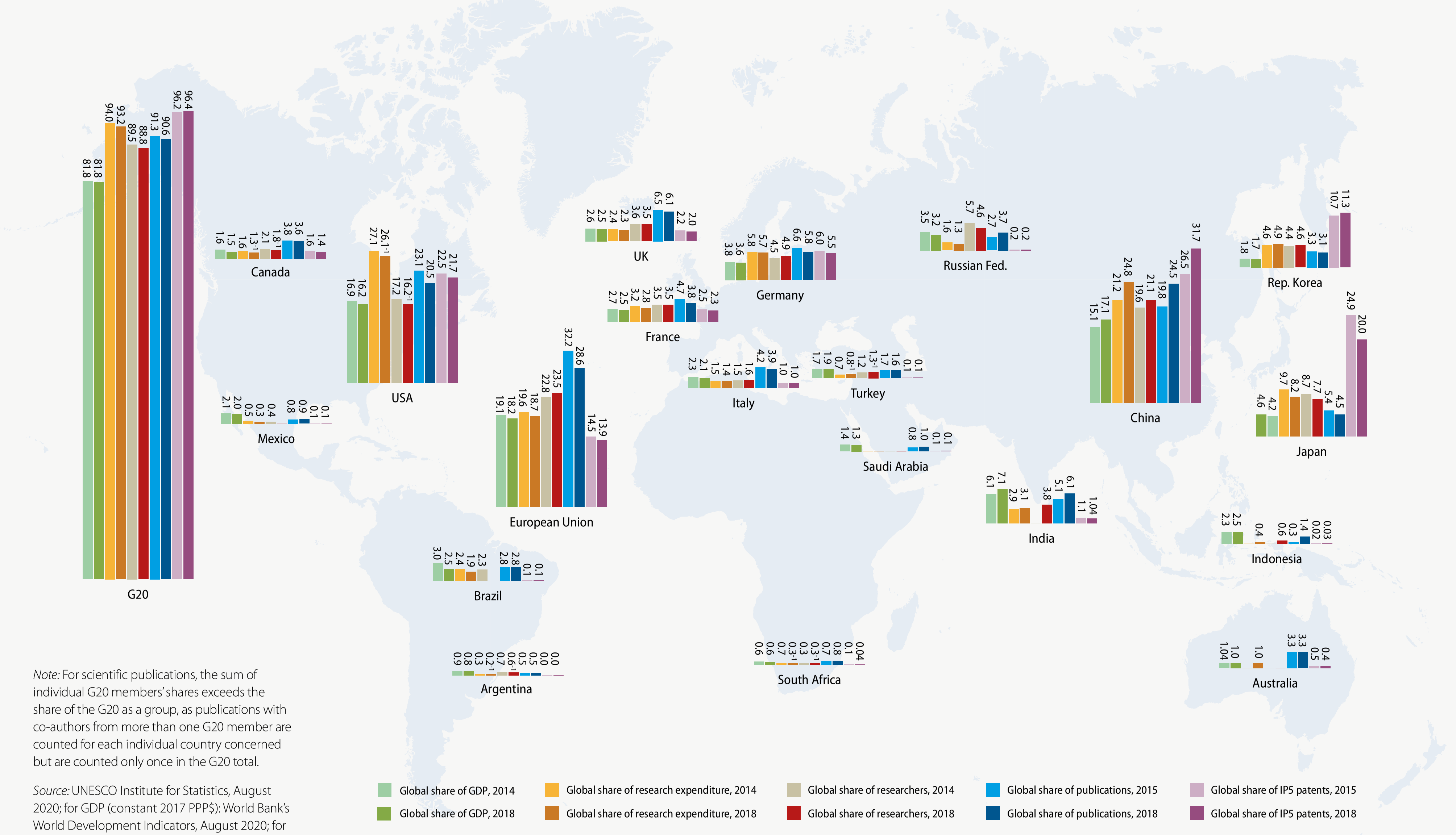
During the pandemic, countries have turned to science

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

Many governments rapidly established ad hoc scientific committees to manage the crisis. This enabled them to witness, first hand, the advantages of having local experts to monitor and control the progression of the virus.

Crisis management is reactive, by definition. Permanent structures can provide governments with scientific advisory

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



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

Source: UNESCO Institute for Statistics, August 2020; for GDP (constant 2017 PPP$): World Bank's World Development Indicators, August 2020; for publications: Scopus (Elsevier), excluding Arts, Humanities and Social Sciences, data treatment by Science-Metrix; for IP5 patents: PATSTAT, data treatment by Science-Metrix services on a wide range of issues over time to inform national strategic planning (see essay on What the Covid-19 pandemic reveals about the evolving landscape of scientific advice).

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

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

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

Pandemic undermining social and environmental gains

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

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

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

The pandemic has energized knowledge systems

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

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

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

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

In October 2020, the World Health Organization[1] reported that Africa accounted for about 13% of 1 000 new or modified existing technologies developed worldwide in response to the pandemic, close to its share of the global population (14%). Of these, 58% involved digital solutions such as chatbots, self-diagnostic tools and contact-tracing apps. A further 25% of solutions were based on three-dimensional (3D) printing and 11% on robotics (see chapter 20).

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

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

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

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

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

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

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

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

THE DUAL DIGITAL AND GREEN TRANSITION

The pandemic has highlighted dependence on global value chains

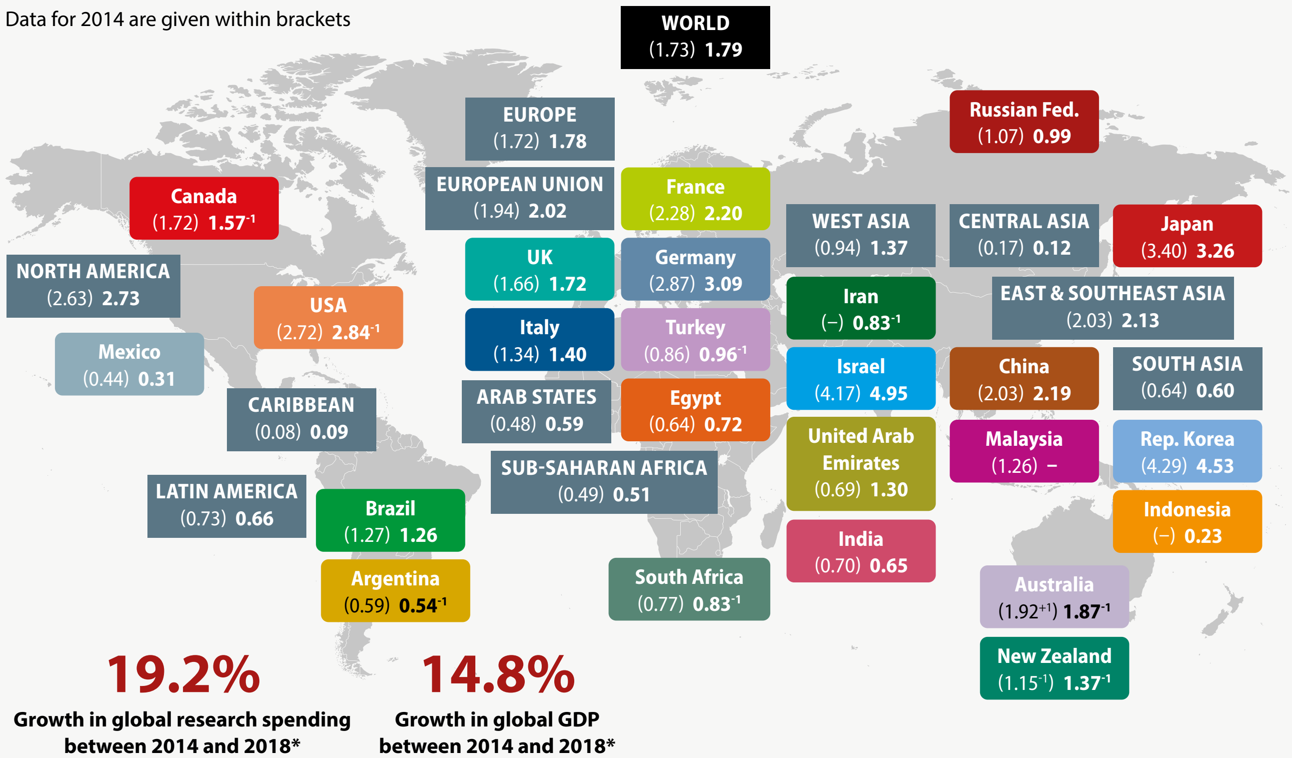
The pandemic has highlighted countries' dependence on global value chains for strategic resources. The complexity of components in modern everyday devices means that manufacturers have recourse to subcontractors abroad who specialize in a narrow field; they, in turn, rely on other suppliers for essential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

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

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

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

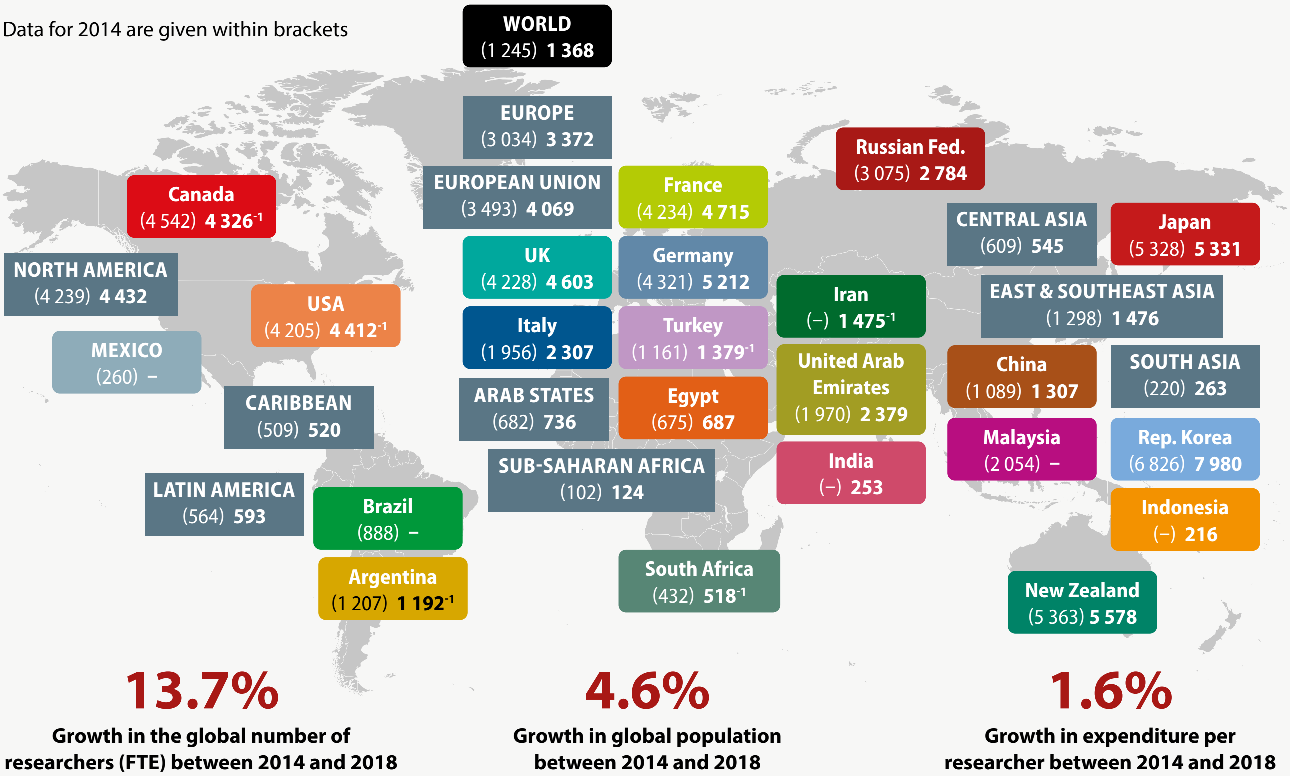
Data for 2014 are given within brackets



*in constant 2017 PPP$ trillions

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

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



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

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

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

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

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

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

Advanced manufacturing seeking to revitalize industry

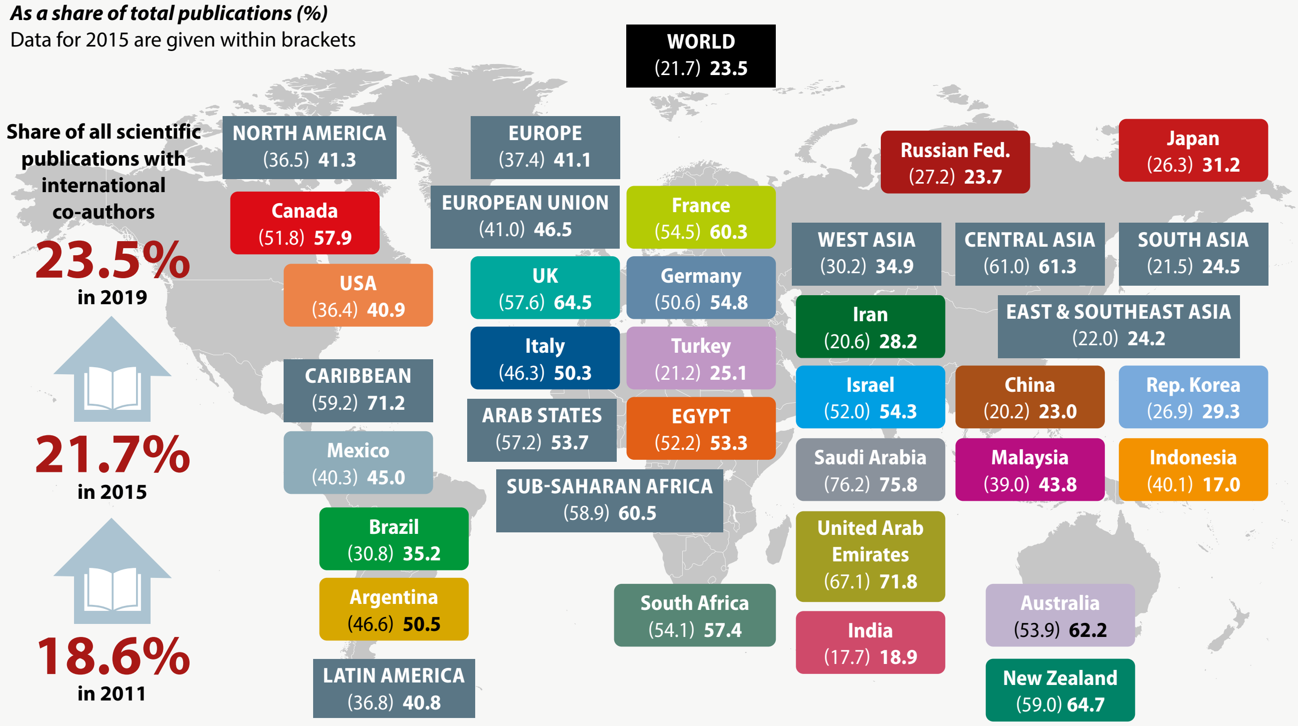
Prior to the pandemic, developed countries were already investing in advanced manufacturing technologies to revitalize their domestic manufacturing sector.

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

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

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

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



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

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

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

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

Industry 4.0 a common agenda

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

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

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

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

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

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

Helping firms digitalize

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

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

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

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

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

The AI race

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

The Russian president, Vladimir Putin, stated in 2017 that 'whoever becomes the leader in this sphere will become the ruler of the world' (chapter 17).

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

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

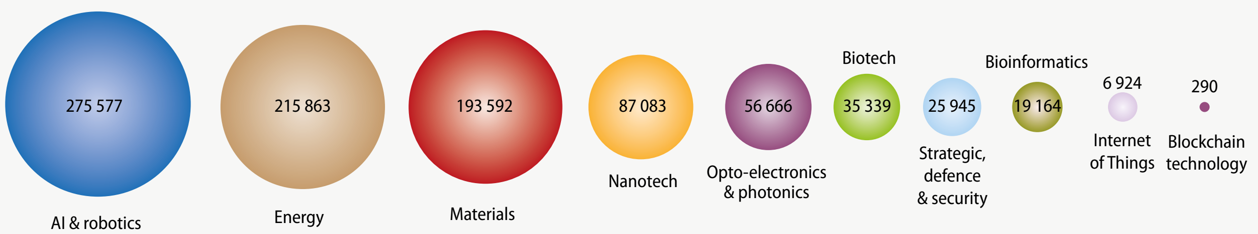
Digital and green agendas advancing in parallel

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

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

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

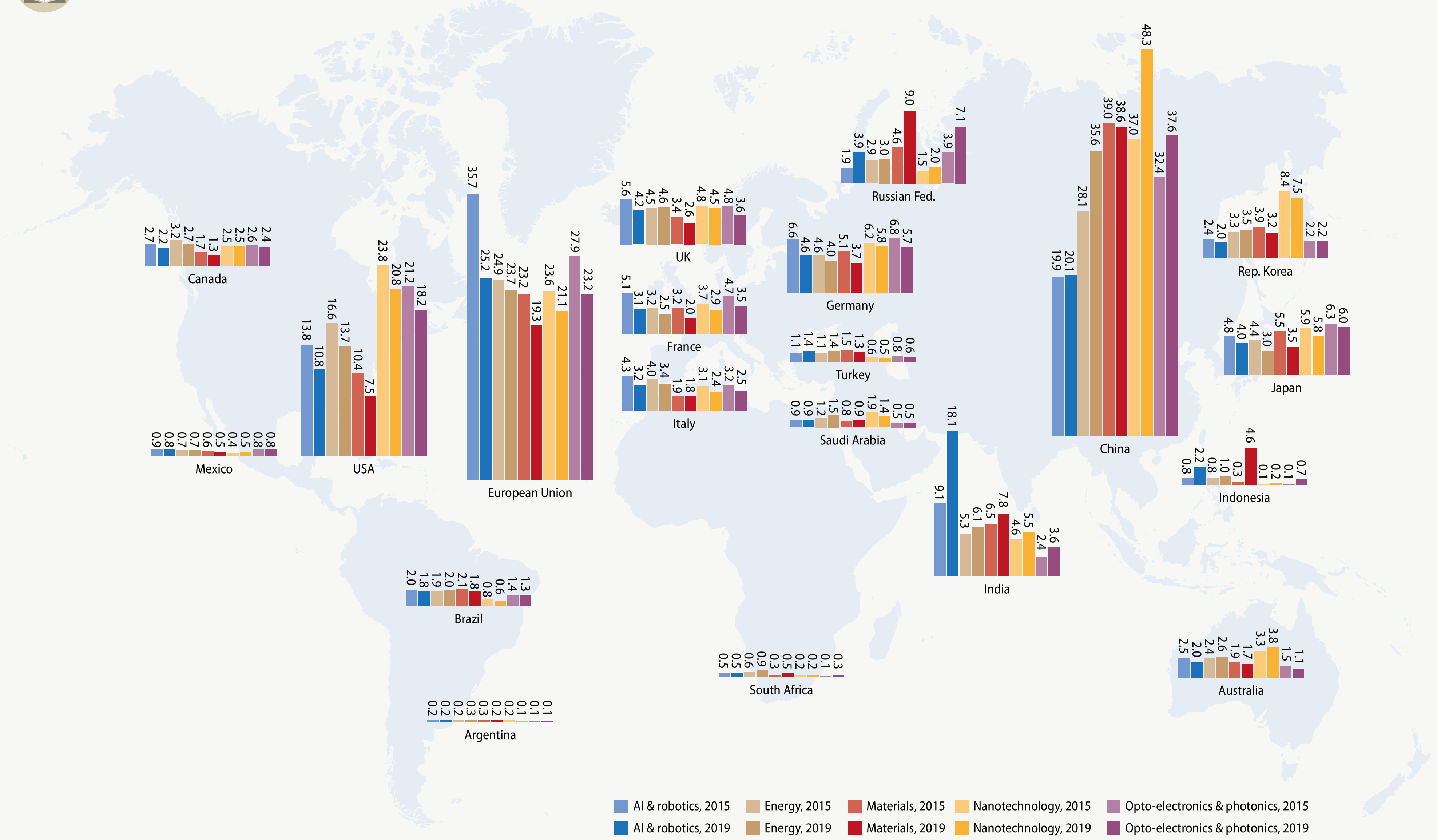
Figure 1.5: **Scientific publications by cross-cutting strategic technology, 2018–2019**



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

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

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



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

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

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

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

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

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

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

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

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

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

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

A risk of greater social inequalities

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

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

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

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

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

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

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

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

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

Anxiety about automation

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

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

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

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

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

Energy at the heart of the dual transition

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

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

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

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

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

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

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

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

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

Nuclear power being phased in ... and out

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

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

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

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

Energy transition encountering resistance

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

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

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

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

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

Governments more attuned to climate-sensitive development

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

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

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

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

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

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

Sustainability science yet to enter mainstream

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

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

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

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

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

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

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

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

POLICY TRENDS

A shift in focus towards well-being

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

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

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

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

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

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

Smart specialization seeking to boost regional autonomy

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

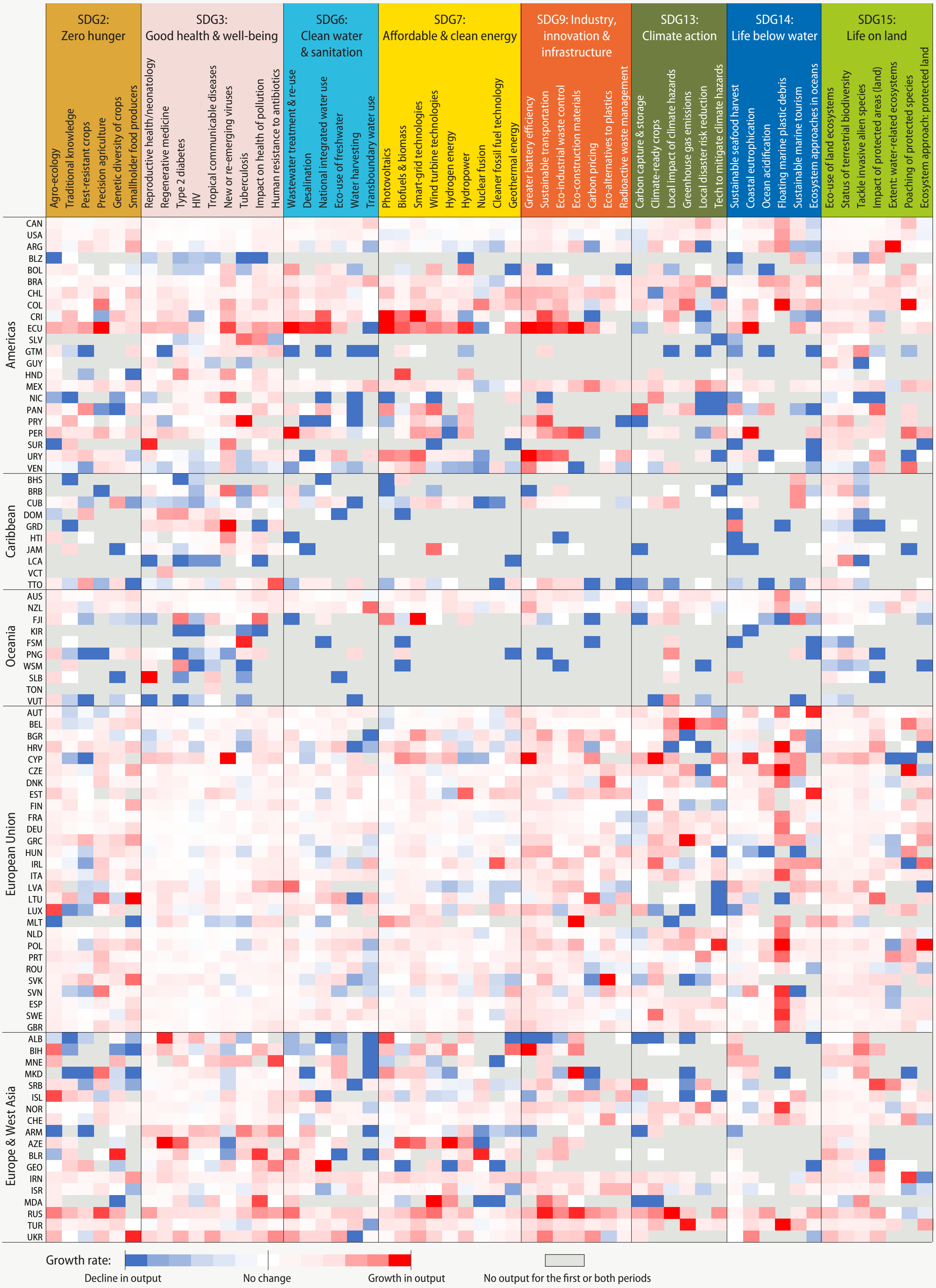
In the EU, receipt of resources from the European Regional Development Fund over the 2014–2020 period was conditional on member states developing smart specialization strategies for their regions, with the choice of technologies falling to local entrepreneurs. Regions with a similar specialization have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

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

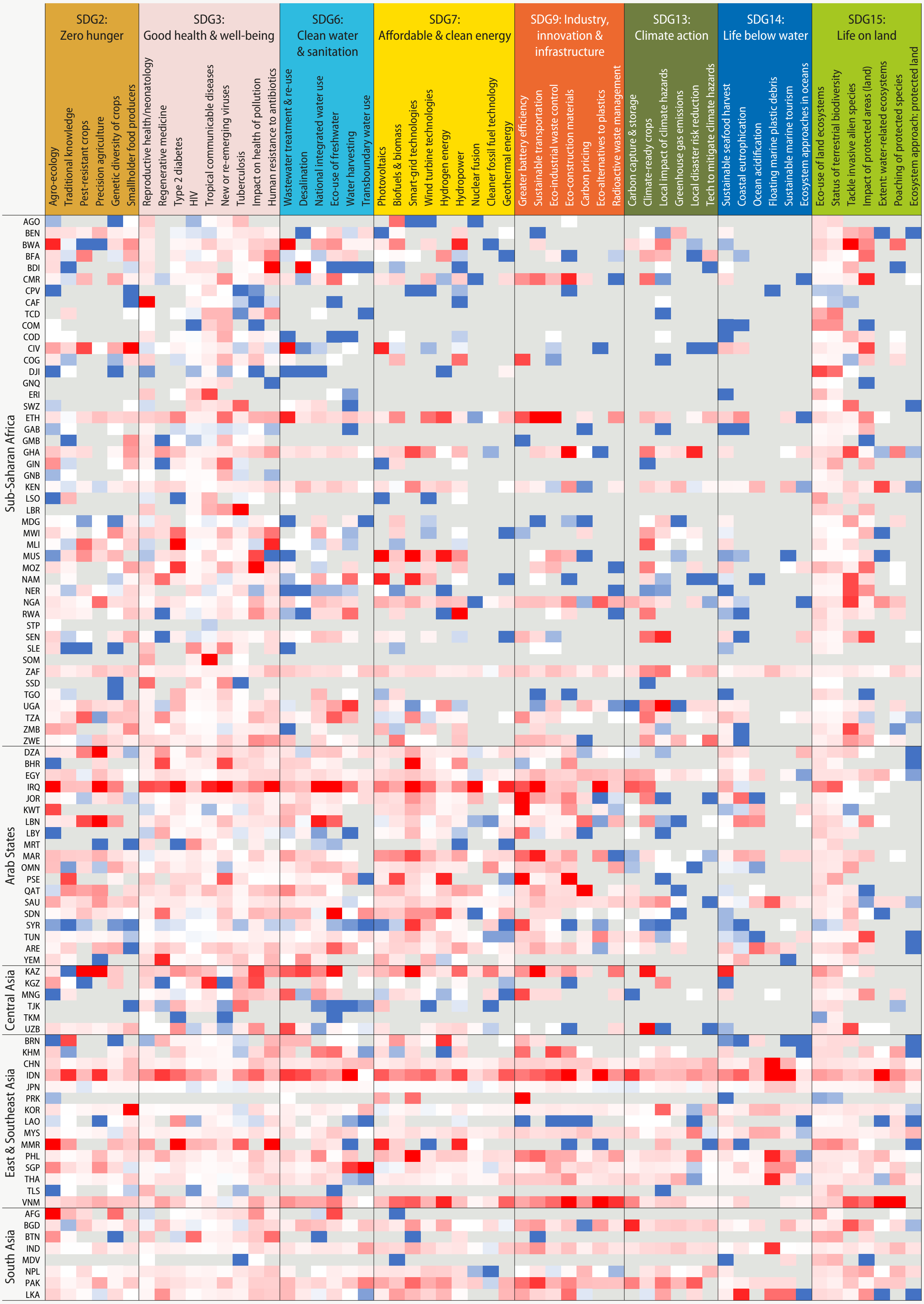
Fostering greater regional autonomy is a priority for the Republic of Korea, a highly centralized state. In 2017, each province was invited to create specialized clusters around their own priorities, under the *Fourth National Plan for the Regional Development of Science and Technology 2013–2017*. The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

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

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



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



Source: Scopus (Elsevier), including Arts, Humanities and Social Sciences; data treatment by Science-Metrix doubling gross domestic expenditure on R&D (GERD) to 0.33% of GDP by 2024 (see chapter 7).

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

Mission-oriented policies a new focus for Europe

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

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

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

TRENDS IN RESEARCH EXPENDITURE

Science has become synonymous with modernity

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

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

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

Research investment has outpaced economic growth

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

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

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

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

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

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

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

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

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

Research spending up in most regions

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

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

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

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

Gains can be fragile

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

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

Financial sustainability a challenge for African start-ups

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

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

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

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

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

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

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

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

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

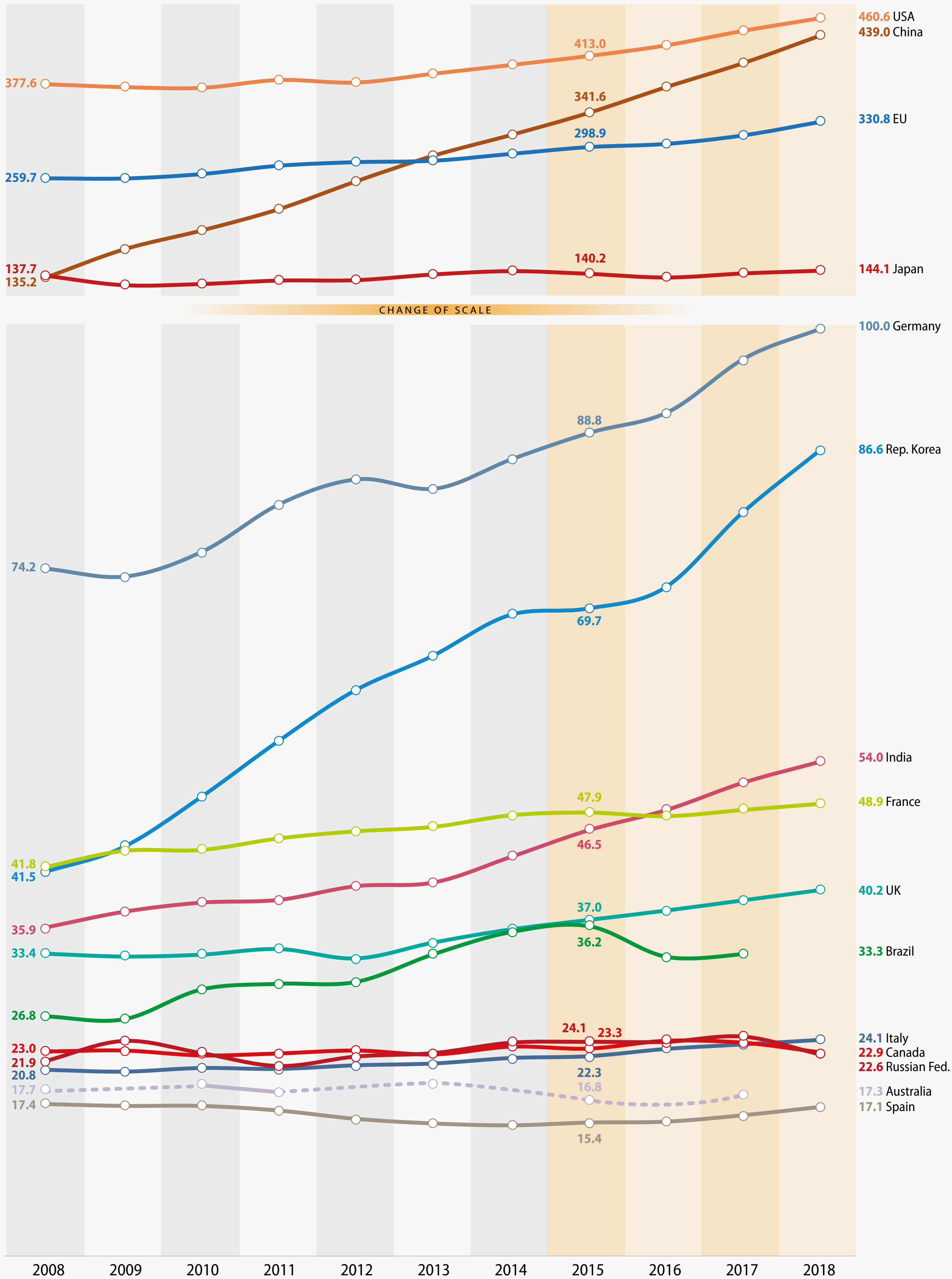
A related challenge for evidence-based policy-making concerns the omission, in many policy frameworks, of any mention of successes or failures experienced by earlier strategies. This oversight suggests that policies may not be drawing upon lessons learned from past experience.

Source: compiled by authors

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

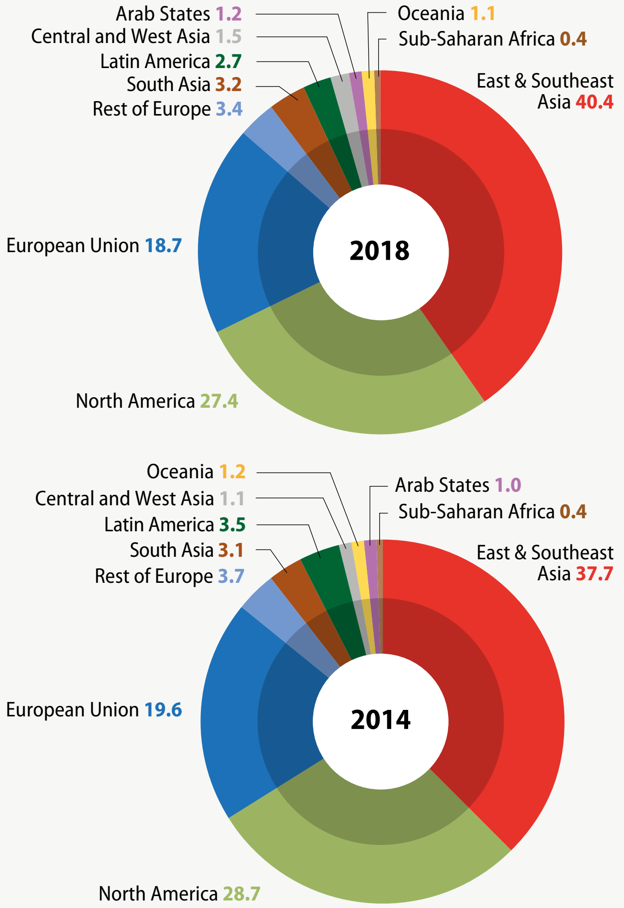
Figure 1.8: **Trends in research expenditure**

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

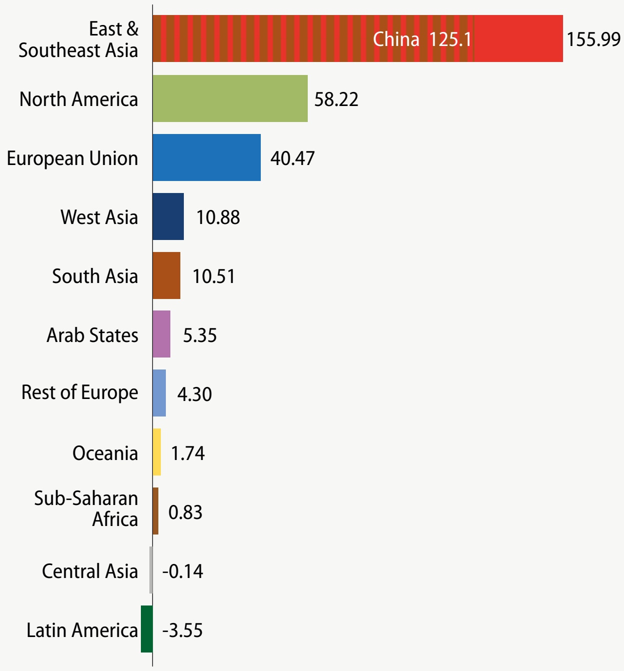


Note: Germany, France, Italy, Spain and the UK are also included in the value for the European Union (EU).

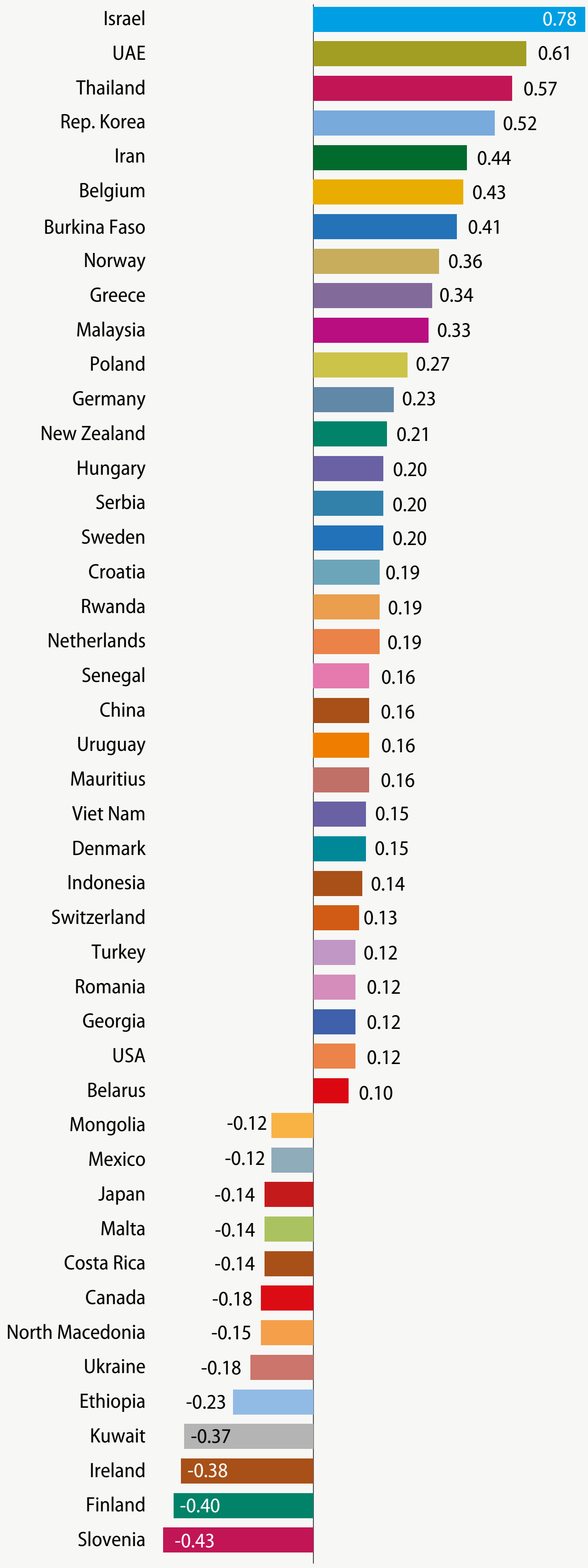
Global shares of GERD by region, 2014 and 2018 (%)



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



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



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

80% of investment in Nigeria's 101 tech hubs comes from offshore sources. In 2019, the Nigerian CcHub acquired the Kenyan iHub, creating West Africa's first 'mega-incubator'. Since its inception in 2011, CcHub has incubated more than 120 early-stage ventures. Whereas CcHub has adopted a commercial model, charging for workspace and creating its own Growth Capital Fund – Nigeria's first fund targeting social innovation – iHub's donor-funded model ultimately proved unsustainable (see chapter 18).

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

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

Efforts to boost university–industry ties

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

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

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

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

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

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

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

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

Space industry spawning public–private partnerships

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

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

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

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

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

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

Basic research: a new division of labour

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

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

Big data are a vital resource for the health sector, which is a major economic driver for both Switzerland and the USA. As the cost of genome sequencing has dropped with the growing sophistication of related technologies, programmes have produced torrents of data on individual human genomes, spawning a booming pharmacogenetic industry. Precision medicine personalizes medicine by tailoring it to the patient's unique genome. In 2019, 25% of the 48 new molecular entities approved by the US Food and Drug Administration's Center for Drug Evaluation and Research were personalized medicines, according to the Personalized Medicine Coalition. In order to analyse this burgeoning volume of data, pharmaceutical companies will become highly dependent on AI and cloud computing, obliging them to collaborate more with data giants (see chapter 5).

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

TRENDS IN RESEARCHERS

Researcher density on the rise

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

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

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

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

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

Measures to boost the status of researchers

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

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

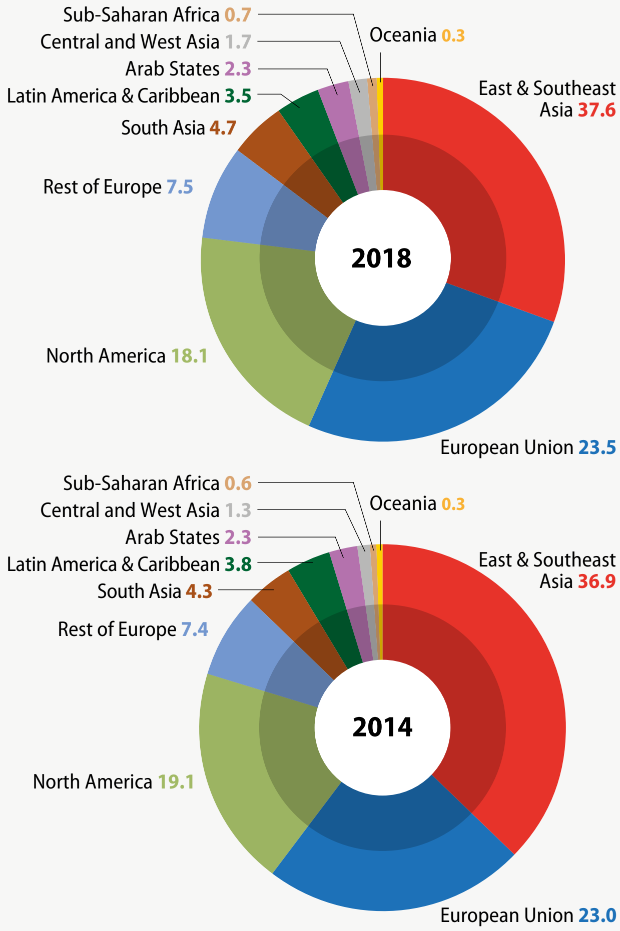
Between 2014 and 2018, Russian research spending dropped by 6% in constant prices and the researcher pool (in FTE) shrank by 9.5%. By 2018, the average age of Russian researchers was 47 years and almost one in four had reached retirement age. The introduction of wage growth policies and various research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

Women a minority in Industry 4.0 fields

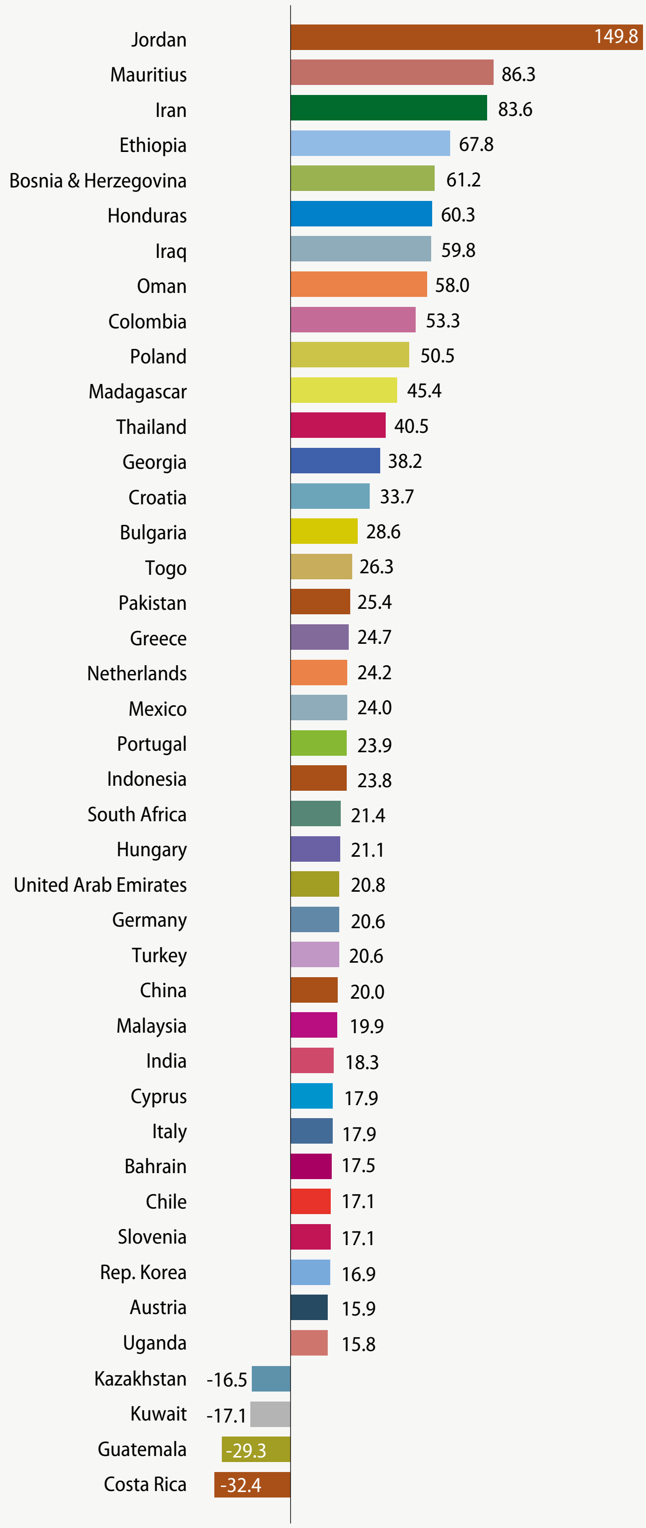
Women accounted for one in three (33%) researchers in 2018. They have achieved parity (in numbers) in life sciences in many countries and even dominate this field, in some cases. However, they make up just one-quarter (28%) of tertiary graduates in engineering and 40% of those in computer sciences. Just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

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

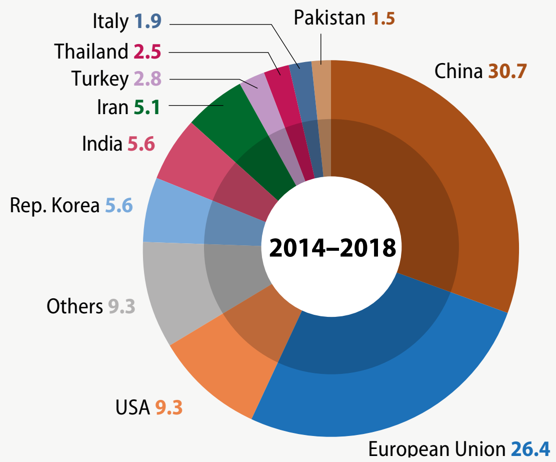
Global shares of researchers by region, 2015 and 2018 (%)



Change in researchers (FTE) per million inhabitants, 2014–2018 (%)
Among countries with a change of at least 15%



Contribution to growth in the number of researchers worldwide, 2014–2018 (%)
Top ten contributors and rest of the world



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

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

TRENDS IN PATENTING

China opening up domestic market

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

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

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

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

Reforms to make it easier to patent

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

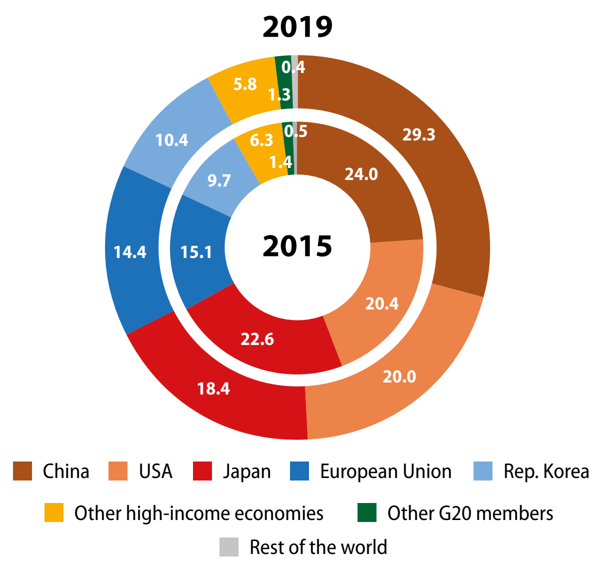
Around the world, procedures for filing patent applications can be complex and the cost of patenting high. European companies currently need to file for patent protection in all 27 member states. Once the process of ratification of the agreement for a Unified Patent Court (2013) is complete, companies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

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

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

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

Top four countries and selected groupings



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

Source: PATSTAT; data treatment by Science-Metrix

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

Start-ups being snapped up by foreign multinationals

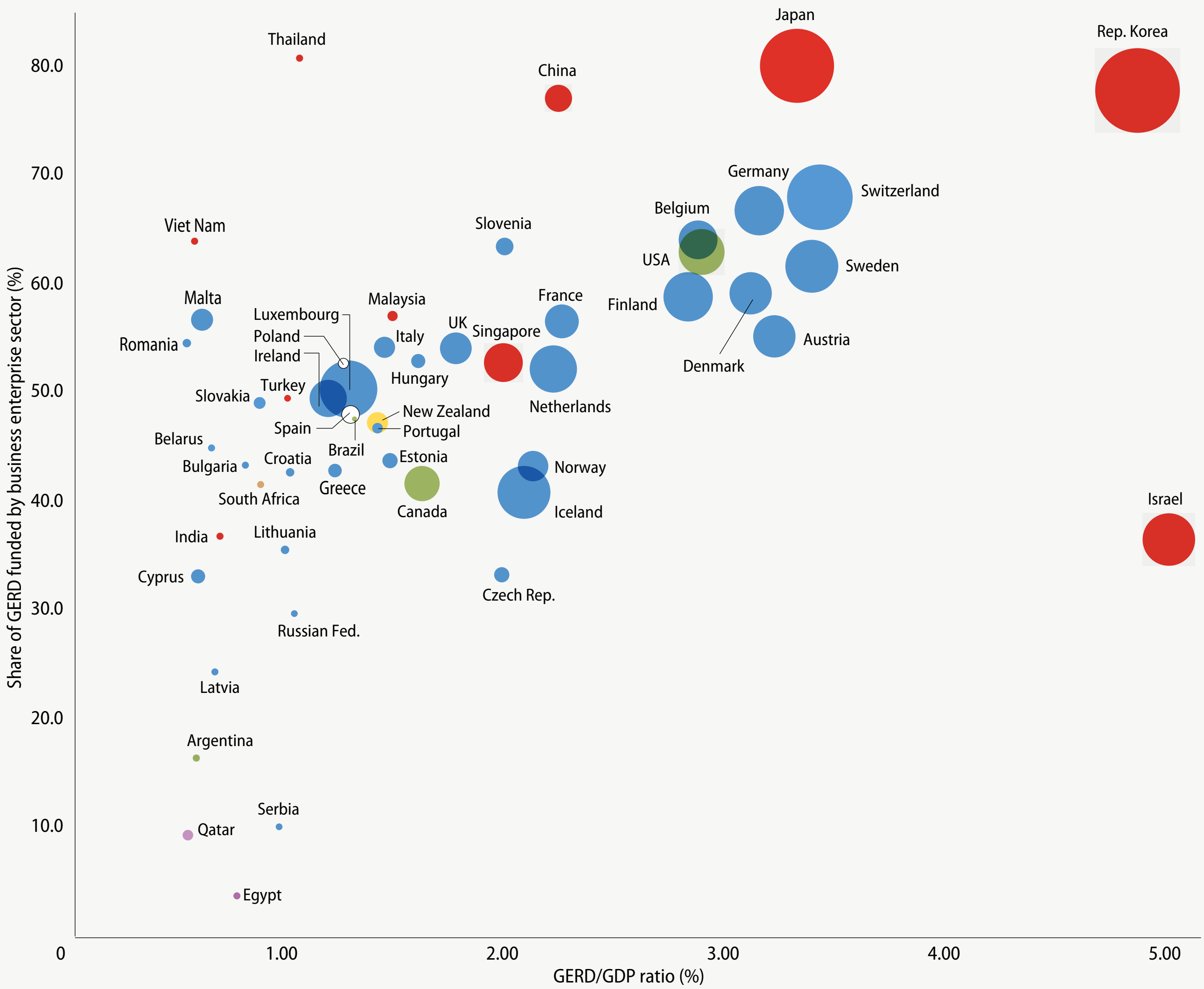
Fewer than half of the patents obtained by inventors from Israel are owned by Israeli companies. This means that knowledge is being created in Israel then transferred to a foreign company. Increasingly, Israeli intellectual property is being obtained by means of the acquisition of Israeli firms and start-ups.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

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

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

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

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



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

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

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

Relinquishing patent rights for the common good

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

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

TRENDS IN SCIENTIFIC PUBLISHING

Strong growth in cross-cutting technologies

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

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

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

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

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

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

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

There were just 18 000 more publications in biotechnology in 2019 than in 2015. This compares with an additional 148 000 publications in AI and robotics over the same period, to which countries from all income groups contributed.

Rapid shifts in the publishing landscape

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

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

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

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

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

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

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

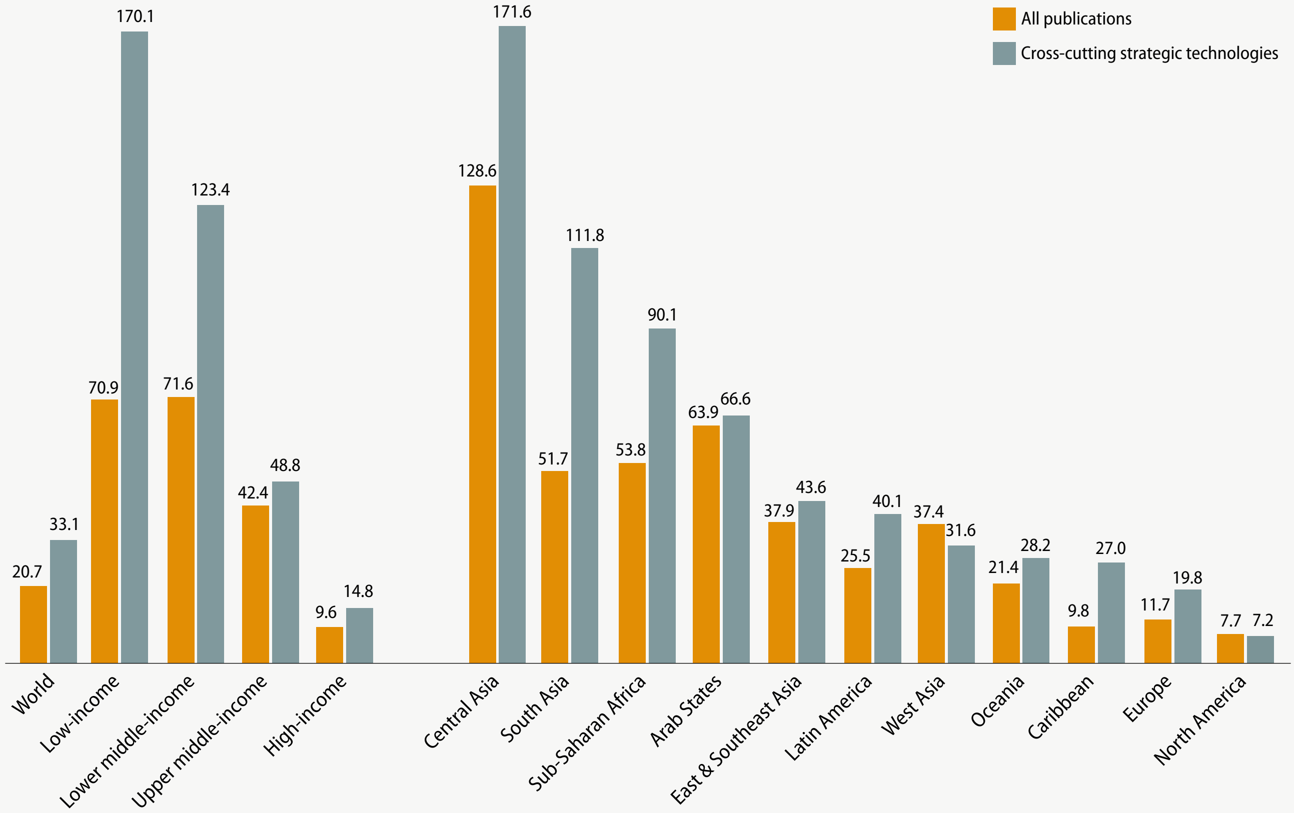
TRENDS IN INTERNATIONAL SCIENTIFIC COLLABORATION

More international scientific collaboration

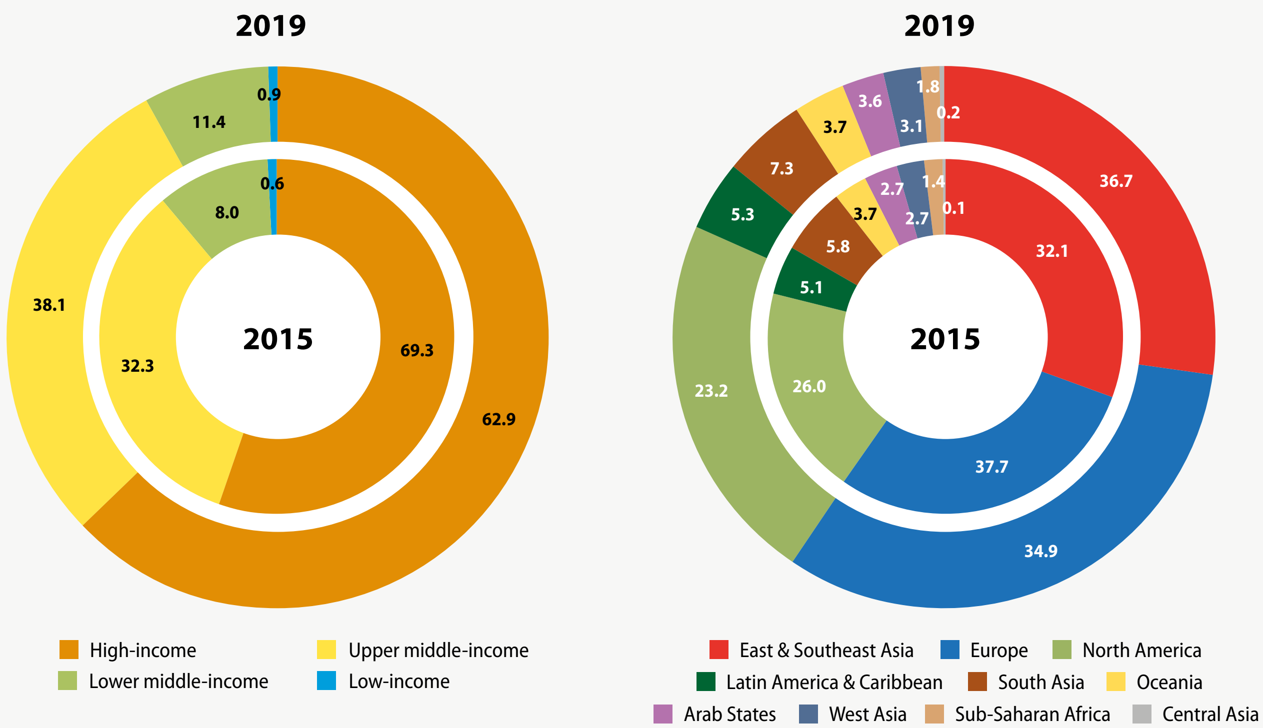
At the global level, the rate of international scientific collaboration rose from 22% to 24% between 2015 and 2019 (Figure 1.4). This average masks wide disparities among income groups and countries. Growth was fastest in high-income countries (from 30% to 36%). In the EU, the share of papers co-authored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

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

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



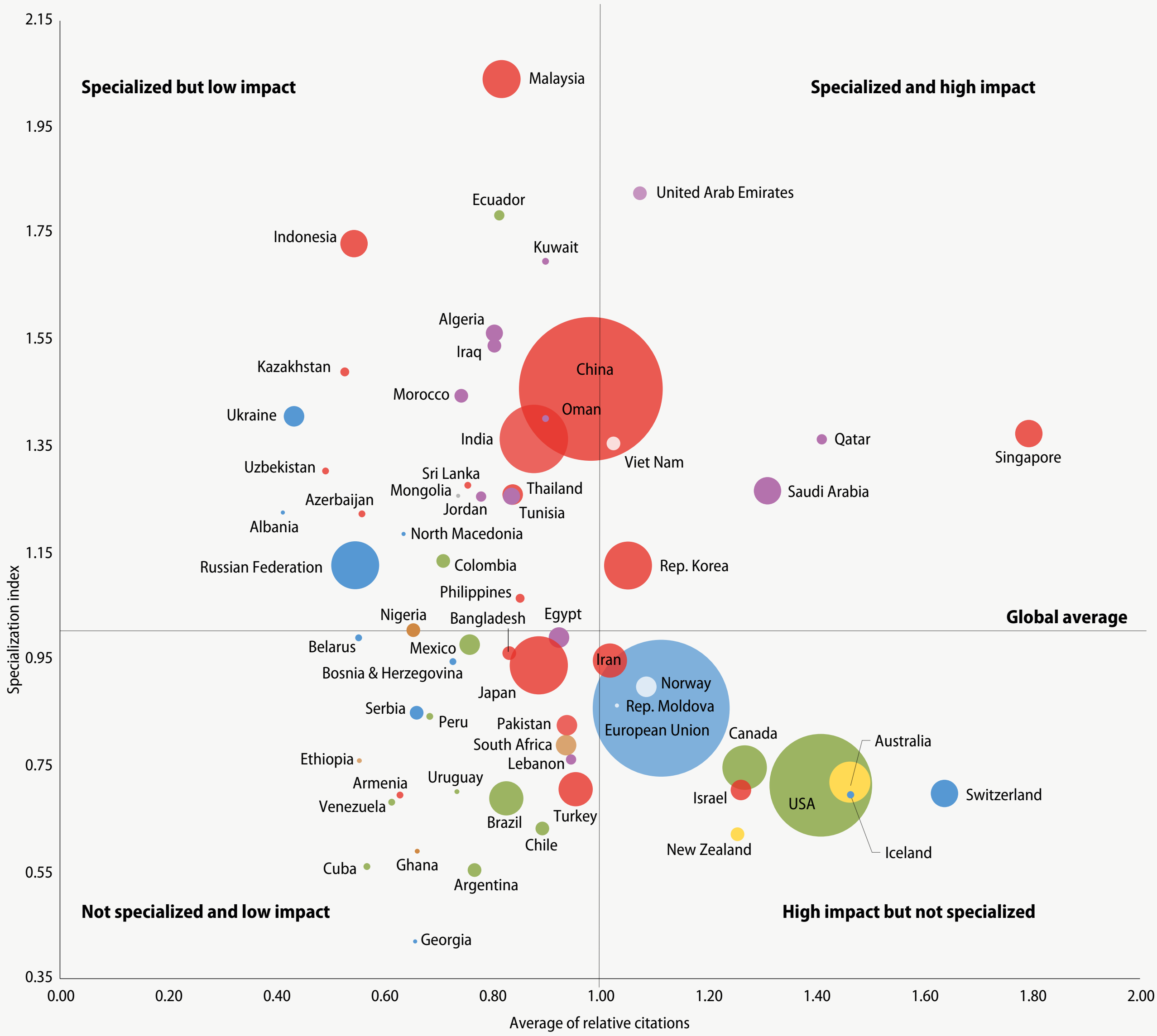
Global shares of scientific publications, 2015 and 2019 (%)
By income group and region



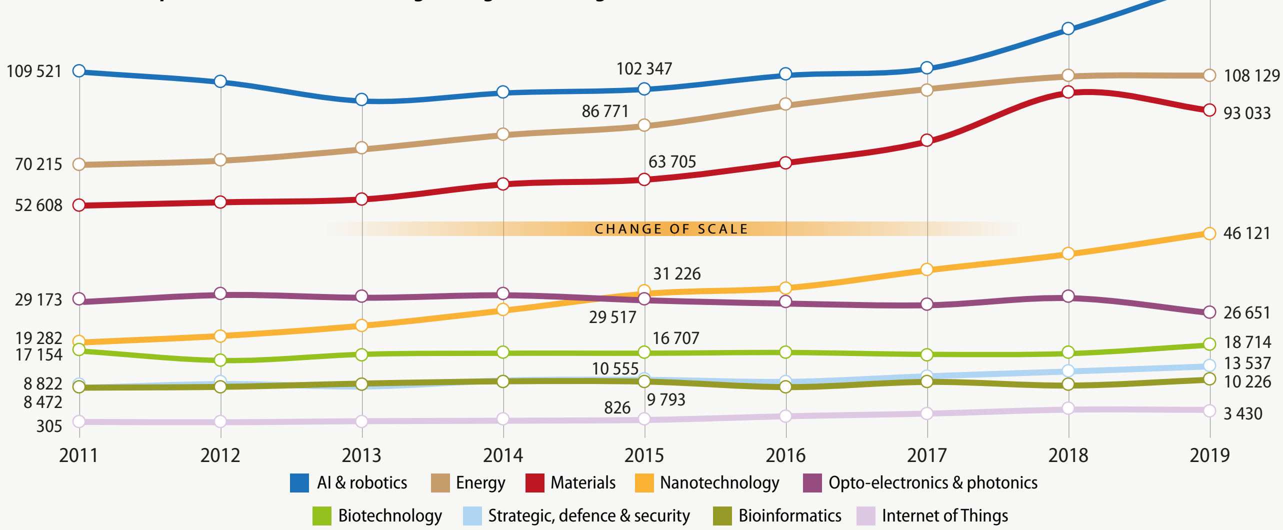
Source: Scopus (Elsevier), excluding Arts, Humanities and Social Sciences; data treatment by Science-Metrix

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

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



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



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

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

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

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

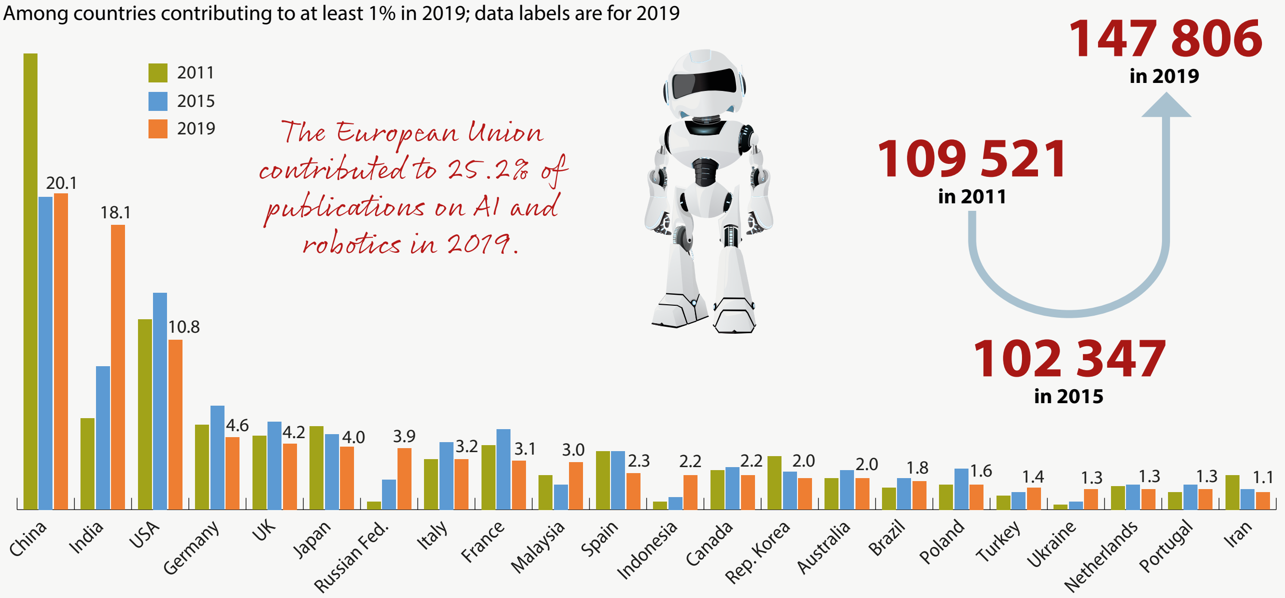
The Russian Federation has bucked the global trend, with its own level of international scientific collaboration having dropped from 27% to 24% over the 2015–2019 period (Figure 1.4).

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

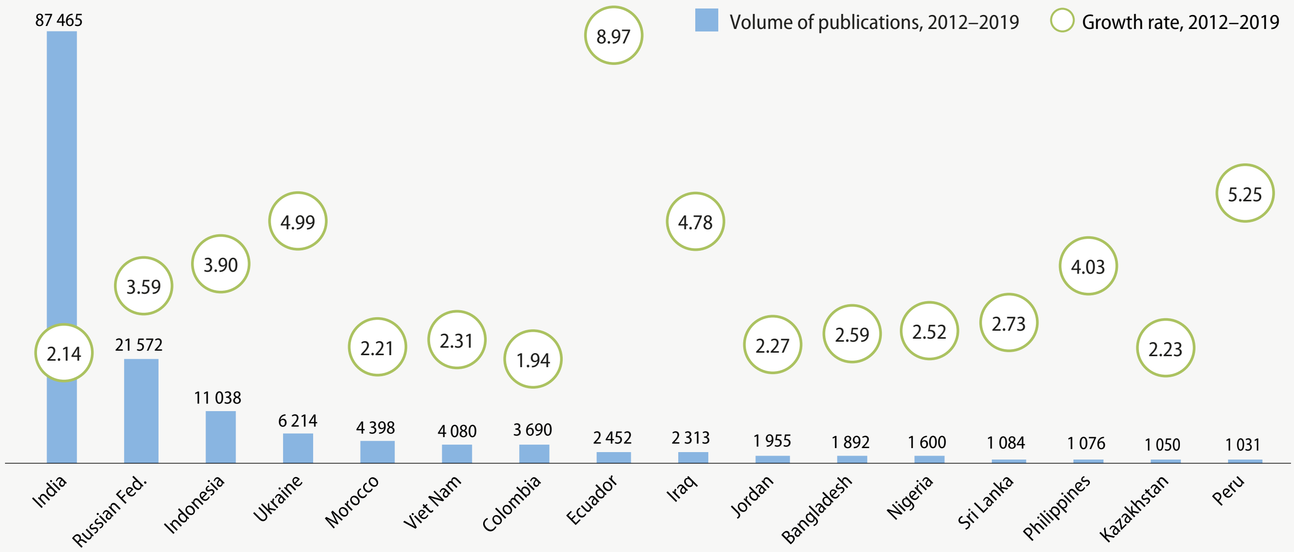
Figure 1.13: **Trends in scientific publishing on artificial intelligence and robotics**

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

Global publications on AI & robotics



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



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

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

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

Talent market and diaspora drivers of change

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

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

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

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

Environmental sciences highly collaborative

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

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

Science can serve a common cause

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

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

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

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

Greater intraregional scientific collaboration

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

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

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

A CLOSER LOOK AT COUNTRIES AND REGIONS

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

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

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

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

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

Global publications on energy

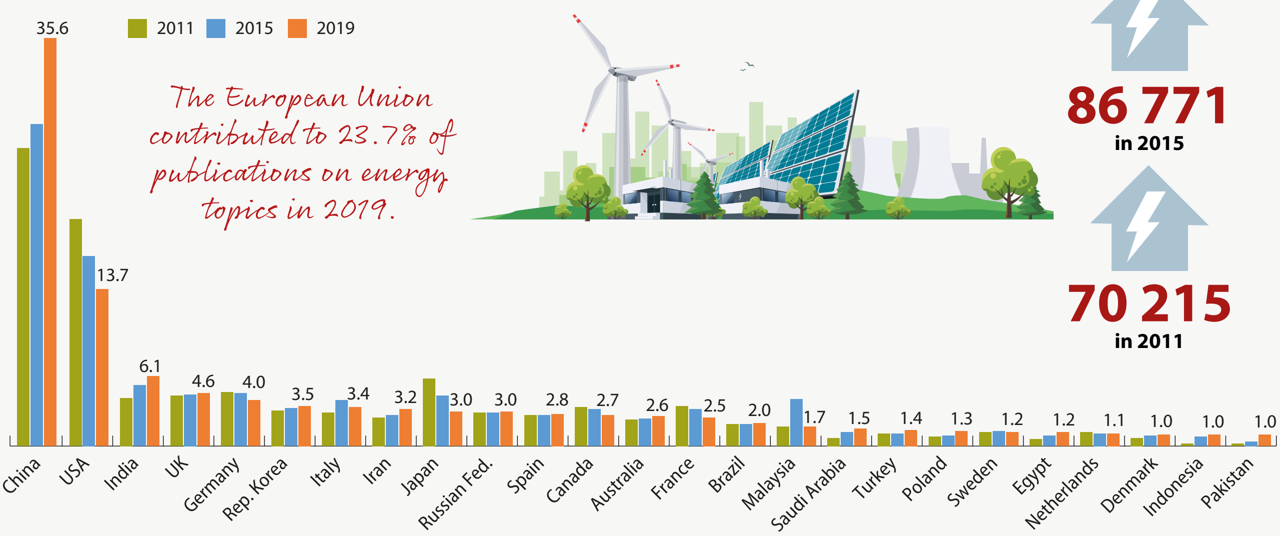
108 129 in 2019

86 771 in 2015

70 215 in 2011

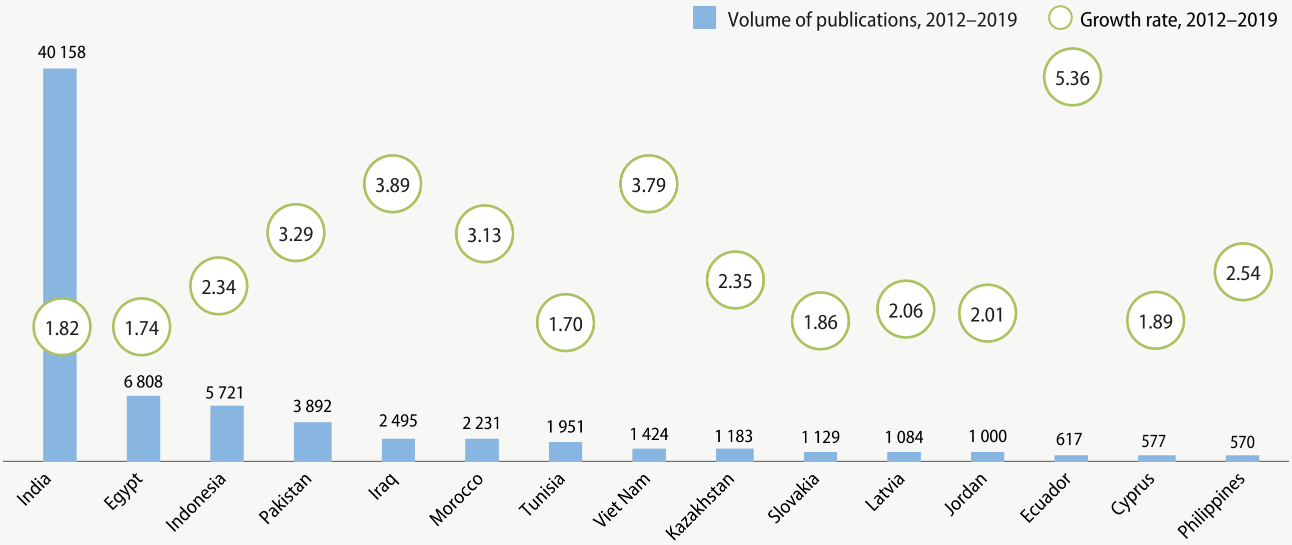
Share of global publications on energy, 2011, 2015 and 2019 (%)

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



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

Among countries with at least 500 publications, arranged by volume



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Global publications on materials science

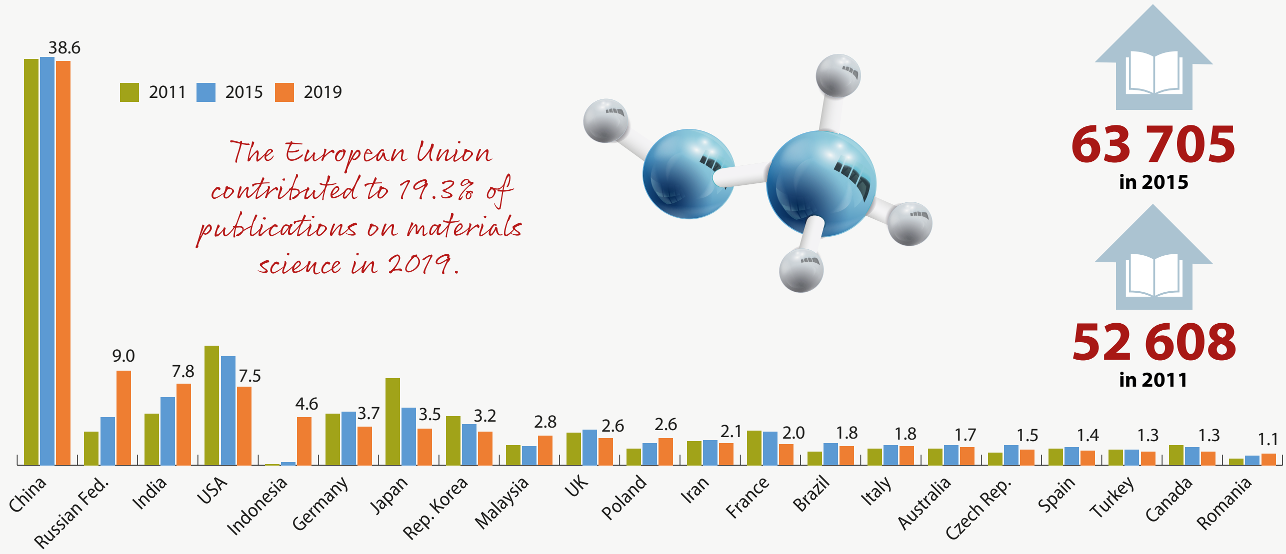
93 033 in 2019

63 705 in 2015

52 608 in 2011

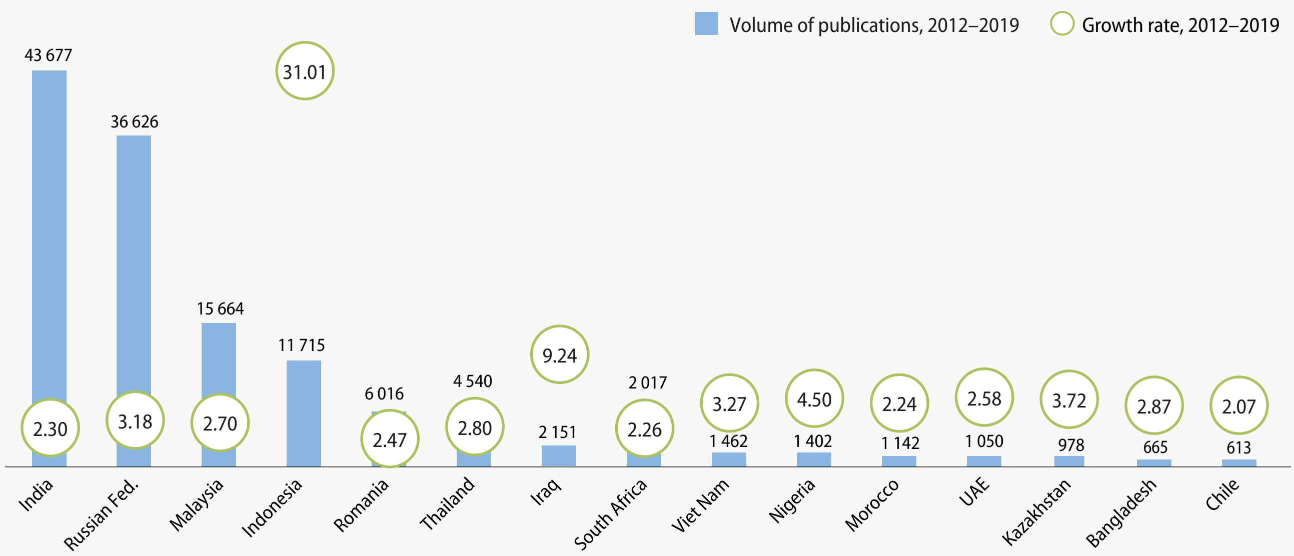
Share of global publications on materials science, 2011, 2015 and 2019 (%)

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



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

Among countries with at least 500 publications, arranged by volume



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

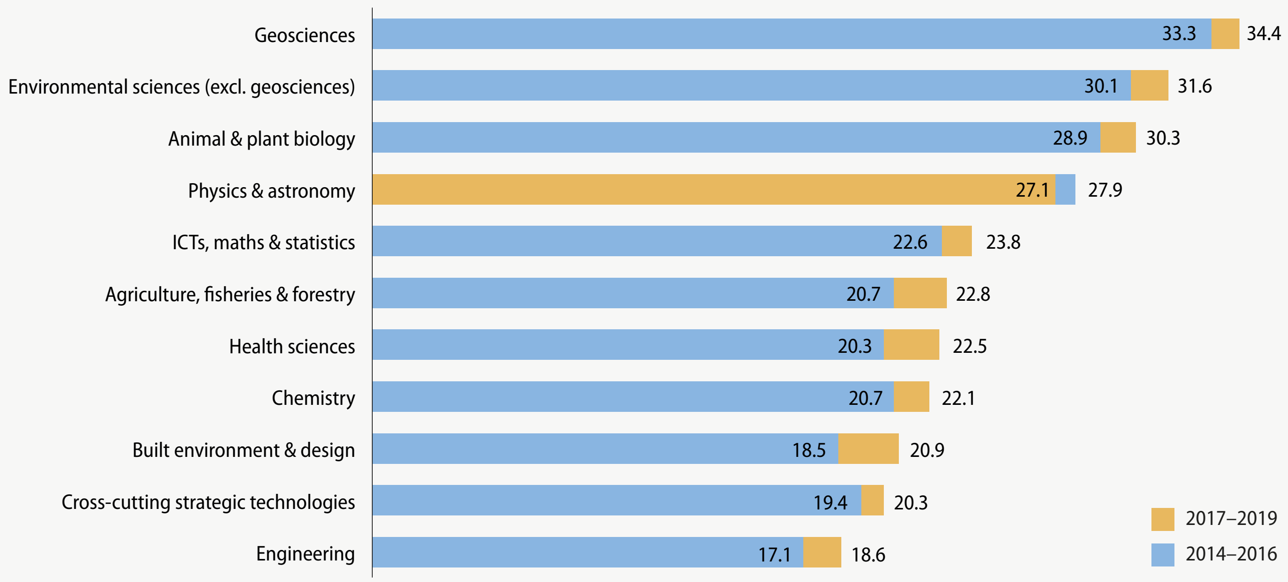
Countries are also developing their own smart specialization strategies, a *de facto* prerequisite for EU accession. The first to complete these were Montenegro in 2019 and Serbia in 2020. These strategies could provide the missing link for countries struggling to integrate their research and economic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

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

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

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

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



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Although services dominate the economy in **Southern Africa** (chapter 20), it is manufacturing that has been identified as a key growth engine.

Steps have been taken towards closer integration. A Regional Development Fund was operationalized in 2017 and the draft Protocol on Industry would provide the Secretariat of the Southern African Development Community (SADC) with a legal mandate to implement regional industrial programmes. Although a free trade area was established in 2008, not all member countries are participating in it.

Several countries are exploring e-governance to improve the delivery of public services and make it easier to do business, including Madagascar and Namibia. However, a lack of private-sector competition has made digital services unaffordable for many citizens and businesses, even as the geographical coverage of communication infrastructure has expanded.

South Africa is the only country with a strong patenting record. Malawi and Namibia have taken steps to strengthen their intellectual property regime. Legislation passed by Eswatini in 2018 to establish an intellectual property tribunal had not been followed by a decree of application a year later. In 2018, ministers adopted the *SADC Regional Framework and Guidelines on Intellectual Property Rights* to foster mutual co-operation on reforming national intellectual property regimes.

Half of countries[13] have published explicit STI policies since 2010. Others have plans to develop or update their own strategies, including the Democratic Republic of Congo, Malawi, Lesotho, Tanzania and Zambia.

Only Mauritius, the Seychelles and South Africa have an electrification rate above 50%. Since SADC opened a Centre for Renewable Energy and Energy Efficiency in Namibia in 2015, the share of renewables in the region's power supply has risen from 24% to 39% (2018).

Through partnerships with the African Development Bank, World Bank and others, countries are expanding the electricity grid and off-grid solutions. The Democratic Republic of Congo's plans to build the massive Grand Inga dam have raised social and environmental concerns.

Hydropower accounted for about 81% of Zambia's installed generation capacity in 2019 but insufficient rainfall has made it an unreliable resource. In 2019, the government introduced a feed-in-tariff scheme for small-scale solar and small hydropower projects. In 2020, it adopted a *National Nuclear Policy* to help curtail reliance on hydropower.

Climate-smart agricultural practices have risen on the policy agenda following severe episodes of drought or flooding. Zambia's *Climate-Smart Agriculture Investment Plan* (2019) predicts that climate change could diminish the yields of key crops by 25% but, crucially, that climate-smart agriculture could increase crop yields by 23%.

South Africa is leading the development of an African Open Science Platform to facilitate international collaboration and data-intensive research. The country also hosts the Square Kilometre Array, the world's largest telescope. It holds great potential for stimulating scientific mobility and intra-African scientific collaboration and applications in fields such as AI and big data.

Countries in **South Asia** (chapter 21) are key beneficiaries of loans awarded within China's Belt and Road Initiative to fund major upgrades to infrastructure. One flagship project is the China–Pakistan Economic corridor, which is developing roads, ports and coal- and oil-fired plants, among other infrastructure.

The push for infrastructure development and industrialization is taking place on a parallel path to research and development. Chronic underspending on R&D means that the region is largely a recipient of foreign scientific expertise and technology.

Bangladesh, Nepal, Pakistan and Sri Lanka all have explicit STI policies but a lack of adequate instruments is impeding implementation. Owing to the modest size of public research budgets and small research pool, there is also a risk of funds being spread too thinly across research centres operating in a wide range of areas.

One priority is to foster technology transfer to SMEs. In Sri Lanka, for instance, the *National Policy Framework for the Development of SMEs* (2016) is accompanied by a national technology development fund co-financed by the government and private sector.

The pharmaceutical industries of Bangladesh, Pakistan and Sri Lanka hold potential but remain reliant on imports of raw materials. In Bangladesh, the Active Pharmaceutical Ingredients Industrial Park at Munshiganj is expected to be operational by 2023. The park will enable companies to produce the main chemical components of drugs themselves, thereby lowering the cost of domestic drugs and boosting their international competitiveness.

In Sri Lanka, pharmaceutical exports had been stagnating since 2016 but, with the Covid-19 crisis having spurred demand, the government and private sector invested US$ 30 million in a new pharmaceutical manufacturing plant in 2020.

Digital economies are emerging. For instance, Bhutan now has a FabLab for developers of digital projects and Pakistan is home to several 'tech unicorns' – start-ups valued at more than US$ 1 billion. This boom has led some governments to make plans for 'smart' infrastructure such as cities and schools. One challenge will be to ensure that these plans incorporate sustainability principles.

In 2016, the rising cost of fossil fuel imports, coupled with declining rainfall that made hydropower an unsustainable option, inspired Sri Lanka to launch a community-based project (*Soorya Bala Sangramaya,* or Battle for Solar Energy) that promotes small rooftop solar power plants for households and businesses through public–private partnerships.

In **India** (chapter 22), the government launched the Digital India programme in 2015 to transform the ecosystem of public services. Blockchain is now widely integrated within central government.

In 2016, the government embarked on one of the boldest economic experiments of modern times by demonetizing two of the largest banknotes in circulation, in a push to reduce the size of the informal economy. The government then shifted its focus to creating a fully cashless economy. The share of Indians with a bank account rose from 53% to 80% between 2014 and 2017. These developments have taken place against a backdrop of sharp growth in access to Internet, which has fuelled the digital economy, including e-commerce.

The flagship Make in India programme has sought to promote investment in manufacturing and related infrastructure, among other things. Although it may have helped to improve the business environment, it has had little tangible impact on manufacturing itself. Since Covid-19, the manufacturing sector has been developing frugal (low-cost) technologies, including lung ventilators.

Since 2016, the Startup India initiative has boosted the number of start-ups but these remain concentrated in the services sector, in general, and software development, in particular.

Overall research intensity remains stagnant and the density of scientists and engineers remains one of the lowest among BRICS countries, despite having risen somewhat.

The government has reduced the tax incentive for firms conducting R&D, which is consistent with the finding of the previous *UNESCO Science Report* (2015) that the tax regime had 'not resulted in the spread of an innovation culture across firms and industries'. Pharmaceuticals and software still account for the majority of patents. Although inventive activity by Indian inventors has surged, foreign multinational corporations remain assignees for the vast majority of patents.

The phenomenon of 'jobless growth' that has plagued India since 1991 has worsened. Moreover, in 2017, the size of the workforce contracted for the first time since independence. Another concern is the low employability of graduates, including those enrolled in STEM subjects, although this indicator did improve over 2014–2019. The ambitious National Skills Development Mission aims to train about 400 million Indians over 2015–2022.

In 2018, investment in renewable sources exceeded that in fossil fuels. India's efforts are considered 2°C compatible but insufficient to meet the *Paris Agreement* target of 1.5°C.

The government is planning to add 46 GW of coal-fired capacity by 2027, even though plans for other coal plants were cancelled in 2017 after being deemed uneconomical.

Air and water pollution remain life-threatening challenges in India. The government is striving for universal electrification and the diffusion of electric and hybrid vehicles.

Made in China 2025 (2015) sets out to help ten strategic industries reduce **China's** (chapter 23) reliance on certain core foreign technologies through government subsidies, the mobilization of state-owned enterprises and pursuit of intellectual property acquisition. These cutting-edge manufacturing sectors include electric cars, aerospace engineering, biomedicine and advanced robotics and AI.

By 2030, China aims to be 'the world's primary centre for innovation in AI'. It is already the world's biggest owner of AI patents but lacks top-tier talent in this field. The government has launched megaprogrammes in science and engineering to 2030 that include quantum computing and brain science.

High technology, technology transfer and intellectual property protection are among sources of tension in the current trade dispute between China and the USA. The Foreign Investment Law (2020) sets out to make it easier to do business in China.

China's own strategic industries desire greater government protection of their intellectual property. The Anti-Unfair Competition Law was amended in April 2019 and the Patent Law in 2020 to offer better protection for trade secrets and patent-owners' rights, respectively. China has also established its first courts specializing in intellectual property.

The Law on Promoting the Transformation of Scientific and Technological Achievements (1993), also known as China's Bayh-Dole Act, was amended in 2015 to help universities and public research institutes transfer technology to industrial organizations. This may encourage both central and local governments and enterprises to invest more in basic research, which accounted for just 6% of GERD in 2018.

China is targeting carbon neutrality by 2060. In order to reach its 20% target for non-fossil energy consumption by 2030, it is developing nuclear power, hydropower, wind and solar energy. In parallel, the number of permits granted for new coal plants has risen since 2019.

Chinese companies are being encouraged to engage in scientific co-operation with countries partnering in the Belt and Road Initiative. The adoption of a series of guidelines in 2017 aims to set this initiative on a 'greener' trajectory.

Following the Covid-19 outbreak in the city of Wuhan, the National People's Congress adopted measures in February 2020 restricting wildlife trade and banning consumption of bushmeat and market sales of farmed wild animals like civets.

Japan (chapter 24) is facing a fairly unique set of structural challenges. The Japanese market is shrinking as the population ages, leading companies to purchase enterprises abroad to 'buy time and labour'. As a result, investment is leaving Japan's shores, hollowing out the country's industrial base. To compound matters, inward investment flows remain low, suggesting that the business environment might be losing its attractiveness abroad.

To address these challenges, the government adopted Society 5.0 in 2017, a blueprint for a super-smart society. It is the centrepiece of the country's new growth strategy, which envisions a transformation to a sustainable, inclusive socio-economic system enabled by digital technologies, including AI and robotics. For instance, autonomous vehicles and drones could be deployed to bring key services to depopulated areas, such as postal deliveries and care for the aged. 'Smart agriculture' is being explored to compensate for labour shortages. AI is already being used to improve disaster readiness and response.

The rising price of electrical power in industry poses an acute challenge. Following the Great East Japan Earthquake in 2011, nuclear power plants suspended operations for mandatory inspections and upgrades over 2013–2015. To compensate, imports of oil, gas and coal have risen and self-sufficiency has declined. The government has restarted nuclear reactors since 2016 to bolster energy security. Plans to build new coal power plants could compromise targets to reduce greenhouse gas emissions. The Fukushima Prefecture, itself, plans to be fully powered by renewables by 2040.

Government research expenditure has declined, reflecting the tight fiscal situation. Industry was the only sector to see a rise in research expenditure over 2014–2017, with strong growth observed in space-related expenditure as companies embraced the 'space business'.

In 2019, the government launched a 'Moonshot' programme to develop disruptive technologies, with a focus on problem-solving tied to such challenges as large-scale natural disasters, cyberterrorism and global warming. By setting ambitious targets, the programme hopes to attract researchers from around the world.

Universities have developed closer ties with the private sector, as reflected in the growing number of university start-ups over 2013–2018. This development follows efforts under way since 2004 to reform the university system which have led to the semi-privatization of national universities.

These reforms have also impinged on academic productivity by diversifying researchers' workload. Japan is one of the rare countries to have seen the volume of its scientific publications decline since 2011.

In parallel, enrolment in master's and doctoral degree programmes has dropped, suggesting that the young may have become disillusioned with an academic career.

The **Republic of Korea** (chapter 25) boasts the world's second-highest research intensity. Investment in research contributed an estimated 40% of national GDP over 2013–2017.

Since 2017, the government has been pursuing innovation-driven and income-led growth, in partial pursuit of previous government policy.[14] The *Future Vision for Science and Technology: towards 2040* (2010) has been revised to emphasize quality of life, consumption based on social values and support for SMEs.

The revised strategy contains no reference to nuclear technology, reflecting emerging doubts over the safety of nuclear power,[15] even though the Republic of Korea is a leader for the manufacture of nuclear reactors. Hydrogen and fuel cell technologies have received attention from the present government, as they are perceived as a way of compensating for the loss of nuclear energy.

The SDGs for affordable and clean energy (SDG7) and climate action (SDG13) are proving a challenge; ambitious targets to 2040 for renewable power generation will require considerable infrastructural investment. One government plan in the works is to help farmers transform degraded farming areas into solar farms.

In line with the *I-Korea 4.0* (2017) strategy for Industry 4.0, the country has begun installing a designated network for the Internet of Things and is commercializing 5G. The Personal Information Protection Act (2017) was amended in January 2020 to authorize commercial use and analysis of personal information.

One trend of some concern is the slide witnessed in scientific and technological competitiveness since 2010, even though research expenditure has increased.

Consequently, the government has striven to restructure the innovation ecosystem, including through the establishment of a National Science, Technology and Innovation Office in 2017 to improve co-ordination of the system. Other measures include merging administrative online systems for research; increasing researchers' autonomy by enabling them to design their own projects in basic science; evaluating research with a focus on process, rather than outcome; and a shift towards 'disruptive innovation' to regain competitiveness.

Establishing greater regional autonomy has been another policy priority. The government has created national innovation clusters centred on regional priorities. Public institutions and state-owned enterprises have been relocated to the provinces to support this endeavour. The Ministry for Small and Medium-sized Enterprises (est. 2017) is supporting this initiative and there are plans for SMEs, more generally, to play a greater role in national innovation.

In **Southeast Asia and Oceania** (chapter 26), the Regional Comprehensive Economic Partnership signed in November 2020 has the potential to bind more closely the economies of the Association of Southeast Asian Nations (ASEAN) with Australia, China, Japan, the Republic of Korea and New Zealand.

The recent publishing record suggests that stronger bilateral ties have been forged among ASEAN scientific communities since the ASEAN Economic Community came into force in 2015. At the multilateral level, however, there have been few effective initiatives since 2015 to close the capacity gap, as ASEAN has a limited operational budget and member states do not tend to share resources.

Research intensity has dipped in Australia and Singapore and progressed in each of Malaysia, New Zealand, Thailand and Viet Nam, creating greater convergence.

There is growing awareness that the digital transformation inherent to Industry 4.0 presents a great challenge for business, government and society at large. In the less developed countries, the priority is to raise the technical and managerial capability of the workforce and accelerate Internet penetration to make the most of this 'revolution'.

Several ASEAN countries have launched initiatives to integrate Industry 4.0 technologies into manufacturing. For instance, the *Making Indonesia 4.0* strategy aims to ramp up industrial performance by transitioning to high-tech, high value-added and specialized activities. The government introduced a 300% tax reduction on research expenditure for firms in 2019.

Another example is Singapore's Standards Mapping for for Smart Industry Readiness Index, which defines good practices with regard to reliability, interoperability, safety and cybersecurity in areas related to Industry 4.0.

Several countries are pinning their hopes on special economic zones to attract investment and foster innovation, including Cambodia, Thailand and Indonesia. Thailand's Eastern Economic Corridor of Innovation aims to establish linkages within the national innovation system, with the bio-industry being one focus area.

In striving to improve the ease of doing business, all governments will need to take care to preserve a regulatory framework that is protective of the environment and workforce.

Most countries have developed a strategic plan or performance monitoring framework for the SDGs but few have been able to provide a comprehensive report on their progress. Although policy-makers acknowledge the need to develop capacities in renewable energy, the transition from fossil fuels presents a challenge.

The Pacific Island countries are among the most committed to solar and wind energy. For them, these technologies offer the tantalizing promise of greater energy independence and a lesser reliance on costly fuel imports.

Susan Schneegans (b. 1963: New Zealand) is Editor in Chief of the *UNESCO Science Report* series. In 2013 and 2014, she co-edited three reports profiling the national innovation systems of Botswana, Malawi and Zimbabwe, within UNESCO's Global Observatory of Science, Technology and Innovation Policy Instruments. From 2002 to 2013, she was Editor of the UNESCO journal, *A World of Science*, which she also founded. She holds a Master of Arts degree from the University of Auckland (New Zealand).

Jake Lewis (b. 1994: UK) serves as Deputy Editor for the *UNESCO Science Report*. He holds an advanced degree in Philosophy from the University of Cambridge (UK). Over 2018–2019, he was Editor and Community Manager for InsSciDE, a science diplomacy research project under the European Union's Horizon 2020 programme.

Tiffany Straza (b. 1987: Canada) serves as Deputy Editor and Statistician for the *UNESCO Science Report*. She holds a PhD from the University of Delaware (USA) in Oceanography, with a specialization in marine microbial ecology. Her work has focused on communicating science and building inclusive systems for environmental management. This led her to provide technical backstopping on sound ocean and island management in the Pacific Islands region from 2013 to 2019.

ENDNOTES

1 See: https://tinyurl.com/covid-health-innovation-afr

2 Ultimately, ZTE avoided bankruptcy after paying a consequential fine and agreeing to allow the US government to monitor its operations.

3 In February 2021, 66 SMEs and mid-tier firms in traditional sectors such as tourism, real estate, education and health care were awarded the Smart Automation Grant as part of the government's National Economic Recovery Plan (Penjana) in response to the Covid-19 pandemic (see chapter 26).

4 Most EU member states have released national AI strategies, as have Canada, China, India, Japan, Mauritius, the Russian Federation, Saudi Arabia, United Arab Emirates, USA and Viet Nam. Others are in the process of elaborating their own AI strategy, including Bangladesh, Malaysia and Tunisia.

5 For the Malabo Convention to enter into force, 15 African countries must ratify it. As of May 2020, only eight had done so: Angola, Ghana, Guinea, Mauritius, Mozambique, Namibia, Rwanda and Senegal.

6 In India, the majority of robots have been installed in four industries, in descending order: automotive; chemicals, rubber and plastics; metal; and electrical and electronics.

7 Bhutan is the only carbon-negative country in the world. Its Constitution requires that 'a minimum of 60% of the country's total land be maintained under forest cover for all time'.

8 See: https://en.unesco.org/sites/default/files/usr15_tracking_trends_in_innovation_and_mobility.pdf

9 NASA is returning human spaceflight capabilities to the USA for the first time in nearly a decade with the development of the next-generation Space Launch System. The latter is now almost complete and should be far superior to the defunct Space Shuttle (see chapter 5).

10 The Querétaro Aerospace Cluster in Mexico dates from 2012, when multinational corporations that include Airbus, Delta and Bombardier joined forces with local entrepreneurs, research centres and the specialized University of Aeronautics of Querétaro to form this innovation cluster (see chapter 7).

11 Since much of this output involved international scientific collaboration, global publishing totals will add up to more than 100%.

12 The Balik (Returning) Scientist Act (2018) builds upon the Balik Science programme (1975). It covers the cost of repatriating voluntary Filipino STI personnel to the Philippines. The Department of Science and Technology hopes to woo 235 Balik Scientists over 2018–2022 (see chapter 26).

13 Angola, Botswana, Eswatini, Namibia, Seychelles, South Africa, Tanzania and Zimbabwe

14 As explored in the previous edition of the *UNESCO Science Report* (2015), the Park Guen-hye government had aimed to engender a creative economy, through a cultural shift towards greater entrepreneurship.

15 These doubts have arisen in the wake of the Fukushima Daïchi Nuclear Power Plant disaster of 2011 in Japan (see Chapter 24).

Table 1.1: **Global trends in population, GDP and Internet penetration, 2015 and 2018**

	Population (millions)		Share of global population (%)		GDP (constant 2017 PPP$ billions)		Share of global GDP (%)		Internet users per 100 population	
	2015	2018	2015	2018	2015	2018	2015	2018	2015	2019
World	**7 371.65**	**7 623.14**	**100.00**	**100.00**	**111 572.24**	**123 921.67**	**100.00**	**100.00**	**41.68**	**48.40**
High-income	1 317.84	1 336.22	17.88	17.53	58 393.14	62 180.54	52.34	50.18	78.87	87.99
Upper middle-income	2 489.47	2 547.57	33.77	33.42	34 635.03	39 839.99	31.04	32.15	51.57	60.38
Lower middle-income	2 679.21	2 792.32	36.34	36.63	16 470.51	19 425.00	14.76	15.68	23.45	29.06
Low-income	885.12	947.04	12.01	12.42	2 073.55	2 476.14	1.86	2.00	12.83	17.53
Americas	**975.79**	**1 001.65**	**13.24**	**13.14**	**29 586.63**	**31 384.17**	**26.52**	**25.33**	**62.44**	**75.32**
North America	356.90	364.17	4.84	4.78	20 474.17	21 918.82	18.35	17.69	76.11	89.41
Latin America	581.05	598.77	7.88	7.85	8 841.44	9 163.95	7.92	7.39	55.69	67.91
Caribbean	37.84	38.71	0.51	0.51	271.01	301.40	0.24	0.24	37.23	57.66
Europe	**822.27**	**829.46**	**11.15**	**10.88**	**28 681.87**	**30 779.74**	**25.71**	**24.84**	**72.23**	**82.16**
European Union	508.56	511.68	6.90	6.71	21 093.72	22 607.01	18.91	18.24	77.77	85.05
Southeast Europe	17.90	17.72	0.24	0.23	231.31	254.15	0.21	0.21	63.23	74.80
European Free Trade Assoc.	13.86	14.24	0.19	0.19	886.25	939.28	0.79	0.76	91.26	95.11
Eastern Europe	281.95	285.82	3.82	3.75	6 470.59	6 979.30	5.80	5.63	61.89	76.81
Africa	**1 180.80**	**1 274.21**	**16.02**	**16.71**	**5 612.87**	**6 130.69**	**5.03**	**4.95**	**23.96**	**24.20**
Sub-Saharan Africa	953.42	1 033.08	12.93	13.55	3 555.34	3 834.12	3.19	3.09	20.52	18.21
Arab States in Africa	227.38	241.13	3.08	3.16	2 057.53	2 296.58	1.84	1.85	38.40	50.04
Asia	**4 353.78**	**4 477.14**	**59.06**	**58.73**	**46 311.07**	**54 127.88**	**41.51**	**43.68**	**35.81**	**42.94**
Central Asia	71.48	75.22	0.97	0.99	774.47	876.02	0.69	0.71	42.81	54.04
Arab States in Asia	153.42	162.22	2.08	2.13	3 400.25	3 571.97	3.05	2.88	55.69	70.07
West Asia	103.04	107.09	1.40	1.40	1 535.48	1 799.86	1.38	1.45	51.25	72.94
South Asia	1 749.36	1 814.01	23.73	23.80	8 996.76	10 979.85	8.06	8.86	16.22	20.21
East & Southeast Asia	2 276.49	2 318.60	30.88	30.42	31 604.10	36 900.18	28.33	29.78	48.74	57.31
Oceania	**39.03**	**40.72**	**0.53**	**0.53**	**1 379.94**	**1 499.34**	**1.24**	**1.21**	**65.64**	**69.41**
Other groupings										
Least developed countries	942.30	1 011.00	12.78	13.26	2 433.00	2 815.98	2.18	2.27	13.71	17.74
All Arab States	380.80	403.35	5.17	5.29	5 457.78	5 868.55	4.89	4.74	45.37	58.09
OECD	1 275.10	1 296.63	17.30	17.01	55 038.06	58 890.90	49.33	47.52	76.50	85.62
G20	4 723.61	4 826.67	64.08	63.32	91 421.33	101 355.99	81.94	81.79	47.63	54.84
Org. Islamic Co-op.	1 734.69	1 838.15	23.53	24.11	15 927.97	17 885.89	14.28	14.43	30.36	38.14
Selected countries										
Argentina	43.08	44.36	0.58	0.58	1 032.32	1 012.07	0.93	0.82	68.04	74.29^{-2}
Australia	23.93	24.90	0.32	0.33	1 143.65	1 238.54	1.03	1.00	84.56	86.55^{-2}
Brazil	204.47	209.47	2.77	2.75	3 079.19	3 057.47	2.76	2.47	58.33	70.43^{-1}
Canada	36.03	37.07	0.49	0.49	1 705.54	1 813.03	1.53	1.46	90.00	91.00^{-2}
China	1 406.85	1 427.65	19.08	18.73	17 403.45	21 229.73	15.60	17.13	50.30	54.30^{-2}
Egypt	92.44	98.42	1.25	1.29	977.16	1 118.72	0.88	0.90	37.82	57.30
France	64.45	64.99	0.87	0.85	2 898.40	3 051.03	2.60	2.46	78.01	83.30
Germany	81.79	83.12	1.11	1.09	4 183.10	4 448.72	3.75	3.59	87.59	88.10
India	1 310.15	1 352.64	17.77	17.74	7 146.03	8 787.69	6.40	7.09	17.00	20.10^{-1}
Indonesia	258.38	267.67	3.51	3.51	2 622.49	3 043.74	2.35	2.46	21.98	47.70
Iran	78.49	81.80	1.06	1.07	996.70	–	0.89	–	45.33	70.00^{-1}
Israel	7.98	8.38	0.11	0.11	315.37	351.25	0.28	0.28	77.35	86.80
Italy	60.58	60.63	0.82	0.80	2 456.24	2 549.69	2.20	2.06	58.14	74.39^{-1}
Japan	127.99	127.20	1.74	1.67	5 044.06	5 197.07	4.52	4.19	91.06	91.28^{-1}
Korea, Rep.	50.82	51.17	0.69	0.67	1 982.96	2 162.01	1.78	1.74	89.90	96.20
Malaysia	30.27	31.53	0.41	0.41	750.49	868.20	0.67	0.70	71.06	84.20
Mexico	121.86	126.19	1.65	1.66	2 350.43	2 522.84	2.11	2.04	57.43	70.10
Russian Federation	144.99	145.73	1.97	1.91	3 743.06	3 915.64	3.35	3.16	70.10	82.60
Saudi Arabia	31.72	33.70	0.43	0.44	1 551.67	1 604.01	1.39	1.29	69.62	95.70
South Africa	55.39	57.79	0.75	0.76	711.16	729.80	0.64	0.59	51.92	56.17^{-2}
Turkey	78.53	82.34	1.07	1.08	2 042.98	2 329.55	1.83	1.88	53.74	74.00
UK	65.86	67.14	0.89	0.88	2 924.55	3 077.77	2.62	2.48	92.00	92.50
USA	320.88	327.10	4.35	4.29	18 768.63	20 105.79	16.82	16.22	74.55	88.50^{-1}

Note: Eastern Europe refers to those countries that are not members of the European Union. Global and regional estimates are derived from national data without extrapolation to other countries. OECD stands for the Organisation for Economic Co-operation and Development.

Source: World Bank's World Development Indicators, August 2020

Table 1.2: **Global trends in research expenditure, 2014 and 2018**

	Gross domestic expenditure on R&D (GERD) [PPP$ billions]			Share of global GERD (%)		GERD as share of GDP (%)		GERD per capita (PPP$)			GERD per researcher (FTE) [PPP$ thousands]		
	2014	2018	Change (%)	2014	2018	2014	2018	2014	2018	Change (%)	2014	2018	Change (%)
World	**1 482.68**	**1 767.27**	**19.19**	**100.00**	**100.00**	**1.73**	**1.79**	**236.16**	**269.52**	**14.13**	**164.40**	**166.96**	**1.56**
High-income	1 011.23	1 137.40	12.48	68.20	64.36	2.31	2.40	805.72	890.75	10.55	194.28	195.71	0.74
Upper middle-income	407.70	551.59	35.29	27.50	31.21	1.39	1.57	170.74	223.81	31.08	187.48	199.15	6.22
Lower middle-income	62.20	76.56	23.09	4.20	4.33	0.48	0.49	27.94	32.40	15.96	126.63	123.21	-2.70
Low-income	1.55	1.72	10.97	0.10	0.10	0.22	0.22	3.66	3.81	4.10	145.21	138.34	-4.73
Americas	**476.69**	**531.35**	**11.47**	**32.15**	**30.07**	**2.05**	**2.12**	**536.66**	**576.51**	**7.43**	**245.02**	**230.33**	**-6.00**
North America	425.21	483.43	13.69	28.68	27.35	2.63	2.73	1 200.02	1 327.48	10.62	284.19	295.60	4.01
Latin America	51.44	47.89	-6.90	3.47	2.71	0.73	0.66	96.60	86.72	-10.23	217.39	184.61	-15.08
Caribbean	0.03	0.03	0.00	0.00	0.00	0.08	0.09	22.75	23.52	3.38	44.57	45.47	2.02
Europe	**345.51**	**390.28**	**12.96**	**23.30**	**22.08**	**1.72**	**1.78**	**423.13**	**472.56**	**11.68**	**125.38**	**124.80**	**-0.46**
European Union	290.35	330.83	13.94	19.58	18.72	1.94	2.02	572.19	646.65	13.01	153.86	150.40	-2.25
Southeast Europe	0.82	1.05	28.05	0.06	0.06	0.57	0.65	64.57	86.45	33.89	55.69	54.72	-1.74
European Free Trade Assoc.	16.63	18.82	13.17	1.12	1.07	2.65	2.87	1 208.43	1 317.70	9.04	225.11	230.21	2.27
Eastern Europe	37.70	39.57	4.96	2.54	2.24	0.97	0.95	134.43	138.96	3.37	70.91	73.66	3.88
Africa	**14.90**	**17.85**	**19.80**	**1.01**	**1.01**	**0.54**	**0.59**	**24.93**	**26.82**	**7.58**	**137.19**	**141.05**	**2.81**
Sub-Saharan Africa	6.51	7.34	12.75	0.44	0.42	0.49	0.51	14.36	14.49	0.91	156.79	147.32	-6.04
Arab States in Africa	8.39	10.51	25.27	0.57	0.59	0.59	0.65	57.51	67.48	17.34	78.35	92.60	18.19
Asia	**627.58**	**808.05**	**28.76**	**42.33**	**45.72**	**1.62**	**1.70**	**159.01**	**196.99**	**23.89**	**159.28**	**167.32**	**5.05**
Central Asia	0.95	0.81	-14.74	0.06	0.05	0.17	0.12	14.72	11.72	-20.38	25.83	24.44	-5.38
Arab States in Asia	6.94	10.17	46.54	0.47	0.58	0.40	0.53	106.66	143.09	34.16	176.41	144.28	-18.21
West Asia	15.54	26.05	67.63	1.05	1.47	0.94	1.37	150.77	242.22	60.66	71.18	93.41	31.23
South Asia	45.61	56.49	23.85	3.08	3.20	0.64	0.60	30.18	35.59	17.93	144.92	140.30	-3.19
East & Southeast Asia	558.54	714.52	27.93	37.67	40.43	2.03	2.13	253.47	315.45	24.45	174.77	193.03	10.45
Oceania	**18.01**	**19.75**	**9.66**	**1.21**	**1.12**	**1.74**	**1.81**	**496.95**	**514.61**	**3.55**	**42.05**	**46.90**	**11.53**
Other groupings													
Least developed	1.80	2.03	12.78	0.12	0.11	0.19	0.21	3.89	4.08	4.88	137.35	132.04	-3.87
All Arab States	15.33	20.69	34.96	1.03	1.17	0.48	0.59	72.61	91.15	25.53	109.07	109.09	0.02
OECD	988.49	1 114.38	12.74	66.67	63.06	2.36	2.43	779.71	859.34	10.21	206.90	204.27	-1.27
G20	1 393.89	1 647.65	18.21	94.01	93.23	1.93	1.99	299.38	343.87	14.86	182.53	188.45	3.24
Org. Islamic Co-op .	48.73	69.04	41.68	3.29	3.91	0.45	0.60	45.96	59.20	28.81	92.17	89.86	-2.51
Selected countries													
Argentina	4.28	4.03^{-1}	-5.84	0.29	0.23^{-1}	0.59	0.54^{-1}	100.28	91.63^{-1}	-8.63	83.09	76.86^{-1}	-7.50
Australia	–	17.30	–	–	0.98^{-1}	–	1.87^{-1}	–	703.57^{-1}	–	–	–	–
Brazil	35.56	33.30	-6.36	2.40	1.88^{-1}	1.27	1.26^{-1}	175.35	160.23^{-1}	-8.62	197.54	–	–
Canada	23.47	22.85^{-1}	-2.64	1.58	1.29	1.72	1.57	658.16	616.40	-6.34	144.91	150.68^{-1}	3.98
China	313.94	439.02	39.84	21.18	24.84	2.03	2.19	224.33	307.51	37.08	205.96	235.26	14.23
Egypt	5.14	6.99	35.99	0.35	0.40	0.64	0.72	56.89	71.03	24.85	84.26	103.44	22.76
France	47.55	48.88	2.80	3.21	2.77	2.28	2.20	740.75	752.06	1.53	174.97	159.49	-8.85
Germany	85.96	99.99	16.32	5.80	5.66	2.87	3.09	1 055.35	1 202.88	13.98	244.26	230.80	-5.51
India	43.55	54.04	24.09	2.94	3.06	0.70	0.65	33.62	39.95	18.83	–	158.11	–
Indonesia	–	6.26		–	0.35	–	0.23	–	23.40	–	–	108.36	–
Iran	–	11.40^{-1}		–	0.64^{-1}	–	0.83^{-1}	–	141.28^{-1}	–	–	95.79^{-1}	–
Israel	10.19	13.81	35.53	0.69	0.78	4.17	4.95	1 297.90	1 647.67	26.95	–	–	–
Italy	22.15	24.15	9.03	1.49	1.37	1.34	1.40	366.62	398.30	8.64	187.40	172.67	-7.86
Japan	143.48	144.12	0.45	9.68	8.16	3.40	3.26	1 119.47	1 133.01	1.21	210.10	212.53	1.16
Korea, Rep.	68.98	86.62	25.57	4.65	4.90	4.29	4.53	1 363.09	1 692.64	24.18	199.68	212.10	6.22
Malaysia	8.23	–		0.56	–	1.26	–	275.50	–	–	134.12	–	–
Mexico	7.04	5.59	-20.60	0.47	0.32	0.44	0.31	58.50	44.27	-24.32	224.85	–	–
Russian Fed.	24.00	22.57	-5.96	1.62	1.28	1.07	0.99	165.89	154.88	-6.64	53.94	55.62	3.11
South Africa	4.64	5.16^{-1}	11.21	0.31	0.29^{-1}	0.77	0.83^{-1}	85.12	90.55^{-1}	6.38	196.96	174.89^{-1}	-11.21
Turkey	10.83	14.22^{-1}	31.30	0.73	0.80^{-1}	0.86	0.96^{-1}	140.19	175.26^{-1}	25.02	120.76	127.05^{-1}	5.21
UK	36.00	40.24	11.78	2.43	2.28	1.66	1.72	550.28	599.32	8.91	130.16	130.19	0.02
USA	401.74	460.58^{-1}	14.65	27.10	26.06^{-1}	2.72	2.84^{-1}	1 260.66	1408.08^{-1}	11.69	299.78	309.94^{-1}	3.39

Note: GERD figures are in PPP$ (constant 2005 prices). Many of the underlying data are estimated by the UNESCO Institute for Statistics for developing countries, in particular. Furthermore, in a substantial number of developing countries data do not cover all sectors of the economy.

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

Table 1.3: **Global trends in research personnel, 2014 and 2018**

	Researchers (FTE, thousands)			Share of global researchers (%)		Females, in head counts (%)	Researchers per million inhabitants (FTE)			Technicians per million inhabitants (FTE)		
	2014	2018	Change (%)	2014	2018	2018	2014	2018	Change (%)	2014	2018	Change (%)
World	**7 789.79**	**8 854.29**	**13.67**	**100.00**	**100.00**	**33.25**	**1 245.3**	**1368.0**	**9.86**	**301.7**	**311.3**	**3.18**
High-income	4 885.91	5 333.83	9.17	62.72	60.24	29.59	3 994.7	4301.1	7.67	1 021.7	1 047.1	2.49
Upper middle-income	2 256.87	2 762.41	22.40	28.97	31.20	42.65	955.0	1141.1	19.49	358.1	425.3	18.77
Lower middle-income	633.92	739.42	16.64	8.14	8.35	42.79	275.8	312.2	13.20	83.5	73.8	-11.62
Low-income	13.09	18.64	42.37	0.17	0.21	19.54	33.1	45.1	36.13	20.1	22.7	12.94
Americas	**1 797.28**	**1 918.33**	**6.74**	**23.07**	**21.67**	**49.80**	**2 046.7**	**2131.6**	**4.15**	**33.1**	**45.1**	**36.25**
North America	1 502.09	1 603.66	6.76	19.28	18.11	–	4 239.1	4 432.2	107.72	1 353.0	1 280.2	-5.38
Latin America	294.49	313.95	6.61	3.78	3.55	49.77	563.7	592.9	5.19	531.2	556.6	4.78
Caribbean	0.70	0.72	2.02	0.01	0.01	50.24	509.2	519.5	2.02	273.8	268.4	-1.97
Europe	**2 446.37**	**2 746.56**	**12.27**	**31.40**	**31.02**	**34.85**	**3 034.4**	**3372.0**	**11.12**	**930.4**	**977.0**	**5.01**
European Union	1 772.36	2 081.75	17.46	22.75	23.51	33.78	3 492.9	4069.2	16.50	1 336.2	1 413.6	5.79
Southeast Europe	16.21	18.23	12.47	0.21	0.21	51.21	1 290.8	1487.2	15.21	236.7	275.3	16.31
European Free Trade Assoc.	74.43	83.05	11.58	0.96	0.94	36.59	5 406.9	5876.6	8.69	2 525.0	2 631.7	4.23
Eastern Europe	583.37	563.53	-3.40	7.49	6.36	39.04	2 153.5	2053.8	-4.63	357.1	362.8	1.60
Africa	**194.59**	**221.28**	**13.72**	**2.50**	**2.50**	**41.82**	**307.9**	**326.4**	**6.01**	**86.0**	**93.3**	**8.49**
Sub-Saharan Africa	46.54	59.93	28.77	0.60	0.68	33.48	102.3	123.8	20.97	36.4	38.5	5.77
Arab States in Africa	148.05	161.36	8.99	1.90	1.82	44.87	837.0	866.2	3.49	202.7	214.5	5.82
Asia	**3 326.52**	**3 941.58**	**18.49**	**42.70**	**44.52**	**28.43**	**845.0**	**969.9**	**14.79**	**130.2**	**133.6**	**2.61**
Central Asia	29.07	27.68	-4.77	0.37	0.31	44.90	609.1	545.0	-10.52	104.0	75.4	-27.50
Arab States in Asia	29.53	40.33	36.58	0.38	0.46	34.17	354.7	458.2	29.18	148.8	149.3	0.34
West Asia	68.21	126.51	85.48	0.88	1.43	33.95	826.6	1494.0	80.74	160.1	491.5	207.00
South Asia	336.37	415.29	23.46	4.32	4.69	39.14	219.7	262.8	19.61	86.0	67.7	-21.28
East & Southeast Asia	2 863.35	3 331.77	16.36	36.76	37.63	26.31	1 297.9	1475.6	13.70	209.8	224.1	6.82
Oceania	**25.03**	**26.53**	**6.01**	**0.32**	**0.30**	**33.25**	**1 978.9**	**2005.6**	**1.35**	**382.4**	**464.6**	**21.50**
Other groupings												
Least developed	21.65	28.21	30.35	0.28	0.32	21.98	49.1	62	26.27	20.6	23.3	13.11
All Arab States	177.58	201.69	13.58	2.28	2.28	42.60	681.9	736	7.93	185.4	193.7	4.48
OECD	4 478.64	4 987.73	11.37	57.49	56.33	28.96	3 622.6	3959	9.29	926.9	976.2	5.32
G20	6 973.47	7 865.54	12.79	89.52	88.83	30.82	1 504.3	1654	9.95	405.0	406.8	0.44
Org. Islamic Co-op .	533.53	681.62	27.76	6.85	7.70	40.17	499.5	609	21.93	94.1	140.9	49.73
Selected countries												
Argentina	51.46	52.4^{-1}	1.79	0.66	0.59^{-1}	54.07^{-1}	1 206.9	1 192.23^{-1}	-1.22	318.8	398.1	24.87
Brazil	179.99	–	-	2.31	–		887.7		–	969.9	–	–
Canada	161.98	158.89^{-1}	-1.91	2.08	1.80^{-1}	–	4 541.9	4 325.64^{-1}	-4.76	1 353.0	1 268.4^{-1}	-6.25
China	1 524.28	1 866.11	22.43	19.55	21.12	–	1 089.2	1 307.12	20.01	–	–	–
Egypt	61.06	67.59	10.70	0.78	0.76	45.6	675.2	686.72	1.70	351.6	369.6	5.12
France	271.77	306.45	12.76	3.49	3.47	28.3^{-1}	4 233.6	4 715.32	11.38	1 809.3	1 805.5^{-1}	-0.21
Germany	351.92	433.23	23.10	4.51	4.90	27.9^{-1}	4 320.7	5 211.87	20.63	1 883.2	2 018.0	7.16
India	–	341.82	–	–	3.87	–	–	252.70	–	95.5	73.1	-23.46
Indonesia	–	57.82	–	–	0.65	45.8	–	215.99	–	16.3^{+2}	34.7	112.88
Iran	–	118.99^{-1}	–	–	1.35^{-1}	31.2^{-1}	–	1 474.91^{-1}	–	160.6^{+1}	496.8^{-1}	209.34
Italy	118.18	139.85	18.34	1.52	1.58	34.3^{-1}	1 956.4	2 306.77	17.91	–	–	–
Japan	682.94	678.13	-0.70	8.76	7.67	16.6	5 328.4	5 331.15	0.05	537.0	524.3	-2.36
Korea, Rep.	345.46	408.37	18.21	4.43	4.62	20.4	6 826.3	7 980.40	16.91	1 228.2	1 251.1	1.86
Malaysia	61.35	–	–	0.79	–	48.2^{-2}	2 054.2	–	–	212.2	233.4	9.99
Mexico	31.32	–	–	0.40	–	–	260.2	–	–	115.6	140.3^{-2}	21.37
Russian Fed.	444.87	405.77	-8.79	5.71	4.59	39.2	3 075.1	2 784.33	-9.46	496.6	437.8	-11.84
South Africa	23.57	29.52^{-1}	25.21	0.30	0.33^{-1}	44.9^{-1}	432.2	517.72^{-1}	19.80	141.7	129.5^{-1}	-8.61
Turkey	89.66	111.89^{-1}	24.80	1.15	1.27^{-1}	37.0^{-1}	1 160.9	1 379.41^{-1}	18.82	208.3	353.7^{-1}	69.80
UK	276.58	309.07	11.75	3.55	3.50	38.7^{-2}	4 227.6	4 603.31	8.89	1 255.5	1 305.4^{-2}	3.97
USA	1 340.10	1 434.42^{-1}	7.04	17.19	16.23^{-1}	–	4 205.3	4 412.44^{-1}	4.93	–	–	–

Note: Researchers are counted in full-time equivalents (FTE). Global and regional estimates are based on the available FTE data for the countries. The share of female researchers is based on available head count data for the most recent year between 2015 and 2018. See Table 1.1 for regional terms.

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

Table 1.4: **Global trends in scientific publications, 2015 and 2019**

	Volume		Change (%)	Global share (%)		Publications per million inhabitants		Publications with international co-authors (%)		Cross-cutting strategic technologies: Volume		Cross-cutting strategic technologies: Change (%)	Cross-cutting strategic technologies: Global share (%)	
	2015	2019	2015–2019	2015	2019	2015	2019	2015	2019	2015	2019	2015–2019	2015	2019
World	**2 178 625**	**2 629 248**	**20.68**	**100.00**	**100.00**	**295.24**	**340.90**	**21.69**	**23.48**	**351 447**	**467 883**	**33.13**	**100.00**	**100.00**
High-income	1 509 655	1 654 704	9.61	69.29	62.93	1 139.12	1 226.93	30.40	35.46	212 582	244 026	14.79	60.49	52.16
Upper middle-income	702 587	1 000 301	42.37	32.25	38.05	282.22	389.91	24.89	27.41	140 207	208 580	48.77	39.89	44.58
Lower middle-income	174 394	299 319	71.63	8.00	11.38	65.09	105.76	29.11	29.63	33 977	75 894	123.37	9.67	16.22
Low-income	13 923	23 799	70.93	0.64	0.91	15.73	24.58	72.13	69.96	1 014	2 739	170.12	0.29	0.59
Americas	**658 936**	**724 263**	**9.91**	**30.25**	**27.55**	**672.69**	**714.78**	**34.99**	**39.44**	**77 773**	**87 323**	**12.28**	**22.13**	**18.66**
North America	565 726	609 538	7.74	25.97	23.18	1 568.56	1 648.32	36.52	41.29	66 316	71 063	7.16	18.87	15.19
Latin America	107 634	135 039	25.46	4.94	5.14	185.24	223.39	36.75	40.82	12 516	17 534	40.09	3.56	3.75
Caribbean	2 833	3 110	9.78	0.13	0.12	74.87	79.78	59.20	71.16	237	301	27.00	0.07	0.06
Europe	**822 170**	**918 168**	**11.68**	**37.74**	**34.92**	**995.42**	**1 099.43**	**37.35**	**41.14**	**117 410**	**140 646**	**19.79**	**33.41**	**30.06**
European Union	700 849	752 472	7.37	32.17	28.62	1 368.20	1 457.36	41.01	46.54	99 892	108 910	9.03	28.42	23.28
Southeast Europe	8 125	8 967	10.36	0.37	0.34	453.84	507.60	43.47	52.68	1 160	1 156	-0.34	0.33	0.25
European Free Trade Assoc.	54 041	61 685	14.14	2.48	2.35	3 897.85	4 299.42	66.28	69.91	6 055	6 811	12.49	1.72	1.46
Eastern Europe	105 579	152 895	44.82	4.85	5.82	374.47	533.12	25.33	24.54	15 432	30 547	97.95	4.39	6.53
Africa	**61 236**	**92 133**	**50.46**	**2.81**	**3.50**	**51.86**	**70.53**	**53.95**	**55.40**	**8 966**	**14 537**	**62.13**	**2.55**	**3.11**
Sub-Saharan Africa	30 805	47 374	53.79	1.41	1.80	32.31	44.67	58.89	60.52	3 112	5 916	90.10	0.89	1.26
Arab States in Africa	30 951	45 665	47.54	1.42	1.74	136.12	185.84	49.81	50.98	5 910	8 704	47.28	1.68	1.86
Asia	**900 254**	**1 262 260**	**40.21**	**41.32**	**48.01**	**206.78**	**279.46**	**22.61**	**24.43**	**184 247**	**281 245**	**52.65**	**52.43**	**60.11**
Central Asia	2 528	5 780	128.64	0.12	0.22	35.37	75.62	60.96	61.28	536	1 456	171.64	0.15	0.31
Arab States in Asia	32 414	58 153	79.41	1.49	2.21	211.28	352.07	70.77	62.15	6 923	12 443	79.73	1.97	2.66
East & Southeast Asia	699 375	964 627	37.93	32.10	36.69	307.22	413.75	22.03	24.17	147 103	211 303	43.64	41.86	45.16
South Asia	126 301	191 638	51.73	5.80	7.29	72.20	104.42	21.45	24.46	24 939	52 818	111.79	7.10	11.29
West Asia	59 727	82 087	37.44	2.74	3.12	579.63	757.01	30.15	34.89	8 687	11 431	31.59	2.47	2.44
Oceania	**80 984**	**98 304**	**21.39**	**3.72**	**3.74**	**2 074.98**	**2 381.70**	**53.55**	**61.61**	**9 298**	**11 924**	**28.24**	**2.65**	**2.55**
Other groupings														
Least developed	13 826	23 572	70.49	0.63	0.90	14.67	22.78	72.90	71.30	1 081	2 881	166.51	0.31	0.62
Arab States	58 447	95 817	63.94	2.68	3.64	153.49	233.19	57.21	53.66	11 944	19 840	66.11	3.40	4.24
OECD	1 439 908	1 549 257	7.59	66.09	58.92	1 122.70	1 182.48	30.49	35.72	195 786	215 660	10.15	55.71	46.09
G20	1 989 718	2 381 962	19.71	91.33	90.59	420.57	489.53	23.33	25.31	316 697	419 013	32.31	90.11	89.56
Org. Islamic Co-op .	183 243	300 234	63.84	8.41	11.42	105.63	160.31	36.35	36.80	33 640	59 098	75.68	9.57	12.63
Selected countries														
Argentina	10 982	12 280	11.82	0.50	0.47	254.95	274.23	46.60	50.47	897	1 071	19.40	0.26	0.23
Australia	71 691	87 187	21.61	3.29	3.32	2 995.55	3 459.36	53.94	62.23	8 366	10 736	28.33	2.38	2.29
Brazil	61 006	74 270	21.74	2.80	2.82	298.36	351.91	30.75	35.21	6 699	8 596	28.32	1.91	1.84
Canada	82 595	94 578	14.51	3.79	3.60	2 292.61	2 528.08	51.84	57.94	9 533	10 699	12.23	2.71	2.29
China	431 654	644 655	49.35	19.81	24.52	306.82	449.62	20.23	22.98	98 669	149 832	51.85	28.08	32.02
Egypt	14 728	23 224	57.69	0.68	0.88	159.32	231.34	52.17	53.33	2 402	3 787	57.66	0.68	0.81
France	101 491	101 081	-0.40	4.66	3.84	1 510.19	1 486.96	54.50	60.34	14 016	12 788	-8.76	3.99	2.73
Germany	144 201	152 348	5.65	6.62	5.79	1 763.12	1 824.15	50.56	54.79	19 974	20 814	4.21	5.68	4.45
India	110 282	161 066	46.05	5.06	6.13	84.17	117.87	17.67	18.88	22 725	47 333	108.29	6.47	10.12
Indonesia	6 080	37 513	516.99	0.28	1.43	23.53	138.62	40.10	17.03	1 811	9 195	407.73	0.52	1.97
Iran	41 292	60 562	46.67	1.90	2.30	526.06	730.42	20.60	28.17	6 629	9 091	37.14	1.89	1.94
Israel	16 393	18 671	13.90	0.75	0.71	2 054.65	2 191.59	51.96	54.26	1 852	1 949	5.24	0.53	0.42
Italy	91 895	103 577	12.71	4.22	3.94	1 516.96	1 710.60	46.34	50.27	12 500	13 718	9.74	3.56	2.93
Japan	117 020	119 347	1.99	5.37	4.54	914.32	940.78	26.27	31.24	17 564	18 129	3.22	5.00	3.87
Korea, Rep.	71 719	81 327	13.40	3.29	3.09	1 411.15	1 587.63	26.89	29.33	12 992	15 793	21.56	3.70	3.38
Malaysia	22 405	30 172	34.67	1.03	1.15	740.15	944.36	39.01	43.84	7 428	9 912	33.44	2.11	2.12
Mexico	18 321	23 508	28.31	0.84	0.89	150.35	184.27	40.28	44.95	2 662	3 414	28.25	0.76	0.73
Russian Fed.	60 156	96 394	60.24	2.76	3.67	414.91	660.81	27.17	23.73	9 558	20 666	116.22	2.72	4.42
Saudi Arabia	17 681	25 205	42.55	0.81	0.96	557.45	735.51	76.22	75.84	3 672	4 994	36.00	1.04	1.07
South Africa	14 706	21 062	43.22	0.68	0.80	265.52	359.68	54.13	57.42	1 622	2 623	61.71	0.46	0.56
Turkey	36 308	43 245	19.11	1.67	1.64	462.35	518.34	21.16	25.12	3 876	5 927	52.92	1.10	1.27
UK	141 834	160 174	12.93	6.51	6.09	2 137.31	2 353.92	57.58	64.49	16 960	19 316	13.89	4.83	4.13
USA	502 105	538 259	7.20	23.05	20.47	1 546.66	1 619.40	36.40	40.91	58 082	61 890	6.56	16.53	13.23

Note: The sum of the regional values exceeds the world number because papers with multiple authors from different regions are counted for each of these regions.

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

Table 1.5: **Global trends in scientific publications on selected cross-cutting strategic technologies, 2015 and 2019**

	Volume											
	AI & robotics		Biotechnology		Energy		Materials		Nanoscience & nanotech		Opto-electronics	
	2015	2019	2015	2019	2015	2019	2015	2019	2015	2019	2015	2019
World	**102 347**	**147 806**	**16 707**	**18 714**	**86 771**	**108 129**	**63 705**	**93 033**	**31 226**	**46 121**	**29 517**	**26 651**
High-income	65 365	74 661	9 869	9 394	49 997	57 245	31 625	40 729	21 104	27 979	18 560	15 330
Upper middle-income	33 075	50 340	6 531	9 333	36 903	53 560	32 529	48 484	13 290	24 657	11 813	11 872
Lower middle-income	13 052	37 389	2 283	2 937	7 890	12 701	6 097	15 194	2 035	3 588	1 293	1 816
Low-income	280	1 037	79	120	249	607	89	284	33	103	31	67
Americas	**20 633**	**24 969**	**3 934**	**4 161**	**19 674**	**21 445**	**9 471**	**10 588**	**8 457**	**11 053**	**7 623**	**5 964**
North America	16 628	18 727	2 876	2 603	16 859	17 434	7 623	8 088	8 075	10 514	6 901	5 354
Latin America	4 211	6 524	1 122	1 651	3 152	4 394	1 974	2 661	478	670	800	655
Caribbean	92	144	36	20	53	60	26	44	6	6	4	5
Europe	**40 993**	**47 402**	**4 883**	**4 984**	**26 524**	**31 950**	**19 124**	**28 125**	**8 181**	**11 040**	**9 781**	**8 299**
European Union	36 554	37 207	4 284	4 246	21 637	25 662	14 797	17 913	7 355	9 717	8 244	6 178
Southeast Europe	382	336	79	86	325	313	201	302	41	37	37	30
European Free Trade Assoc.	1 851	2 034	191	215	1 635	1 837	680	804	589	861	382	334
Eastern Europe	3 624	9 658	528	666	4 004	5 586	4 423	10 466	767	1 280	1 580	2 283
Africa	3 207	4 752	551	844	2 710	4 443	1 185	2 451	400	604	310	445
Sub-Saharan Africa	823	1 539	221	383	1 169	2 018	334	965	91	168	61	125
Arab States in Africa	2 389	3 225	334	467	1 563	2 450	862	1 505	311	441	254	330
Asia	**46 913**	**84 072**	**9 285**	**11 355**	**45 754**	**64 150**	**39 692**	**60 953**	**19 968**	**32 818**	**14 800**	**14 896**
Central Asia	142	569	15	11	194	317	102	304	6	80	62	149
Arab States in Asia	1 908	3 936	286	458	2 466	4 125	883	2 050	719	1 008	283	294
Southeast Asia	33 662	50 330	6 854	8 491	36 498	50 194	33 248	49 993	17 598	28 957	13 139	13 030
South Asia	9 956	29 049	1 896	2 179	5 045	7 976	4 599	7 961	1 566	2 875	837	1 118
West Asia	2 173	2 402	473	657	2 579	3 744	1 667	2 250	612	927	648	565
Oceania	**2 918**	**3 469**	**368**	**412**	**2 198**	**3 066**	**1 328**	**1 671**	**1 078**	**1 809**	**466**	**308**
Other groupings												
Least developed countries	325	1 126	82	132	289	630	95	295	32	111	33	67
All Arab States	4 091	6 868	558	833	3 785	6 187	1 581	3 219	886	1 340	498	577
OECD	60 878	66 911	9 396	9 105	45 852	51 576	28 260	32 085	18 834	24 861	16 979	13 274
G20	91 303	128 003	15 220	16 808	76 010	96 361	58 375	84 400	28 953	43 399	27 521	25 161
Org. Islamic Co-op.	9 685	20 149	1 759	2 604	11 790	15 537	5 659	13 942	1 740	2 767	1 426	1 585
Selected countries												
Argentina	218	250	116	120	205	336	162	179	59	64	32	20
Australia	2 520	3 003	325	342	2 077	2 840	1 202	1 541	1 045	1 743	432	286
Brazil	2 037	2 640	684	1 032	1 641	2 181	1 331	1 654	256	293	405	341
Canada	2 792	3 217	413	431	2 752	2 937	1 111	1 227	794	1 143	780	630
China	20 414	29 766	3 891	5 608	24 352	38 521	24 863	35 942	11 554	22 270	9 559	10 010
Egypt	610	837	166	302	760	1 247	404	784	236	279	132	201
France	5 215	4 536	512	461	2 755	2 667	2 031	1 900	1 170	1 350	1 374	945
Germany	6 712	6 726	827	776	3 950	4 305	3 262	3 441	1 949	2 684	1 995	1 507
India	9 276	26 779	1 770	1 918	4 562	6 609	4 152	7 257	1 433	2 550	717	969
Indonesia	822	3 229	57	138	670	1 098	166	4 264	16	86	42	182
Iran	1 357	1 613	406	590	2 366	3 463	1 514	1 952	369	548	312	314
Israel	745	638	59	56	165	196	122	216	236	361	308	215
Italy	4 380	4 773	496	436	3 429	3 683	1 242	1 651	953	1 128	959	664
Japan	4 891	5 917	973	953	3 778	3 293	3 481	3 295	1 841	2 225	1 847	1 603
Korea, Rep.	2 426	3 029	1 304	1 108	2 900	3 786	2 510	3 009	2 630	3 452	645	592
Malaysia	1 685	4 404	357	446	3 550	1 821	1 137	2 598	258	307	236	138
Mexico	969	1 228	204	324	605	761	362	505	120	218	234	213
Russian Fed.	1 986	5 704	254	273	2 527	3 259	2 949	8 357	455	903	1 161	1 898
Saudi Arabia	927	1 265	192	195	1 075	1 662	519	849	584	639	159	146
South Africa	511	701	85	145	529	959	214	441	72	84	40	93
Turkey	1 094	2 073	247	355	943	1 544	929	1 242	181	240	224	159
UK	5 700	6 192	472	578	3 903	4 947	2 166	2 458	1 488	2 072	1 410	950
USA	14 149	15 893	2 526	2 231	14 435	14 862	6 636	7 001	7 419	9 614	6 251	4 841

Note: The sum of the numbers for the various regions exceeds the total number because papers with multiple authors from different regions are counted for each of these regions.The six cross-cutting technologies featured here were followed by bioinformatics, Internet of Things, strategic, defence and security studies and blockchain technology. See Table 1.1 for regional terms.

	Global share (%)											
	AI & robotics		Biotechnology		Energy		Materials		Nanoscience & nanotech		Opto-electronics	
	2015	2019	2015	2019	2015	2019	2015	2019	2015	2019	2015	2019
World	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
High-income	63.87	50.51	59.07	50.20	57.62	52.94	49.64	43.78	67.58	60.66	62.88	57.52
Upper middle-income	32.32	34.06	39.09	49.87	42.53	49.53	51.06	52.11	42.56	53.46	40.02	44.55
Lower middle-income	12.75	25.30	13.66	15.69	9.09	11.75	9.57	16.33	6.52	7.78	4.38	6.81
Low-income	0.27	0.70	0.47	0.64	0.29	0.56	0.14	0.31	0.11	0.22	0.11	0.25
Americas	**20.16**	**16.89**	**23.55**	**22.23**	**22.67**	**19.83**	**14.87**	**11.38**	**27.08**	**23.97**	**25.83**	**22.38**
North America	16.25	12.67	17.21	13.91	19.43	16.12	11.97	8.69	25.86	22.80	23.38	20.09
Latin America	4.11	4.41	6.72	8.82	3.63	4.06	3.10	2.86	1.53	1.45	2.71	2.46
Caribbean	0.09	0.10	0.22	0.11	0.06	0.06	0.04	0.05	0.02	0.01	0.01	0.02
Europe	**40.05**	**32.07**	**29.23**	**26.63**	**30.57**	**29.55**	**30.02**	**30.23**	**26.20**	**23.94**	**33.14**	**31.14**
European Union	35.72	25.17	25.64	22.69	24.94	23.73	23.23	19.25	23.55	21.07	27.93	23.18
Southeast Europe	0.37	0.23	0.47	0.46	0.37	0.29	0.32	0.32	0.13	0.08	0.13	0.11
European Free Trade Assoc.	1.81	1.38	1.14	1.15	1.88	1.70	1.07	0.86	1.89	1.87	1.29	1.25
Eastern Europe	3.54	6.53	3.16	3.56	4.61	5.17	6.94	11.25	2.46	2.78	5.35	8.57
Africa	**3.13**	**3.22**	**3.30**	**4.51**	**3.12**	**4.11**	**1.86**	**2.63**	**1.28**	**1.31**	**1.05**	**1.67**
Sub-Saharan Africa	0.80	1.04	1.32	2.05	1.35	1.87	0.52	1.04	0.29	0.36	0.21	0.47
Arab States in Africa	2.33	2.18	2.00	2.50	1.80	2.27	1.35	1.62	1.00	0.96	0.86	1.24
Asia	**45.84**	**56.88**	**55.58**	**60.68**	**52.73**	**59.33**	**62.31**	**65.52**	**63.95**	**71.16**	**50.14**	**55.89**
Central Asia	0.14	0.38	0.09	0.06	0.22	0.29	0.16	0.33	0.02	0.17	0.21	0.56
Arab States in Asia	1.86	2.66	1.71	2.45	2.84	3.81	1.39	2.20	2.30	2.19	0.96	1.10
Southeast Asia	32.89	34.05	41.02	45.37	42.06	46.42	52.19	53.74	56.36	62.78	44.51	48.89
South Asia	9.73	19.65	11.35	11.64	5.81	7.38	7.22	8.56	5.02	6.23	2.84	4.19
West Asia	2.12	1.63	2.83	3.51	2.97	3.46	2.62	2.42	1.96	2.01	2.20	2.12
Oceania	**2.85**	**2.35**	**2.20**	**2.20**	**2.53**	**2.84**	**2.08**	**1.80**	**3.45**	**3.92**	**1.58**	**1.16**
Other groupings												
Least developed countries	0.32	0.76	0.49	0.71	0.33	0.58	0.15	0.32	0.10	0.24	0.11	0.25
All Arab States	4.00	4.65	3.34	4.45	4.36	5.72	2.48	3.46	2.84	2.91	1.69	2.17
OECD	59.48	45.27	56.24	48.65	52.84	47.70	44.36	34.49	60.32	53.90	57.52	49.81
G20	89.21	86.60	91.10	89.82	87.60	89.12	91.63	90.72	92.72	94.10	93.24	94.41
Org. Islamic Co-op.	9.46	13.63	10.53	13.91	13.59	14.37	8.88	14.99	5.57	6.00	4.83	5.95
Selected countries												
Argentina	0.21	0.17	0.69	0.64	0.24	0.31	0.25	0.19	0.19	0.14	0.11	0.08
Australia	2.46	2.03	1.95	1.83	2.39	2.63	1.89	1.66	3.35	3.78	1.46	1.07
Brazil	1.99	1.79	4.09	5.51	1.89	2.02	2.09	1.78	0.82	0.64	1.37	1.28
Canada	2.73	2.18	2.47	2.30	3.17	2.72	1.74	1.32	2.54	2.48	2.64	2.36
China	19.95	20.14	23.29	29.97	28.06	35.63	39.03	38.63	37.00	48.29	32.38	37.56
Egypt	0.60	0.57	0.99	1.61	0.88	1.15	0.63	0.84	0.76	0.60	0.45	0.75
France	5.10	3.07	3.06	2.46	3.18	2.47	3.19	2.04	3.75	2.93	4.65	3.55
Germany	6.56	4.55	4.95	4.15	4.55	3.98	5.12	3.70	6.24	5.82	6.76	5.65
India	9.06	18.12	10.59	10.25	5.26	6.11	6.52	7.80	4.59	5.53	2.43	3.64
Indonesia	0.80	2.18	0.34	0.74	0.77	1.02	0.26	4.58	0.05	0.19	0.14	0.68
Iran	1.33	1.09	2.43	3.15	2.73	3.20	2.38	2.10	1.18	1.19	1.06	1.18
Israel	0.73	0.43	0.35	0.30	0.19	0.18	0.19	0.23	0.76	0.78	1.04	0.81
Italy	4.28	3.23	2.97	2.33	3.95	3.41	1.95	1.77	3.05	2.45	3.25	2.49
Japan	4.78	4.00	5.82	5.09	4.35	3.05	5.46	3.54	5.90	4.82	6.26	6.01
Korea, Rep.	2.37	2.05	7.81	5.92	3.34	3.50	3.94	3.23	8.42	7.48	2.19	2.22
Malaysia	1.65	2.98	2.14	2.38	4.09	1.68	1.78	2.79	0.83	0.67	0.80	0.52
Mexico	0.95	0.83	1.22	1.73	0.70	0.70	0.57	0.54	0.38	0.47	0.79	0.80
Russian Fed.	1.94	3.86	1.52	1.46	2.91	3.01	4.63	8.98	1.46	1.96	3.93	7.12
Saudi Arabia	0.91	0.86	1.15	1.04	1.24	1.54	0.81	0.91	1.87	1.39	0.54	0.55
South Africa	0.50	0.47	0.51	0.77	0.61	0.89	0.34	0.47	0.23	0.18	0.14	0.35
Turkey	1.07	1.40	1.48	1.90	1.09	1.43	1.46	1.34	0.58	0.52	0.76	0.60
UK	5.57	4.19	2.83	3.09	4.50	4.58	3.40	2.64	4.77	4.49	4.78	3.56
USA	13.82	10.75	15.12	11.92	16.64	13.74	10.42	7.53	23.76	20.85	21.18	18.16

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

UNESCO SCIENCE REPORT

The race against time for smarter development

EXECUTIVE SUMMARY

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

This seventh edition of the report monitors the development path that countries have been following over the past five years from the perspective of science governance. It documents the rapid societal transformation under way, which offers new opportunities for social and economic experimentation but also risks exacerbating social inequalities, unless safeguards are put in place.

The report concludes that countries will need to invest more in research and innovation, if they are to succeed in their dual digital and green transition. More than 30 countries have already raised their research spending since 2014, in line with their commitment to the Sustainable Development Goals. Despite this progress, eight out of ten countries still devote less than 1% of GDP to research, perpetuating their dependence on foreign technologies.

Since the private sector will need to drive much of this dual green and digital transition, governments have been striving to make it easier for the private sector to innovate through novel policy instruments such as digital innovation hubs where companies can 'test before they invest' in digital technologies. Some governments are also seeking to improve the status of researchers through pay rises and other means. The global researcher population has surged since 2014.

The Covid-19 pandemic has energized knowledge production systems. This dynamic builds on the trend towards greater international scientific collaboration, which bodes well for tackling this and other global challenges such as climate change and biodiversity loss. However, sustainability science is not yet mainstream in academic publishing, according to a new UNESCO study, even though countries are investing more than before in green technologies.

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