CHAPTER 1

THE GLOBAL INNOVATION INDEX 2018: ENERGIZING THE WORLD WITH INNOVATION

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Since the release of the Global Innovation Index (GII) last year, the initial upswing in the global economy has been transforming into momentum for more broad-based global economic growth. Current economic figures show a level of optimism that has been long awaited. The global economy might well have taken off with a, sometimes surprising, significant growth performance in various countries and a partial reversal of their faltering levels of productivity.

Now the challenge is for the global economy to reach a comfortable cruising speed that can be upheld for the next several years.

Key findings in brief

The seven key findings of the GII 2018 are:

1. Becoming optimistic about global innovation and growth is possible.
2. Continued investments in breakthrough energy innovations are essential for global growth and to avert an environmental crisis.
3. China's rapid rise shows the way for other middle-income economies.
4. Richer economies, with more diverse industry and export portfolios, are likelier to score high in innovation.
5. Focusing on translating innovation investments into results is key.
6. Strong regional innovation imbalances persevere, hampering economic and human development.
7. Most top science and technology clusters are in the U.S., China, and Germany; Brazil, India, and Iran also make the top 100 list.

Sustaining the resumption of global growth

As the GII 2018 goes to print, and after almost a decade of uneven, often unsustained, progress, the global economy is now picking up speed and showing more broad-based growth. The world's leading economic institutions predict that global economic activity will strengthen, reaching almost 4% in 2018 and 2019.[1] Initial forecasts keep being revised upward, producing the best result since 2011. World trade and the ratio of trade growth to GDP growth are also set for recovery after a decade of lower trend growth.[2]

Growth in emerging economies, on one hand, and the closing of output gaps in high-income economies relative to the post-crisis years on the other hand, are among the drivers of this upswing.

Low- and middle-income economies are foreseen to grow close to 5% on average in 2018 and 2019.[3] China and, increasingly, India make an overarching contribution to sustaining this trend.[4] Certain countries part of the Association of Southeast Asian Nations (ASEAN)—notably Cambodia, the Philippines, and Viet Nam, as well as other Asian countries such as Bangladesh, Myanmar, and Pakistan—also sustain this expansion.[5] That aside, economic growth is also predicted to be relatively strong in several Sub-Saharan African economies, including Ethiopia, Kenya, Rwanda, and Senegal.[6] Commodity-exporting countries, notably Brazil and the Russian Federation (Russia)—which are overcoming recessions—also benefit from a swift turnaround driven by rising commodity prices.[7] If fundamentals remain positive, Latin America might experience more positive prospects in the next couple of years.

The revised global economic situation is mainly driven by an improved, sometimes striking, recovery in high-income economies, in particular in the United States of America (U.S.), Australia, and many countries in Western Europe, including Germany and France. Among high-income countries, however, some witness a further faltering of economic activity (e.g., Canada; Japan; and the United Kingdom [U.K.]), while others see no upward revisions in the last projections (see, for example, the Republic of Korea).[8]

In terms of more medium- and long-term fundamentals, global growth rates experienced before the economic crisis remain distant for nearly all countries. This is also a result of a decade of sub-par investment and lower productivity that has accompanied the global economy's holding pattern.[9] Worse, it is currently unclear whether the global economy will reach a robust cruising speed and altitude for a sufficient length of time to ensure sustained global growth.[10]

The concerns expressed in last year's GII have not faded. It is fair to say that the following points deserve continued attention.

First, at the global level, investment and productivity growth rates are still historically low. The welcome news is that productivity growth in high-income economies is now more rapid. This change in trend is also fortunately reinforced by a tangible upsurge in total factor productivity.[11] Yet it is too early to rejoice. At the global level, the 'productivity crisis' is not over (see 'Productivity growth, 1970–2018', Figure 1)—the productivity pick-up might be only cyclical in nature.[12] It is true that perceptions of slower average productivity growth might be due to measurement issues and related structural changes such as a shift to digital transactions and services.[13] Yet more fundamental drivers are probably at stake. For one, global foreign direct investment fell strongly by 16% between 2016 and 2017.[14] The low levels of investment at the national level are equally striking (see 'Investment growth, 2006–16', Figure 1); investment is simply not picking up at the same speed as economic growth or trade, lowering prospects of future potential growth. And then there has been another debate over whether modern technology creation and diffusion is effective enough to rival growth rates of previous decades, going back to the Industrial Revolution.[15]

Second, similar to last year when the first green spurts of growth surfaced, we are still wary of the potential downside risks that could affect the global outlook in the years to come. For many economic and geopolitical reasons—such as the build-up of financial vulnerabilities and increased protectionism—the global economy might well descend again before it truly operates at a full speed.[16]

Although most analysts concur with this unpleasant appraisal, suggestions for how to counter this potential obstacle diverge. As the editors of the GII, we believe that there is a renewed need to better prioritize policies that foster new sources of innovation-driven growth.

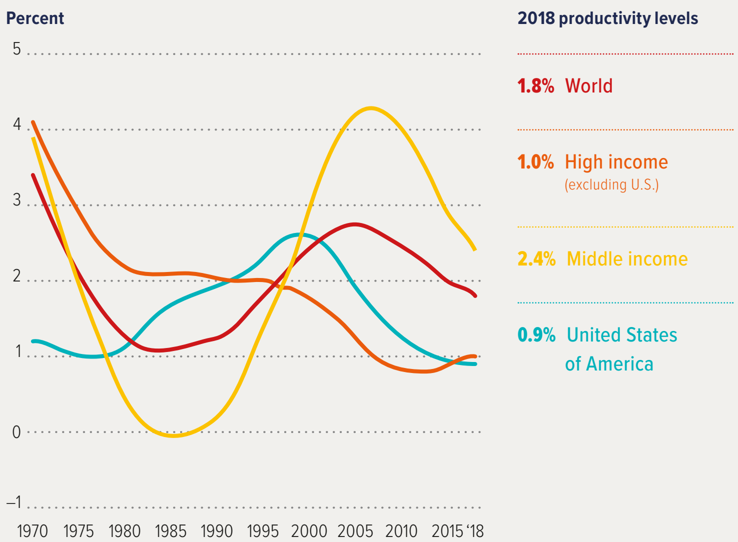
Re-inventing and managing the sources for innovation-driven growth

Laying the foundations for innovation-driven growth is paramount to ensuring that we move beyond a short-lived cyclical recovery.[17]

Investments in innovation and the creation of intangible assets are central to this goal.[18] These investments are crucial to spurring breakthrough technologies and innovations

Figure 1.
Global productivity, investment, and business R&D falling short?

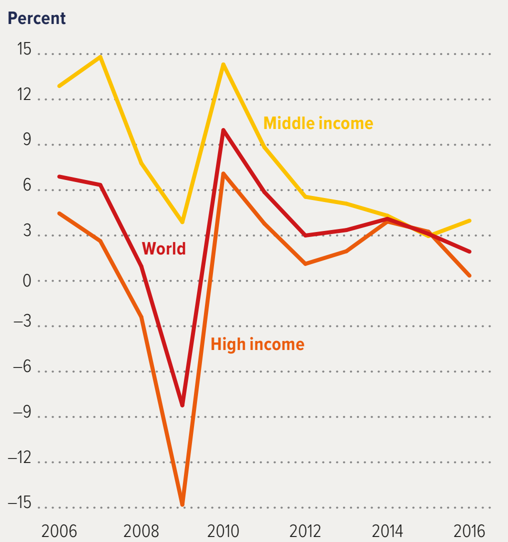
Productivity growth, 1970–2018



Source: Conference Board Total Economy Database, May 2018.

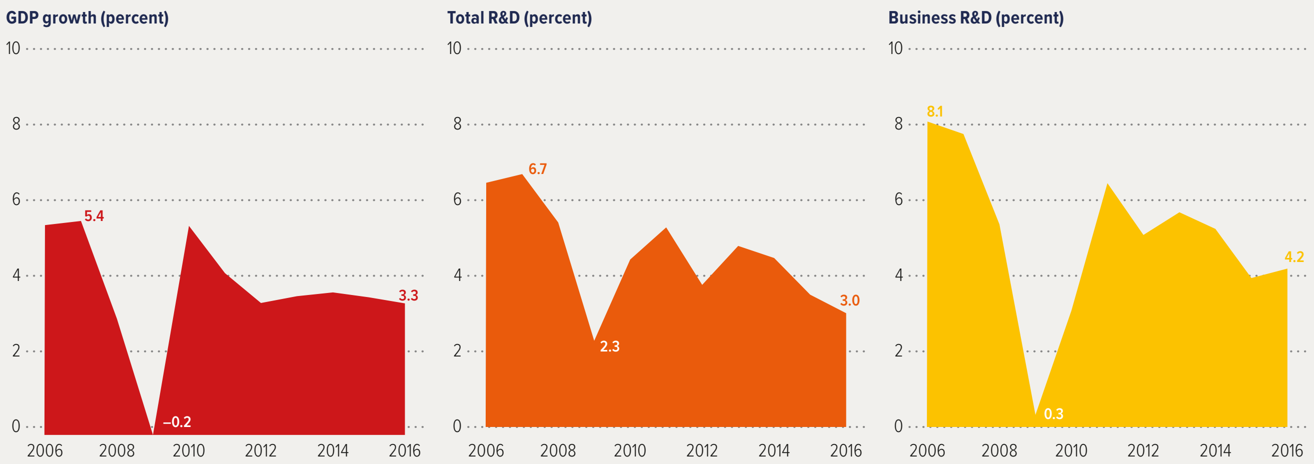
Note: 'Productivity growth' refers to the growth rate of GDP per person employed. The high income category excludes the U.S.

Investment growth, 2006–16



Source: World Bank World Development Indicators database, May 2018.

Global R&D expenditures growth, 2006–16



Source: Authors' estimates, based on the UNESCO Institute for Statistics (UIS) database and the IMF World Economic Outlook database, May 2018.

BOX 1

Mixed post-crisis R&D performance across countries

Countries showed considerable variation in their global R&D expenditure patterns after the 2008–09 financial crisis (Table 1.1).

Countries such as Germany, Israel, Italy, the United Kingdom (U.K.), the United States of America (U.S.), and Brazil experienced a decline in R&D spending in 2009, but their global and business expenditures on R&D (GERD and BERD) had fully recovered by 2016 (the latest year for which data are available). Chile and Colombia saw a steep decline in BERD in 2009 but their BERD growth rates leaped in the aftermath of the crisis.

France, Poland, the Republic of Korea, China, and Costa Rica proved to be among the economies most resilient to the crisis. They saw strong and constant growth in both GERD and BERD during whole 2010–16 period.

Some countries have not yet returned to their pre-crisis R&D spending levels. Finland, Portugal, and Spain still spend less on R&D than they did in 2008. In Latvia, in contrast, GERD and BERD had recovered in 2014 but experienced a new fall in 2016.

Finally, some countries, such as South Africa, still struggle to recover their business R&D spending but demonstrate sound total R&D spending.

Table 1.1: Gross domestic expenditure on R&D (GERD): Crisis and recovery compared

Countries with no fall in GERD during the crisis that have expanded since

	CRISIS		RECOVERY			
	2008	2009	2010–2013*	2014	2015	2016
France	100	104	108	114	115	115[p]
Korea	100	106	139	166	168	173
Mexico	100	105	114	127[ep]	130[ep]	125[ep]
Poland	100	113	150	187	207	n/a
Turkey	100	111	138	171	185	n/a
Argentina	100	117[bp]	138[p]	137[p]	149[p]	n/a
China	100	126	177	231	253	276
Russia	100	111	108	118	118	117
Colombia†	100	100	132	201	197	189
Costa Rica†	100	133	147	177	n/a	n/a
Egypt†	100	168	222	284	334	344
India†	100	106	118	n/a	119	n/a

Countries with a fall in GERD during the crisis but above pre-crisis levels in 2016

	CRISIS		RECOVERY			
	2008	2009	2010–2013*	2014	2015	2016
Austria	100	97	110[e]	122[e]	123	126[p]
Chile	100	92[b]	108	123[b]	129	125[bp]
Estonia	100	94	146	118	123	108
Germany	100	99	109	116	120	123[e]
Greece	100	90[e]	84	94	108	111[p]
Israel	100	96[d]	106[d]	120[d]	125[d]	129[de]
Italy	100	99	102	107[e]	108	104[p]
Slovak Republic	100	97	162	206	286	199
Sweden	100	94	96[p]	96[p]	104	107[p]
United Kingdom	100	99[e]	101[e]	108[e]	111	114[p]
United States	100	99[d]	101[d]	107[d]	110[dp]	112[dp]
Brazil†	100	99	115	133	128	n/a
Singapore	100	82	96	115	n/a	n/a
South Africa	100	93	87	97	102	n/a

Countries with GERD below crisis levels in 2016

	CRISIS		RECOVERY			
	2008	2009	2010–2013*	2014	2015	2016
Finland	100	97	95	84	77	75
Iceland	100	98	79[b]	79	89	92
Latvia	100	67	98	112	105	76
Portugal	100	106	94	83	81	84[p]
Spain	100	99	93	87	88	89[p]
Romania	100	75	75	67	89	93
Mongolia†	100	89	91	111	78	94

Source: OECD MSTI, March 2018; data used: Gross domestic expenditure on R&D (GERD) at constant 2010 PPP$, base year = 2008 (index 100).

Notes: *Average values for the 2010–13 period; † Country data source is the UNESCO UIS database: UNESCO-UIS Science & Technology Data Center, update from March 2018. Data used: GERD in '000 PPP$ (in constant prices, 2005).

b: time series break; **d:** new OECD definition of data point; **e:** estimated value; **p:** provisional value.

that will have a major impact in the longer term. Given the long cycles from initial concept to successfully deployed breakthrough innovation—sometimes lasting more than four to five decades—the essential groundwork facilitating these radical advances needs to take place now.[19]

In fact, from a historical perspective, the global landscape of investment in science and technology as well as in education and human capital has undergone important positive shifts over the last three decades.[20] Today it is no longer a few high-income economies such as the U.S., Japan, and certain European countries that carry out research and development (R&D), for example. R&D is now a common pursuit or, at a minimum, a serious policy ambition in most economies—including those in Asia where R&D has new momentum. The worldwide estimated total of R&D expenditures has continued to rise, more than doubling over the 20 years between 1996 and 2016, with businesses increasingly bearing the brunt of R&D investments.

This holds true for intellectual property (IP) filings as well, which reached record levels in 2016.[21] The latest figures point to an 8.3% patent filing growth in 2016, much higher than it had been in the previous six years, although that growth is mainly driven by China.[22]

R&D intensity, defined as R&D expenditures divided by GDP, has also been stable or even intensified over recent years, even comparing 2000 with 2016. In terms of world averages, R&D intensity rose from 1.5% to 1.7% in that period.[23] Within the Organisation for Economic Co-operation and Development (OECD) region, growth in R&D intensity has been even more significant—climbing from 2.1% to close to 2.4%, an increase in part also affected by negative or lower GDP growth.[24] Israel and the Republic of Korea have continued to have the highest R&D intensities, at 4.3% and 4.2% respectively. China has maintained its steady increase, reaching 2.1% in 2016.

However, R&D is still highly concentrated in high-income and a very few middle-income economies; the trend is worse for basic R&D, which continues to be conducted mainly in a few high-income economies. Excluding China, in middle-income economies R&D intensity improved only marginally, from 0.5% in 2000 to 0.6% in 2016. Low-income economies still hover around 0.2% to 0.4% across 2000–16, showing how nascent their innovation systems still are. Broadly speaking, the same is true for IP, which is increasingly filed in a growing array of middle- and low-income economies, but nevertheless is still quite concentrated.[25]

Moreover, progress in R&D growth has been less sustained in recent years. R&D growth has slowed and—because of a lag in data—it is still uncertain whether or not the economic upturn for 2017–19 will feed into significantly increased R&D expenditures.

'Global R&D expenditures growth, 2006–16', Figure 1 and Box 1 illustrate R&D developments before and after the economic crisis. Global gross R&D expenditure (GERD) growth fell in the aftermath of the global financial crisis of 2009.[26] In an uncharacteristic anticyclical move, governments stepped in to stimulate R&D effectively.[27] Some slowdown also occurred right after the crisis, with recovery as of 2010 holding up until 2013 but then declining, from 4.8% to 3% in 2016. Tighter government budgets in certain high-income countries and slower spending growth in key emerging countries explain part of this slowdown.

In 2016, GERD grew at 3%, slightly slower than world GDP growth.[28] This rate is also slower than the rate before the crisis, when GERD grew at 6.5% and 6.7% in 2006 and 2007 respectively. Business R&D investments (BERD) returned to faster growth as of 2010. A noticeable slowdown in the following years of 2014 and 2015 occurred, stabilizing at lower levels in 2016 compared with pre-crisis levels.

Across OECD countries, R&D spending grew by only 1.2% in 2016 because of government R&D plateauing; its slight growth was powered by R&D expenditures by higher education institutions.[29] Australia, the Republic of Korea, and the United Arab Emirates are among the high-income countries that markedly increased investments in 2016.[30] In turn, high R&D investing economies such as the U.S., Canada, Israel, Germany, France, and Japan faced a notable drop in R&D expenditure growth in 2016. The U.S., for instance, had only 0.9% growth in BERD (3.1% in 2015) and 1.6% growth in GERD (2.9% in 2015). Related growth in Japan is negative.[31]

Again, not all is doom and gloom. Nine years after the crisis, the worst-case scenario of permanently reduced R&D growth has so far been avoided, thanks to the anticyclical innovation policies and the role of R&D champions such as China, Germany, and the Republic of Korea. Furthermore, R&D funding allocated by governments in the OECD countries showed a strong increase of 2.5% in 2016, with the U.S. being a key driver and with further increases in 2017 for Germany and Japan.[32]

Another partially positive message can be found on the business front. Global business R&D spending is increasing at faster pace in 2016 (4.2%) than in 2015. Thankfully the loss in momentum we feared in the GII 2017 has not materialized for world aggregate spending. In the OECD, however, the opposite is observed. According to the latest OECD data, real business R&D expenditure grew by only 0.9% in 2016, compared with 2.2% in 2015 and 4.1% in 2014.[33]

But is R&D growth currently aligned with growth in the economy in a sustainable way? In the absence of complete aggregate data, solid published data—including from our GII Knowledge Partner PwC's Strategy&—indicate that the top 1,000 and 2,500 world R&D companies raised their R&D expenditures between 2015 and the first half of 2017 as part of six consecutive years of increases in R&D investments by the top private R&D spenders.[34] The R&D expenditures of the top 1,000 R&D spenders reached an all-time high in 2016 and 2017.[35] Relative to revenue, R&D intensity too is actually the same or higher than it was before the crisis.[36]

Nevertheless, year-on-year growth of corporate top R&D spending is still mostly lower than it was before the crisis. Despite the many challenges that warrant faster rather than slower growth in innovation expenditures, companies fear that the increasing prospect of economic nationalism will soon have a sustained negative impact on innovation expenditures.[37] For example, China's corporate R&D spending—having experienced double-digit growth rates for many years—declined for the first time in 2016.

Turning to the future, as governments prepare policies to sustain the current growth momentum, a focus on R&D and innovation should be a priority. Looking forward, if innovation expenditures are aligned with economic growth over the next years, what would this mean for future innovation scenarios? What if India and other emerging countries in Asia, and hopefully also in other world regions, followed the high innovation expenditure and patenting growth of China in the next several years? Such dynamics could create the basis of productive knowledge spillovers as well as opportunities for collaboration and for the generation of new knowledge and innovation.

Part and parcel of encouraging these dynamics is an active approach to better explaining the relationship of innovation in general and R&D expenditures in particular to growth. The second element of this goal is the harder but more important task of practically ensuring that economic gains from innovation are also materializing in terms of employment and wage growth in developed and developing countries alike. At the moment, upcoming new technology advances such as industry 4.0, automatization and robots, and artificial intelligence are often seen more as threats than opportunities.[38]

At its best, innovation is not only a driver of economic growth but also a wellspring of solutions to pressing societal matters such as aging, pollution, and the spread of diseases. The impacts that innovation has achieved and will continue to achieve in the near future are worth more than money and percentage point increases in economic growth. They are central to overcoming important challenges that mankind faces in the 21st century.

With this in mind, the 2018 GII edition on the theme of 'Energizing the World with Innovation' elaborates on the opportunities and challenges of the current and future energy innovation landscape. The world will continue to be powered in the context of increased energy demand and increasing concerns with environmental sustainability. This edition of the GII shows that innovation is squarely in the centre of this effort.

Energizing the world with innovation

Global energy demand is reaching unprecedented levels as a result of a growing world population along with rapid urbanization and industrialization, particularly in developing and emerging economies. Projections indicate that by 2040 the world will require up to 30% more energy than it needs today.[39] At the same time, conventional approaches to energy supply—particularly in cities—are unsustainable in the face of climate change. This requires shifting towards cleaner and more efficient methods of producing energy through traditional sources as well as scaling up the use of renewable sources.[40]

As a result of these challenges, higher levels of technological and non-technological innovation are needed on the supply side of the energy equation (including cleaner energy sources), the demand side (including smart cities, homes, and buildings; energy efficient industries; and transport and future mobility), and in enabling technologies for the optimization of energy

BOX 2

Innovation, energy, and the United Nations

In 2015 the United Nations (UN) Member States adopted the 2030 Agenda for Sustainable Development (the 2030 Agenda) and the Paris Agreement.[1] Both recognize that effective national innovation systems are key to promoting scientific and technological solutions that lead to improvement in energy efficiency systems.

The 2030 Agenda and its 17 Sustainable Development Goals (SDGs) and 232 indicators apply to all countries universally and set out an ambitious global path towards a sustainable future for all. Goal 7 calls for 'access to affordable, reliable, sustainable and modern energy for all'. It highlights international cooperation to facilitate access to clean energy research and technology and promote investment in energy infrastructure and clean energy technology. The UN General Assembly also emphasized the importance of access to energy in a recent resolution.[2] The majority of the 17 SDGs rely on technology and innovation as a means of implementation, and all are interlinked. Goal 9 explicitly refers to innovation and to several specific innovation factors referenced in the GII.[3] The High-level Political Forum (HLPF), which has a central role in the global review of the 2030 Agenda, will meet from 9 to 18 July 2018, coinciding with the GII launch on 10 July 2018.[4]

Energy production and use account for two-thirds of total global greenhouse gas emissions and 80% of CO2; they are closely linked with climate change. The Paris Agreement—which entered into force in 2016 under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC)—brings together countries in a common effort to address climate change. Article 10.5 of the Agreement explicitly recognizes the critical role of technological innovation for an effective response to climate change also helping to accelerate the implementation of nationally determined contributions (NDCs), national adaptation plans, and mid-century (2050) strategies to achieve the Paris Agreement.

The GII provides countries with a data-based tool for policy making and contributes to the shared endeavour of achieving the SDGs and the full implementation of the Paris Agreement. WIPO GREEN also promotes clean energy innovation and diffusion by connecting those seeking solutions with technology and service providers.[5]

Notes

Notes for this box appear at the end of the chapter.

systems (including smart grids and new advanced energy storage technologies).

The chapters of the 11th edition of GII explore these issues and illustrate the contribution innovation makes to addressing and solving the energy equation in specific geographies and contexts. They also take a candid look at the obstacles and rigidities that could stand in the way of such innovations.

Five messages emerge from this year's GII theme:

1. Innovation has a key role in meeting increasing global energy demand.
2. Energy innovations are happening globally, while objectives differ across countries.
3. New energy innovation systems need to emerge, with efforts along all stages, including energy distribution and storage.
4. Obstacles to the adoption and diffusion of energy innovations remain numerous.
5. Public policy plays a central role in driving the energy transition.

Innovation has a key role in meeting increasing global energy demand

Access to energy is a prerequisite for maintaining a basic standard of living and economic development, and—in the context of the GII—is a necessary input for innovation. Yet access to energy eludes millions around the world. For many developing countries, energy access is a basic element of equality (Chapter 13).

Innovation is a major driver in the energy transition currently underway.[41] Technological development is accelerating and renewable energy costs have decreased at a remarkable pace over past decades (Chapter 3).

The Kyoto Protocol and the Paris Climate Change Accord have placed an increased focus on renewable energy, and on its integration with innovative local distribution and storage solutions (see Box 2). This trend reflects a commitment to decarbonize the economy, and is driven by the falling costs and increased competitiveness of these technologies (Chapter 2).

Lower costs of renewable energy technologies have combined with increasing energy efficiencies. Solar photovoltaic (PV) module costs have fallen by about four-fifths in just the six years from 2010 to 2016.[42] Onshore wind is one of the most competitive sources of new generation capacity.[43] Offshore wind and concentrated solar power (CSP) technologies are becoming relevant energy supply options. Technologies for previously fringe energy sources, such as tidal and geothermal power, are entering the market as genuine players in the contemporary energy space (Chapter 6). The potential of biomass as an energy source has significantly heightened as a result of new technologies that can convert a much wider variety of biomass into commercial biofuel. Many economies also see the energy transition as a way to achieve energy independence from external sources (Chapter 8 addresses the example of India).

New energy innovation systems need to emerge.

The transition to a global low-carbon energy sector can stimulate employment and economic growth. Recent employment estimates show that the transition to a green economy would lead to a net increase of approximately 18 million jobs across the world.[44] Increased economic growth would be generated by higher investment in renewables and energy efficiency, and enhanced through pro-growth policies, particularly carbon pricing (Chapter 3).

Energy innovations are happening globally, while objectives differ across countries

Energy innovations can have disruptive effects across many sectors. For example, battery storage technology is acting as a leap enabler, allowing off-grid customer self-sufficiency and self-production thanks to the rapid development of small-scale renewable technologies. A breakthrough in the cost of lithium-ion batteries is effectively transforming the automotive industry. Ultra-high voltage lines and smart grids are opening the possibility that power and electricity can be transported across long distances, even countries.

Distributed energy generation, the digitalization of energy systems, and the coupling of diverse energy applications are major innovation trends that are transforming the energy sector. Smart grids and digital energy in particular are heavily disruptive of current structures and innovation systems. Distributed and decentralized energy generation, combined with information and communication technology (ICT) developments, are transforming the way power systems are operated and regulated (Chapter 3). Power storage technology can play an active role in modulating the supply-demand of renewable energies (Chapter 12). The emergence of intelligent networks has the potential to change the role and business models of distribution companies and present opportunities for small innovative businesses. This is effectively leading to a 'democratization of electricity'. Customers and end-users have unprecedented access, control, and choice (Chapter 2).

Examples of energy innovations flourish around the world, showing that innovation in the energy sector is not the privilege of more advanced or high-income economies. The potential of emerging economies for the adoption and deployment of renewable energy technologies is enormous. China's rapid expansion of PV facilities has attracted worldwide attention.[45] India and China are delving deeper into the downstream applications of PV technologies, including PV-hybrid plants and PV-grid integrations (Chapter 11). PV technologies can supply electricity to populated as well as remote areas due to its modularity.

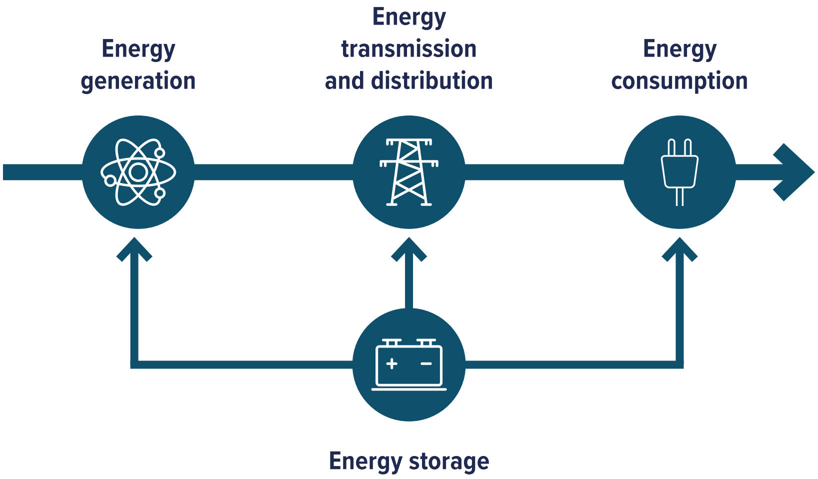
Breakthrough innovation can also happen at the grassroots level. Small-scale renewable systems to provide electricity to people living far from the grid are on the rise. Grassroots communities in Sub-Saharan Africa are applying simple innovations to improve their production and use of woodfuel in ways that address their practical needs while also addressing global challenges (Chapter 9). The adoption of energy innovations in developing countries also offers them the opportunity to leapfrog because conventional energy sources and the associated institutions and regulations are not yet fully installed.

New energy innovation systems need to emerge, with efforts along all stages, including energy distribution and storage

The global energy transition requires a change in innovation systems to one where the production of knowledge and technology for the energy sector is encouraged by means of technological linkages between large companies and their suppliers. Indeed, private-sector investment is of central importance to the new energy ecosystem. This new ecosystem integrates small business innovators through corporate venture capital and with support of technological institutions (Chapter 7). How well companies innovate with new types of energy and distribution technologies will determine their ability to survive the energy transformation

Figure 2.

Stages of the energy system value chain



and to compete against the many start-ups and entrepreneurial firms eyeing the energy market (Chapter 2).

Innovation has been uneven across the different stages of the energy system value chain (Figure 2).[46]

There is an increasing market need for energy storage technologies to act as reliable buffer systems, creating an opportunity for new disruptive technologies to enter the market (Chapter 6). Given the rapid growth of renewable energy development, more energy transmission technologies are needed to cope with the imbalance between energy supply and demand (Chapter 12). This imbalance also calls for more flexible energy systems and for innovation in technology solutions that support the integration of variable renewable energy.[47] Energy waste disposal, including but not limited to nuclear waste or, for example, the recycling of batteries, is also in need of further innovative solutions.

In contrast to global commitments by governments and industry in favour of the energy transition, it is often debated whether the world is investing enough in technologies and projects supporting it, and whether R&D and innovations are being produced at the necessary levels and speed to enable this transition.

Global private-sector investment in green energy sources and inventions (patents filed) in energy technologies have grown at unprecedented levels in the past decade. Both have remained high in recent years, but have experienced slower growth since 2011. This slowdown could be a sign of existing obstacles in the diffusion of energy innovations.[48]

In the period 2004–17, the world invested US$2.9 trillion in renewable energy sources.[49] The period 2004–10 was characterized by a boom in investment, with a compound annual growth rate (CAGR) in investments equal to 32%. In contrast, in the period 2011–17, these investments have stagnated.[50] The levels of investment recorded in 2017 are 2% higher than those registered in 2016, but remain 13% lower than the record set in 2015 of US$323.4 billion of new investment in renewable energy.

The 2018 *Global Landscape of Renewable Energy Finance* also highlights waning growth in annual investments in renewable energy in 2016.[51]

A slowdown can also be observed in the growth of green energy-related patents. WIPO's *World Intellectual Property Indicators 2017* showed that—first and foremost—patent applications in energy-related technologies in categories such as solar energy, fuel cells, wind energy, and geothermal energy significantly increased over recent years, up until 2013.[52] Since then, however, patent applications in the field of energy-related technologies have declined. A decrease has also been observed in the number of cleantech patents granted by the United States Patent and Trademark Office (USPTO): between 2014 and 2016 the number of cleantech patents granted in the U.S. declined by 9%.[53]

According to an analysis done by WIPO for the GII 2018, the total number of patent families and PCT international patent applications in green energy technologies almost doubled between 2005 and 2013.[54] The number of patent families rose from 65,105 in 2005 to 113,457 in 2012, growing annually at about 8.3%. PCT international patent applications rose from 9,043 in 2007 to 17,880 in 2013, growing 12% each year (Figure 3; see also WIPO, 2018b).

Yet this period of accelerated growth in the number of published green energy inventions has been followed by a period of deceleration—even a slow decline. The number of published green energy patent families peaked in 2012—with the underlying invention usually happening about 18 months before the patent publication. Hence the peak of inventive activity was around 2010. Since then, a decrease in the absolute number of patent families has been observed every year until 2015—a reduction from peak to bottom by 3.8%, from 113,547 families in 2012 to 109,266 in 2015.

Similarly, published PCT international patent applications peaked in 2013, followed by a decrease of 11.4% between 2013 and 2017—dropping from 17,880 to 15,840, an annual decrease of 3%.

With regard to patent families, although most green energy technologies have seen a downward trend in the annual number of patents published since 2012, the decline has been most pronounced in nuclear power generation technologies and alternative energy production technologies. The latter notably include renewable energy technologies, such as solar energy, wind energy, and fuel cells. In contrast, inventions in energy conservation technologies and green transportation technologies have continued to grow, but at a slower pace.

An analysis conducted by the European Patent Office (EPO) for the GII 2018 confirms the above-mentioned slowdown for smart-grid technology. Related inventions as measured by numbers of new patent families show accelerated growth followed by deceleration, and even a decline in the number of internationally oriented smart-grid patent families.[55] Accelerated growth was observed between 2005 and 2011. The number of new patent families in smart-grid technologies grew from 441 to 2,500 in 2005–11. In the same time, the number of internationally oriented smart-grid patent families increased six-fold, from fewer than 200 in 2005 to 1,168 in 2011. In 2012 the trend changed. While the growth of new smart-grid patent families slowed, the number of internationally oriented smart-grid patent families dropped considerably by 41%, to 685 by 2014.

Why are these slowdowns or declines in green investment taking place in the face of increased need for energy innovation?

The reasons for green investment and green energy patenting slowdown are not entirely clear. Many factors could be at play, including a lack of prioritization of green energy innovation as a result of declining oil and fossil fuel prices, which decrease the incentives to go green. Also the decreasing profit margins in the area of select renewable energy technologies and the ensuing changing industry structures have led to an overall decrease in patenting, although innovation remains strong.[56] Moreover, potentially the issue is now more one of failing technology adoption than an actual need for a redoubling of innovation. In other words, the green energy technologies required to curb emissions exist, yet the obstacles to their diffusion are manifold.

Obstacles to the adoption and diffusion of energy innovations remain numerous

Energy innovation is taking place mostly on the supply side. One of the biggest challenges with respect to energy innovation seems to be on the side of diffusion and adoption, which are slow and missing incentives. Complementary social and organizational innovations are therefore needed.

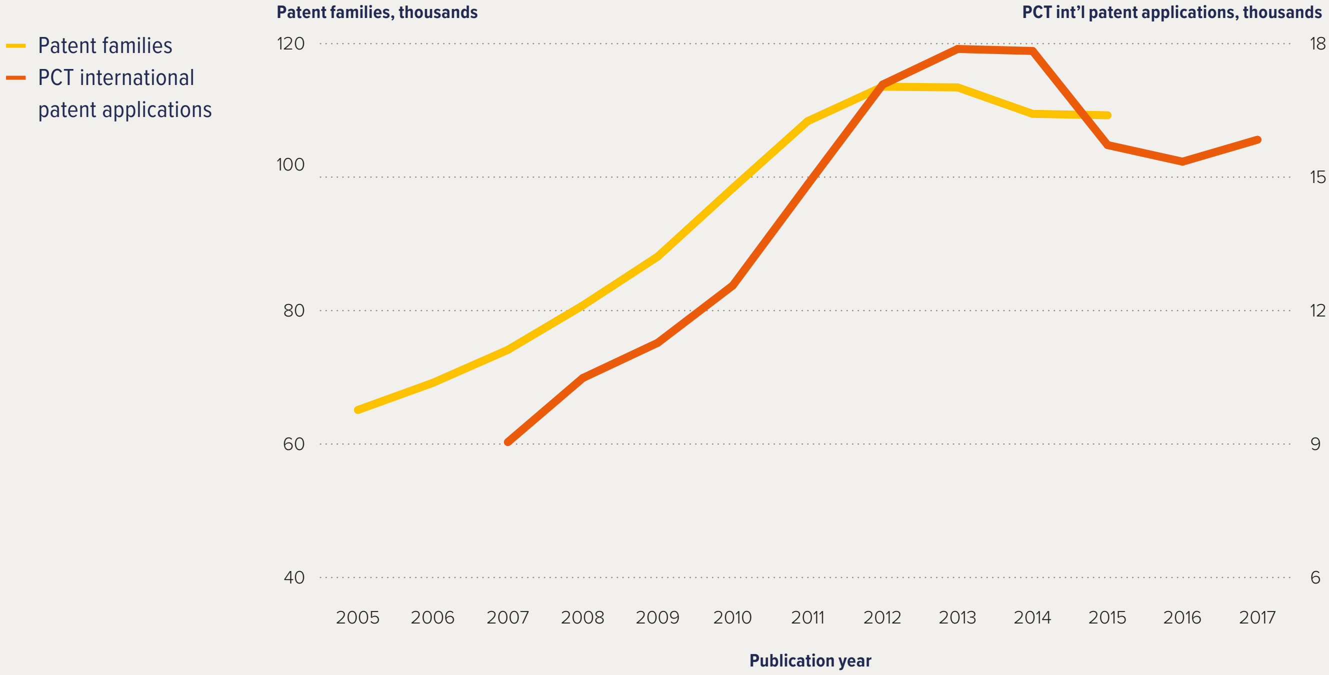
New energy technologies need to demonstrate their viability with respect to their energy performance. The public and private interests that support the dominant—often fossil fuel–based—energy technologies also need to be addressed to allow large-scale adoption.

Moving from research and innovation to the adoption and commercialization of energy innovations remains difficult for developing countries. The costs linked to the commercialization of innovations are often underestimated and under-recorded (Chapter 8).

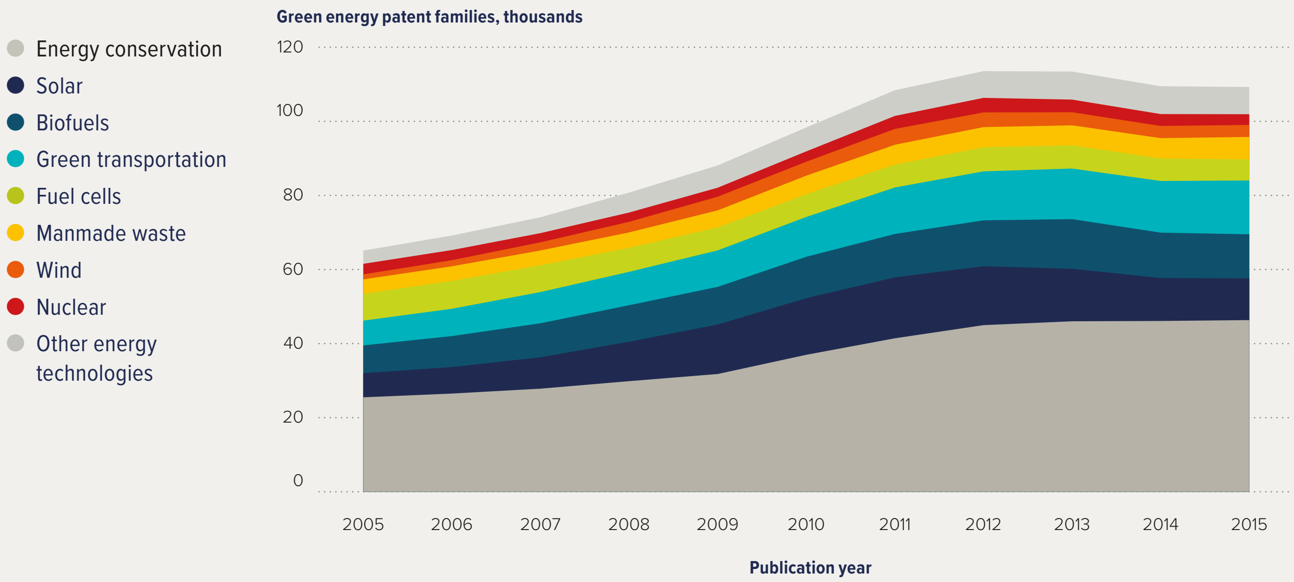
Technology adaptation after technological learning is also very important. This is a challenge that is often underestimated with regard to the availability of skills and technical knowhow in low- and middle-income economies (Chapter 13).

Figure 3.
Green energy patent filings

Number of patent families and PCT int'l patent applications in green energy technologies, 2005–17



Total number of patent families in green energy technologies, 2005–15



Sources: WIPO, Patent families and PCT international patent applications based on WIPO Statistics Database and PATSTAT and WIPO IPC Green Inventory; Total number of patent families based on PATSTAT and WIPO IPC Green Inventory.

Notes: 'Patent families' are those with at least one granted application in one patent office. All patent data refer to published applications.

Innovation efforts around grid infrastructure and grid integration also need additional support both from governments and from industry.[57]

Finally, changes in the consumption behaviour of consumers need to receive strong 'buy in' from society and necessarily must be gradual. This is particularly important for low-income economies that still need to make difficult trade-offs between basic needs (e.g., nutrition, health, housing, education) and energy imperatives. Supplying consumers with the right information about the sustainability of their purchasing decisions, and limiting the ability of firms to 'greenwash' their products and services with false claims, are central to empowering consumer decisions.

The GII helps to create an environment in which innovation factors are continually evaluated.

Public policy plays a central role in driving the energy transition

Delivering on global commitments to mitigate climate change generates additional and positive forces to address the energy equation. However, innovation and technological change alone will not be enough to achieve the energy transition. This transformation requires complementary changes in institutions, business strategies, and user practices.[58] The role of government is vital in implementing strong incentives and regulations to drive the transition. Public policies need to be coherent in supporting this process.

Public authorities therefore play a central role in stimulating energy innovations. Policy makers have a responsibility to provide funding mechanisms that stimulate innovation. Funding mechanisms can take several forms:

- In Viet Nam (Chapter 13), government grants from the Ministry of Industry and Trade and the Ministry of Science and Technology played a central role in stimulating private-sector investments in energy transformation technologies.
- In Brazil, the provisions for mandatory investment in research, development, and innovation (RDI) in the exploration and production of oil contracts and the legislation of mandatory RDI investment in the electric power sector are both successful drivers in making Brazil's power generation the cleanest in the world (Chapter 7).
- Targeted technological innovation programmes can help the development of key and strategic energy technologies (e.g., the Inova Petro programme in Brazil, Chapter 7; and China's Development Plan on Renewable Energy, Chapter 12).
- Government procurement and international collaboration can promote higher levels of private-sector investment in transformational clean energy technologies (Chapter 10).
- Private-sector funding can be incentivized through tax exemptions, favoured tax status for high-tech enterprises and small and medium-sized enterprises, and co-finance loans (Chapter 7, Chapter 10, and Chapter 12).
- The creation of focused research institutes (e.g., the Solar Energy Research Institute of Singapore, or SERIS, is also a possibility (Chapter 11 on Singapore).

Governments often play the role of risk taker both by promoting mechanisms that stimulate investment and the diffusion of technologies with disruptive potential and by supporting projects with high technological risk (Chapter 7). Policy incentives are lacking in sectors with the least progress in innovation for decarbonization such as the heavy industries, freight transport, and aviation (Chapter 3).

Innovations in commercial and financial models are instrumental in the scale-up of renewable energies, which calls for constant innovation in business models and policy design (e.g., renewable energy green power certificates in China, see Chapter 12). Investments in R&D can also scale up grassroots innovations and local communities so that technology development addresses their needs and aspirations, particularly in low- and middle-income economies (Chapter 9).

Technological cooperation and innovation networks are an important element of an innovation ecosystem.[59] International cooperation is often used by emerging economies as a way to learn from other countries and ensure technology diffusion and transfer (Chapter 11, Chapter 12, and Chapter 13). Initiatives that include small businesses in the innovation processes of large companies have succeeded in fostering learning and technology transfer within national innovation systems (Chapter 7 on Brazil).

It is important to seek R&D efficiencies (Chapter 7). Policy monitoring is thus central to understanding whether public and private resources are being properly employed to fulfil a successful energy transition.

The energy transition hence requires much more than technological innovation. It also demands the invention and promotion of innovative organizational, institutional, social, and political structures.

Favourable regulatory frameworks can incentivize energy innovations. Improving national legal and regulatory frameworks can support innovation and contribute to a more conducive environment (Chapter 11). This can also increase investor confidence and favour investments in disruptive technologies. A robust regulatory framework enables new energy technologies to play a significant part in the future of a country's energy supply. For example, a positively evolving regulatory environment has made Australia an ideal place for the rapid penetration of battery technologies into its national energy landscape (Chapter 6). Prescribing a reduction in specific energy consumption norms for energy-intensive industries has resulted in large savings of electricity in India (Chapter 8).

The role of the effect of subsidies on innovation is currently underappreciated. Although subsidies might be critical to fostering the uptake of, for example, solar energy panels by private households, their role in driving innovation on the supply-side across this and other energy technologies is unclear.

IP rights and IP protection can also encourage innovation in renewable energy technologies (Chapter 11 on Singapore and Chapter 12 on China).

The GII 2018 conceptual framework

The GII helps to create an environment in which innovation factors are continually evaluated. It provides a key tool of detailed metrics for 126 economies this year, representing 90.8% of the world's population and 96.3% of the world's GDP (in current US dollars).

Four measures are calculated: the overall GII, the Input and Output Sub-Indices, and the Innovation Efficiency Ratio (Figure 4).

- **The overall GII score** is the simple average of the Input and Output Sub-Index scores.
- **The Innovation Input Sub-Index** is comprised of five input pillars that capture elements of the national economy that enable innovative activities: (1) Institutions, (2) Human capital and research, (3) Infrastructure, (4) Market sophistication, and (5) Business sophistication.
- **The Innovation Output Sub-Index** provides information about outputs that are the results of innovative activities within the economy. There are two output pillars: (6) Knowledge and technology outputs and (7) Creative outputs.
- **The Innovation Efficiency Ratio** is the ratio of the Output Sub-Index score to the Input Sub-Index score. It shows how much innovation output a given country is getting for its inputs.

Each pillar is divided into three sub-pillars and each sub-pillar is composed of individual indicators, for a total of 80 indicators this year.

Further details on the GII framework and the indicators used are provided in Annex 1. It is important to note that each year the variables included in the GII computation are reviewed and updated to provide the best and most current assessment of global innovation. Other methodological issues—such as missing data, revised scaling factors, and countries added or removed from the sample—also impact year-on-year comparability of the rankings (details of these changes to the framework and factors impacting year-on-year comparability are provided in Annex 2).

Most notably, a more stringent criterion for the inclusion of countries in the GII was adopted in 2016, following the Joint Research Centre (JRC) recommendation of past GII audits (see Annex 3 in this report and in previous years' editions). Economies and countries were included in the GII 2018 only if 66% of data were available within each of the two sub-indices and if at least two of sub-pillars in each pillar could be computed. This more stringent criterion for inclusion in the GII ensures that country scores for the GII and for the two Input and Output Sub-Indices are not particularly sensitive to the missing values. As noted by the audit, this more stringent threshold notably improved the confidence in the country ranks for the GII and the two sub-indices, and thus the reliability of the GII rankings (see Annex 3). Although this year these remain constant, the rules on missing data and minimum coverage per sub-pillar will be progressively tightened, leading to the exclusion of countries that fail to meet the desired minimum coverage in any sub-pillar (see Annex 2 for more details).

In addition, this year Annex 1 introduces a box, produced by Nesta, on big data. This new element offers an overview of how new measures based on big data may provide better measurement indicators in the future. The box further delves into how, as our world becomes more digitalized and new data sources become

Figure 4.
Framework of the Global Innovation Index 2018

available, big data is creating opportunities for a more complete understanding of both existing and previously unexplored questions that are difficult or impossible to capture with traditional metrics.

The Global Innovation Index 2018 results

The Rankings section beginning on page xix presents the results in tabular form of all economies included in the GII 2018 for the GII and the Input and Output Sub-Indices. The GII 2018 results have shown consistency in areas such as top rankings and the innovation divide. However, there have also been some new high-level developments this year, as described below.

Movement at the top, led by Switzerland, the Netherlands, and Sweden

In 2018 the GII shows interesting changes in the top 10. Switzerland leads the rankings for the eighth consecutive year, while the Netherlands and Sweden swap their positions, ranking 2nd and 3rd respectively. The U.K. gains one spot, moving to the 4th position. Singapore jumps to the 5th spot, moving up two positions since last year. The U.S., which had been stable at the 4th spot for the last two years, moves down to the 6th this year. Finland follows, gaining one position since 2017 and taking the 7th place. Denmark, which has moved up two positions each year since 2016, loses two positions this year, ranking 8th. Germany and Ireland, instead, remain stable at the 9th and 10th spots respectively.

Figure 5 shows movement in the top 10 ranked economies over the last four years:

1. *Switzerland*
2. *Netherlands*
3. *Sweden*
4. *United Kingdom*
5. *Singapore*
6. *United States of America*
7. *Finland*
8. *Denmark*
9. *Germany*
10. *Ireland*

The top 25 of the GII 2018 also show interesting movement. Among the most significant, Israel moves up by six positions this year, almost reaching the top 10 (11th). China, which entered the top 25 in 2016, continues its spectacular rise and moves up by five places this year, becoming the 17th most innovative economy in the world. Apart from these large movements, the Republic of Korea now takes the 12th place, losing one position, while Japan gains one position, making it to 13th place. After leaving the top 10 in 2015, Hong Kong (China) ranks 14th, gaining two positions since last year. France moves down one spot, now ranking 16th. Canada (18th) and Norway (19th) remain stable, while Australia moves up three places, ranking 20th, after previously falling in the rankings for two consecutive years. In turn, Austria (21st) and New Zealand (22nd) lose one spot each; Estonia improves its ranking by one, taking the 24th place and displacing the Czech Republic, which leaves the top 25 this year. Belgium (25th) returns to the top 25 this year after two years.

2018 results: The world's top innovators

The following section describes and analyses the prominent features of the GII 2018 results for the global leaders in each component of the GII and the best performers in light of their income level.[60] A short discussion of the rankings at the regional level follows.[61]

The top 10 in the Global Innovation Index

Switzerland earns the number 1 position in the GII for the eighth consecutive year. It has maintained this top spot since 2011, as well as its number 1 position in the Innovation Output Sub-Index and in the Knowledge and technology outputs pillar since 2012. This year it also gains the 1st spot in the Creative outputs pillar, consolidating its leadership in innovation outputs. Switzerland becomes the 2nd economy in the world in innovation quality, taking the spot of Japan, which ranks 1st this year (see Box 5 on innovation quality). Despite these important achievements, Switzerland loses positions in all innovation inputs pillars except for Human capital and research, where it gains two spots. In this pillar, Switzerland improves in the sub-pillar Research and development (R&D), where it gains six positions and ranks 2nd. At the indicator level, its rank in researchers and R&D expenditures improves considerably and its 3rd positions in global R&D companies and the quality of universities are preserved. Thanks to these gains, the country improves its ranking in the Innovation Input Sub-Index, where it moves to 2nd place, and in

Figure 5.
Movement in the GII top 10

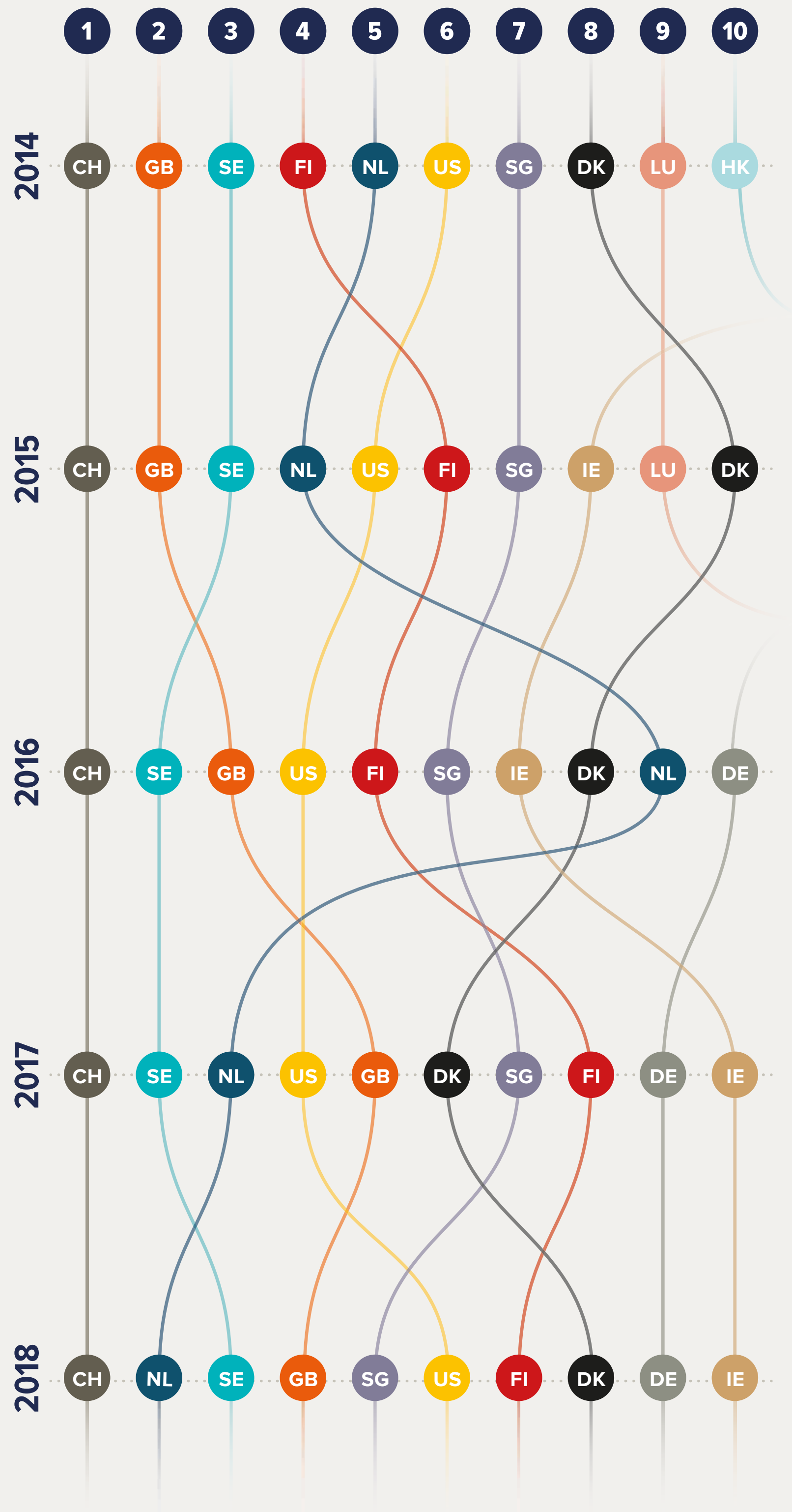
Since 2011 Switzerland has ranked 1st in the GII every year.

In 2015 Ireland entered the top 10 and Hong Kong (China) exited.

After 2016 no country has entered or exited the top 10.

Sweden maintained 2nd place for the second time in 2017.

In 2018 the Netherlands and Sweden traded 2nd and 3rd place.



KEY

DK Denmark **HK** Hong Kong (China) **NL** Netherlands **CH** Switzerland
FI Finland **IE** Ireland **SG** Singapore **GB** United Kingdom
DE Germany **LU** Luxembourg **SE** Sweden **US** United States of America

Source: Global Innovation Index Database, Cornell, INSEAD, and WIPO.
Note: Year-on-year GII rank changes are influenced by performance and methodological considerations; see Annex 2. ISO-2 codes are used to identify economies.

the Innovation Efficiency Ratio, where it gains the 1st spot this year. As in previous years, it ranks among the top 25 in all sub-pillars, with only three exceptions: Business environment (44th), Education (32nd), and Information and communication technologies (ICTs, 30th). Switzerland ranks 1st in several important indicators, including patent families in 2 or more offices, PCT patent applications by origin, and IP receipts, while it loses its 1st rank in high- and medium-high-tech manufactures. With its solid output performance and increasingly diversified range of high-quality outputs, Switzerland remains the most innovative economy in the world. Switzerland also presents a few areas of weakness, especially on the input side. These include ease of starting a business, expenditure on education, productivity growth, and ease of getting credit.

Despite the exceptional relative performance of Switzerland and other small countries—as measured by population—in the top 20 (see also Box 3), it is evident that in terms of absolute, unscaled innovation inputs and outputs, large countries overshadow small countries (see Figure 6). In other words, while the innovation performance of Switzerland, Israel, or smaller countries such as Singapore, Malta, Honk Kong (China) relative to their GDP or other scaling factors is outstanding or at least noteworthy, their overall shares in the number of global researchers, global R&D expenditures, total number of patent applications by origin, and publications worldwide is less impressive, particularly relative to the U.S. and China, which dominate these rankings by far.

The Netherlands moves up one spot in 2018, becoming the 2nd most innovative economy in the world. It ranks 2nd in the Innovation Output Sub-Index and 4th in the Innovation Efficiency Ratio. The Netherlands strengthens its already-strong output pillars, maintaining 2nd position in Knowledge and technology outputs and gaining the 3rd spot in Creative outputs. The country keeps its 9th position in the Innovation Input Sub-Index, albeit gaining seven positions in Human capital and research (12th) and four in Institutions (7th). In the former, it improves in all sub-pillars, most significantly in Education (8th), but also in the graduates in science and engineering and tertiary inbound mobility indicators. In Institutions, the Netherlands gains positions in its Regulatory environment and Business environment, especially in regulatory quality and ease of starting a business. On the innovation input side, its best ranks are in Business sophistication, where the Netherlands keeps its 1st spot. In this pillar, it maintains its 1st rank in Knowledge absorption, where it ranks 1st in IP payments and in ICT services imports. This year the Netherlands also gains the 1st position in Online creativity and the 2nd spot in Knowledge diffusion, where it ranks 1st in IP receipts and FDI outflows. Areas of weakness persist and include the sub-pillar Tertiary education (48th) and indicators pupil-teacher ratio, gross capital formation, ease of getting credit, and productivity growth.

Sweden moves down to the 3rd position this year, albeit remaining the top Nordic economy in the GII 2018. It ranks among the top 10 in all pillars except for Market sophistication (12th) where it loses two positions since last year. Sweden also ranks lower in Human capital and research (7th) and Business sophistication (5th). As a result of these downward movements, its rank in the Innovation Input Sub-Index moves down from the 2nd to the 3rd position. Its Innovation Output Sub-Index remains stable at the 3rd spot. Indeed, on the output side, Sweden gains five positions in Creative outputs (6th) and keeps its 3rd spot in Knowledge and technology outputs. In the former, it shows a remarkable improvement in Online creativity, where it ranks 3rd globally. Other sub-pillars where Sweden makes considerable progress are Ecological sustainability (12th, up by eight positions) and Trade, competition, and market scale (24th, up four). At the indicator level, the country keeps its 1st position in PCT patent applications by origin and gains a 1st rank in IP receipts and rule of law. Finally, and as in previous years, areas of weakness include pupil-teacher ratio, GDP per unit of energy use, ease of getting credit, GERD financed by abroad, FDI inflows, and productivity growth.

The United Kingdom (U.K.) moves to 4th place this year, getting closer to the top 3. The U.K. gains three positions in the Innovation Input Sub-Index and keeps its 6th spot in the Innovation Output Sub-Index. The pillar where the U.K. improves its rank is Business sophistication (12th), especially thanks to the gains in Knowledge absorption (24th). At the sub-pillar level, other significant increases are in Knowledge diffusion (16th), Investment (8th), and Creative goods and services (2nd). FDI inflows, market capitalization, cultural and creative services exports, and printing and other media manufactures are among the indicators that contributed to these improved ranks.[62] Despite these important gains, the U.K. loses between two and five positions in Institutions (14th), Human capital and research (8th), and Infrastructure (7th). Items such as ease of getting credit, expenditure on education, and ICT services imports and exports lose the most positions. The U.K. maintains its 1st spot in

Figure 6.
Large high-income economies, and upper-middle income China, overshadow small countries in absolute innovation performance

Source: Authors, researchers and R&D expenditures based on the UNESCO Institute for Statistics (UIS) database; Patents by origin based on WIPO Statistics Database; Scientific and technical publications based on Clarivate Analytics, special tabulations from Thomson Reuters, Web of Science, Science Citation Index (SCI), and Social Sciences Citation Index (SSCI).

quality of scientific publications, government's online service, and e-participation; it loses its 1st spot in ICT and business model creation. Thanks to its historic universities and the quality of its scientific publications, the U.K. is still the 5th world economy in quality of innovation (see Box 5 on the quality of innovation).

Singapore moves up two positions and takes the 5th spot this year. It keeps its top spot in the Innovation Input Sub-Index and gains two positions in the Innovation Output Sub-Index (15th). Singapore ranks in the top 5 in all input pillars, confirming its 1st position in Institutions and gaining a top rank in Human capital and research too, although this is partly due to data becoming unavailable on two indicators—government funding per pupil and school life expectancy. It also holds 2nd position in Business sophistication. In terms of innovation outputs, Singapore maintains its 11th position in Knowledge and technology outputs, while losing three spots in Creative outputs (35th). At the sub-pillar level, Singapore still holds a top rank in Political environment, Regulatory environment, and Tertiary education, while losing it in Investment (2nd this year). Indicators identified as relative weaknesses include expenditure on education, pupil-teacher ratio, environmental performance, productivity growth, and trademarks and industrial designs by origin. Apart from these areas of opportunity, Singapore keeps its 1st place in various indicators, including government effectiveness, regulatory quality, PISA results, IP payments, and FDI outflows. This year Singapore also gains (or re-gains) a top rank in five other indicators: political stability and safety, market capitalization, FDI inflows, high- and medium-high-tech manufactures, and high-tech exports.

The United States of America (U.S.) ranks 6th in the GII this year. Its position deteriorates in both the innovation input and output sides, losing one and two positions in the Innovation Input Sub-Index (6th) and Output Sub-Index (7th) respectively. At the pillar level, the U.S. loses ground in Human capital and research (21st), Infrastructure (24th), and Creative outputs (14th). In Human capital and research, Tertiary education (88th) moves down mainly because data on tertiary enrolment for the U.S. were unavailable this year. In Infrastructure, General infrastructure (21st) is the sub-pillar that loses most spots, with gross capital formation dropping by 10. In Creative outputs, Online creativity (19th) moves down 12 positions as a result of the substitution of the indicator video uploads on YouTube (where the U.S. ranked 1st last year) with a new variable, mobile app creation (14th). Despite these downward movements, the U.S. remains among the largest world contributors in all dimensions of innovation inputs and outputs, including R&D expenditures, patent applications by origin, and scientific and technical publications (see Figure 6). The U.S. also keeps its top ranking in pillar 4—Market sophistication—and improves its position in Institutions (13th) and Knowledge and technology outputs (6th), where it gains 3rd spots in Business environment and Knowledge impact. In the former, it improves in both its indicators. In the latter, the U.S. keeps its 1st place in computer software spending while improving in high- and medium-high-tech manufactures. Other sub-pillars where the country makes some progress are Regulatory environment (12th), ICTs (10th), Knowledge creation (6th), and Intangible assets (35th). The country holds the top rank in many important indicators, including global R&D companies expenditures, quality of universities, venture capital deals, state of cluster development (see also the special section on clusters, which shows that the U.S. has largest number of clusters in the world), quality of scientific publications, computer software spending, IP receipts, ICTs and organizational model creation, and cultural and creative services exports. It also gains a top rank in entertainment and media market.

Finland moves up to 7th position this year from 8th in 2017. Finland's upward movement is the result of improvements on the innovation output side that more than compensate for the drops on the input side. Indeed, Finland drops one spot in the Innovation Input Sub-Index (5th) and gains five positions in the Output Sub-Index (8th). On the input side, it loses between nine and two positions in Human capital and research (4th), Infrastructure (17th), and Market sophistication (15th). At the sub-pillar level, 7 out of 15 input sub-pillars move down, while the sub-pillar Innovation linkages moves from the 5th to the 2nd position. The largest drops are in Investment (15th), Ecological sustainability (39th), and Knowledge absorption (15th). On the output side, Finland gains two positions in Knowledge and technology outputs (8th) and seven positions in Creative outputs (11th). Finland maintains a top spot in patent families and also gains the 1st rank in PCT patent applications by origin and IP receipts and the 2nd rank in the newly introduced indicator, mobile app applications. Weak indicators include pupil-teacher ratio, gross capital formation, GDP per unit of energy use, ease of getting credit, and creative goods exports.

Denmark ranks 8th in this year's GII, dropping two positions from last year. This downward

BOX 3

Do small countries unduly top innovation rankings? They don't.

Whether small countries unduly lead innovation rankings is a legitimate question. This question is regularly brought up as part of technical discussions about innovation rankings or, indeed, any rankings on topics ranging from connectivity to competitiveness.[1]

A look at the 2018 league table of the Global Innovation Index (GII) confirms the surprising presence of a number of countries or economies with small populations, small geographic sizes, or—when compared with large ones such as the United States of America (U.S.) or China—relatively small economies as defined by gross domestic product (GDP). Among the GII top 20, one can find, for example, the Netherlands, the Nordic EU countries,[2] Singapore, Israel, and Luxembourg—in spite of the fact that large economies such as the U.S., Germany, and now China are also part of this top-ranked group. Small economies are equally present among the top-ranked economies in the World Economic Forum's Global Competitiveness Index and the International Telecommunication Union's ICT Development Index, for instance.[3]

Beyond the mere observation that these economies score high, there are at least two reasons to suspect a 'small country advantage'.

- The first reason relates to sheer size issues and the characteristics of innovation systems, which might advantage small countries to perform better at innovation, mostly as a result of agglomeration effects. In country rankings, averages in terms of innovation metrics and not the top scores of the country's most innovative cities or regions are used to assess innovation performance. This might favour really small economies or city states because geographic differences or innovation imbalances are often less accentuated in small economies than in large ones, so a more uniform performance on innovation inputs and outputs prevails across their territories. This holds true for economies with small populations such as Cyprus, Honk Kong (China), Luxembourg, Malta, and Singapore. The small size advantage is most glaring in infrastructure or ICT indices. Connecting households in large, less densely populated territories to broadband, for example, is frequently harder than it is in small city states or small countries. In the case of innovation, a series of spatial factors (e.g., distance, density, factor mobility, governance structure) may facilitate the accumulation, transfer, and absorption of knowledge and increase innovation potential.

  Large countries in turn often have top innovation clusters with top innovation performance, but other regions are less endowed. Take the U.S. It achieves top scores in education, quality of research, excellence of start-ups, and most innovation inputs and outputs in its top innovation clusters such as Silicon Valley. If parts of California or Boston were countries, they could top most, if not all, innovation rankings. Nonetheless, the national performance of the U.S. as measured in the GII is based on average performance across all U.S. states, which is naturally lower. As a result, the U.S. scores lower than Switzerland in the GII.

- The second reason to suspect a small country advantage is more a measurement issue. To make economies comparable in international rankings, composite indices typically scale many if not all of the underlying input and output performance data by size factors. The idea is not to compare absolute innovation inputs or outputs; the objective is to compare relative innovation intensity and performance. For example, rather than comparing the number of researchers or patents from Germany or China directly to the numbers from Iceland and Luxembourg, these data are scaled by population or GDP.[4] The key assumption behind the scaling approach is that there is a (log) linear or proportional relationship between country size and innovation performance. Arguably, however, this proportionality assumption might not be always true, with biases possible in either direction.

Whether or not these two factors actually lead to a significant small country bias or advantage is an empirical question.

For this edition of the GII and based on the 2017 dataset, the statistical independence of the GII score and the GII ranks relative to country size (proxied by population size—but also product and trade diversification, which are proxies for the homogeneity of the country's economic structures) was tested. The core findings of this analysis, described more fully in a paper on uncovering the effects of country-specific characteristics on innovation performance on the GII website,[5] are as follows:

- All editions of the GII demonstrate the positive link between innovation performance and the economy's level of development as measured by GDP per capita, aka the 'GII bubble chart' (Figure 9). In other words, the top-ranked economies, whether large or small, are mostly high-income countries at higher levels of development. What drives which side of the equation is a chicken-and-egg causality dilemma: across countries, higher levels of economic development are associated with higher levels of innovation; and more innovation is associated with higher levels of economic development.
- Turning to the size factors, country size as reflected by population size is not correlated with

the GII score in a statistically significant way. In contrast, when we look only at high-income economies, we note a positive and statistically significant correlation between country size and innovation performance, even when controlling for levels of development proxied by GDP per capita.[6]

When one simply plots the (log of) population of all countries covered in the GII 2017 and high-income countries only against their scores (see Figure 3.1) there appears to be a slight negative relationship between the two variables. However, this correlation is not statistically significant. To the contrary, when controlling for levels of development, a positive but non-significant correlation is seen between country size and innovation performance. Put simply: among all economies, a small size bias does not exist. In contrast, when one only looks at high-income economies, we note a positive and statistically significant correlation between country size and innovation performance when running tests for all relevant economies. In brief: among rich countries, and without implying causality, more densely populated larger economies score better on the GII (red line).[7]

When one deletes oil exporters among resource-rich economies, this finding also applies (pink line). In contrast, when one excludes 'small natural resource–endowed countries'—defined as resource-rich and having fewer than 5 million inhabitants, such as Bahrain or Trinidad and Tobago—mostly at the bottom left of Figure 3.1's high-income panel, the positive relationship becomes statistically insignificant (solid blue line).[8]

The analysis performed for this year's GII then turns to the question of whether countries with more homogeneous economies—that have less diverse sectors and fewer products, and a correspondingly less diversified export portfolio—perform better or worse in terms of innovation performance.

In a nutshell, this analysis finds a negative correlation between a country's GII score and its product concentration.[9] Quite intuitively, the more diversified a country's economy is, the better it does on innovation. When controlled for levels of development proxied by GDP per capita, however, this relationship is non-significant when all countries are included. It remains significant for the group of high-income countries alone. Put simply, and without implying causality, richer economies happen to be more innovative when their economic structures are more diverse.

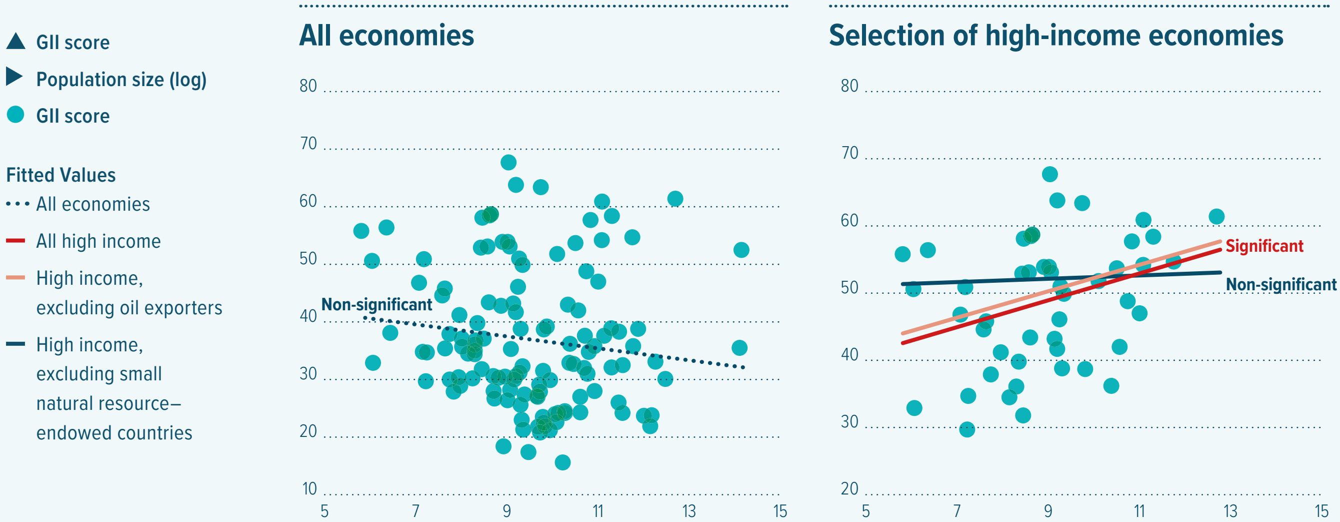
The same holds true for export product concentration but even more strongly.[10] There is a statistically significant and strong negative correlation between a country's GII score and its export product concentration. That is, the more diversified a country's export basket is, the higher its innovation performance as measured by its GII score. This is valid both for all countries and for high-income countries.

Notes

Notes for this box appear at the end of the chapter.

Figure 3.1: GII score vs population size: All economies and a selection of high-income economies

Source: Authors' calculations based on the GII 2017 database and World Population Prospects for population size, available at https://esa.un.org/unpd/wpp/.
Note: All economies panel includes 127 economies; Selection of high-income economies panel includes 48 economies.



movement halts a notable forward shift within the top 10 that began in 2015. This year Denmark loses one spot in both the Innovation Input and Output Sub-Indices, where it ranks 7th and 13th respectively. Downward movements in two input pillars—Human capital and research (6th) and Business sophistication (14th)—contribute to Denmark's fall. The country, however, improves in Knowledge and technology outputs (15th, up one). At the sub-pillar level, Denmark gains the most positions in Knowledge impact (22nd), Knowledge absorption (26th), and Political environment (9th). It ranks in the top 3 in a number of indicators, including researchers, ICT use, environmental performance, and scientific and technical publications. It also achieves a good rank in the new indicator, mobile app creation. Opportunities for further improvement still exist, notably in Tertiary education (25th), General infrastructure (43rd), Trade, competition, and market scale (37th), and Knowledge absorption (26th). As in previous years, relatively weak indicators include graduates in science and engineering, gross capital formation, utility models by origin, productivity growth, and trademarks by origin.

Germany maintains its 9th spot this year, keeping its 17th position in the Innovation Input Sub-index and gaining two places in the Innovation Output Sub-Index (5th). It ranks in the top 25 economies across all pillars and in the top 10 for both output pillars. This year Germany safeguards most of its respectable positions while improving in Institutions (16th), Infrastructure (19th), and Business sophistication (13th). In these three pillars it improves the most in Business environment (15th), Ecological sustainability (31st), Innovation linkages (14th), and Knowledge absorption (22nd). On the output side, Germany gains only in the sub-pillar Knowledge impact (17th, up four). As in previous years, Germany is 1st in logistics performance and patent applications by origin, 2nd in global R&D companies expenditures, and 3rd in state of cluster development and quality of scientific publications. Thanks to these excellent ranks, Germany maintains its 4th spot in the quality of innovation aggregate (Box 5). Despite these important achievements, the country has still opportunity for improvement in areas such as ease of starting a business, expenditure on education, gross capital formation, GERD financed by abroad, FDI inflows, productivity growth, new businesses, and printing and other media manufactures.

Ireland maintains its 10th position this year. On the input side, it improves in Infrastructure (4th) and Human capital and research (17th). On the output side, it gains one spot in Knowledge and technology outputs (4th) and loses six in Creative outputs (19th). As a result of these movements, Ireland exits the top 10 for the Innovation Efficiency Ratio, ranking 13th this year. Ireland ranks in the top 25 across all pillars except Market sophistication (29th), where it loses four positions. At the sub-pillar level, Ireland is still number 1 in Knowledge diffusion, thanks to its 1st spots in FDI outflows and ICT services exports. The country holds top positions in IP payments and FDI inflows and shows a better ranking than in 2017 in a number of important indicators, including tertiary enrolment, researchers, gross capital formation, environmental performance, and high-tech exports. Ireland shows weakness in some particular indicators, including expenditure on education, government funding per pupil, domestic credit to private sector, intensity of local competition, industrial designs by origin, and cultural and creative services exports.

The top 10 in the Innovation Input Sub-Index

The Innovation Input Sub-Index considers the elements of an economy that enable innovative activity across five pillars. The top 10 economies in the Innovation Input Sub-Index are Singapore, Switzerland, Sweden, the U.K., Finland, the U.S., Denmark, Hong Kong (China), the Netherlands, and Canada. Hong Kong (China) and Canada are the only economies in this group that are not also in the GII top 10.

Hong Kong (China) keeps the 8th spot in the Innovation Input Sub-Index this year and ranks 14th overall, up from 16th in 2017. It retains its good position in Market sophistication (2nd) and gains the 1st spot in Infrastructure. Hong Kong (China) improves also in Human capital and research (25th) and Business sophistication (15th), bringing all its input pillars into the top 25. The economy, however, falls seven positions in Institutions, where it moves to the 10th spot. While all the sub-pillars within Institutions move down, the fall in this pillar is also the result of the removal of the variable ease of paying taxes. In six of the 15 input sub-pillars, Hong Kong (China) ranks in the top 10, holding high spots in Regulatory environment (3rd), Ecological sustainability (2nd), Credit (2nd), and Knowledge absorption (3rd). It also gains several places in Education (52nd), thanks to its 2nd spot in PISA results and a newly available indicator, school life expectancy. Weak indicators on the input side include expenditure on education, global R&D companies expenditures, GERD financed by abroad, IP payments, and ICT services imports. Despite these weaknesses, Hong Kong (China) ranks in the top 3 in a number of important indicators, including regulatory quality, ease of starting a business, PISA results, GDP per unit of energy use, market capitalization, JV-strategic alliance deals, high-tech imports, and FDI inflows.

Canada remains in the 10th position in the Innovation Input Sub-Index, maintaining also its 18th spot in the GII rankings. Canada's strength on the input side is a result of having top 25 rankings in all input pillars. Canada shows particular strengths in Institutions (5th) and Market sophistication (3rd), while further improving in Human capital and research (18th). Top 10 sub-pillar rankings for Canada this year are all Institution sub-pillars—Political environment (5th), Regulatory environment (8th), and Business environment (5th); all Market sophistication sub-pillars—Credit (8th), Investment (1st), and Trade, competition, and market scale (7th); and General infrastructure (8th). All these sub-pillars are also identified as relative strengths for Canada. At the indicator level, Canada keeps top 3 ranks in ease of starting a business and venture capital deals.

The top 10 in the Innovation Output Sub-Index

The Innovation Output Sub-Index variables provide information on elements that are the result of innovation within an economy. Although scores on the Input and Output Sub-Indices might differ substantially, leading to important shifts in rankings from one sub-index to another for particular countries, the data confirm that efforts made to improve enabling environments are rewarded with better innovation outputs. The top 10 economies in the Innovation Output Sub-Index this year are Switzerland, the Netherlands, Sweden, Luxembourg, Germany, the U.K., the U.S., Finland, Ireland, and China.

The 10 economies leading the Innovation Output Sub-Index remain broadly consistent with their rankings in 2017, with few shifts and two substitutions: Germany moves upward within the top 10, while the U.S. and Ireland move downward. Finland and China enter the top 10, while the Republic of Korea and Iceland exit. Eight of these economies are ranked in the GII top 10; the profiles of the other two economies, Luxembourg and China, are discussed below.

Luxembourg ranks 4th in the Innovation Output Sub-Index in 2018 and 15th in the overall GII. On the output side, Luxembourg gains one position in Knowledge and technology outputs (14th) and loses the 1st place in Creative outputs (2nd this year). At the indicator level, the country maintains its strengths in cultural and creative services exports, national feature films, and generic top-level domains (TLDs); it also gains strength in PCT patent applications by origin, FDI outflows, and ICTs and business model creation. The only weak indicator among Luxembourg's output indicators is creative goods exports.

China attains 10th position in the Innovation Output Sub-Index this year, up by one from 2017. Indeed, it is the first time that China enters a top 10 ranking in one of the main indices of the GII. China also gains many spots in the GII ranking, moving up to the 17th place this year (see also Box 4 on the innovation divide). Its weight in both the input and output sides of the innovation process is huge. As Figure 6 shows, in absolute terms, China's number of patent applications by origin and scientific and technical publications, as well as its number of researchers, is the highest in the world. China ranks 5th in Knowledge and technology outputs, down one from last year, and gains five spots in Creative outputs (21st). In Knowledge and technology outputs, it moves up in Knowledge creation (4th, up one place) and Knowledge diffusion (22nd, up two places), but loses one position in Knowledge impact (2nd). These positive movements are due in particular to some variables, such as scientific and technical publications (up 12), as well as FDI outflows, computer software spending, and ISO 9001 quality certificates. In the same pillar, China ranks 1st in several important indicators: patents and utility models by origin and high-tech exports. In Creative outputs, China goes up in all sub-pillars, especially in Online creativity (84th, up 20 positions). Looking at single indicators within Creative outputs, China keeps its top spot in two indicators—industrial designs and creative goods exports—and gains the 3rd spot in trademarks by origin. Thanks to these good ranks, the country maintains its first spot among middle-income economies in the quality of innovation aggregate (for more details, see Box 5). Areas of improvement that could help China progress in its rise in the GII ranks are cultural and creative services exports, national feature films, printing and other media manufactures, and Wikipedia edits.

[2018] is the first time that China enters a top 10 ranking in one of the main indices of the GII.

BOX 4

The global innovation divide

With the single exception of China—an upper-middle income economy—a stable group of high-income economies composes the top 25 of the GII.[1] China entered this group in 2016 and has consistently moved up in the rankings to reach 17th place this year. Methodological changes to the GII aside, China's innovation prowess is evident in various areas; it shows some of its strongest improvements in global R&D companies, high-tech imports, the quality of its scientific publications, and tertiary enrolment. China also improves its performance in various key areas of innovation (see Figure 6 and the discussion on the top 10 in this chapter's main text). In particular, China's score in Knowledge and technology outputs continues to be above that of the top 10 group average. This year the difference in scores between China and the top 10 is closing in Institutions, both Market and Business sophistication, and Creative outputs, but it is increasing in Human capital and research and Infrastructure. Within the 11–25 group, China continues to perform above its peers in Business sophistication and Knowledge and technology outputs.

The distance between the top 25 group and the groups that follow remains evident. Figure 4.1 shows the average scores for six groups: (1) the top 10, composed of all high-income economies; (2) ranks 11 through 25, which are also all high-income economies with the sole exception of upper-middle-income China; (3) other high-income economies; (4) upper-middle-income economies; (5) lower-middle-income economies; and (6) low-income economies.

The top 10 and the rest of the top 25

The performance of the top 10 economies continues to be above that of all other economies in the top 25 in most indicators. Yet various economies in the 11 through 25 group show scores above those of the top 10 in at least one pillar. Hong Kong (China) (14th) is the sole economy in that cluster that shows scores higher than those of economies in the top 10 in three pillars: Institutions, Infrastructure, and Market sophistication. Conversely, France (16th) and Belgium (25th) are the only two economies in this cluster with scores below those of the top 10 in every pillar.

This year the Czech Republic drops out of the top 25 group; improved scores in Business environment and a consistent strength in Human capital and research puts Belgium back in the group. In this group Israel (11th) is the fastest mover closing into the top 10. This year Israel's score in Business sophistication is not only above the average of the top 10 but also above that of number 1 ranked Switzerland.

Middle-income economies: China alone in the top 25 with Malaysia and Bulgaria edging closer

Aside from China, which is already in the top 25, the only middle-income economies that continue to edge closer to this group are Malaysia (35th) and Bulgaria (37th). This year Malaysia moves ahead in the rankings with strengths in Tertiary education, Knowledge diffusion, and Creative goods and services. In particular, Malaysia shows top 5 rankings for graduates in science and engineering, ease of protecting minority investors, high-tech imports and exports, and creative goods exports.

Aside from Malaysia and Bulgaria, the divide between the top 11 through 25 group and the other high-income economies and the upper-middle income group remains as wide as in previous years. In most pillars—with the two exceptions of Institutions and the Human capital and research—partly driven by potential methodological considerations, this difference is actually larger than the divide noted in 2017. The few economies in the upper-middle-income group that are among the top 50 are Croatia (41st), Thailand (44th), the Russian Federation (46th), Romania (49th), and Turkey (50th). Lower-middle-income countries in the top 50 are Ukraine (43rd), Viet Nam (45th), and the Republic of Moldova (48th). Among these, Thailand, the Islamic Republic of Iran (65th), and Viet Nam are three middle-income economies noted as climbing in the rankings since 2016. The consistent improvement in performance that is evident in Institutions, Human capital and research, Knowledge and technology outputs (Thailand); in Institutions, Knowledge and technology outputs, and Creative outputs (the Islamic Republic of Iran); and in Institutions for Viet Nam is behind these advances.

Top performers by income group

Analysing economies in relation to their income-group peers can illustrate important relative competitive advantages and help decision makers glean important lessons for improved performance that are applicable on the ground. The GII also assesses results relative to the development stages of countries. This assessment is shown in Figure 7.

Table 1 shows the 10 best-ranked economies in each index by income group. Switzerland, the Netherlands, and Sweden are among the high-income top 10 on the three main indices, and the top 3 in one of them—the Innovation Output Sub-Index.

Interestingly, only a few of these countries perform above the high-income group average—and this occurs in only four pillars. Croatia and the Russian Federation perform higher in Infrastructure; Thailand, South Africa (58th), Colombia (63rd), Peru (71st), Kazakhstan (74th), Mauritius (75th), Azerbaijan (82nd), and Albania (83rd) in Market sophistication; the Russian Federation, Colombia, and Brazil (64th) in Business sophistication; and Croatia, Thailand, Romania, and Islamic Republic of Iran in Knowledge and technology outputs.

Low-income economies show effort but lose momentum

This year the difference in performance between the low-income economies and the lower-middle-income group is less than the one noted in 2017 in four pillars: Infrastructure, Market sophistication, Knowledge and technology outputs, and Creative outputs. In addition, the low-income group performs above the lower-middle-income group in Institutions. Although this may reflect efforts to improve overall performance, a previously bridged gap between both of these groups in Business sophistication opens again this year. This could suggest that previously achieved gains in strengthening institutions might require revisiting in order to keep promoting stronger business environments.

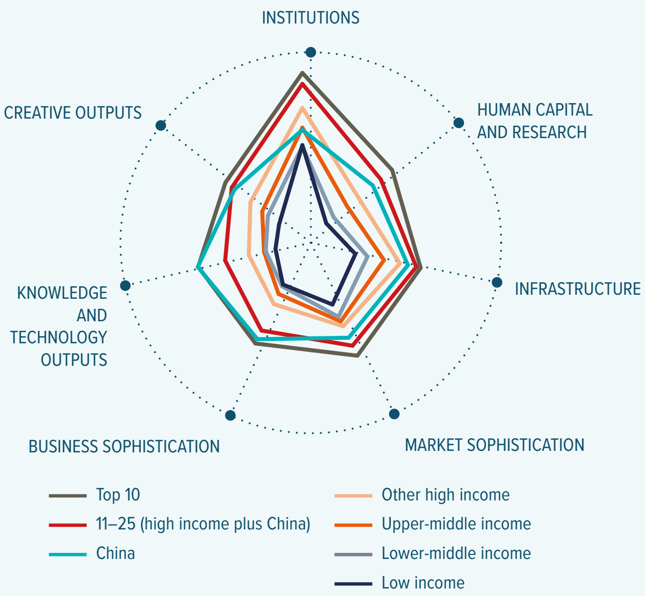
The regional innovation divide

Regional performance as measured by average scores shows that the Northern America is the top performing region (average score of 56.4, 2 economies) with top average scores for all pillars. This region, however, also shows the largest average score reduction this year, followed by Latin America and the Caribbean. Europe (46.67, 39 economies), catching up with Northern America, comes in 2nd, followed by South East Asia, East Asia, and Oceania (43.88, 15 economies), and Northern Africa and Western Asia (33.76, 19 economies). Latin America and the Caribbean (30.31, 18 economies) is in the 5th position, followed by Central and Southern Asia (28.24, 9 economies), and Sub-Saharan Africa (24.53, 24 economies).

This year these scores show that South East, East Asia, and Oceania has the greatest average improvement, followed by Central and Southern Asia, with improved scores in Institutions, Market sophistication, and Knowledge and technology outputs.

Figure 4.1: Innovation divide: Stable at top 10, China moving up

Source: Global Innovation Index Database, Cornell, INSEAD, and WIPO.



Note

1 The only non-European economies in the top 25 this year are Canada and the U.S. (Northern America); Israel (Northern Africa and Western Asia); Australia, Hong Kong (China), Japan, New Zealand, the Republic of Korea, and Singapore (South East Asia, East Asia, and Oceania).

Among the 10 highest-ranked upper-middle-income economies, nine remain from 2017: China (17th this year), Malaysia (35th), Bulgaria (37th), Thailand (44th), the Russian Federation (46th), Romania (49th), Turkey (50th), Montenegro (52nd), and Costa Rica (54th). The newcomer to this group of the 10 best upper-middle-income performers is Croatia (41st), which displaces South Africa (58th this year).

China, Malaysia, Bulgaria, Croatia, Thailand, Romania, and Montenegro are among the group's 10 best-ranked upper-middle-income economies across all three main indices and in the Innovation Efficiency Ratio.

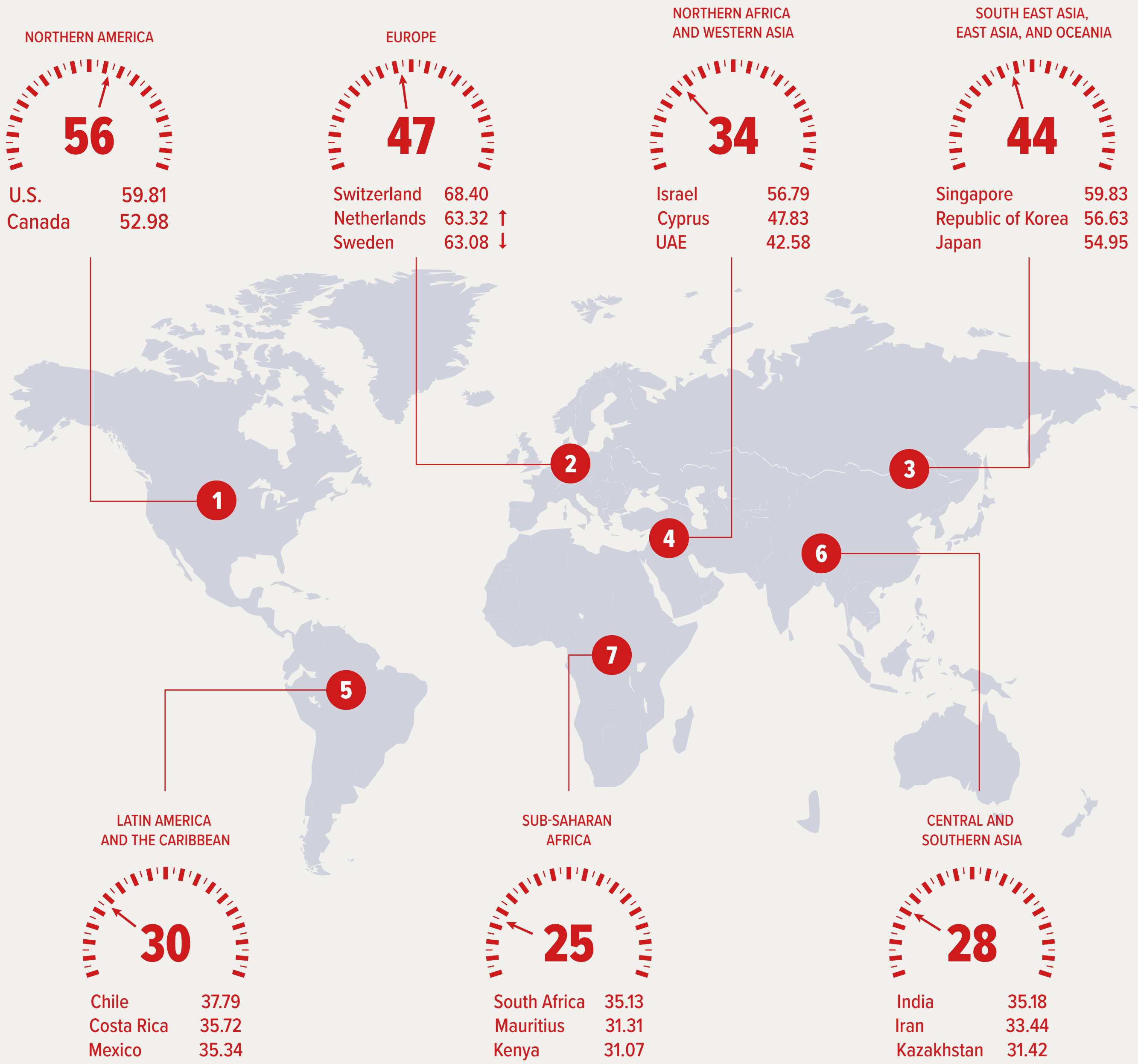
The same analysis for lower-middle-income countries shows that nine of the top 10 countries from 2017 remain in the top 10 this

Figure 7.

Global leaders in innovation in 2018

Every year, the Global Innovation Index ranks the innovation performance of nearly 130 economies around the world.

Top innovation regions by GII score



Innovation leaders by income group

HIGH INCOME (ABOVE $12,236)	UPPER-MIDDLE INCOME ($3,956–12,235)	LOWER-MIDDLE INCOME ($1,006–3,955)	LOW INCOME (UNDER $1,005)
Switzerland.......68.40	China.................53.06	Ukraine ....38.52 ↑	Tanzania............28.07
Netherlands......63.32 ↑	Malaysia.............43.16 ↑	Viet Nam .... 37.94 ↓	Rwanda.............26.54
Sweden............63.08 ↓	Bulgaria............42.65 ↓	Moldova........... 37.63 ★	Senegal............26.53

Source: Global Innovation Index Database, Cornell, INSEAD, and WIPO.

Notes: Position movements are indicated by arrows (↑↓), new entrants by stars (★). Regional averages appear in the centre of the dial. Economies are classified according to the World Bank Income Group Classification (July 2017). Year-on-year GII rank changes are influenced by performance and methodological considerations; some data are incomplete. See Annex 2.

Table 1: Ten best-ranked economies by income group (rank)

	Global Innovation Index	Innovation Input Sub-index	Innovation Output Sub-index	Innovation Efficiency Ratio
High-income economies (47 in total)				
1	**Switzerland (1)**	Singapore (1)	**Switzerland (1)**	**Switzerland (1)**
2	**Netherlands (2)**	**Switzerland (2)**	**Netherlands (2)**	Luxembourg (2)
3	**Sweden (3)**	**Sweden (3)**	**Sweden (3)**	**Netherlands (4)**
4	United Kingdom (4)	United Kingdom (4)	Luxembourg (4)	Malta (7)
5	Singapore (5)	Finland (5)	Germany (5)	Hungary (8)
6	United States of America (6)	United States of America (6)	United Kingdom (6)	Germany (9)
7	Finland (7)	Denmark (7)	United States of America (7)	**Sweden (10)**
8	Denmark (8)	Hong Kong (China) (8)	Finland (8)	Estonia (12)
9	Germany (9)	**Netherlands (9)**	Ireland (9)	Ireland (13)
10	Ireland (10)	Canada (10)	Israel (11)	Israel (14)
Upper-middle-income economies (34 in total)				
1	**China (17)**	**China (27)**	**China (10)**	**China (3)**
2	**Malaysia (35)**	**Malaysia (34)**	**Bulgaria (34)**	Iran, Islamic Rep. (11)
3	**Bulgaria (37)**	**Croatia (42)**	**Malaysia (39)**	**Bulgaria (19)**
4	**Croatia (41)**	Russian Federation (43)	**Croatia (42)**	Turkey (25)
5	**Thailand (44)**	**Bulgaria (44)**	Turkey (43)	**Thailand (33)**
6	Russian Federation (46)	South Africa (48)	**Thailand (45)**	**Croatia (37)**
7	**Romania (49)**	**Romania (49)**	Iran, Islamic Rep. (46)	Costa Rica (43)
8	Turkey (50)	Colombia (50)	**Romania (48)**	**Romania (47)**
9	**Montenegro (52)**	**Montenegro (51)**	Costa Rica (51)	**Malaysia (48)**
10	Costa Rica (54)	**Thailand (52)**	**Montenegro (55)**	**Montenegro (56)**
Lower-middle-income economies (30 in total)				
1	**Ukraine (43)**	Georgia (53)	**Ukraine (35)**	**Ukraine (5)**
2	**Viet Nam (45)**	**India (63)**	**Moldova, Rep. (37)**	**Moldova, Rep. (6)**
3	**Moldova, Rep. (48)**	**Viet Nam (65)**	**Viet Nam (41)**	Armenia (15)
4	**Mongolia (53)**	**Mongolia (66)**	**Mongolia (47)**	**Viet Nam (16)**
5	**India (57)**	**Ukraine (75)**	Armenia (50)	**Mongolia (30)**
6	Georgia (59)	Tunisia (77)	**India (57)**	Kenya (41)
7	Tunisia (66)	**Moldova, Rep. (79)**	Georgia (62)	Egypt (45)
8	Armenia (68)	Philippines (82)	Tunisia (63)	Pakistan (46)
9	Philippines (73)	Morocco (84)	Kenya (64)	**India (49)**
10	Morocco (76)	Kyrgyzstan (85)	Jordan (67)	Jordan (50)
Low-income economies (15 in total)				
1	**Tanzania, United Rep. (92)**	Rwanda (73)	**Tanzania, United Rep. (71)**	**Tanzania, United Rep. (31)**
2	Rwanda (99)	**Uganda (98)**	Madagascar (85)	Madagascar (40)
3	**Senegal (100)**	**Nepal (101)**	**Senegal (90)**	Zimbabwe (69)
4	**Uganda (103)**	**Senegal (102)**	Zimbabwe (99)	**Senegal (70)**
5	Madagascar (106)	**Tanzania, United Rep. (106)**	Mali (100)	Mali (73)
6	**Nepal (108)**	Benin (110)	**Malawi (108)**	**Mozambique (88)**
7	Mali (112)	**Malawi (111)**	**Mozambique (109)**	**Malawi (89)**
8	Zimbabwe (113)	**Mozambique (112)**	**Uganda (111)**	Guinea (102)
9	**Malawi (114)**	Niger (113)	**Nepal (114)**	**Nepal (107)**
10	**Mozambique (115)**	Burkina Faso (117)	Guinea (118)	**Uganda (108)**

Notes: Economies with top 10 positions in the GII, the Input Sub-Index, the Output Sub-Index, and the Innovation Efficiency Ratio within their income groups are highlighted in bold. Year-on-year GII rank changes are influenced by performance and methodological considerations; some country data are incomplete. See Annex 2.

year. These include Ukraine (43rd), Viet Nam (45th), the Republic of Moldova (48th), Mongolia (53rd), India (57th), Tunisia (66th), Armenia (68th), the Philippines (73rd), and Morocco (76th). New this year to the top 10 lower-middle-income countries is Georgia (59th), which displaces Kenya (78th). Five of the top 10 lower-middle-income countries—Ukraine, Viet Nam, the Republic of Moldova, Mongolia, and India—have rankings in the group's top 10 for each of the three indices and the Innovation Efficiency Ratio.

A strong consistency is also evident among low-income countries, with eight out of 10 economies remaining in the top 10 in this group. The United Republic of Tanzania remains the top-ranked low-income country (92nd), gaining four positions from last year. Following in the ranking of low-income countries are Rwanda (99th); Senegal (100th); Uganda (103rd); Madagascar (106th); Nepal (108th); Mali (112th), which takes the spot left by Ethiopia, which is not included in the GII this year; Zimbabwe (113th), which takes the place of Benin (121st); Malawi (114th); and Mozambique (115th). Ranking well across all main indices of the GII, the United Republic of Tanzania, Senegal, Uganda, Nepal, Malawi, and Mozambique are among the top 10 low-income countries. All economies in the low-income top 10, except Rwanda, are in the low-income top 10 in the Innovation Efficiency Ratio.

Effectively translating innovation inputs to outputs: The notion of innovation efficiency

How does one translate massive investments in education, a high number of qualified researchers, and high R&D expenditures into high-quality innovation outputs?

How do economies with severe budget constraints on the input side nevertheless manage to shine with a surprising number of innovation outputs?

These questions are a source of concern to most science and technology ministers and high-level policy makers. Some high-income countries—despite massive investment in innovation inputs—do not generate a correspondingly high level of innovation outputs. In turn, some low- and middle-income countries manage to generate a comparatively high level of innovation outputs despite a more frugal approach to spending on inputs.

Over the years, the GII has made a number of attempts to determine how economies effectively translate innovation inputs into innovation outputs. One effort is encapsulated in the so-called Innovation Efficiency Ratio—simply calculated as the ratio of the Output Sub-Index score over the Input Sub-Index score. The Innovation Efficiency Ratio constitutes an important contribution to understanding the relationship between inputs and outputs, possibly shedding light on the effectiveness of innovation systems and policies.

The 10 countries with the highest Innovation Efficiency Ratios are countries that combine certain levels of innovation inputs with more robust output results (see Table 1 on the best-ranked economies by income group): Switzerland, Luxembourg, China, the Netherlands, Ukraine, the Republic of Moldova, Malta, Hungary, Germany, and Sweden. New lower- and upper-middle-income economies have joined the top 10 most efficient economies this year: the Republic of Moldova and Ukraine are now part of this group. Although Turkey and Viet Nam exit, Viet Nam continues to be within the top 20. Among upper-middle-income economies, the Islamic Republic of Iran and Bulgaria are in the top 20 in terms of efficiency. Aside from Viet Nam, and from the lower-middle-income group, the top 20 includes Armenia.

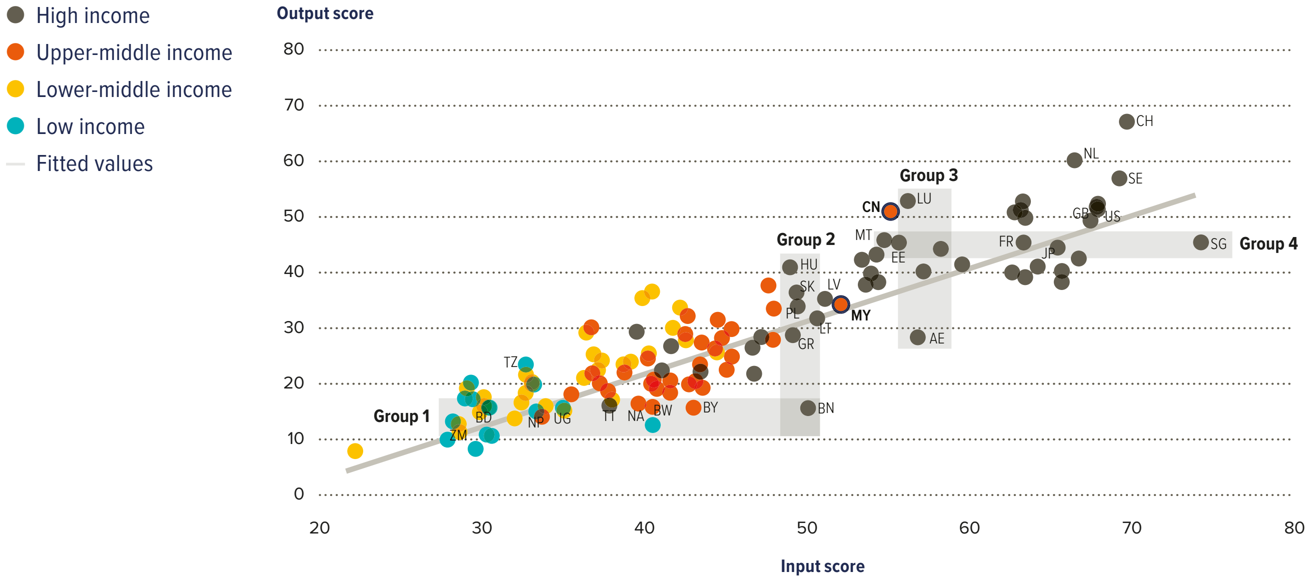
That said, using this ratio to form a cross-country ranking of innovation efficiency has to be taken with a grain of salt.

First, economies might reach a relatively high Innovation Efficiency Ratio as a result of particularly low input scores.[63] As a result, the ratio must be analysed jointly with GII, Innovation Input Sub-Index, and Innovation Output Sub-Index scores, and with the development stages of the economies in mind. Second, this ratio assumes a rather linear relationship between inputs and outputs, which is rarely the case in practice. As evidenced by the many economies that struggle to convert inputs effectively into outputs, sound innovation ecosystems and their successful workings continue to be more like a black box than a function of the ratio of inputs to outputs. Third, from a statistical perspective, taking the ratio of two indices and plugging in the uncertainty bounds for each index (in this case, the input and output sides) results in efficiency ratios that are volatile with high uncertainty bounds that complicate the ability to distinguish the performance between many countries in a relevant way (see the JRC audit in Annex 3).

Another approach, which is more statistically fitting, is to plot the Input-Output performance in a way similar to the way we plot GII scores against the economies' level of development (aka the 'Bubble Chart', see Figure 9; see also Figure 2 in Chapter 1 of the GII 2012 for the same Innovation Output Sub-Index vs. Innovation Input Sub-Index ratio).

Figure 8.

Innovation Output Sub-Index score vs Innovation Input Sub-Index score by income group, 2018



Source: Global Innovation Index Database, Cornell, INSEAD, and WIPO.

Notes: This figure and the related analysis benefited strongly from the comments of our colleagues at the JRC, in particular Michaela Saisana. China and Malaysia (highlighted) are two upper-middle-income economies that manage to move into the high-income group in both innovation input and output. ISO-2 codes are used to identify economies; see page 37 for a list of the codes.

Many of economies covered do indeed sit on the projected line that neatly predicts a linear output-to-input ratio (Figure 8). As expected, high-income economies sit more towards the right, whereas low-income economies sit to the left. But there are important outliers that strongly over- or under-deliver with respect to their efficiency in obtaining outputs for inputs.

First, there are marked differences among high-income countries (ISO-2 codes are provided for countries that are identified in Figure 8). Switzerland (CH), the Netherlands (NL), Sweden (SE), Germany, Ireland, Luxembourg (LU), and also Hungary (HU) stand out for producing many outputs for their given level of inputs. Singapore (SG), Australia, Japan (JP), Hong Kong (China), Canada, New Zealand, and Norway, as well as many resource-rich economies such as the United Arab Emirates (AE), Brunei Darussalam (BN), Saudi Arabia, Qatar, Bahrain, Oman, and Trinidad and Tobago (TT), stand out as high-income economies that—assuming that both inputs and outputs are properly measured—tend to get less 'bang for their buck' (see also Box 3 on country size).

Second, a few upper- and lower-middle economies stand out. Two upper-middle income countries—China (CN) and Malaysia (MY)—manage to move into the group of high-income countries in both innovation input and innovation output, although China strongly overperforms in the said efficiency relationship, whereas Malaysia slightly underperforms. Among lower-middle economies, Ukraine, the Republic of Moldova, and Viet Nam (and other countries such as Armenia, Mongolia, Egypt, and Pakistan) stand out as performing better than would be expected by their income level, whereas Kyrgyzstan, El Salvador, and the Plurinational State of Bolivia underperform.

Third, analysing economies at similar levels of innovation inputs or outputs provides interesting policy insights and comparisons:

- Group 1 countries in Figure 8, for example, have almost identical innovation output scores but rather different innovation input scores. For instance, high-income Trinidad and Tobago (TT) and upper-middle-income countries Namibia (NA), Botswana (BW),

BOX 5

Measuring the quality of innovation

Measuring the quality of innovation-related input and output indicators is essential to understanding their significance. To this end, three indicators were introduced into the GII in 2013: (1) quality of local universities (indicator 2.3.4, QS university ranking, average score of top 3 universities); (2) internationalization of local inventions (indicator 5.2.5, patent families filed in three offices, changed to patent families filed in at least two offices in the GII 2016); and (3) the number of citations that local research documents receive abroad (indicator 6.1.5, citable documents H index). Figure 5.1 shows how the scores of these three indicators add up and captures the top 10 highest performing high- and middle-income economies.

Top 10 high-income group: Japan and Switzerland on top, France in for first time

The top 5 high-income economies in the quality of innovation in 2018 are Japan, Switzerland, the United States of America (U.S.), Germany, and the United Kingdom (U.K.). This year both Japan and Switzerland move ahead of the U.S. in innovation quality. While Japan reclaims the top spot in innovation quality—the position it held in 2016—Switzerland reaches 2nd position for the first time. The Republic of Korea moves up, overtaking Sweden this year, while France enters the top 10 for the first time, with Denmark exiting.

In 2018 Japan gains ground in the quality of its universities with a higher overall score for its three best universities: the University of Tokyo, Kyoto University, and Tokyo Institute of Technology. The country also shows improvement in the quality of its publications. Japan also shares the top score in patent families among high-income economies—it is tied with Switzerland, the Republic of Korea, and Finland.

Since 2017 Switzerland has been among the highest-scoring high-income economies in patent families, and this year it remains one of the world leaders in this indicator. Its scores for the quality of its top three universities—the Swiss Federal Institute of Technology (ETH Zurich), École polytechnique fédérale de Lausanne (EPFL), and the University of Zurich—and the quality of its scientific publications have remained relatively stable over the last five years.

A factor behind the downward movement of the quality of innovation in the U.S. is that the country's score in patent families drops this year—it has been around half of Japan's score for the last two years. The U.S., along with the U.K., has been the top economy in the quality of scientific publications since 2013. For the third year in a row, the U.S. outranks the U.K. in the quality of its universities, taking the 1st place in this indicator globally thanks to top scores for Massachusetts Institute of Technology (MIT), Stanford, and Harvard University.

Germany retains the 4th spot in the quality of innovation, ahead of the U.K. A moderately enhanced quality of universities—led by the Technical University of Munich (TUM), the Ludwig Maximilian University of Munich, and Heidelberg University—along with improved performance in patent families helps Germany remain the 4th economy in the quality of innovation globally. In the latter indicator, Germany scores above the U.S. as well as the U.K., the Netherlands, and France. The U.K. again takes the 5th position in innovation quality: it retains 1st place in the quality of its universities and improves its score in patent families, where the country is 21st among the high-income group for second consecutive year. Its lower absolute scores for its top three universities—Cambridge, Oxford, and University College London—result in a lower overall score in that variable.

The Republic of Korea moves one position above Sweden to 6th, echoing its 2016 quality of innovation ranking. This year not only does this country maintain the highest score in patent families but also improves its performance in the quality of its scientific publications and the quality of its universities, assisted by high scores for Seoul National University, the Korea Advanced Institute of Science and Technology (KAIST), and Pohang University of Science and Technology (Postech). Sweden, on the other hand, improved its score in patent families while also showing a slight reduction in score in the quality of scientific publications and the quality of universities, the result of reduced scores for Lund and Uppsala Universities.

The Netherlands remains 8th for second consecutive year and increasing its scores in all three quality components. The most noticeable improvement for this country comes from patent families, where it ranks 10th globally. The quality of its universities also shows progress, with higher scores for Delft University of Technology, the University of Amsterdam, and Eindhoven University of Technology. This year France enters the high-income top 10 group at 9th place, with scores for patent families above those of the U.K. and for the quality of its scientific publications above those of Switzerland. France also benefits from a high score for the quality of its universities boosted by those for École Normale Supérieure, Paris (ENS); École Polytechnique; and the Pierre and Marie Curie University (UPMC) this year.

Denmark drops out of the high-income top 10 in 2018, standing now at the 13th position globally. In addition to France and Finland's enhanced performance, this is the result of improved scores in patent families and the quality of scientific publications for Canada (11th) and in the quality of universities and patent families for Israel (12th). Finland stays in the top 10 for the second consecutive year with a top score in patent families and an improved score for the quality of scientific publications.

Top 10 middle-income economies: China and India lead with the gap narrowing; Mexico and Malaysia up the most

Among the middle-income group, the top 5 remain steady with China, India, and the Russian Federation at the top, followed by Brazil and Argentina. Mexico and Malaysia are advancing the most in this group.

Although more than half of the countries in the top 10 middle-income group move up in the quality of innovation rankings this year, most of their scores are still significantly below those of the countries in the top 10 high-income group. Without China, the difference in average scores between these two groups is expanding in quality of universities (29.15) and quality of scientific publications (25.59), and more dramatically in patent families (33.13).

China remains the top middle-income economy for sixth consecutive year and is the only country closing the gap with the high-income group, especially in patent families (29th) and quality of scientific publications (14th). In the quality of scientific publications and the quality of its universities, China performs above the high-income group average, and, in the latter indicator, above the score of top-ranked Japan. This reflects the high-quality scores achieved by Tsinghua, Peking, and Fudan Universities this year. Nonetheless, China moves down one position to 17th in the overall quality ranking in 2018, mostly because Austria moves ahead of both Belgium and China.

Although the majority of middle-income group economies depend on the quality of their universities to improve their overall quality of innovation, China is the one middle-income country that shows a more balanced distribution among the three quality components. Other middle-income economies that are beginning to show such balanced distribution this year are South Africa, India, the Russian Federation, Malaysia, and Turkey.

India is 2nd among the middle-income economies for the third consecutive year, with rankings that are edging slightly closer to those of China. This year India remains 2nd in both the quality of its universities and the quality of its scientific publications among middle-income economies. This is possible because of an improved quality of scientific publications and the high quality of university scores for the Indian Institute of Science Bangalore and the Indian Institute of Technology—both Delhi and Bombay. Although India's score for patent families drops slightly in 2018, its overall performance in this indicator still drives it up to the 5th position in the group.

The Russian Federation remains 3rd in the middle-income group, moving up to 27th overall. Although showing a reduction in patent families, the country achieved better performance in the quality of its scientific publications and higher scores for its top three universities: Lomonosov Moscow State University, Saint-Petersburg State University, and Novosibirsk State University.

Brazil is stable as the 4th middle-income economy in the quality of innovation and the 28th overall this year. It is also the highest ranked from Latin America and the Caribbean. Although its score for patent families decreases slightly this year, its improved scores for the University of São Paulo, University of Campinas, and Federal University of Rio de Janeiro, along with a higher quality of scientific publications score, moves it up one position in the overall quality rankings.

Argentina also remains stable in this top 10 group at 5th, moving up one position to 29th in the overall quality rankings. Mexico follows as the 3rd middle-income country in Latin America and the Caribbean, reaching the 6th position. This is the only movement among the top 10 middle-income economies in 2018. Behind this movement are a higher Mexican score for patent families, an improved quality of scientific publications, and better scores for its National Autonomous University of Mexico (UNAM) and the Monterrey Institute of Technology and Higher Education (ITESM).

Although not in the top 10 in either group, Chile and Colombia are the closest other Latin American countries, respectively at 35th and 44th position globally. While all countries in Latin America and the Caribbean in the top 10 perform relatively well in the quality of their universities, they are relatively weak in patent families.

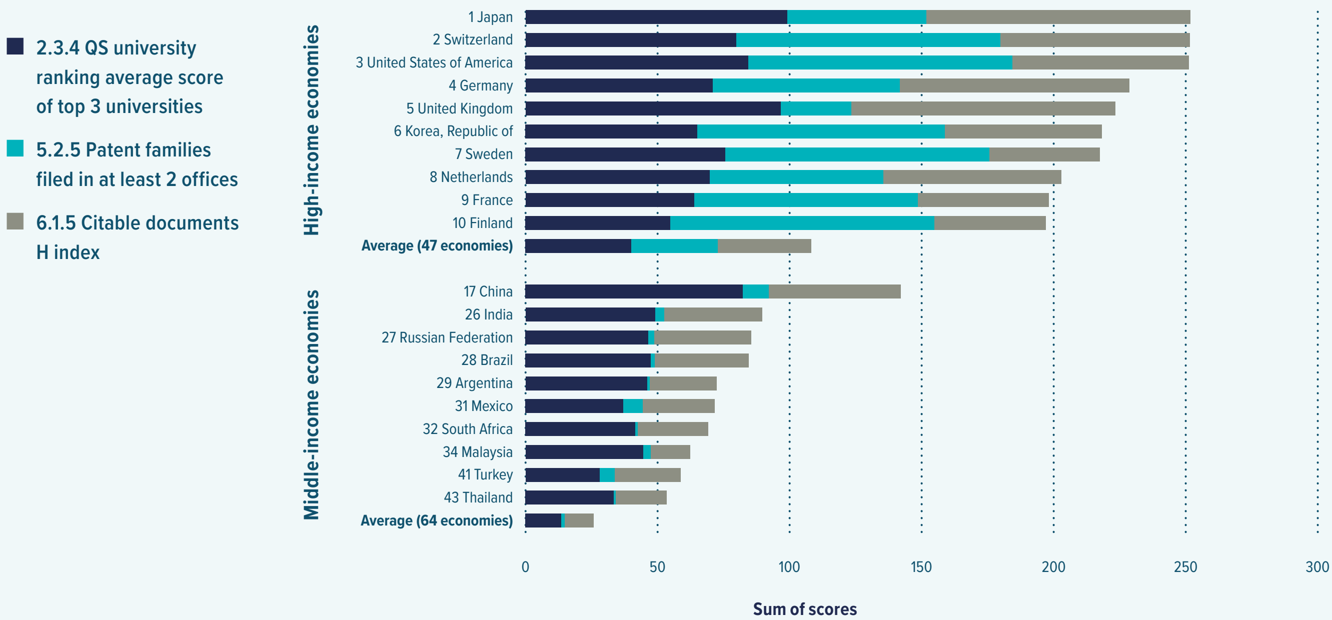
This year South Africa, 7th among middle-income economies, shows a reduced score for patent families, although it displays improvement in both the quality of its universities (with better scores for the University of Cape Town, the University of Witwatersrand, and Stellenbosch University) and a higher quality of scientific publications. Malaysia (34th) shows improvement in its quality of universities with higher scores for both Malaya University (UM) and Putra Malaysia University (UPM); it also has a higher quality of scientific publications score.

In future editions of the GII, and taking note of the fact that many advanced countries want to move beyond quantity to quality, this set of indicators will be refined.

Figure 5.1: Metrics for quality of innovation: Top 10 high- and top 10 middle-income economies

Source: Global Innovation Index Database, Cornell, INSEAD, and WIPO.

Note: Numbers to the left of the economy name are the innovation quality rank. Economies are classified by income according to the World Bank Income Group Classification (July 2017). Upper- and lower-middle income categories are grouped together as middle-income economies.



and Belarus (BY) all show innovation outputs at a level similar to that of low-income countries such as Uganda (UG) and Nepal (NP). Furthermore, Tanzania (TZ), a low-income country, is particularly noteworthy for achieving high innovation output scores relative to its input scores.

- Groups 2 and 3 harbour high-income countries with almost identical innovation inputs but with very different levels of innovation output. In group 2, Brunei Darussalam (BN) is the only high-income country with an innovation input score equivalent to that of Hungary (HU) (which is an outlier among the outperformers) and an innovation output score similar to that of Bangladesh (BD) (which performs relatively better for its level of innovation input). Other high-income economies in this group that relatively underperform in their innovation output are Greece (GR) and Lithuania (LT); those that relatively overperform are Latvia (LV), Poland (PL), and Slovakia (SK). Similarly, for group 3, the United Arab Emirates (AE) is the outlier in underperformance and Luxembourg (LU) is the outlier in overperformance.
- Group 4 consists of countries with the same income level (high) and the same level of output but very different levels of input. In this group, a noteworthy example is Estonia (EE), which, with lower levels of input, produces an innovation output score that is the equivalent of some top 20–ranked high-income countries such as France (FR) and Japan (JP).

A total of 20 economies compose the group of innovation achievers—three more than last year.

Even this analysis has to be used with caution. The fact of the matter is that we are still considerably better at measuring innovation inputs (and increasingly also their quality) than we are at measuring innovation outputs. This is not a problem of the GII per se. It is a problem of all existing innovation metrics, which often resort to intermediate innovation outputs such as patents or high-tech production or trade items to proxy the more complex phenomenon of innovation. A key challenge is to find metrics that capture innovation as it occurs in the world today. Direct official measures that quantify innovation outputs remain extremely scarce. For example, there are no official statistics on the amount of innovative activity—defined as the number of new products, processes, or other innovations—for any given innovation actor, let alone for any given country. Most measures also struggle to appropriately capture the innovation outputs of a wider spectrum of innovation actors, such as the services sector, public entities, and so on.

Clustering innovation over- and underachievers relative to GDP: The GII bubble chart

The GII helps to identify economy-specific performance in innovation relative to its level of GDP. Figure 9 on pages 36–37 presents the GII scores plotted against GDP per capita in PPP$ (in natural logs), following a slight methodological improvement over that of previous years.[64] Identical to previous years, the economies that appear close to the trend line show results that are in accordance with what is expected based on their level of development. The further up and above the trend line a country appears, the better its innovation performance is when compared with that of its peers at the same stage of development. Yellow-coloured bubbles in the figure correspond to the innovation leaders, orange correspond to the innovation achievers (innovation leaders and innovation achievers all appear above the trend line), brown represents countries performing as expected for their level of development (some appear above the trend line, some at the line, and some below it), and red represents countries performing below expected for their level of development.

In the group of innovation leaders we find the same top 25 economies as in 2017, with two exceptions: Belgium is moving back into this group while the Czech Republic is moving out. All of these innovation leaders are high-income economies, with the sole exception of China, which belongs to the upper-middle-income group. These economies show mature innovation systems with solid institutions and high levels of market and business sophistication, allowing investment in human capital and infrastructure to translate into quality innovation outputs.

Economies that perform at least 10% above their peers for their level of GDP are called 'innovation achievers.' These are shown in Table 2, listed by income group, region, and years as an innovation achiever. These economies show better results in innovation because they continuously improve their innovation systems, have more structured institutional frameworks, develop linkages that allow knowledge absorption and the flow of highly skilled human capital, and foster a higher integration with international markets. Although these traits translate into proper resource allocation for education, higher levels of economic growth, and income for workers, they are not homogenous among these economies.

Table 2: Innovation achievers: Income group, region, and years as an innovation achiever

Economy	Income group	Region	Years as an innovation achiever (total)
Moldova, Rep.	Lower-middle income	Europe	2018, 2017, 2016, 2015, 2014, 2013, 2012, 2011 (8)
Viet Nam	Lower-middle income	South East Asia, East Asia, and Oceania	2018, 2017, 2016, 2015, 2014, 2013, 2012, 2011 (8)
India	Lower-middle income	Central and Southern Asia	2018, 2017, 2016, 2015, 2014, 2013, 2012, 2011 (8)
Kenya	Lower-middle income	Sub-Saharan Africa	2018, 2017, 2016, 2015, 2014, 2013, 2012, 2011 (8)
Armenia	Lower-middle income	Northern Africa and Western Asia	2018, 2017, 2016, 2015, 2014, 2013, 2012 (7)
Ukraine	Lower-middle income	Europe	2018, 2017, 2016, 2015, 2014, 2012 (6)
Mongolia	Lower-middle income	South East Asia, East Asia, and Oceania	2018, 2015, 2014, 2013, 2012, 2011 (6)
Malawi	Low income	Sub-Saharan Africa	2018, 2017, 2016, 2015, 2014, 2012 (6)
Mozambique	Low income	Sub-Saharan Africa	2018, 2017, 2016, 2015, 2014, 2012 (6)
Rwanda	Low income	Sub-Saharan Africa	2018, 2017, 2016, 2015, 2014, 2012 (6)
Georgia	Lower-middle income	Northern Africa and Western Asia	2018, 2014, 2013, 2012 (4)
Thailand	Upper-middle income	South East Asia, East Asia, and Oceania	2018, 2015, 2014, 2011 (4)
Montenegro	Upper-middle income	Europe	2018, 2015, 2013, 2012 (4)
Bulgaria	Upper-middle income	Europe	2018, 2017, 2015 (3)
Madagascar	Low income	Sub-Saharan Africa	2018, 2017, 2016 (3)
Serbia	Upper-middle income	Europe	2018, 2012 (2)
Costa Rica	Upper-middle income	Latin America and the Caribbean	2018, 2013 (2)
South Africa	Upper-middle income	Sub-Saharan Africa	2018 (1)
Tunisia	Lower-middle income	Northern Africa and Western Asia	2018 (1)
Colombia	Upper-middle income	Latin America and the Caribbean	2018 (1)

Note: Income group classification follows the World Bank Income Group Classification (July 2017); regional classification follows the online version of the United Nations publication Standard Country or Area Codes for Statistical Use, originally published as Series M, No. 49, and now commonly referred to as the M49 standard (April 2018).

A total of 20 economies compose the group of innovation achievers—three more than last year. Nine countries entered this group this year and six exited.[65] New entrants include Colombia, Tunisia, South Africa, Costa Rica, Serbia, Montenegro, Thailand, Georgia, and Mongolia. Among these, Colombia, Tunisia, and South Africa join this group for the first time. Countries that left this group are Uganda, Senegal, Tajikistan, Malta, Burundi, and the United Republic of Tanzania.

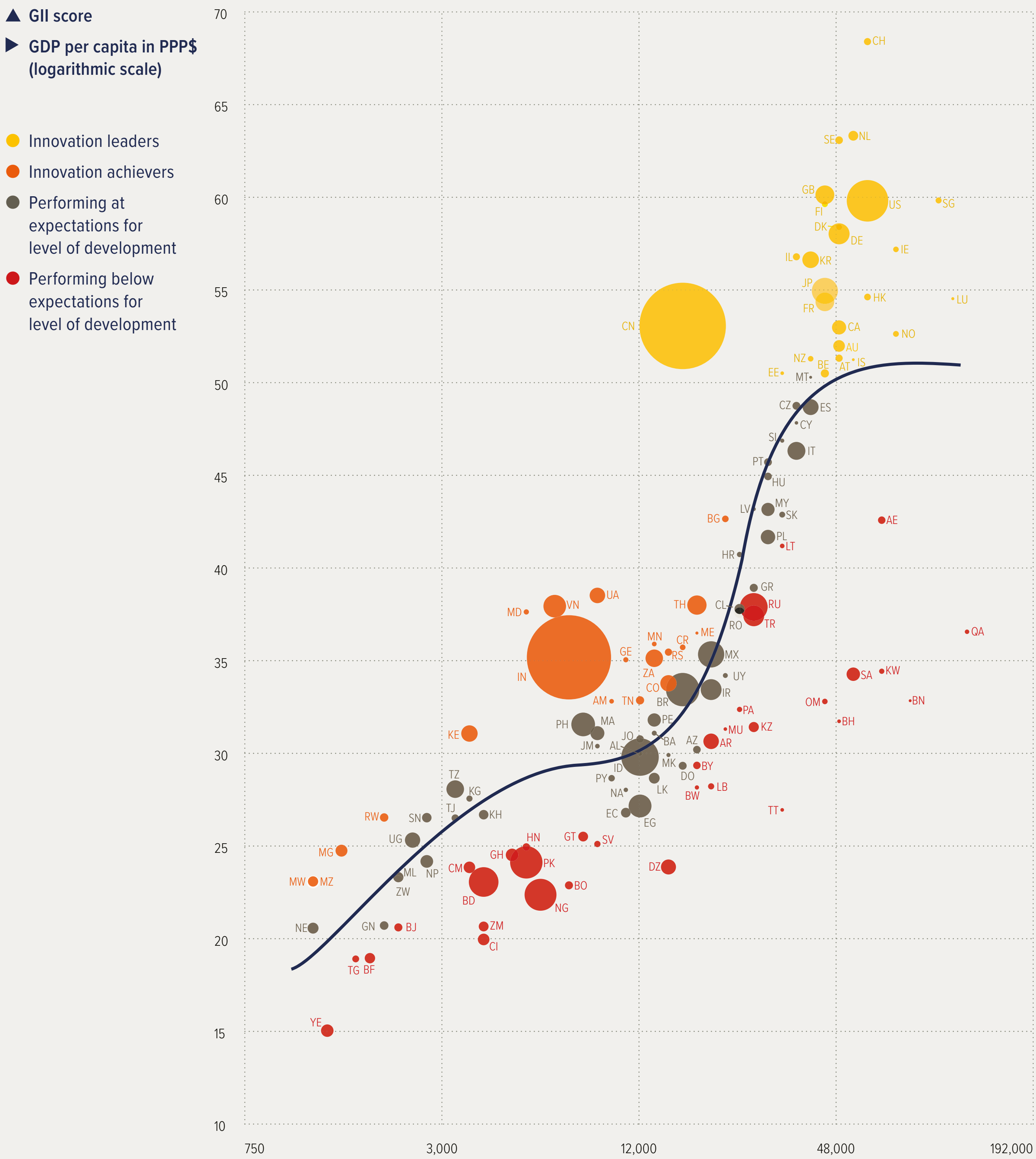
Of these 20 economies—six in total, the most from any region—come from Sub-Saharan Africa. These are followed by five economies in the Eastern region of Europe; three each from the Northern Africa and Western Asia region and the South East Asia, East Asia, and Oceania region; two from Latin America and the Caribbean; and one from Central and Southern Asia region.

Importantly, Kenya, Rwanda, Mozambique, Malawi, and Madagascar stand out for being innovation achievers at least three times in the previous eight years. Kenya, the chief innovation achiever in the region, has been considered as such every year since 2011. For the very first time, South Africa—which boasts a much higher GDP per capita than other countries in the region—also joins this group of achievers from Sub-Saharan Africa. In other regions, this year Mongolia, Thailand, and Montenegro make a comeback after two years, while Georgia, Serbia, and Costa Rica re-enter after three years or more. Most of these economies perform above their peers in terms of having a better business environment, and more accessible investment and financial frameworks. Some are strong in productivity growth, FDI net inflows, and have a strong focus on the use and production of technology and ICT goods or services, as reflected in their high-tech net imports and ICT services exports.

This analysis also allows for the identification of economies that perform at least 10% below their peers for their level of GDP. This cluster includes 34 countries from different regions and income groups: 9 are from the high-income group (6 of these are from the Northern Africa and Western Asia region: Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates); 10 are from the upper-middle-income group, including Algeria, Argentina, Lebanon, the Russian Federation, and Turkey; 12 are from the lower-middle-income group, including Bangladesh, Bolivia, Cameroon, and Ghana; and 3 are low-income economies, namely Benin, Burkina Faso, and Togo.

Figure 9.

GII scores and GDP per capita in PPP$ (bubbles sized by population)



Note: The trend line is the cubic spline with five knots determined by Harrell's default percentiles. (R^2 = 0.7064).

ISO-2 Country Codes

Code	Country/Economy
AE	United Arab Emirates
AL	Albania
AM	Armenia
AR	Argentina
AT	Austria
AU	Australia
AZ	Azerbaijan
BA	Bosnia and Herzegovina
BD	Bangladesh
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BH	Bahrain
BJ	Benin
BN	Brunei Darussalam
BO	Bolivia, Plurinational State of
BR	Brazil
BW	Botswana
BY	Belarus
CA	Canada
CH	Switzerland
CI	Côte d'Ivoire
CL	Chile
CM	Cameroon
CN	China
CO	Colombia
CR	Costa Rica
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
DO	Dominican Republic
DZ	Algeria
EC	Ecuador
EE	Estonia
EG	Egypt
ES	Spain
FI	Finland
FR	France
GB	United Kingdom
GE	Georgia
GH	Ghana

Code	Country/Economy
GN	Guinea
GR	Greece
GT	Guatemala
HK	Hong Kong (China)
HN	Honduras
HR	Croatia
HU	Hungary
ID	Indonesia
IE	Ireland
IL	Israel
IN	India
IR	Iran, Islamic Republic of
IS	Iceland
IT	Italy
JM	Jamaica
JO	Jordan
JP	Japan
KE	Kenya
KG	Kyrgyzstan
KH	Cambodia
KR	Korea, Republic of
KW	Kuwait
KZ	Kazakhstan
LB	Lebanon
LK	Sri Lanka
LT	Lithuania
LU	Luxembourg
LV	Latvia
MA	Morocco
MD	Moldova, Republic of
ME	Montenegro
MG	Madagascar
MK	The former Yugoslav Republic of Macedonia
ML	Mali
MN	Mongolia
MT	Malta
MU	Mauritius
MW	Malawi
MX	Mexico
MY	Malaysia
MZ	Mozambique
NA	Namibia

Code	Country/Economy
NE	Niger
NG	Nigeria
NL	Netherlands
NO	Norway
NP	Nepal
NZ	New Zealand
OM	Oman
PA	Panama
PE	Peru
PH	Philippines
PK	Pakistan
PL	Poland
PT	Portugal
PY	Paraguay
QA	Qatar
RO	Romania
RS	Serbia
RU	Russian Federation
RW	Rwanda
SA	Saudi Arabia
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SN	Senegal
SV	El Salvador
TG	Togo
TH	Thailand
TJ	Tajikistan
TN	Tunisia
TR	Turkey
TT	Trinidad and Tobago
TZ	Tanzania, United Republic of
UA	Ukraine
UG	Uganda
US	United States of America
UY	Uruguay
VN	Viet Nam
YE	Yemen
ZA	South Africa
ZM	Zambia
ZW	Zimbabwe

Regional rankings

This section discusses regional and sub-regional trends, with snapshots for some of the economies leading in the rankings.

To put the discussion of rankings further into perspective, Figure 10 presents, for each region, bars representing the median pillar scores (second quartile) as well as the range of scores determined by the first and second quartile; regions are presented in decreasing order of their average GII rankings (except for the EU, which is placed at the end).

Northern America (2 economies)

Northern America, the UN-defined region that includes the U.S. and Canada, holds two of the top 25 economies in this year's GII. Both the U.S. and Canada are high-income economies. The U.S. ranks 6th overall this year, down two from 2017, and is in the top 10 economies in both the Innovation Input Sub-Index (6th) and the Innovation Output Sub-Index (7th). Canada keeps the 18th position overall and the 10th in Innovation Input Sub-Index, but loses three positions in the Innovation Output Sub-Index (26th).

Sub-Saharan Africa (24 economies)

For several editions, the GII has noted that Sub-Saharan Africa performs relatively well on innovation. Since 2012 the region has had more countries among the group of innovation achievers than any other region. It will be important for Africa to preserve its current innovation momentum.

As last year, this year South Africa takes the top spot among all economies in the region (58th), followed by Mauritius (75th), Kenya (78th), Botswana (91st), the United Republic of Tanzania (92nd), Namibia (93rd), Rwanda (99th), and Senegal (100th). Among these, Kenya, the United Republic of Tanzania, and Namibia improve their GII ranking compared to 2017, while Rwanda and Senegal remain stable and the other three economies (South Africa, Mauritius, and Botswana) lose positions.

The remaining 16 economies in this region can be found at ranks lower than 100. Nine of them have improved since 2017: Madagascar (106th), Cameroon (111th), Mali (112th), Zimbabwe (113th), Malawi (114th), Nigeria (118th), Guinea (119th), Zambia (120th), and Niger (122nd).

Because of issues with data coverage, Ethiopia and Burundi drop out of the GII this year, while Ghana is added back after having dropped out in 2017 (see Annex 2).

Latin America and the Caribbean (18 economies)

Latin America and the Caribbean includes only upper- and lower-middle-income economies, with three exceptions: Chile, Uruguay, and Trinidad and Tobago, which are all high-income economies. Still leading the region in the GII rankings for another year, Chile (47th) loses one position this year; it is followed by Costa Rica (54th, down one) and Mexico (56th, up two).

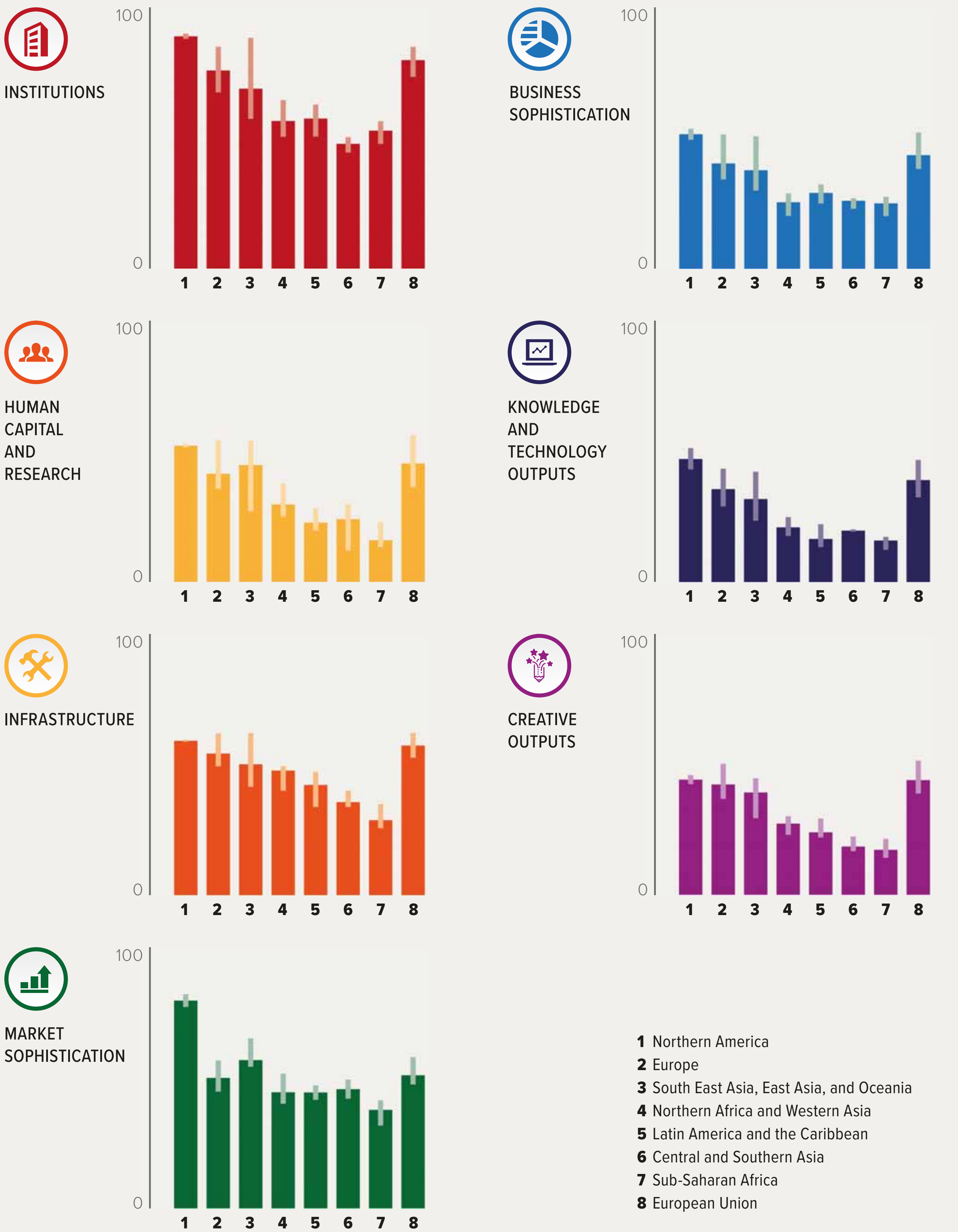
Following these countries, and ranking in the top half of the GII this year, are Uruguay (62nd) and Colombia (63rd). The top 100 economies overall include Brazil (64th), Panama (70th), Peru (71st), Argentina (80th), Jamaica (81st), Dominican Republic (87th), Paraguay (89th), Trinidad and Tobago (96th), and Ecuador (97th). The remaining economies in the region rank below 100 in the GII this year: Guatemala (102nd), El Salvador (104th), Honduras (105th), and the Plurinational State of Bolivia (117th).

Although important regional potential exists, the GII rankings of countries in Latin America relative to other regions have not steadily improved. Until this year, no economies from this region had been identified as innovation achievers. In 2018, thanks to the new approach used to draw the trend line curve of the bubble chart (see Figure 9), two Latin American economies—Costa Rica and Colombia—are identified as innovation achievers.

As last year, and because of the minimum data coverage threshold rule applied in the GII, Nicaragua and the Bolivarian Republic of Venezuela are still unable to be included in the GII 2018 (see Annex 2).

Chile ranks 47th in the GII this year, at the top spot in the region but down one position since 2017. It holds a place in the top 50 economies across three pillars: Institutions (37th), Business sophistication (48th), and Knowledge and technology outputs (48th). Its improvements in 2018 lie in Institutions (37th, up four), and in both output pillars, where it gains one spot in each. In Institutions, Chile improves the most in the sub-pillar Business environment (47th). This

Figure 10.
Median scores by regional group and by pillar



Source: Global Innovation Index Database, Cornell, INSEAD, and WIPO.

Note: The bars show the median scores (second quartiles); the lines show the range for scores between the first and third quartiles. Countries/economies are classified according to the United Nations geographical classification. The European Union overlaps (it includes 27 European countries and Cyprus in Western Asia).

progress is also related to the removal of the variable ease of paying taxes. In Knowledge and technology outputs, the country gains six positions in Knowledge impact (46th), thanks to improvements in productivity growth, computer software spending, and high- and medium-high-tech manufactures. In Creative outputs (58th), Chile improves the most in Creative goods and services (72nd), with a better ranking in printing and other media manufactures. The sub-pillars that lose the most positions are Trade, competition, and market scale, Innovation linkages, and Online creativity and mobile app creation (72nd, a weakness). Chile shows areas of weakness also in Human capital and research in a total of four indicators—government funding per pupil, pupil-teacher ratio, tertiary inbound mobility, and global R&D companies expenditures. Other weak indicators include the state of cluster development, GERD financed by abroad, ICT services exports, and industrial designs by origin.

India has ... outperformed on innovation relative to its GDP per capita for many years in a row.

Brazil is ranked 64th in the GII 2018, moving up five positions since 2017. The country advances the most this year in Knowledge and technology outputs (64th). Institutions (82nd), Business sophistication (38th), and Creative outputs (78th) also gain positions. Brazil's upward movement in Institutions is also due to the removal of the variable ease of paying taxes, where it ranked 124th last year. In Business sophistication, the country gains the most positions in Knowledge workers (43rd), and in particular in GERD financed by business and females employed with advanced degrees, but also in university/industry research collaboration. In Knowledge and technology outputs, Brazil moves up several spots in Knowledge impact (84th), which this year ceases to be a weakness for the country. In this pillar, it improves in important variables such as patents by origin, productivity growth, high-tech exports, and ICT services exports. In Creative outputs, its major gains are in Intangible assets (77th) and Creative goods and services (92nd), and primarily in ICT and business model creation, cultural and creative services exports, and creative goods exports. Despite these improvements, Brazil is relatively weak in the sub-pillars Business environment and Credit and in particular indicators such as ease of starting a business, PISA results, graduates in science and engineering, tertiary inbound mobility, gross capital formation, JV-strategic alliance deals, productivity growth, new businesses, and printing and other media manufactures.

Central and Southern Asia (9 economies)

Economies of the Central and Southern Asia region see further improvements in their GII rankings in 2018, with seven economies improving their rankings and India moving forward into the top half of the GII (Box 6).

India maintains its top place in the region, moving up three spots—from 60th last year to 57th this year. The Islamic Republic of Iran remains 2nd in the region, with a spectacular 10-position jump to the 65th spot (see also Box 4). Kazakhstan moves up four positions, ranking 74th this year. The remaining economies rank in order within the region as follows: Sri Lanka shows a two-position improvement this year (88th); this is followed by Kyrgyzstan (94th), Tajikistan (101st), Nepal (108th), Pakistan (109th), and Bangladesh (116th). Despite the improvements in data coverage in the region, Bhutan does not meet the 66% data coverage threshold (see Annex 2) and is thus excluded from the 2018 GII.

India remains 1st in the region and moves up to the 5th position in the GII rankings among lower-middle-income economies. India has also outperformed on innovation relative to its GDP per capita for many years in a row. This year India ranks 57th in the overall GII, gaining three positions since 2017. The country confirms its rank among the top 50 economies in two pillars—Market sophistication (36th) and Knowledge and technology outputs (43rd)—and is among the top 25 in two sub-pillars—Trade, competition, and market scale (16th) and Knowledge diffusion (25th).

This year India improves in four out of the seven GII pillars: Institutions (80th, up 12 spots), Human capital and research (56th, up 8), Market sophistication (36th, up 3), and Creative outputs (75th, up 10). In Institutions, India gains the most spots in Business environment (106th), mostly thanks to the removal of the variable ease of paying taxes, where it ranked 118th in 2017, and to a much-improved ranking in ease of resolving insolvency. In Human capital and research, Tertiary education (45th) gains several positions, with better rankings in tertiary enrolment and graduates in science and engineering, where it gains the 6th spot globally. Other significant improvements in this pillar are in school life expectancy and researchers. In Market sophistication, it improves both in Credit (70th) and Investment (35th), mostly as a result of gains in ease of getting credit, ease of protecting minority investors, and applied tariff rate. Other gains for India are

BOX 6

Central and Southern Asia: A heterogeneous region with India and Iran most actively pursuing the innovation agenda

Central and Southern Asia is a rather heterogeneous region. Most of its economies belong to the lower-middle-income group, although it does include two upper-middle-income economies, the Islamic Republic of Iran and Kazakhstan, and one low-income country, Nepal.

In terms of the GII rankings, India is the only economy from the region in the top half of the GII, and it has been climbing in the rankings since 2016. The Islamic Republic of Iran (65th), which is moving closer to the top half of the GII this year, has also improved its ranking remarkably since 2014, when it ranked 120th. The other seven economies in this group can be loosely grouped as follows: In the first group are countries whose GII ranks have moved up and down in the last few years. One of them is Kazakhstan, which ranks 74th this year. Sri Lanka has also moved recently, while increasing its ranking since 2017. In the second group are Nepal, Pakistan, and Bangladesh, which have recently boosted their GII rankings, but from low ranks. Finally, Kyrgyzstan has improved its rank considerably in the last few years, and comes in at 94th this year.

Despite the evident differences among them, the economies of this region are achieving good results in a number of important areas, notably Market sophistication and its sub-pillar Investment. Tajikistan, for example, ranks 10th globally. Best-ranked indicators in this pillar include ease of getting credit, microfinance loans, and domestic market scale. Knowledge and technology outputs is another pillar where the region performs relatively well, especially thanks to good rankings in productivity growth. By contrast, Institutions and Creative outputs are the areas where, on average, Central and Southern Asia performs less well.

In sum, some of the economies in Central and Southern Asia are already occupying key leading positions in the global innovation landscape. India and the Islamic Republic of Iran are rapidly improving their GII rankings and gaining top spots in key innovation input and output factors. The other economies in the region can still benefit from realizing untapped potential. Plans for this are underway and need additional support—Bangladesh's strategy to further boost its IT services industry is a good example. The Bangladeshi government plans for this sector aim at training professionals and promoting the use of modern technologies to attract foreign investments, strengthen the export capacity of domestic small and medium-sized enterprises, and increase the value addition of the industry to 1% of the Bangladesh's GDP.[1] First results of these initiatives include the newly opened Samsung R&D centre in Bangladesh, and planned additional investments from global leaders such as International Business Machines Corporation (IBM) and LG in Bangladesh.[2]

Notes

1 BASIS, 2014.
2 ITC News, 2014. See also https://basis.org.bd/resource/About_Industry.pdf.

in Creative outputs, and especially in Online creativity (67th), where it ranks well in the newly introduced indicator, mobile app creation. At the indicator level, India ranks very well in a number of important indicators, including productivity growth and ICT services exports (1st).

Despite the achievements documented so far, India loses ground in Infrastructure (77th), Business sophistication (64th), and Knowledge and technology outputs (43rd). All the Infrastructure sub-pillars move down, with Ecological sustainability (119th) losing the most and becoming one of India's relative weaknesses this year. In Business sophistication, the country drops in all sub-pillars, and especially in Knowledge workers (97th), the result of two newly available indicators—knowledge-intensive employment and females employed with advanced degrees—and Knowledge absorption (66th), where research talent in business enterprises loses several spots from 2017. Despite this fall in Business sophistication, India gains positions in this pillar in a number of important indicators: patent families in two or more offices, IP payments, high-tech imports, ICT services imports, and FDI inflows. In Knowledge and technology outputs (43rd), India loses several positions in Knowledge impact (42nd) while keeping its 55th spot in Knowledge creation and entering the top 25 in Knowledge diffusion (25th). In this pillar, it improves the most in scientific and technical publications, high- and medium-high-tech manufactures, and FDI outflows.

India still has more potential, with the sub-pillar Education and some important indicators marked as relative weaknesses. These include

PISA results, environmental performance, females employed with advanced degrees, new businesses, and entertainment and media market.

Northern Africa and Western Asia (19 economies)

Israel (11th, up by six, the most striking upward move in the region) and Cyprus (29th, up by one) achieve the top two spots in the region for the sixth consecutive year. Third in the region is the United Arab Emirates (38th), which moves down three places from last year.

Seventeen of the 19 economies in the Northern Africa and Western Asia region are in the top 100, including Turkey (50th), Qatar (51st), Georgia (59th), Kuwait (60th), Saudi Arabia (61st), Tunisia (66th), Armenia (68th), Oman (69th), Bahrain (72nd), Morocco (76th), Jordan (79th), Azerbaijan (82nd), Lebanon (90th), and Egypt (95th). Of all the economies in the region, Egypt sees the most improvement in its overall GII ranking, having moved up 10 spots. The other two economies in the region, Algeria and Yemen, rank 110th and 126th respectively.

Israel moves up six places, from 17th to 11th, getting very close to the top 10 and remaining number 1 in the Northern Africa and Western Asia region. Israel is the only economy in the region to rank in the top 10 for any pillar (3rd, Business sophistication; and 7th, Knowledge and technology outputs). This year Israel improves in all pillars, with the most significant gains in Institutions (34th) and Creative outputs (15th). In Creative outputs, Israel improves the rankings of some indicators and comes in 4th in the newly introduced indicator, mobile application creation. At the sub-pillar level, Israel ranks third in Research and development (R&D) and gains the top rank in Innovation linkages. It also ranks 1st in a number of important indicators, including researchers, R&D expenditures, venture capital deals, GERD performed by business, research talent in business enterprise, ICT services exports, and Wikipedia edits. Other top 3 ranks include university/industry research collaboration (3rd) and GERD financed by abroad (2nd). Beyond this, Israel's weaknesses are found mostly in the input side of the GII. These include government funding per pupil, PISA results, tertiary inbound mobility, gross capital formation, firms offering formal training, and GERD financed by business. On the output side, two areas of weakness are found in the pillar Creative outputs: trademarks by origin and printing and other media manufactures.

South East Asia, East Asia, and Oceania (15 economies)

This year all economies within the South East Asia, East Asia, and Oceania region are ranked within the top 100 in the GII. Except for Cambodia and Brunei Darussalam, all other economies in the region are in the top 100 in the Innovation Input Sub-Index, the Innovation Output Sub-Index, and the Innovation Efficiency Ratio.

Seven of these 15 economies rank in the top 25 of the GII: Singapore (5th), the Republic of Korea (12th), Japan (13th), Hong Kong (China) (14th), China (17th), Australia (20th), and New Zealand (22nd). The top four economies in the region also rank in the top 25 overall for both the Innovation Input Sub-Index and the Innovation Output Sub-Index.

Malaysia follows New Zealand, moving up two positions to 35th thanks to increases in most pillars—Institutions (43rd), Human capital and research (31st), Infrastructure (43rd), Business sophistication (39th), and Knowledge and technology outputs (33rd). Malaysia is also among the middle-income economies that move closer to the top 25 this year (see Box 4 on the innovation divide).

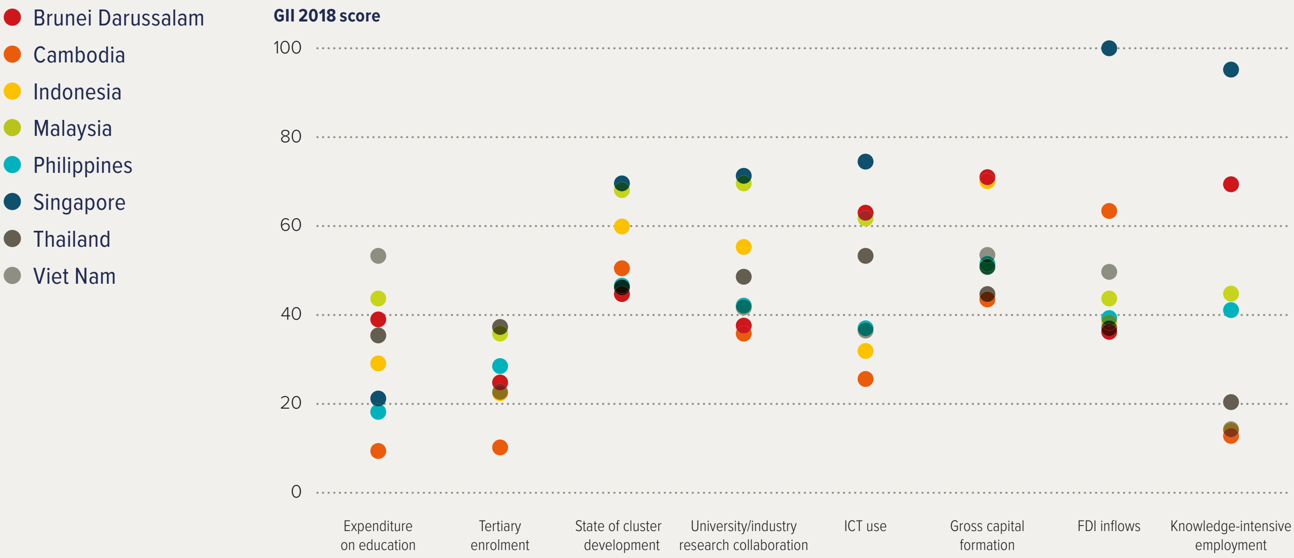
Thailand makes enormous progress this year, moving up seven positions and reaching the 44th place overall. It gains between 3 and 15 spots in all pillars except for Infrastructure, where it loses one, and Knowledge and technology outputs, stable at the 40th position (see also Box 4). Viet Nam gains another two positions, ranking 45th this year (see Box 4). Mongolia (53rd) follows Viet Nam, ranking in the top half of the GII this year as well. Brunei Darussalam, the Philippines, Indonesia, and Cambodia rank 67th, 73rd, 85th, and 98th, respectively.

As noted last year (see Box 6 in GII 2017), ASEAN economies are making great progress in innovation and socioeconomic development indicators. In 2018 again, most of the ASEAN economies included in the GII improve their GII rankings. Figure 11 shows the scores of these economies in selected innovation input and output indicators. As noted last year, a certain stability exists at the top of the ASEAN rankings. Singapore has the highest scores among ASEAN members in many of the selected indicators, excluding expenditure on education (topped again by Viet Nam), tertiary enrolment (where data are not available for Singapore, and Thailand leads the ASEAN countries),

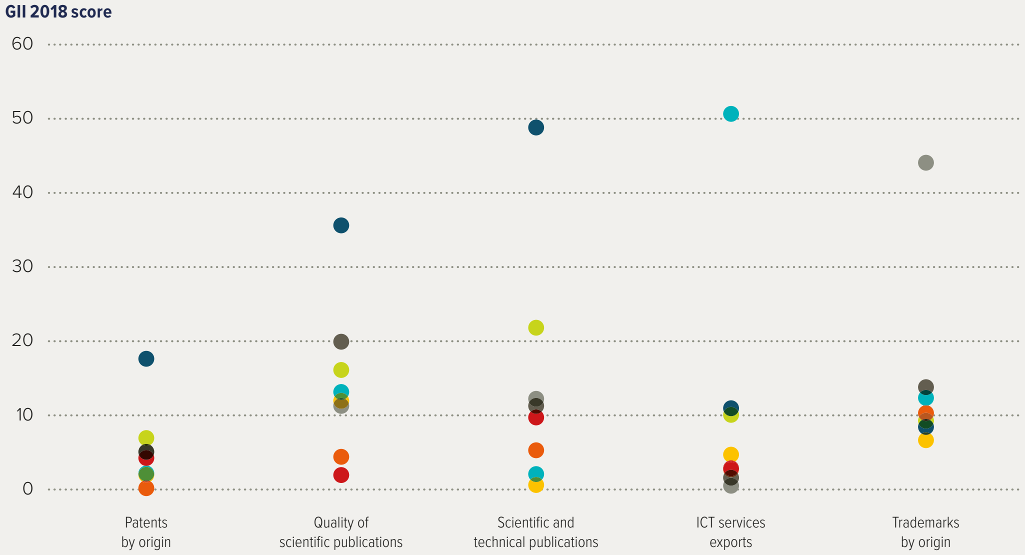
Figure 11.

ASEAN scores in selected input and output indicators

Selected input indicators



Selected output indicators



Source: Global Innovation Index Database, Cornell, INSEAD, and WIPO.

Note: No data are available for Lao People's Democratic Republic or Myanmar, which are also omitted from the GII 2018.

gross capital formation (topped again by Brunei Darussalam), ICT service exports (topped again by the Philippines), and trademarks by origin (topped by Viet Nam this year). As noted last year, Cambodia is relatively new in the global innovation landscape. Within the ASEAN group, the economy is second after Singapore in FDI inflows and scores relatively well in the state of cluster development. Despite this, Cambodia is still lagging behind in most of the input indicators selected here. In output indicators, the weakest indicator among those selected is patent applications by origin.

Japan has risen in the GII rankings each year for the last six years, taking the 13th place in 2018.

As for the other economies in the group, Viet Nam shows the best score of the group in expenditure on education and trademarks by origin. It is also performing well in gross capital formation and FDI inflows; at the same time, it has some of the lowest scores in tertiary enrolment, university/industry research collaboration, and knowledge-intensive employment. In the output indicators selected here, Viet Nam has the lowest score of the group in ICT services exports, but ranks well also in scientific and technical publications. This year Thailand is the strongest in the ASEAN group for tertiary enrolment and the second strongest in quality of scientific publications and trademarks by origin. Malaysia ranks 2nd in half of the input indicators selected here—expenditure on education, tertiary enrolment, state of cluster development, and university/industry research collaborations. It also scores well in ICT use and knowledge-intensive employment. In output indicators, Malaysia has the second highest score in the group in patent applications by origin and scientific and technical publications. It also scores well in the quality of its scientific publications and ICT services exports, where, however, its distance from the number 1 in the group, the Philippines, is the greatest among output indicators. Indeed, as we noted last year, the distance between top performers and the other economies is larger in output than in input indicators.

As happens in various countries, the Vietnamese government has assigned responsibilities to ministries, agencies, and local governments to undertake actions to improve Viet Nam's innovation performance guided by the GII and to address missing and outdated data, in collaboration with WIPO. With the knowledge gained, Viet Nam's Ministry of Science and Technology has published a handbook on the GII including detailed guidance on definitions, data sources, and indications of how to access original data. A series of workshops has also been organized to introduce the GII framework to ministries and local governments and to support them in designing action plans to address their assigned mission of improving specific aspects of the Vietnamese innovation system. In a short period of time, GII has been considered to be an important element in the agenda of both central and local governments.

The Republic of Korea (Korea) moves down one position from 2017, ranking 12th this year. It loses three positions in the Innovation Output Sub-Index, dropping from 9th to 12th place, but gains two spots in the Innovation Input Sub-Index, from 16th to 14th. On the input side, Korea improves in Institutions (26th, up nine) and loses positions in Business sophistication (20th), while the other three input pillars remain stable. The country keeps its 2nd spot in Human capital and research and its 1st rank in the sub-pillar Research and development, as well as its 2nd position in the indicator R&D expenditures. On the output side, Korea loses positions in both pillars, with three of the six output sub-pillars moving downward: Knowledge creation, Knowledge diffusion, and Creative goods and services. While the country drops three spots in Knowledge and technology outputs (9th), it maintains its top rankings in patents applications by origin and PCT patent applications and gains it in high-tech exports. In Creative outputs (17th, down by two), Korea also keeps its 1st spot in industrial designs by origin and ranks 8th in the newly introduced indicator, mobile app creation. The country's areas of relative weakness include ICT services exports and printing and other media manufactures on the side of outputs; and tertiary inbound mobility, GDP per unit of energy use, venture capital deals, GERD financed by abroad, ICT services imports, and FDI inflows on the inputs side.

Japan has risen in the GII rankings each year for the last six years, taking the 13th place in 2018. Japan ranks 12th (down by one) in the Innovation Input Sub-Index and 18th in the Innovation Output Sub-Index (up by two). This year it improves its rank in Institutions (8th, up by five), Market sophistication (10th, up two), and Creative outputs (31st, up five). In Institutions, it improves the most in Business environment. In Market sophistication, Japan keeps its 3rd rank in Trade, market scale, and competition, while gaining one spot in Credit (11th). In Creative outputs the country advances in all sub-pillars, especially thanks to major improvements in trademarks by origin and a good rank in the newly introduced indicator, mobile app creation. Japan ranks in the top 10 economies for six sub-pillars: Political environment and Business environment (both 7th), Research and development (5th), Information and communication technologies

(5th), Trade, competition, and market scale (3rd), and Knowledge absorption (8th). Japan ranks 1st in a number of input and output indicators, including GERD financed by business, patent families in two or more offices, patents by origin, PCT patent applications, and IP receipts. Despite these achievements, Japan moves down two spots in Human capital and research (16th), losing positions in Education (49th) and Research and development (R&D, 5th) and the indicators expenditure on education, school life expectancy, tertiary inbound mobility, researchers, and R&D expenditures. Opportunities for further improvement are found in various areas, including in ease of starting a business, ease of getting credit, FDI inflows, productivity growth, new businesses, ICT services exports, and cultural and creative services exports.

Europe (39 economies)

As last year, in this year's edition of the GII, 15 of the top 25 economies come from Europe. This region is home to the top 3 economies of the GII 2018: Switzerland (1st), the Netherlands (2nd), and Sweden (3rd). Following these regional leaders among this group of top 25 are the U.K. (4th), Finland (7th), Denmark (8th), Germany (9th), Ireland (10th), Luxembourg (15th), France (16th), Norway (19th), Austria (21st), Iceland (23rd), Estonia (24th), and Belgium (25th). It should be noted that most of the economies in this region have the fewest missing values, leading them to display the most accurate GII rankings (see Annex 2). This includes the following economies with 100% data coverage in the Innovation Input Sub-Index, the Innovation Output Sub-Index, or both: Denmark, Finland, Germany, France, Austria, the Czech Republic, Italy, Portugal, Hungary, Poland, Romania, and the Russian Federation.

Eighteen economies follow among the top 50 and have maintained relatively stable rankings since 2014: Malta (26th), the Czech Republic (27th), Spain (28th), Slovenia (30th), Italy (31st), Portugal (32nd), Hungary (33rd), Latvia (34th), Slovakia (36th), Bulgaria (37th), Poland (39th), Lithuania (40th), Croatia (41st), Greece (42nd), Ukraine (43rd), the Russian Federation (46th), the Republic of Moldova (48th), and Romania (49th).

The remaining European economies remain among the top 100 economies overall (see Box 7). The region's rankings continue as follows: Montenegro (52nd), Serbia (55th), Bosnia and Herzegovina (77th), Albania (83rd), The former Yugoslav Republic of Macedonia (84th), and Belarus (86th).

France moves down one spot this year, from 15th to 16th. It ranks 16th in both the Innovation Input Sub-Index and Output Sub-Index, respectively down one spot and up two. It ranks in the top 25 economies in all pillars, showing improvements in Institutions (21st), Human capital and research (11th), Infrastructure (10th), and Knowledge and technology outputs (19th). In Institutions, France's most-improved sub-pillar is Business environment (22nd). In Human capital and research, various indicators—government funding per pupil, school life expectancy, tertiary enrolment, and graduates in science and technology—move up. In Infrastructure, France gains several positions in Ecological sustainability (27th), where it gains 2nd place in environmental performance. In Knowledge and technology outputs, Knowledge impact (32nd) and Knowledge diffusion (14th) move up four spots each, with computer software spending and FDI outflows improving the most. France presents relatively weak ranks in pupil-teacher ratio, gross capital formation, ease of getting credit, GERD financed by abroad, FDI inflows, utility models by origin, productivity growth, new businesses, and printing and other media manufactures.

Identifying regional top science and technology clusters

Successful innovation clusters, and thus agglomerations of innovation activity, are considered essential for national innovation performance. Recognizing this fact, innovation policy instruments are often designed and applied at the sub-national level. In addition, most ministers in charge of innovation and R&D financing around the world also pursue the ultimate (but challenging) goal of harbouring state-of-the-art top innovation clusters of their own.

To this end, countries have shown particular interest in assessing and monitoring innovation performance in their states, regions, or cities. In this context, various countries have approached the GII publishers with the desire to apply the GII framework to the sub-national level with a view to measuring sub-national performance. In February 2017, the Indian government, for example, decided to benchmark the performance of Indian states in the 'India Innovation Index', using the GII framework while adding India-centric parameters.[66] The idea is to

BOX 7

The European Union's role in shaping national innovation performance

The Global Innovation Index (GII) uses countries or geographic areas—as defined by the United Nations Statistics Division—as units of analysis when assessing the innovation performance of countries. Although efforts are underway to measure innovation clusters within countries, supra-national country groupings are not explicitly the subject of study in the GII.

This is for a good reason. The vast majority of countries design their supply- and demand-side innovation policies primarily on the national level.[1] Almost no country has delegated the funding or steering of innovation policies to the supra-national level.

The European Union (EU), composed of 28 member states, is an exception.[2] At the supra-national level it controls direct and indirect EU-wide innovation policy levers. Direct EU-level actions focus on creating platforms for transnational and transregional partnerships, as well as investing in research and commercializing innovation.[3] The Horizon 2020 research and innovation programme, for example, proposes nearly €80 billion of innovation funding from 2014 to 2020.[4]

Likewise, many EU regulations indirectly impact GII parameters, including framework conditions. Examples are the creation of the European Single Market, support for the mobility of students and researchers, and access to finance, as well as harmonized rules that relate to innovation outputs. Take the case of intellectual property (IP): nowadays regulations on IP rights are mostly devised at the EU level, including efforts to introduce unitary patent protection across Europe, complementing the EU trademark and EU Community design, which are valid in all EU countries.

At the same time, many aspects of innovation policy and regulation (in particular in the area of education but also in the field of IP), and the brunt of R&D budgets, are still shouldered on the national or often also the sub-national level. The EU R&D funding thus accounts for about 10% of total public investment in research and innovation in the EU (see note 3).

With this in mind, a natural question to ask is: How do the EU countries fare as a group in terms of innovation?

The European Innovation Scoreboard (EIS) 2017 finds that the EU is catching up with the United States of America (U.S.), yet it is losing ground vis-à-vis the Republic of Korea and Japan and it is trailing the innovation performance of Australia and Canada too.[5] The EU's performance lead over Brazil, India, the Russian Federation, and South Africa is significant; its lead over China is decreasing.

For various technical reasons, computing a GII ranking for the EU as a whole regional bloc is not possible. The main reasons are the lack of EU-level key indicators comparable to GII indicators on government effectiveness, environmental performance, or the intensity of local competition, since these are indices or data that exist only at the specific country level. Still, the GII shows that the EU hosts many of the GII's key innovation players. Among the GII rankings, countries such as Sweden, the Netherlands, the United Kingdom, Finland, Denmark, Ireland, and more recently Germany are regularly in the top 10—thus seven out of the 10 top innovating countries are in the EU. The EU as a whole is clearly an important force for innovation, in particular if one considers the EU-wide efforts on education, the R&D expenditure of the region, and the combined IP filings or its output in the area of total high-tech manufacturing.

The GII also documents some longstanding innovation policy concerns of the EU: First, it showcases the persistent differences in innovation performance within the EU region.[6] While the above-mentioned EU countries are in the top 10, others such as Italy, Portugal, Latvia, Hungary, Bulgaria, Slovakia, Poland, and Lithuania are between the top 30 and 40, while Croatia, Greece, and Romania are in the top 50. Second, the GII also shows the important strengths that the EU harbours on the side of innovation input—including academic components such as scientific publications—versus lower performance on firm innovation components such as business R&D or innovation outputs. This has been classically referred to as the 'EU paradox' since the mid-1990s: With excellent EU higher education systems and good research infrastructure and scientific research results, some struggle to translate these assets into marketable innovations.[7] Third, the GII also attests that entrepreneurial activity is sometimes more constrained than would be ideal. Over the last decades, EU policy makers have deplored that the European start-up scene has been less dynamic than the U.S. one. Recent years, however, have witnessed a renewed start-up spurt in many EU capitals—a trend that is worth amplifying in the next months.

How then do EU innovation policies succeed in going beyond and enriching national policy frameworks? What is the 'EU value-added' in the field of innovation?

Putting exact figures to this EU value-added is challenging. The evaluations of past and current EU innovation policy packages reveal important insights, though. They confirm that scientific excellence and the competitiveness of industry's capacity to innovate have been improved by EU policies.[8] Current EU innovation policies are found to produce benefits—and value-added—in terms of scale, speed and scope, notably through the creation of cross border, multidisciplinary networks, the pooling of resources, stronger human resources via better mobility of researchers and doctoral training, and due to their critical mass required to tackle global challenges.[9] Put simply, a majority of EU projects would not have gone ahead without Horizon 2020, for example. To better address the above challenges, EU innovation policy has readjusted its priorities while shifting from supply- or technology-oriented policies to more solution-specific, demand side–oriented policies. Its priorities now include the creation of partnerships involving small firms and a greater focus on spurring actual innovation commercialization.

In turn, administrative procedures and related bureaucracies around EU innovation policies were deemed worthy of improvement, as were the synergies with other research and innovation funding schemes. A current weakness is that the EU programmes are not yet effectively supporting young, fast-growing companies. A number of factors hamper innovation uptake in the marketplace: technological and regulatory obstacles, lack of standards and access to finance, and lack of customer acceptance of new solutions. Looking ahead, the recent *Report of the Independent High Level Group on Maximising the Impact of EU Research & Innovation Programmes* suggests making the EU innovation polices ever more mission-oriented and impact-focused, reducing red tape in R&D funding, and better aligning programmes with national funding.[10]

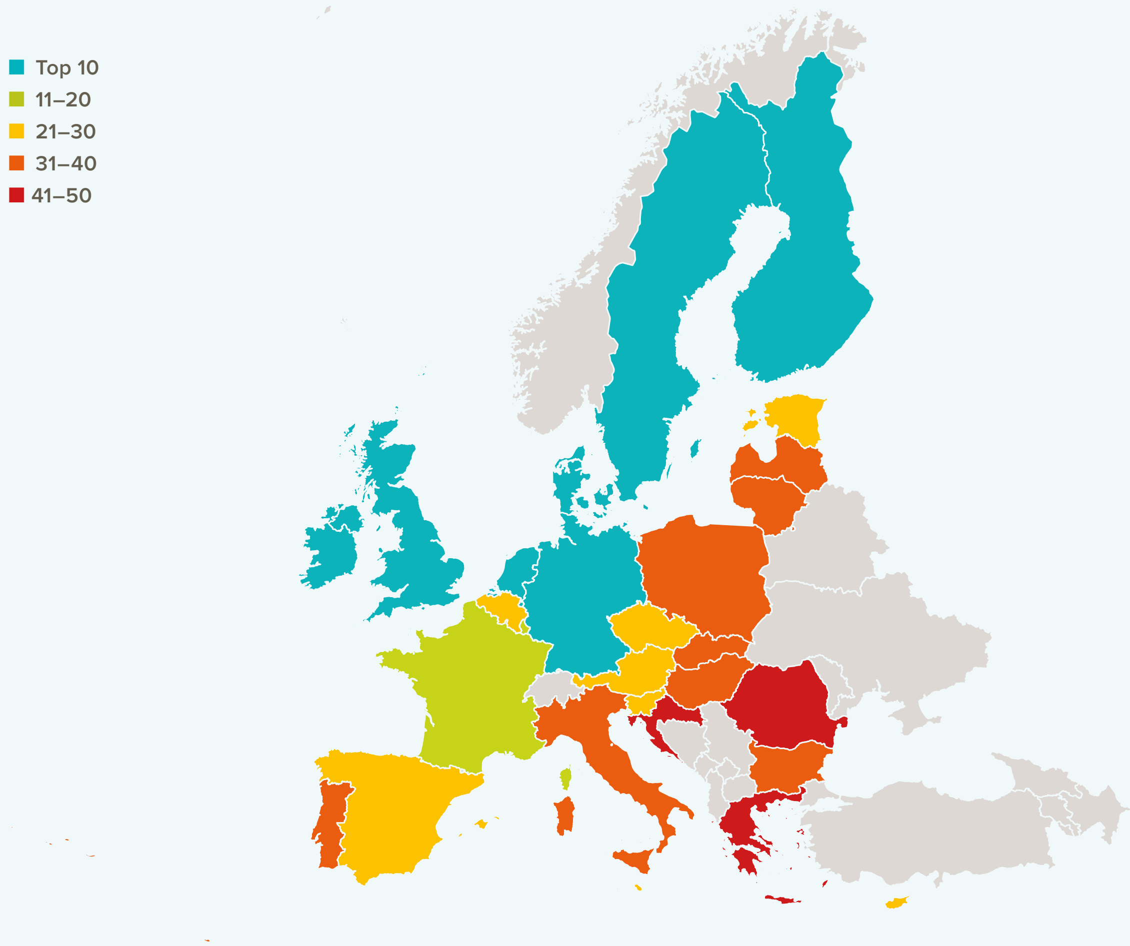
In sum, however, considering the track record of the EU, and not withstanding conceivable enhancements, other world regions might well benefit from emulating similar supra-national innovation policy pooling or coordination.

Notes

Notes for this box appear at the end of the chapter.

Figure 7.1: GII 2018 rankings of EU countries

Source: Global Innovation Index Database, Cornell, INSEAD, and WIPO.



monitor progress of innovation indicators at the state level on real-time basis.

To better capture this important local dimension of innovation systems, measuring inventive, technological, or entrepreneurial performance at the more local level is of crucial importance. The challenge is that official data on the existence and performance of clusters of innovation at the international level are hard to come by. Only a few GII indicators are readily available at the regional or city level for a large set of countries. Thus far, efforts to include an official data point on innovation clusters in the GII from recognized statistical agencies have failed.

To take a step towards improving this data shortage, last year the GII included a Special Section on Clusters in a first attempt at identifying the top sub-national innovation clusters. Its authors Bergquist, Fink, and Raffo proposed a novel approach—drawing on big data (see also Annex 1 Box 1)—to assess inventive cluster capacity. By means of geocoding inventor addresses, the authors identified the largest inventive clusters as measured by WIPO's Patent Cooperation Treaty (PCT) patenting activity, to a very high level of accuracy, thanks to advanced mapping techniques.

The Special Section on Clusters included in this year's GII 2018 is based on a further development of this initial approach. This year the identification of top science and technology clusters rests on international patent filings as last year, with the addition of metrics for scientific publishing activity. In other words, the addresses of authors of scientific publications are used to enrich the existing geocoding exercise (see the Special Section for more details and results). Some of the results are as follows:

- Nine of last year's top 10 clusters are still among the top 10 this year, despite the revised methodology described above.
- Again, Tokyo–Yokohama tops the overall innovation cluster ranking, followed by Shenzhen–Hong Kong.
- The U.S., with 26 clusters, accounts for the highest number, followed by China (16), Germany (8), the U.K. (4), and Canada (4).
- In addition to China, there are clusters from five middle-income countries—Brazil, India, the Islamic Republic of Iran, the Russian Federation, and Turkey—in the top 100.

To highlight the top cluster emanating from this research per country or economy, Table 3 presents the number 1 cluster per economy(ies) that result from this analysis.

In the coming years, attempts to foster the collection of data on local innovation clusters will receive increased attention within the GII as well as other innovation measurement efforts. The discussions triggered by such novel measurement techniques that move beyond official data specific to established city or regional codes—for example, to also include cross-country innovation clusters—will help fine-tune related measurement efforts.

Conclusions

The theme for this year's GII is 'Energizing the World with Innovation'.

This chapter has provided an overview of how innovation can contribute to and address the energy equation while providing a sustainable solution. The global energy transition requires a change in innovation systems to one where the production of knowledge and technology for the energy sector is encouraged by means of technological linkages between large companies and their suppliers. The report also finds that one of the biggest challenges with respect to energy innovation seems to be on the side of diffusion and adoption, which are slow and missing incentives. Complementary social and organizational innovations are needed.

This chapter has also presented the main GII 2018 results, distilling main messages and noting some important evolutions that have taken place since last year (see the Key Findings for more details). The aim of the GII team is to continuously improve the report methodology in concert with its application and related analysis based on the audit, external feedback, changing data availability, and shifting policy priorities. The GII has also undergone a fundamental re-design this year, making some aspects of the report, in particular the Country/Economy Profiles, more accessible, while also innovating on the report analytics—for example, the indication of strengths and weaknesses relative to a country's income group, and an assessment of the relevance of country size or industry structure as determinants of innovation performance (Box 3).

With each new edition, the GII seeks to improve the understanding of the innovation ecosystem with a view to facilitating evidence-based policy making. In this light, the GII team also continues to experiment with the use of novel innovation metrics, as reflected in the inclusion of the mobile app creation indicator 7.3.4 introduced this year.

The majority of our indicator work, however, is invisible to the reader. Every year several dozen new innovation metrics are analysed and tested for inclusion, often to replace existing and currently inadequate data points, on topics such as entrepreneurship, innovation linkages, open innovation, and new metrics for innovation outcomes at the local and national level.

Over the last years, the GII has established itself as a leading reference on innovation, becoming a 'tool for action' for decision makers wishing to improve their countries' innovation performance. In 2017 and 2018, numerous GII workshops in different countries—including Argentina, Belgium, Brazil, Costa Rica, China, Egypt, France, Germany, India, Indonesia, the Islamic Republic of Iran, Kazakhstan, Malaysia, Mexico, Namibia, Sri Lanka, Uganda, the United Arab Emirates, Switzerland, the U.S., Viet Nam, and Zimbabwe, among others—took place, often with the presence of the key concerned ministers and with the direct attention of presidents and prime ministers.

The mission of this work is to apply the insights gleaned from the GII on the ground. In a first step, statisticians and decision makers are brought together to help improve innovation data availability. This work helps to shape the innovation measurement agenda at WIPO and at other international and domestic statistical organizations. In a second step, the challenge is to use the GII metrics and experiences in other countries to leveraging domestic innovation opportunities while overcoming country-specific weaknesses.

Often these activities are an exercise in careful coordination and orchestration among different public and private innovation actors, as well as between government entities at local, regional, and national levels. The GII then becomes a tool for such coordination because the country is united in its common objective: to foster enhanced domestic innovation performance. At best, this coordination leads to policy goals and targets that are regularly revisited and evaluated. For it is those countries that have persevered in their innovation agenda, with consistent focus and set of priorities over time, that have been most successful in achieving the status of innovation leader or achiever relative to their level development.

These exchanges on the ground also generate feedback that, in turn, improves the GII and assists the journey towards improved innovation measurement and policy.

Table 3: Top cluster of economies or cross-border regions within the top 50

Rank	Cluster name	Economies
1	Tokyo–Yokohama	JP
2	Shenzhen–Hong Kong	CN/HK
3	Seoul	KR
4	San Jose–San Francisco, CA	US
5	Beijing	CN
9	Paris	FR
15	London	GB
17	Amsterdam–Rotterdam	NL
20	Cologne	DE
22	Tel Aviv–Jerusalem	IL
28	Singapore	SG
29	Eindhoven	BE/NL
30	Moscow	RU
31	Stockholm	SE
33	Melbourne	AU
37	Toronto, ON	CA
38	Madrid	ES
44	Tehran	IR
45	Milan	IT
48	Zurich	CH/DE

Source: See Table 2 in the Special Section Annex.
Note: Codes refer to the ISO-2 codes; see page 37 for a full list.

Notes for Box 2

1 For a discussion of the 2030 Agenda, see Box 2 in Chapter 1 in Cornell et al., 2017. For details about the Paris Agreement, see http://unfccc.int/paris_agreement/items/9485.php.

2 UN General Assembly Resolution A/RES/72/L224: Ensuring access to affordable, reliable, sustainable and modern energy for all can be found at http://www.un.org/en/ga/search/view_doc.asp?symbol=A/RES/72/224. This resolution, encourages the development, dissemination, diffusion, and transfer of environmentally sound technologies.

3 Specifically, Goal 9 refers to 'Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation'.

4 Details about the HLPF 2018 Forum are available at https://sustainabledevelopment.un.org/hlpf/2018.

5 Information about WIPO GREEN is available at https://www3.wipo.int/wipogreen/en/.

Notes for Box 3

1 Weller (2016) notes that tiny economies lead the innovation rankings. How different structural, geographic, and historical circumstances of an EU member state affects innovation performance has also been studied in the context of the European Innovation Scoreboard (EIS). A closed expert workshop on the contextualization of innovation performance data was organized in Brussels in February 2018 with the participation of GII researchers; see http://ec.europa.eu/growth/industry/innovation/facts-figures/scoreboards_en. For the EIS, a slight positive correlation between GDP and innovation performance is found.

2 These are Sweden, Finland, and Denmark, in order of their 2018 GII ranking.

3 The ICT Development Index 2017 is available at http://www.itu.int/net4/ITU-D/idi/2017/-.

4 The GII 2018 scales 22 variables by GDP and 8 variables by population.

5 See www.globalinnovationindex.org.

6 Any correlation analysis and its related statistical tests should take into account development effects. This means using the part of the GII score that can be explained by country characteristics while controlling for the different levels of economic development, proxied in this case by (log) GDP per capita.

7 There can be multiple reasons that rich countries score better on the GII. An interesting one could be that many small high-income economies such as Luxembourg or Hong Kong (China) are very much service-based economies, and that innovation in the services sector, including in areas such financial innovation, is harder to capture via classic innovation metrics such as scientific publications or patents than innovation in other sectors.

8 These small natural resource–endowed countries are Bahrain, Botswana, Brunei Darussalam, Croatia, Kuwait, Latvia, Lithuania, Mongolia, Oman, Qatar, Trinidad and Tobago, and Uruguay.

9 For details see the paper on uncovering the effects of country-specific characteristics on innovation performance on the GII website. We use as a proxy of product concentration the Hirschman-Herfindahl Index (HHI) for the domestic industry from the UNIDO INDSTAT database, developed by the EQuIP project of UNIDO. The HHI is a measure of concentration and can help to determine the extent to which a country's industrial system is diversified across different industrial sub-sectors (or, conversely, concentrated in a few industrial sub-sectors). See UNIDO, 2015, for details about the EQuIP project.

10 We test for trade concentration by using the HHI for export product diversification sourced from the UN Comtrade database, available at https://comtrade.un.org/, and also derived from UNIDO's EQuIP project. The HHI for export product diversification shows the extent to which a country's industrial exports are diversified across different industrial sub-sectors or products.

Notes for Box 7

1 Dutta et al., 2016.

2 The 28 EU member states are Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom.

3 See https://ec.europa.eu/growth/industry/innovation/policy_en. Input to this box was kindly provided in form of an unpublished Background Note by Daniel W. Bloemers, European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, and his colleagues at the European Commission.

4 See https://ec.europa.eu/programmes/horizon2020/. Also the European Structural and Investment Funds, with a focus on sub-national regions, dedicate around €110 billion to innovation. Additional funding opportunities for innovators and entrepreneurs are provided by the European Fund for Strategic Investments (EFSI) and a recently established Venture Capital Fund-of-Funds.

5 European Commission, 2017a.

6 See also OECD, 2016.

7 European Commission, 1995.

8 High Level Expert Group, 2015.

9 Results of the interim evaluation of Horizon 2020 input studies and evaluation methods can be found https://ec.europa.eu/research/evaluations/index.cfm?pg=h2020evaluation.

10 LAB – FAB – APP, 2017.

Notes for Chapter 1

* Consultant.

1 Conference Board, 2018a; IMF, 2018; OECD, 2018a; World Bank, 2018. For 2018 and 2019, the OECD (2018a) and the IMF (2018) forecast a growth rate of 3.9%, with the OECD revising the two rates slightly upward in November 2017. The World Bank (2018), instead, forecasts a growth rate of 3.1% for 2018 and 3.0% for 2019, with 0.2 and 0.1 upward revisions respectively from June 2017. The Conference Board (2018a) also predicts a slower rate of economic growth at 3.3% for 2018.

2 WTO, 2018.

3 IMF, 2018. According to the Conference Board (2018a) and World Bank (2018), growth rates for emerging and developing economies are forecast to be around 4–4.7% in 2018 and 2019.

4 Conference Board, 2018a; IMF, 2018; OECD, 2018a; World Bank, 2018.

5 The members of ASEAN are Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam. On the innovation achievements of ASEAN countries, see Box 6 in Dutta et al., 2017.

6 Based on IMF World Economic Outlook Dataset (April 2018).

7 IMF, 2018.

8 IMF, 2018; OECD, 2018a.

9 OECD, 2018a; Dutta et al., 2016, 2017.

10 IMF, 2018; OECD, 2018a; World Bank, 2018.

11 Conference Board, 2018b.

12 Conference Board, 2018b; Dutta et al., 2017.

13 See WIPO, 2015a and Box 1.4 in IMF, 2018.

14 UNCTAD, 2018.

15 WIPO, 2015a.

16 IMF, 2018; World Bank, 2018.

17 OECD, 2009; Dutta et al., 2017.

18 See WIPO, 2017a, for examples in coffee, photovoltaic cells, and smartphones.

19 See the historical cases of airplanes and semiconductors in WIPO, 2015b.

20 National Science Board, 2018 and various prior editions, as well as WIPO, 2011 and OECD, 2017.

21 WIPO, 2017c, 2018a.

22 WIPO, 2017b.

23 UNESCO UIS estimates.

24 OECD, 2018b. GPD is the denominator in the R&D intensity equation; slower growth translates, *ceteris paribus,* to increased R&D intensity.

25 WIPO, 2017b.

26 OECD, 2009; Dutta et al., 2017.

27 OECD, 2009.

28 Authors' estimates based on UNESCO-UIS, 2018.

29 OECD, 2018b.

30 Authors' estimates based on UNESCO-UIS data.

31 Authors' estimates based on UNESCO-UIS data.

32 OECD, 2018c.

33 OECD, 2018b.

34 Strategy&, 2017; European Commission, 2017b. The top 2,500 data are a good proxy for up to 90% of the world's business-funded R&D. According to these private sources, the top companies' R&D investment increased by 3.2% between 2016 and 2017 as estimated for the top 1,000 by Strategy& (2017) and by 5.8% as estimated for the top 2,500 by the European Commission (2017b).

35 Strategy&, 2017. According to the European Commission (2017b), the world's top 2,500 companies in terms of investment into R&D increased by 5.8% over 2016, companies with headquarters in the EU did so by 7%.

36 Strategy&, 2017.

37 Strategy&, 2017. Over half of companies expect a moderate to significant impact to their R&D and innovation efforts caused by the economic nationalism.

38 See for more background and a summary of the literature, see Keisner et al., 2016 and WIPO, 2015a and the many news items on this topic.

39 IEA, 2017. The largest contribution to energy demand growth—almost 30%—comes from India, whose share of global energy use is expected to rise to 11% by 2040. Overall, developing countries in Asia account for two-thirds of global energy growth; the rest comes mainly from the Northern Africa and Western Asia, Sub-Saharan Africa, and Latin America and the Caribbean.

40 Sustainability is not limited to greenhouse gas (GHG) emissions. It also encompasses the use of limited energy resources (e.g., fossil fuels); the impact of the exploitation of energy resources; the impact of air pollution, especially in cities; and so on.

41 The current energy transformation is driven by climate change and by addressing energy independence and security, energy resilience, and energy competitiveness, among others (Chapter 3).

42 IRENA, 2018b.

43 IRENA, 2018b.

44 ILO, 2018. Global renewable energy employment reached 10.3 million jobs in 2017, increasing 5.3% over the previous year. China alone accounts for 43% of all renewable energy jobs. See also IRENA, 2018a.

45 See WIPO, 2017a, Chapter 3 'Photovoltaics: Technological Catch-Up and Competition in the Global Value Chain'.

46 See Cornell University, INSEAD and WIPO, 2017, Chapter 11 'Enhancing Innovation in the Ugandan Agri-Food Sector: Progress, Constraints, and Possibilities' for a comparable approach to innovation in agriculture value chains. See also Chapter 5 (Wilson and Kim) in this report for a discussion on how technology-specific assessments and cross-technology comparisons are complementary to innovation system processes and how these are needed for supporting specific energy technologies.

47 For more on the 'flexibility options' to support the integration of variable renewable energy, see IRENA, 2015.

48 Other aspects should also be accounted for. As renewable energies become mature, one can expect that the number of inventions and innovations deaccelerates. Also, innovation might be moving towards technologies that enable more renewable energies, such as electric vehicles or batteries. See also Figure 3, where an increase in energy conservation published patent families is observed.

49 Frankfurt School-UNEP Centre, 2018. Investment data are based on the output of the database of Bloomberg New Energy Finance (BNEF), a database of investors, projects, and transactions in clean energy. It includes projects, investments, and transactions from start-ups, corporate entities, venture capital and private equity providers, banks, and other investors. The following renewable energy projects are included: wind, solar, biomass and waste, biofuels, geothermal and marine projects, and small hydro-electric damns of less than 500 MW. The aggregate renewable energy investment figure of US$2.9 trillion over the period 2004–17 excludes large hydro-electric projects of more than 500 MW. More details on the methodology and definitions used in the BNEF database for the estimation of investments in green energy sources are available in Frankfurt School-UNEP Centre, 2018.

50 CAGR was equal to –0.5% in this period. However, it is important to note that renewable energies deployment keeps growing while the costs of renewable energies keep decreasing.

51 IRENA and CPI, 2018. "Investment" is a financial commitment represented by a firm obligation, for example by means of a Board (or equivalent body) decision, backed by the necessary funds, to provide specified financing through debt, equity or other financial instruments. More information on the methodology is available in IRENA and CPI, 2018. See also Chapter 3 for IRENA's contribution to the GII 2018, 'Innovation Driving the Energy Transition'.

52 WIPO, 2017b.

53 Saha and Muro, 2017.

54 See also WIPO, 2018b, for details on the methodology. A 'patent family' is a set of interrelated patent applications filed in one or more countries or jurisdictions to protect the same invention.

55 'Internationally oriented patent families' are defined as patent families filed by residents in at least two different countries.

56 In photovoltaics (PV), the shift in global value chain production—combined with the steep fall in prices—put many traditional PV manufacturers in the U.S., Europe, and elsewhere under competitive pressure, resulting in bankruptcies and acquisitions. This partly explains the decline in PV patent filings worldwide after 2011. However, the complete picture is more nuanced. With a saturated solar PV market and low prices that result in tight profit margins, surviving firms have stepped up their investments in R&D to develop new cost-competitive PV technology. A closer look at the patent data reveals that patent applications per applicant have continued to grow in the countries where most filings are observed (e.g., China, Japan, U.S.) since 2011, suggesting an increase in patenting among surviving firms. See WIPO, 2017a. On declining prices see IRENA and CPI, 2018.

57 A distinction between central (national) governments on one hand and local (typically municipal) authorities on the other is worth making here. Recent efforts to build 'smart cities' have devoted significant attention (and investment) to smart energy grids, leading to impressive savings and changes in consumers' habits. See for example Singh and Yassine, 2017.

58 Foxon, 2018.

59 See also www.wipo.int/green.

60 Economies are grouped according to the World Bank classification (July 2017) gross national income (GNI) per capita, calculated using the World Bank Atlas method. The groups are: low income, US$1,005 or less; lower-middle income, US$1,006 to US$3,955; upper-middle income, US$3,956 to US$2,235; and high income, US$12,235 or more; see https://blogs.worldbank.org/opendata/new-country-classifications-income-level-2017-2018..

61 Since 2012, the regional groups have been based on the United Nations Classification: EUR = Europe; NAC = Northern America; LCN = Latin America and the Caribbean; CSA = Central and Southern Asia; SEAO = South East Asia, East Asia, and Oceania; NAWA = Northern Africa and Western Asia; and SSF = Sub-Saharan Africa.

62 Note that any assessment of how the U.K.'s planned withdrawal from the European Union affects the country's GII rank would still be speculative, at best. First, most of the data still predate or coincide with the year of the actual related referendum. Only 35% of the U.K.'s indicators are from 2017; the remaining 65% reflect 2016 and earlier years. Second, as noted last year as well, the causal relations between plans or the actual withdrawal from the EU and the GII indicators are complex and uncertain in size and direction.

63 See GII 2012, Chapter 1, which notes on page 22 that 'the over-representation of the efficiency ratio in the media in 2011 out of the proper context—namely GII scores—was unfortunate, with analysts jumping to the conclusion that countries with high efficiency ratios were to be commended when in effect these high ratios often reflected blatant deficiencies in the input side and a performance in the GII well below that of countries with similar GDP per capita'.

64 The GII bubble chart plots GDP per capita against the GII scores and includes a trend line that is extrapolated from available data. It was introduced in the GII 2012. Since then, the following trend line curves were used: (1) polynomial of degree 4 with no intercept was used in 2012 and (2) polynomial of degree 3 with intercept was used from 2013 until the GII 2017. This new choice, while preserving an adequate coefficient of determination (R^2), also allowed the trend line to behave more in accordance with what would be expected from the relationship of both variables plotted. More recently, Advisory Board members to the GII, notably Sibusiso Sibisi, suggested that a piece-wise curve fitting approach using a fit cubic spline could be more appropriate for the GII. The idea was that this could better fit several local curves that are joined together at the boundaries in a suitably smooth manner (i.e., matching boundary values and their derivatives). Moreover, one additional question is whether a spline trend line would favour middle-income countries, resulting in more innovation achievers from this income group. In the run-up to the 2018 GII edition, STATA was used to predict the GII 2018 scores using a restricted cubic spline. Harrell (2001) recommends placing knots at equally spaced percentiles of the original variable's marginal distribution. Five knots determined by Harrell's default percentiles were defined on the bubble chart's x axis, or along the log of GDP per capita in PPP$, for each country included in the GII 2018. The spline construction estimates for each country a variable (and coefficient) for each of the distribution segments resulting in each of Harrell's knots. The prediction is then based on a model with four variables corresponding to the placement of each of the knots, plus the intercept. It was concluded that the empirically and methodologically the cubic spline performs better (i.e., the fitness of the model is higher than the polynomial degree 3 and degree 4 constructions). It was decided to adopt the cubic spline construction, using Harrell's percentile knots for the predictions.

65 See endnote 64, which sets out methodological changes having possibly contributed to this shift as well.

66 NITI Aayog, 2017.

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