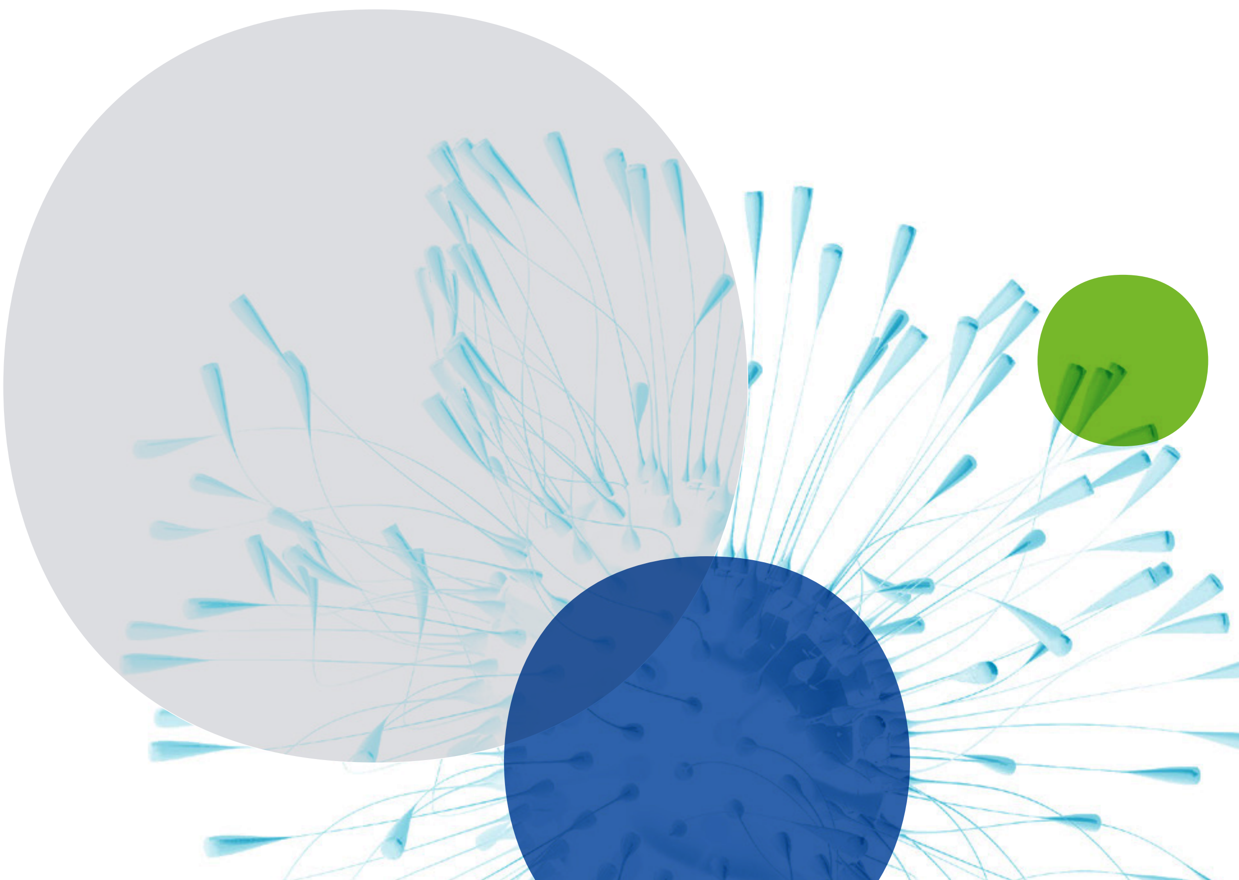
Global Innovation Tracker

What is the current state of innovation?
How rapidly is technology progressing and being embraced?
What are the resulting societal impacts?



Global Innovation Tracker Dashboard

Science and innovation investment

	Scientific publications	R&D investments: Global total	R&D investments: Top corporate R&D spenders	Venture capital: Deal numbers	Venture capital: Deal values	International patent filings
Short term	1.5% 2021 → 2022	5.2% 2020 → 2021	7.4% 2021 → 2022	17.6% 2021 → 2022	−37.8% 2021 → 2022	0.3% 2021 → 2022
Long term (annual growth)	4.9% 2012 → 2022	4.8% 2011 → 2021	n.a.	9.9% 2012 → 2022	20.6% 2012 → 2022	3.6% 2012 → 2022

Technological progress

	Computing power: Moore's Law	Computing power: Green supercomputers	Costs of renewable energy: Solar photovoltaic	Costs of renewable energy: Wind	Electric battery price	Cost of genome sequencing	Drug approvals
Short term	54.6% 2021 → 2022	54.3% 2021 → 2022	−12.8% 2020 → 2021	−13.2% 2020 → 2021	7.1% 2021 → 2022	−23.3%* 2021 → 2022	−26.0% 2021 → 2022
Long term (annual growth)	43.7% 2012 → 2022	35.4% 2013 → 2022	−17.0% 2011 → 2021	−9.6% 2011 → 2021	−15.3% 2012 → 2022	−22.3%* 2012 → 2022	−0.5% 2012 → 2022

Technology adoption

	Safe sanitation	Connectivity: Fixed broadband	Connectivity: Mobile broadband	Robots	Electric vehicles	Cancer radiotherapy
Short term	1.4% 2021 → 2022	4.8% 2021 → 2022	6.0% 2021 → 2022	14.6% 2020 → 2021	59.9% 2021 → 2022	−1.4% 2020 → 2022
Long term (annual growth)	2.4% 2012 → 2022	6.7% 2012 → 2022	14.8% 2012 → 2022	11.7% 2011 → 2021	63.5% 2012 → 2022	−1.3% 2012 → 2022
Penetration	57 of 100 inhabitants in 2022 (45 in 2012)	17.6 per 100 inhabitants in 2022 (16.8 in 2021)	86.9 per 100 inhabitants in 2022 (82.0 in 2021)	n.a.	2.1 of 100 cars in 2022 (1.3 in 2021)	20.9 of 100 countries in 2022 (21.5 in 2020)

Socioeconomic impact

	Labor productivity	Life expectancy	Carbon dioxide emissions	Carbon dioxide emissions
Short term	0.0% 2021 → 2022	−1.3% 2020 → 2021	5.3% 2020 → 2021	1.7%* 2021 → 2022
Long term (annual growth)	2.2% 2012 → 2022	0.0% 2011 → 2021		0.7% 2011 → 2021

Notes: See Data notes at the end of this section for a definition of indicators and their data sources. Long-term annual growth refers to the compound annual growth rate (CAGR) over the indicated period. Historical data may have been updated and could differ from last year's Global Innovation Tracker. Estimates or incomplete data are indicated by an asterisk (*). n.a. indicates not available.

What is the global state of innovation? Is innovation slowing down or accelerating? How is innovation navigating through the global turbulence caused by elevated inflation, rising interest rates and geopolitical conflict in the immediate aftermath of the COVID-19 pandemic?

The Global Innovation Tracker 2023 addresses these crucial questions. It takes the pulse of four key stages in the innovation cycle: (1) science and innovation investment; (2) technological progress; (3) technology adoption; and (4) the socioeconomic impact of innovation.

The main findings this year are as follows:

1. ***Science and innovation investment*** showed a mixed performance in 2022 in the context of many challenges, and a downturn in innovation finance. Scientific publications continued to increase in number, albeit at a slower rate. Global government R&D budgets are expected to grow in real terms in 2022, while R&D expenditure by top corporate spenders rose substantially. But it is unclear whether this can compensate for surging inflation. International patent filings, in turn, stagnated while venture capital investments declined sharply in value in 2022, following extraordinarily high levels in 2021, reflecting a deteriorating climate for risk finance.

2. Strong ***technological progress*** in the fields of information technology, health, mobility and energy continue to deliver new breakthroughs opening up new opportunities for global development. Computing power is historically strong, while the costs of renewable energy and genome sequencing costs are continuing to fall.

3. An observed increase in ***technology adoption*** is gradually making access to safe sanitation and connectivity more widespread. Electric vehicle (EV) uptake is booming, and the desire for greater automation has increased robot installation. However, for the majority of innovation indicators, overall penetration rates remain medium-to-low, and the availability of radiotherapy for cancer treatment continues to be inadequate in many countries.

4. The ***socioeconomic impact*** of innovation remains low. The COVID-19 crisis triggered volatility in labor productivity – which is currently at a standstill – and life expectancy fell for a second consecutive year (with healthy life expectancy continuing to increase, but more slowly). Carbon dioxide emissions continued to grow in 2022, albeit at a lower rate than the post-pandemic surge of 2021 – but with no global reductions in sight.

Science and innovation investment

The innovation environment is full of novel opportunities but also significant challenges. On the one hand, disruption to economies and to life has been more erratic and persistent over the last three years than is normally the case with the business cycle. This has included supply chain disruption, widespread and abnormally high inflation and armed conflict, all of which have weighed on economic recovery and innovation.

On the other hand, innovation continues unabated, partly due to the new Digital Age and the Deep Science innovation waves described in last year's GII 2022 Special theme. Developments in fields as diverse as artificial intelligence, quantum computing, genome sequencing, several green technologies and robotics show a new, possibly groundbreaking dynamic.

Economic growth is projected to slow but remain positive in 2023.[1] Persistent efforts in innovation investment will be key for a recovery and to promote productivity growth, making use of novel innovation opportunities.

Scientific publications

Scientific publications increased substantially throughout the COVID-19 pandemic, with exceptional growth in 2020 (+8.6 percent) and 2021 (8.3 percent). This was driven by a surge in COVID-19- and more generally health-related research, for which early access versions were often published in order to speed up the dissemination of research findings. At the same time, research grants were effectively redirected away from those areas less closely associated with the virus.[2]

In 2022, COVID-19- and health-related research levelled out once again, with the number of scientific articles published not increasing noticeably between 2021 and 2022 (+1.5 percent growth). As well as health, the fields of environmental and energy research are also continuing to grow. Environmental sciences claimed second place in publications, with a solid 10.5 percent growth on 2022. Publications in the energy and fuels field secured ninth spot, with a strong growth rate of 13.2 percent. The field of public, environmental and occupational health grew by 13.4 percent from 2021 to 2022 to rank in 10th position (having been stuck around 17th position prior to the pandemic). Another noteworthy trend is the ascent of India in terms of publication output (ranking fourth in 2022), overtaking the United Kingdom (fifth) and close behind Germany (third).

Research and development (R&D)

Total R&D expenditures

The most recently available data show that global R&D investment grew strongly in 2021 at a rate of 5.2 percent (in real terms), up from 3.2 percent in 2020. This is close to the pre-pandemic growth rate of around 6 percent in 2019. In turn, business R&D expenditure – the most significant component of total global R&D – grew by 7 percent in 2021, the highest growth rate observed since 2014 (see Figure 1).

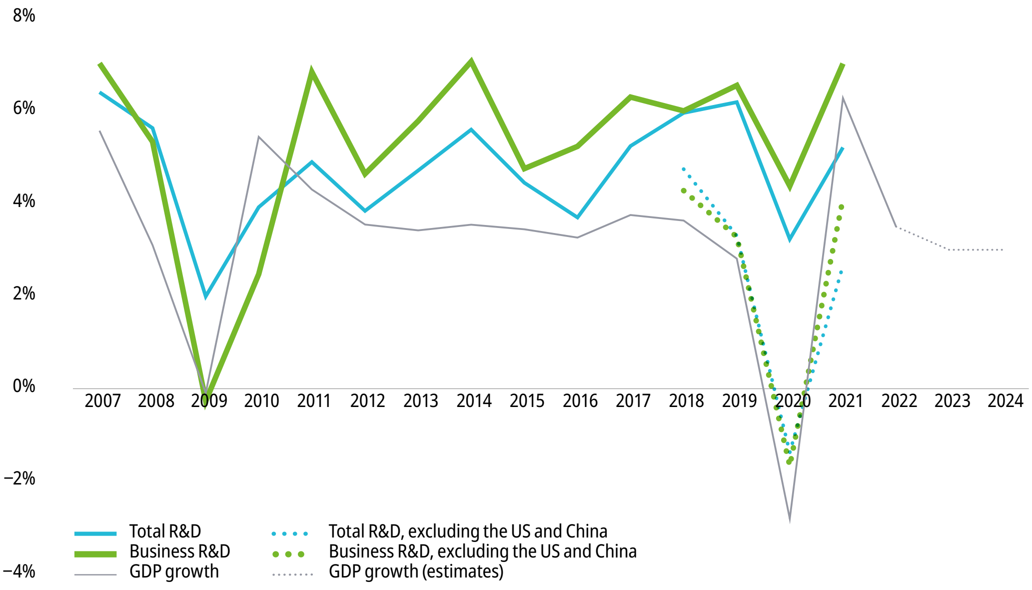
The five economies that spent the most on R&D all experienced significant R&D growth in 2021. In order of R&D budget, they were the United States (+5.6 percent), followed by China (+9.8 percent), Japan (+3.6 percent), Germany (+2.7 percent) and the Republic of Korea (+7.1 percent).[3]

Even excluding the sizeable contributions made by the United States and China, global R&D still experienced a 2.7 percent increase in 2021. This is a notable change from 2020, when these two countries were single-handedly responsible for avoiding a global decline in R&D that year. Again, excluding the United States and China, business R&D witnessed a 4.1 percent growth in 2021, compared to a decline of 1.7 percent in 2020 (see Figure 1).

Data for 2021 data are, however, not yet available for a majority of the large R&D spenders among middle-income economies. Consequently, the effect of the pandemic on low- and middle-income economy R&D budgets remains largely unknown.

That said, relative to what they were pre-pandemic, high-income, upper middle-income and low-income economies have R&D expenditures that are already above pre-pandemic levels. Moreover, most of the world's regions have either returned to or have surpassed pre-pandemic levels, with the exception of Latin America and the Central and Southern Asia region.

Figure 1 GDP growth and total and business R&D growth rates, 2007–2024



Source: WIPO estimates, based on the UNESCO Institute for Statistics database, Organisation for Economic Co- operation and Development (OECD) Main Science and Technology Indicators (March 2022), Eurostat, Ibero-American and Inter-American Network of Science and Technology Indicators (RICYT), China Statistical Yearbook 2022, and the International Monetary Fund's World Economic Outlook Update, July 2023.

To get a sense of what to expect for 2022 and 2023, one must look first at governments' planned R&D budgets and then at company data on R&D expenditure, the latter already partially covering the first quarter of 2023, depending on how the financial year is defined.

Government R&D budget, 2020–2022

Government R&D budget allocations grew robustly in 2020 for the majority of mostly high-income countries, who are also the biggest R&D spenders.[4] This positive outcome can be attributed to government efforts to support R&D expenditures as a counter-cyclical measure; a strategy that effectively sustained 2020 R&D growth.

In 2021, however, government R&D budgets diverged, with declines seen in Japan (−10.9 percent) and the United States (−8.8 percent), the two biggest R&D spenders covered. Declines were also observed in other major economies in 2021. This can be explained by a downward re-adjustment to governments' health R&D budgets in selected high-income economies.[5] Meanwhile, other major economies continued to ramp up their R&D budgets, namely, the Republic of Korea (+10.2 percent), Türkiye (+9.6 percent), Germany (+5.6 percent in 2021) and France (+2.5 percent). Data for China are unavailable; however, official Chinese statistics show an increase in government funding of 6 percent in 2020 and 10 percent in 2021.[6]

For those economies that have already disclosed their planned 2022 R&D budgets, the outlook is mixed. Significant increases in real 2022 R&D budget appropriations are planned for Japan (+15.2 percent) and the Republic of Korea (+6.5 percent), with a smaller increase planned for Germany (+1.0 percent). The United States (−1.8 percent), on the other hand, foresees a decrease. However, this is more than outweighed by the increases planned in Japan and the Republic of Korea. In sum, the total global government R&D budget is expected to grow in real terms in 2022.

Top corporate R&D spenders, 2022–2023

On the corporate side, 2022–2023 R&D data are available for around 1,700 of the top 2,500 biggest corporate R&D spenders worldwide.[7] In 2022, for the first time ever, corporate R&D expenditure worldwide exceeded the trillion dollar mark (USD 1.1 trillion in private R&D), representing a nominal R&D spending growth of around 7.4 percent for the year (see Table 1).[8] Although far under 2021's exceptional growth rate, which stood at close to 15 percent driven by high corporate revenue growth (21 percent), corporate R&D growth in 2022 is fully in line with pre-pandemic levels of around 7–8 percent a year.

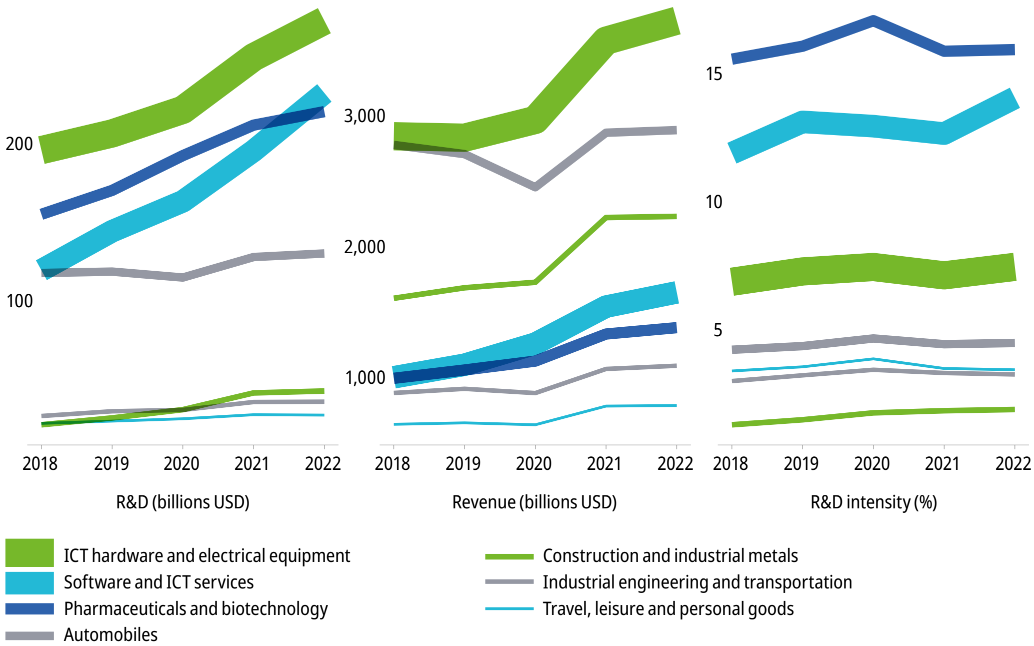
Table 1 R&D and revenue growth rates for top global corporate R&D spenders, 2018–2022

	R&D		Revenue		R&D intensity
Year	Billions USD	Growth (%)	Billions USD	Growth (%)	Growth (%)
2018	774		19,770		3.9
2019	840	8.6	19,746	−0.1	4.3
2020	905	7.7	18,795	−4.8	4.8
2021	1,040	14.9	22,809	21.4	4.6
2022	1,117	7.4	24,613	7.9	4.5

Source: WIPO, based on Bureau van Dijk (BvD) Orbis database. Revenue is in current USD.

The nearly 7.5 percent nominal growth, in 2022, in top corporate R&D spend was primarily driven by software and ICT services, ICT hardware and pharma, with software and ICT services recording exceptionally strong R&D spending growth (roughly 19 percent). The seven industry sectors attracting the greatest R&D investment, in 2022, were: ICT hardware and electrical equipment (1st); software and ICT services (2nd for the first time ever); pharmaceuticals and biotechnology (3rd, overtaken by software and ICT services), automobiles (4th), construction and industrial metals (5th), industrial engineering and transportation (6th), and travel, leisure and personal goods (7th) (see Figure 2).

Figure 2 R&D expenditure and revenue totals of top global corporate R&D spenders, by industry and year, 2018–2022



Source: WIPO, based on BvD Orbis database.

Mirroring an earlier finding, the number of firms increasing R&D in 2022 declined relative to an exceptional year in 2021. The one exception is the travel, leisure and personal goods sector. In 2022, more firms in this sector increased their R&D budget than in 2021.

Ranked by R&D intensity in 2022, pharma (15.9 percent), followed by software and ICT services (14.1 percent), lead by a wide margin from ICT hardware (7.4 percent) in third and automobiles (4.5 percent) in fourth place.

Figure 3 presents the nominal percentage change in R&D expenditure in 2022 for the top 15 firms within the top seven industries. The vertical lines indicate the annual mean by industry. Relative to 2022, a majority of the top 15 R&D companies increased R&D spending. This is most apparent in ICT hardware and in software and ICT services, but also in most other categories. The exception to this is seen in pharmaceuticals and biotechnology, as well as industrial engineering and transportation, where each had more than three companies among the top 15 per sector that recorded a decline.

- Mirroring recent news of how artificial intelligence drives and is fed by such companies, the ICT hardware sector saw graphic card and chipmakers Nvidia, SK Hynix and Mediatek record the most impressive R&D growth in 2022, pushing Apple from third into fourth spot.
- In the field of software and ICT services, Meta (formerly Facebook) maintained its lead in terms of R&D growth (+36.4 percent), the number two slot taken by Uber (+36.2 percent), which had experienced a decline in 2021, followed by Alphabet (formerly Google; +25.1 percent).
- The field of automobiles looked more positive in 2022 than in 2021, with General Motors, Volkswagen and Robert Bosch leading in expenditure, and with a majority of the top 15 R&D-spending firms increasing investment.
- In the field of travel, leisure and personal goods, Roblox (a gaming platform) claimed top spot, followed by Unity Software (a game engine company). Airbnb also returned to positive R&D spending.[9]

Figure 3 Corporate R&D expenditure, selected top R&D spenders worldwide, annual R&D expenditure, 2021 compared to 2022

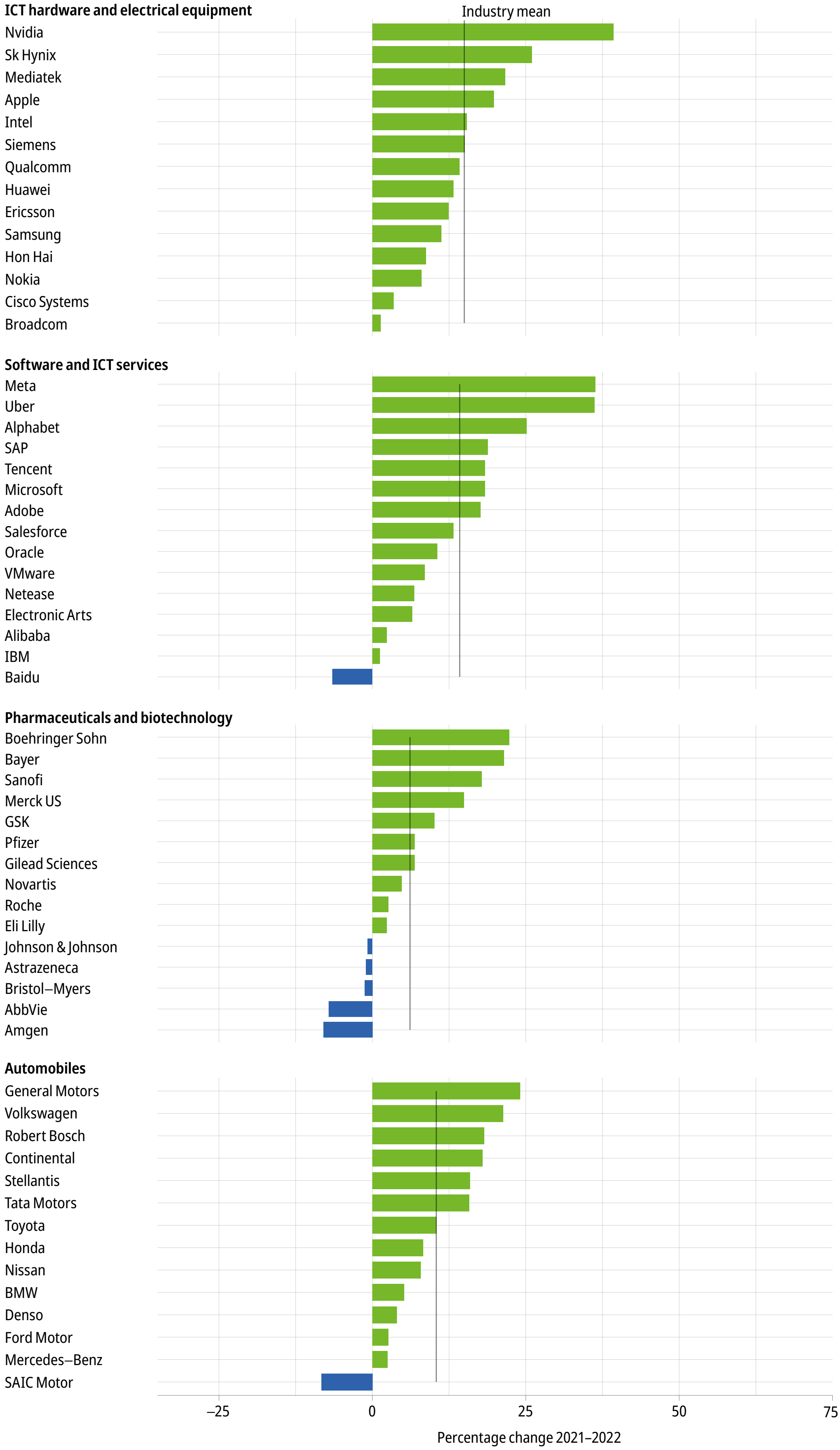
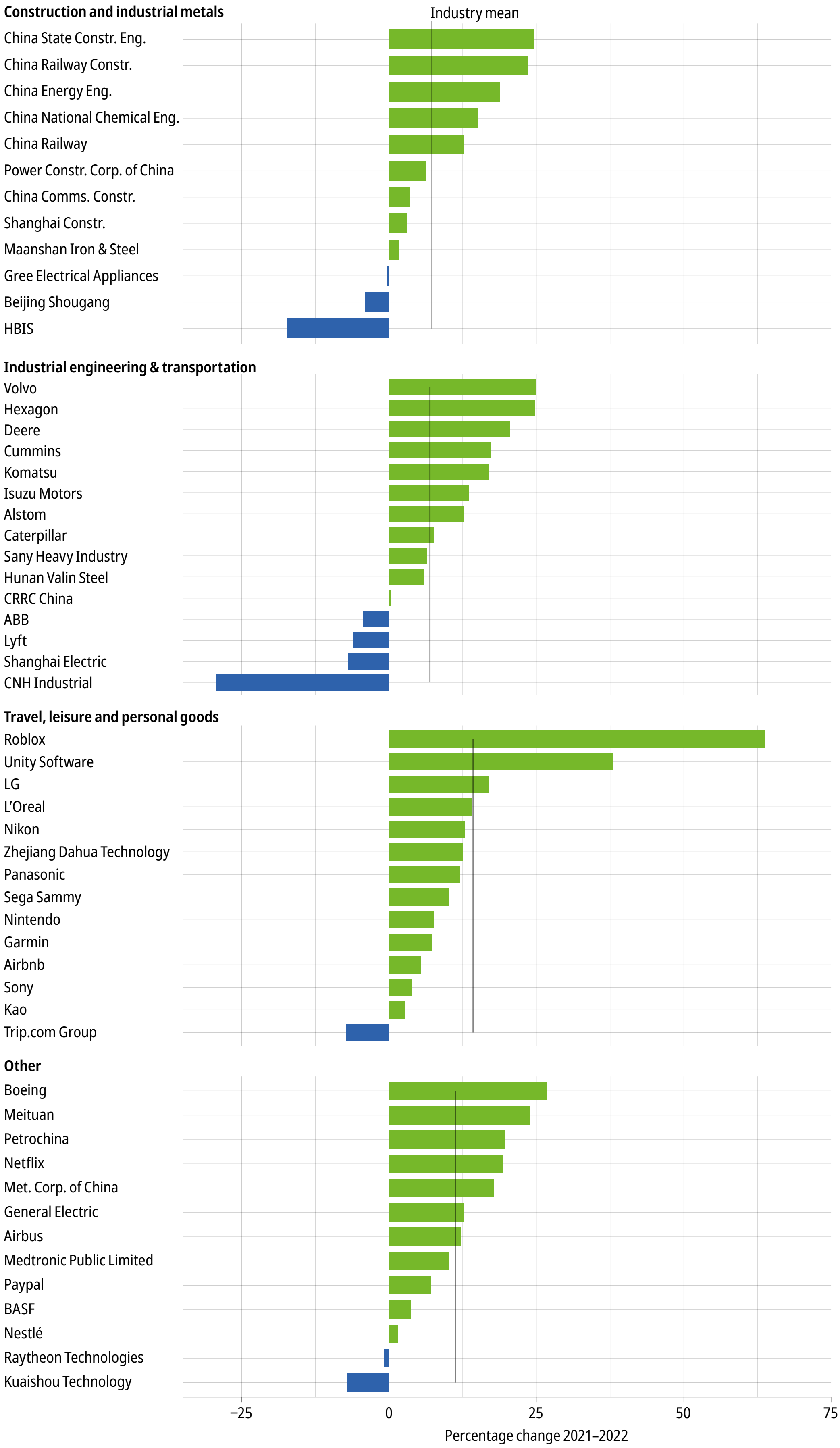


Figure 3 Continued



Source: WIPO, based on BvD Orbis database.

It is important to acknowledge that data presented in Figure 3 primarily focus on top R&D performers, often referred to as "R&D superfirms." A comprehensive evaluation of corporate R&D performance for 2022 would require additional data, including information from small and medium-sized enterprises that may have found innovation finance challenging in an environment where R&D is becoming both costlier and riskier.

Venture capital

After a phenomenal growth in 2021 (at a magnitude last seen just prior to the bursting of the so-called "dotcom bubble"), tighter monetary conditions in 2022 raised fears of a steep drop in venture capital (VC) investment, particularly a possible discontinuation of the VC influx that had benefitted previously underserved regions in 2021.[10] The observed outcome in 2022 contains a nuanced combination of results, but it cannot be claimed that the feared crash materialized. Whereas deals concluded showed a healthy growth of 17.6 percent (see Dashboard) to over 23,000 deals in 2022, the total amount of money invested in VCs went in the opposite direction and was cut back sharply by 37.8 percent (see Figure 4). The fall in VC value, combined with a growth in number of deals concluded, resulted in the average deal value halving from USD 31 million in 2021 to USD 16 million in 2022.

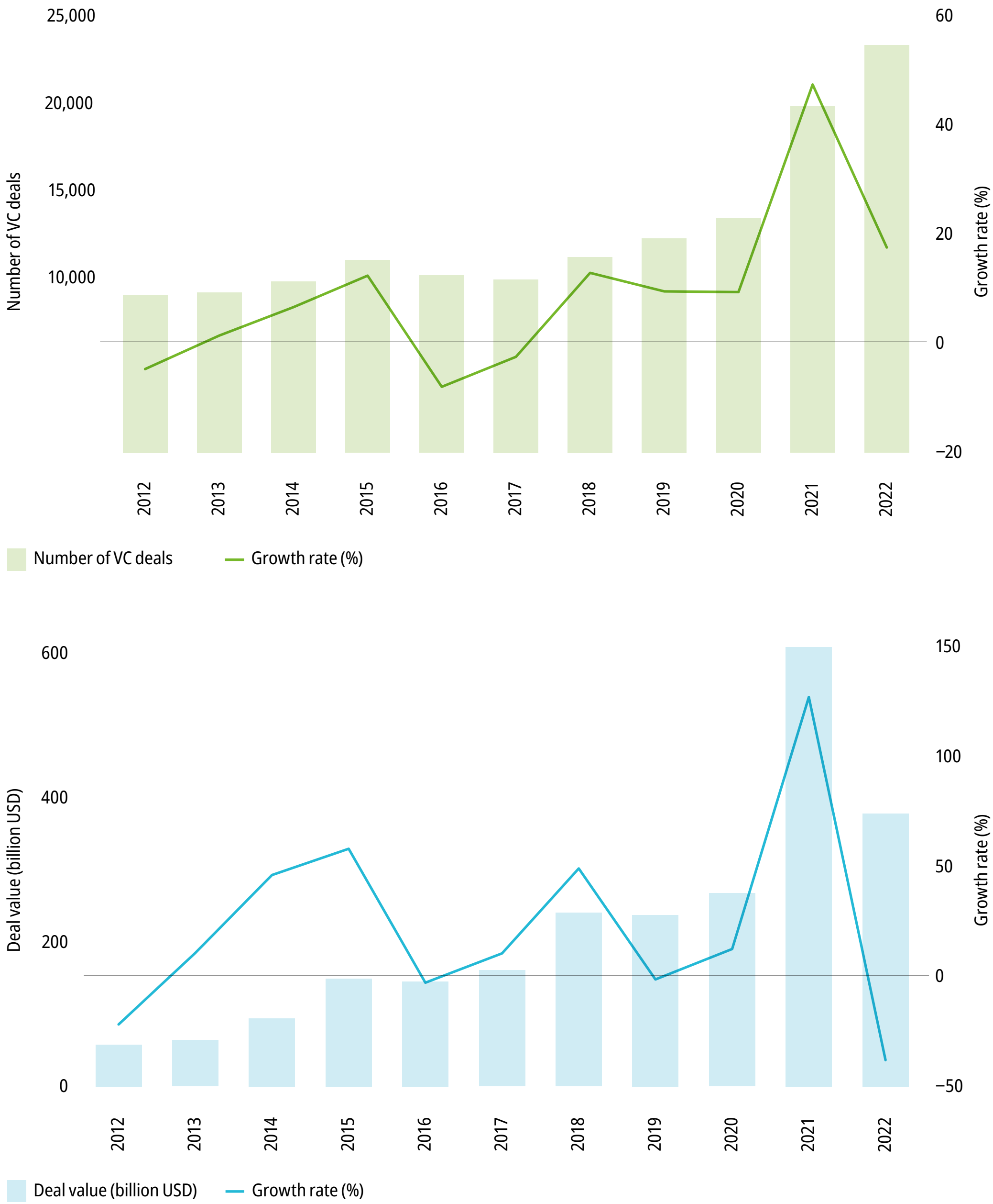
In 2022, for the first time in history, VC deal activity in the Asia Pacific region was on par with Northern America. Deals made per quarter in the Asia Pacific region have more than doubled in the space of two years, from around 1,000 deals in 2020 to approximately 2,200 in 2022. Regional differences show Africa leading, with a 46.6 percent growth in VC deals between 2021 and 2022 (albeit from low absolute levels of from 307 to 450 deals), closely followed by Latin America, with 44.0 percent growth (also from low absolute levels of from 327 to 471) and then Europe, with 39.3 percent (from 3,340 to 4,651). Africa and Latin America were the only two regions to experience a growth in VC deals above 40 percent; something that has occurred only rarely since the bursting of the dotcom bubble.

The amount invested in VC decreased from USD 610 billion in 2021 down to USD 380 billion in 2022. This decline is reminiscent of the financial crisis of 2009, marking a significant drop in VC value. One factor contributing to this decline is a notable increase in inflation, surpassing levels seen in several decades. Higher inflation negatively impacts the valuation of VC firms by necessitating a higher discount rate for future expected cash flows. The lower valuation, as a consequence, restricts the amount of financing VC firms are able to secure. Tighter monetary policy and higher interested rates further compound this effect.

The one continent not to see a decline in money invested was Africa, which remained unchanged from the previous year. Other regions, however, experienced a marked collapse in VC investment: −25 percent in Europe, −40 percent in Northern America and the Asian Pacific region, while Latin America experienced the largest VC deal value drop of −63 percent.

That said, it must be borne in mind that 2021 was an exceptional VC boom year difficult to exceed. This, in combination with elevated inflation in 2022, means that the number of deals and value invested in 2022 is after all rather impressive, being still higher than any other year within the last decade, apart from 2021.

Figure 4 Number of venture capital deals and deal value, 2012–2022



Source: WIPO, based on data by Refinitiv Eikon (private equity screener), accessed April 6, 2023.

International patent filings

Recent economic and political headwinds have impeded international patent filings, with growth throughout 2021 of 0.8 percent that was yet more sluggish in 2022 (0.3 percent), representing the slowest rate of increase since the decline in PCT applications seen in 2009.[11] Overall, this only slightly positive growth nevertheless led to the highest number of PCT filings ever recorded for a single year in 2022 (278,100). In both 2021 and 2022, Asia was the dominant force behind PCT filings, accounting for 54.7 percent of all PCT applications filed in 2022, with China, Japan and the Republic of Korea the strongest Asian international patent filers. In contrast, international patent filings from selected advanced economies, such as the United States (−0.6 percent) and the United Kingdom (−1.7 percent), underwent a decline. The marked slowdown in PCT filing growth from China – the largest filer – continued through 2022, but avoided a decline (0.6 percent growth).[12]

Technological progress

Technological progress continues to shape our world, offering opportunities as well as challenges. Enhanced computing power is playing an increasingly important role in the creation of breakthrough technologies. While supercomputers are becoming faster and more energy-efficient, the cost of producing advanced chips is becoming increasingly expensive, limiting participation in the technological chip race. DNA sequencing costs have dramatically decreased, surpassing what could be expected according to Moore's Law regarding microchip transistor count. Although the falling cost of solar and wind electricity generation has made low-emission technologies commercially competitive, higher material costs (leading to a first-ever increase in electric battery prices) may impact future progress.

Computing power

Breakthroughs in various fields, such as neuroscience, genetics, climate prediction, materials science, astrophysics, energy research and vaccine development, increasingly depend on the availability of supercomputers. Enhanced computing power is vital for the next wave of innovation-driven growth (see discussion of the Digital Age wave in last year's GII 2022 Special theme).

Moore's Law

Thanks to technological progress, Moore's Law predicts that the speed and capability of computer chips (measured by number of transistors per chip) will double every 18–24 months. This prediction has held roughly true for more than five decades since the 1970s, and the resultant increase in computer power over time has been an engine driving technological and social change.

Does Moore's Law still hold true, and will it continue to be up to the task of driving future growth? Experts are concerned that this may not be the case and that Moore's Law could soon run out of steam.[13]

The good news is that – at least for the time being – Moore's Law is holding up well, and considerably better than was expected in the 2022 Edition of the Global Innovation Tracker. Transistor counts for the decade spanning 2012 to 2022 increased annually by 44 percent, doubling every two years. Personal computer transistor counts increased by 62 percent from 2020 to 2022, doubling in under two years.

A transition to new technology yielding higher transistor density with enhanced energy efficiency is behind this success.[14] Renewed efforts by a few countries to produce new generations of chips, as well as recent advances made by graphic card producers, might well serve to sustain Moore's Law into the future as a key driver of future growth.

That said, it is also evident that fulfilling Moore's Law has become increasingly expensive. Factories designed to produce advanced chips cost more than USD 20 billion each, and fewer and fewer countries and firms possess either the know-how or the financial resources required to continue participating in what has become a technological chip race.[15]

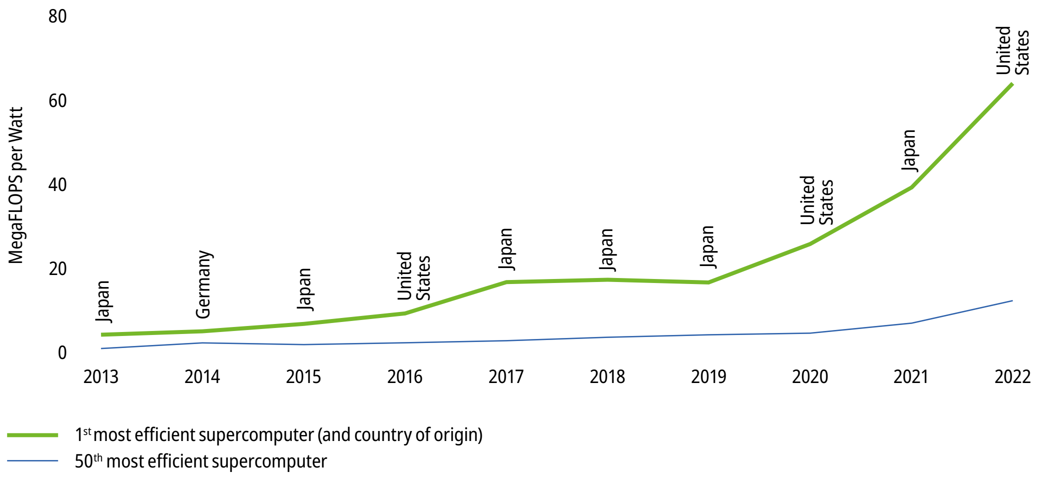
Green supercomputing

Higher-powered computer performance has been increasing exponentially since 2019. Today, the most recent exascale computers are capable of operating at 1,000,000,000,000,000,000 FLOPS (10 to the power of 18). By way of comparison, humans are capable of computing at around 1 FLOP or operation per second, roughly equivalent to one simple mathematical addition. The fastest known supercomputer, the Frontier system in the United States, reached a top speed of more than one exascale in March 2022, followed by Fugaku in Japan and LUMI in Finland. Exascale computers are known to exist in China, too, but are not yet officially recorded in the publicly available data used here.

Speed, however, is not the only important performance metric for supercomputers. The Global Innovation Tracker asks how efficient are the greenest supercomputers, that is to say, how many Gigaflops can they perform per Watt of energy consumed? This is a key question, as a supercomputer consumes vast amounts of energy, similar to what is needed to power a small city.

The performance of energy-efficient (green) supercomputers more than doubled from 2021 to 2022 (54.3 percent, see Dashboard). This is above the longer-term performance trend between 2013 and 2022 (35.4 percent). Figure 5 shows the performance of the greenest supercomputers, as well as the performance of the 50th greenest supercomputer, highlighting the significant differences that exist even among the best of the best.

Figure 5 Performance of the most efficient supercomputers, 2013–2022



Notes: One MegaFLOP is equivalent to 1,000,000 FLOPS. Excludes China, because data are unavailable.
Source: TOP500 and TOPGreen500 Database. www.top500.org/statistics.

The greenest known supercomputer is Henri from the United States, followed by Frontier TDS, also from the United States, while third is France's Adastra (see Table 2). Regrettably, but with some exceptions, few of the fastest supercomputers are also the greenest.

Table 2 Top fastest and top most efficient (green) supercomputers, 2022

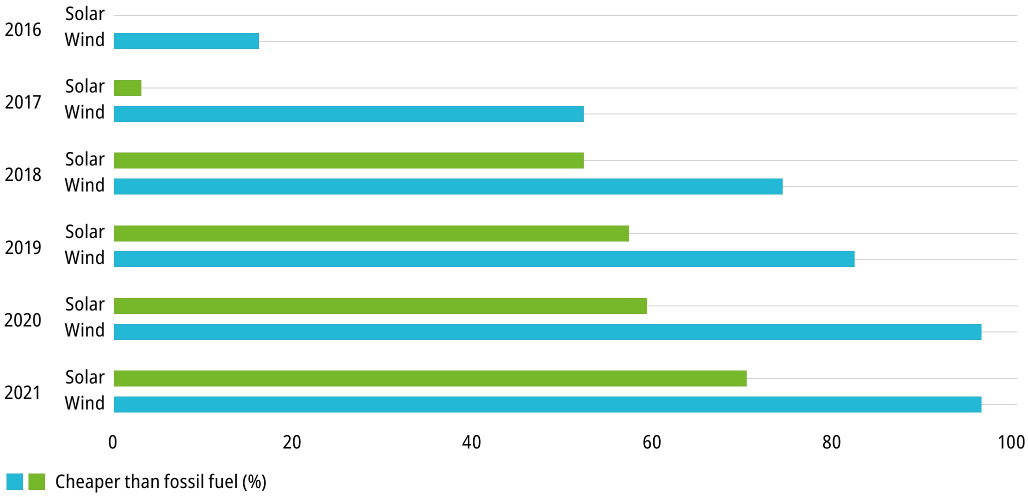
Rank: Green supercomputers	Rank: Supercomputers	Name	Country
1	405	Henri	United States
2	32	Frontier TDS	United States
3	11	Adastra	France
4	15	Setonix – GPU	Australia
5	68	Dardel GPU	Sweden

Source: TOP500.[16]
Note: Data for China are unavailable.

Costs of renewable energy

The falling cost of renewable energy is key to countering climate change and the resultant environmental challenges. Both solar and wind electricity generation costs fell by around 13 percent between 2020 and 2021 (see Dashboard). This means that 70 percent (96 percent) of the solar (wind) generation capacity newly installed in 2021 is cheaper and thus more competitive than the cheapest fossil fuel-fired new generation option (see Figure 6). This makes it possible to target cost-saving incentives at encouraging the adoption of low-emission technologies, instead of relying on regulation or taxation to deter high-emission activities. However, despite this notably positive progress, the decrease in cost recorded in 2021 may not continue into the future, owing to rises in associated material costs that are yet to be passed onto customers.[17] Even though, at present, the exceptionally high price of fossil fuels far outweighs increases in material commodity prices, the future is uncertain, not least because of geopolitical volatility and its unpredictable effect on fossil fuel prices.

Figure 6 Share of newly-installed renewable power generation capacity that is cheaper than the cheapest fossil fuel-fired option, 2016–2021



Source: IRENA Renewable Cost Database.

Notes: "Cheaper than fossil fuel" represents the capacity share of newly added solar and wind projects with a lower (levelized) cost of electricity generation than the cheapest fossil fuel-fired new generation option, at USD 54/MWh for a CCGT in the United States.

Electric battery price

Technological progress has persistently driven down the cost of lithium-ion batteries for over a decade, making EVs increasingly affordable. However, following more than a decade of decreasing prices, the rising cost of raw materials and battery components, coupled with soaring inflation, resulted in a first ever increase in the cost of a lithium-ion battery pack, up 7.1 percent in 2022 compared to the year before (i.e., from USD 141 to USD 151/kWh). Indeed, prices could have risen even further, if not for the greater use of alternative low-cost battery materials like lithium-ion phosphate in the production process and a continued reduction in the use of expensive cobalt.

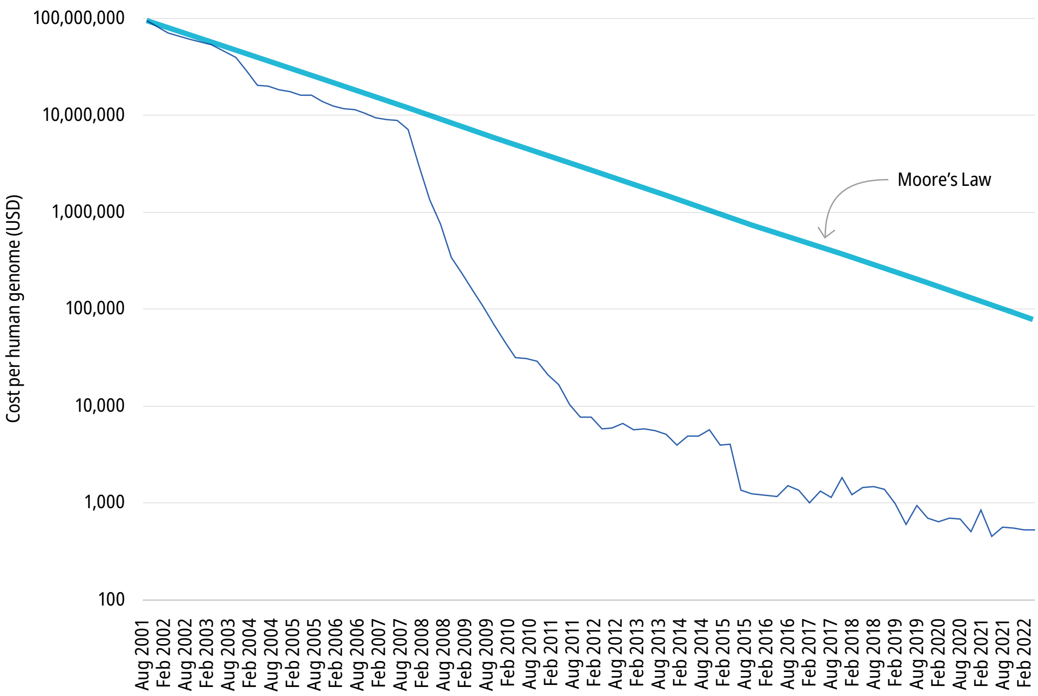
Battery prices are projected to remain at a similar level next year, contrary to significant declines in the past. However, starting in 2024, as lithium prices ease and additional extraction and refining capacity becomes available, battery prices are projected to resume a downward trajectory. The day that battery packs fall to a price of USD 100/kWh (relative to USD 151/kWh today) is thought to be the day that EVs will be no different in purchase price to petrol and diesel powered vehicles. Ambitious policy programs that emphasize the strengthening of domestic supply chains and encourage reshoring of electric battery and EV production have contributed to increased local supply.

Cost of genome sequencing

Part of the ongoing Deep Science innovation wave (see GII 2022 Special theme), future medical innovation is particularly dependent on advances in genetics and stem cell research. In turn, DNA sequencing plays a crucial role in understanding the human genome, which has numerous potential applications in health care, including in the rapid diagnosis of complex diseases and the fight against new viruses such as COVID-19.

The cost and time involved in sequencing a human or other organism's genome are important factors in the success of DNA sequencing technology. The cost of sequencing an entire genome has decreased dramatically over the years, based on estimates valid for the United States. As shown in Figure 7, it has fallen from approximately USD 100 million in 2001 to just over USD 500 in 2022. This rapid decrease in cost, driven by advancements in next-generation DNA sequencing methods, far outpaces the progress expected from Moore's Law, highlighting the remarkable technological progress that has been made in the field.

Figure 7 Cost of sequencing DNA of one human genome, 2001–2022 (USD)



Source: National Human Genome Research Institute (NHGRI), US National Institute of Health.[18]

Going forward, it will be intriguing to further evaluate whether the cost of human sequencing can be reduced even further to below USD 500, with the advent of new sequencing technologies, and made accessible to the general public, especially in health care settings.

New, forward-looking metrics will also be required in order to assess the speed and cost of more advanced DNA sequencing techniques in the future. Emerging long-read DNA sequencing technologies provide for more accurate identification of complex structural variations, but they are more expensive and require different metrics to track progress.[19]

Finally, the pricing and accessibility of DNA sequencing outside of the United States, and particularly in low- and middle-income nations, will be a key metric of success that needs to be developed further.

Drug approvals

Drug approvals provide an insight into the cutting-edge pharmaceutical treatments being introduced to the market. In the United States – which boasts the world's biggest drugs market – there were 37 approvals in 2022, marking a 26 percent decline from 2021. Looking at the 10-year trend shows a slight average annual decline of 0.5 percent over the period.

What can we gather from these numbers? On the one hand, the 37 approvals in 2022 indicates a significant decrease in the number of new drugs entering the market compared to the previous five years. This challenges the optimism surrounding scientific advancements such as mRNA and CRISPR technology, which were expected to stimulate a wave of new pharmaceutical treatments. On the other hand, historical data show that annual drug approval numbers are prone to fluctuation. The 10-year downward trend overall is largely the result of a short-term increase in 2012 and a short-term decrease in 2022. The coming years will reveal whether the decline observed in 2022 was an anomaly or indicative of a more fundamental drop in drug approvals.

Technology adoption

The global state of technology adoption reveals both progress and challenges in addressing pressing global issues. Access to safe sanitation has improved, but over 40 percent of the world's population continues to lack safe sanitation. Industrial robot installation has surged, driven by supply chain disruption and automation efforts, leading to increased efficiency and reshoring. Electric vehicle sales are booming, with positive ripple effects on battery production. Meanwhile, the availability of radiotherapy for cancer treatment remains inadequate in many countries, likely owing to financial constraints, lack of trained personnel and infrastructural challenges. Overall, technology penetration rates are still medium-to-low, with the exception of mobile broadband.

Safe sanitation

In an effort to track the adoption of health-related innovations, the Global Innovation Tracker now includes data on the availability of safe sanitation. Safe sanitation refers to that proportion of the population that uses an improved sanitation facility that is not shared and is safe. This indicator shows important progress over the last two decades, with a notable improvement of 1.4 percent between 2021 and 2022 (compared to 2.4 percent over 2012–2022). Progress has been quickest in Central and Southern Asia (+6.6 percent over 2012–2022) driven by a strong growth in availability of safe sanitation in India and East and South East Asia (+4.6 percent) attributable to progress in China.

In 2022, 57 percent of the world's population (4.5 billion people) had access to safe sanitation. A decade earlier, it was still only 45 percent, and in 2000 it stood at 32 percent. Since 2012, 1.3 billion people have gained access to safe sanitation across all regions, and 2.5 billion since 2000.[20] That said, there is still a long way to go. A little under half of the global population of 3.5 billion people still lacks safe sanitation. To reach the Sustainable Development Goal target of universal coverage by 2030, the annual rate of progress would need to increase to 7.4 percent from 2022 onward, up from 2.4 percent over the last decade. Disaggregated data also reveal significant disparities in access to safe sanitation both between and within countries. The situation remains dire in rural areas, where coverage is lower (46 percent) than in urban areas (65 percent), and in some of the world's regions, such as sub-Saharan Africa, only just under a quarter of people (24 percent) have safe sanitation.

Connectivity

In 2022, fixed broadband subscriptions grew by 4.8 percent, while mobile broadband subscriptions grew by 6 percent, both below the 10-year average. Mobile broadband adoption is more widespread, with 87 subscriptions per 100 inhabitants.[21] In contrast, fixed broadband subscriptions stood at only 17.6 per 100 inhabitants, though these are typically shared within households and therefore cover more people. Penetration rates for fixed broadband – which is often necessary for more advanced applications – remained poor in low-income economies. Connectivity to 5th generation mobile networks (5G) could help make up for lagging fixed broadband subscriptions rates. This new standard allows for faster, more reliable data transmission, and better suits the operation of connected machines, objects and devices (the Internet of Things), and thereby serves as an enabler unlocking the full potential of the digital era.

In 2021, according to estimates, 19 percent of the world's population was covered by 5G. Europe had the highest rollout at 52 percent, followed by Latin America and North America with 38 percent and the Asia-Pacific region at 16 percent. High infrastructure costs, device affordability, and regulatory and adoption barriers remain the primary obstacles to 5G deployment and could foster a digital divide.[22]

Robots and automatization

The number of industrial robots currently in operation grew by 14.6 percent between 2020 and 2021 (see Dashboard) to 3.4 million robots. Major supply chain disruption due to the COVID-19 pandemic and other disruptions to global trade have driven increased automation and reshoring efforts – together boosting new robot installations to a record high of 0.5 million in 2021, representing a growth rate of 31.4 percent on 2020. Robots have also become less complicated to operate, owing to their programming being increasingly intuitive to non-experts, thanks to advancements in user-friendly interfaces and sensor technologies.[23]

The top five markets for industrial robots are China, which leads with 52 percent of new installations, followed by Japan (9 percent), the United States (7 percent), the Republic of Korea (6 percent) and Germany (5 percent). Combined, these five countries represented 78 percent of new robot installations globally, in 2022.[24]

Electric vehicles

Demand for EVs is booming. In just two years, the market share of EV sales worldwide surged from 4 percent in 2020 to 14 percent in 2022. Sales of EVs surpassed 10 million units, marking a remarkable 55 percent increase between 2021 and 2022, while traditional car sales slumped by 3 percent.[25] This was despite the first ever observed increase in electric battery pack prices in 2022 (see Technological progress section above). Moreover, cars are just the first wave: electric buses and trucks will follow soon, while electric three-wheelers are already booming in major markets such as India, where over half of its three-wheeler registrations in 2022 were electric.

Encouraging EV trends are generating positive ripple effects for battery production and supply chains. Ambitious policy programs that put an emphasis on strengthening domestic supply chains and encourage reshoring – such as the European Union's (EU) Net Zero Industry Act and the United States' Inflation Reduction Act – have sparked significant planned investment by major EV and battery makers. To maximize the environmental benefits from EV transition, it is crucial to simultaneously address not only the sources of the electricity used to charge EVs, but raw material extraction and battery disposal.[26]

Nevertheless, at present, out of every car on the world's roads (in 2022) only 2.1 percent are electric (see Dashboard). This represents an EV stock of 26 million, half of which is in China (13.8 million). Europe maintained its position as the second largest market for electric cars worldwide, in 2022, accounting for 30 percent of global stock. EVs remain the fastest growing indicator (+59.9 percent and more than five times the stock in 2018, see Dashboard) in the Global Innovation Tracker this year, and further growth can be expected, regardless of uncertainty concerning how attractive traditional petrol or diesel vehicles will continue to be in the future.

Cancer radiotherapy

To better capture the adoption of health-related innovations, the 2023 Global Innovation Tracker includes data on the availability of cancer therapy equipment. A significant measure in the field of radiation oncology and medical physics is the total number of linear accelerators (LINACs) – devices for delivering high-energy x-rays or electrons to cancers for a therapeutic or palliative purpose – per cancer case requiring radiotherapy.

This metric can be regarded as a measure of the accessibility of cancer treatment infrastructure at the global level. International Atomic Energy Agency (IAEA) and DIrectory of RAdiotherapy Centres (DIRAC) data show cancer therapy has become less widely available, declining by −1.4 percent in the short term (2020–2022) and by −1.3 percent over the last decade (2012–2022). This suggests there has been an increase in cases of cancer requiring radiotherapy without an adequate corresponding increase in the number of LINACs, potentially leading to longer waiting times for patients or the need to travel abroad in order to access treatment.

In addition, there has been little improvement in the number of countries meeting minimum radiotherapy resource requirements over the last two years. Only 20.9 percent of countries worldwide met the minimum requirement in 2022 (see Dashboard). This stagnation in technological penetration is likely due to a variety of factors, including financial constraint, lack of trained personnel, infrastructural challenges and lack of awareness of the clinical role played by radiotherapy in the management of cancer.

Socioeconomic impact

The socioeconomic impact of innovation remains low. Labor productivity has come to a standstill, life expectancy continues to fall (including a slowdown in life expectancy improvement), and carbon dioxide emissions have returned to pre-pandemic levels. This is likely to be a rebound from the profound impact that COVID-19 has had on all three of these indicators. While life expectancy is sure to start increasing again in the future, developments in labor productivity and carbon dioxide emissions are less certain.

Labor productivity

Economists and policymakers around the world have been worrying about low productivity growth and how to revive the broken link between innovation and productivity – the theme of last year's GII 2022, What is the future of innovation-driven growth? – for a number of years. The year 2020 saw a sharp increase in global labor productivity (almost 4 percent). Yet this productivity spike was short-lived. One reason for the strong productivity growth rates seen early on in the pandemic (i.e., 2020) is that it was the less productive, in-person service activities that were most effected by lockdowns. This artificially raised the aggregate economy productivity level rather than it being a result of underlying technological progress. Consequently, hopes for a productivity revival were dashed again when employment readjusted and output per hour worked declined once again in 2021 to about 1 percent growth, and then down to zero in 2022 – the lowest growth rate seen in decades.

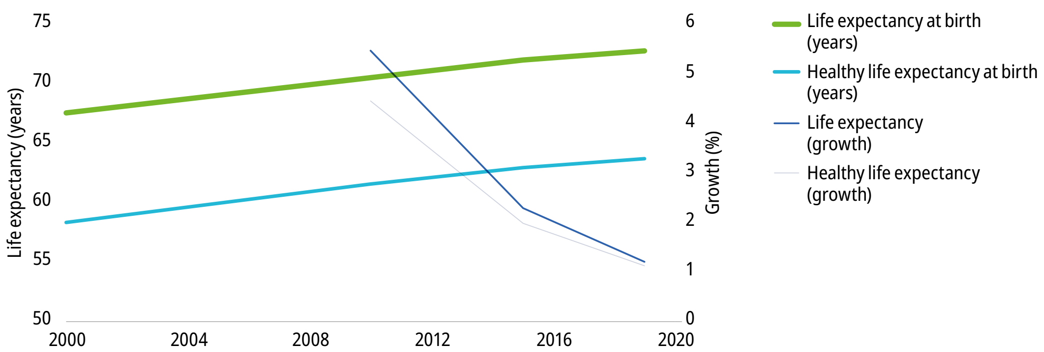
It is also notable how related economic data have fluctuated wildly in the past. In addition to volatile output and employment data (mostly due to lockdowns), changes in inflation, as well as geopolitical tensions, have also influenced productivity measures. Forecasts for 2023 foresee a modest uptick in productivity to about 1 percent, dampened in particular by negative productivity readings in Europe and the United States.[27] Prospects for 2024 and beyond look better, but are highly uncertain. Whether the Digital Age and Deep Science innovation waves outlined in the GII 2022 will reverse this productivity crisis continues to be a matter of debate. Only the next one to two decades will tell.[28]

Life expectancy

Nowadays, life expectancy is around 20 years longer than it was in 1960 (51 years). However, COVID-19 contributed to the first observed drop in life expectancy in 2020, and it continued to fall in 2021. This meant that life expectancy was nearly two years lower in 2021 (71 years) compared to pre-pandemic levels (73 years in 2019).

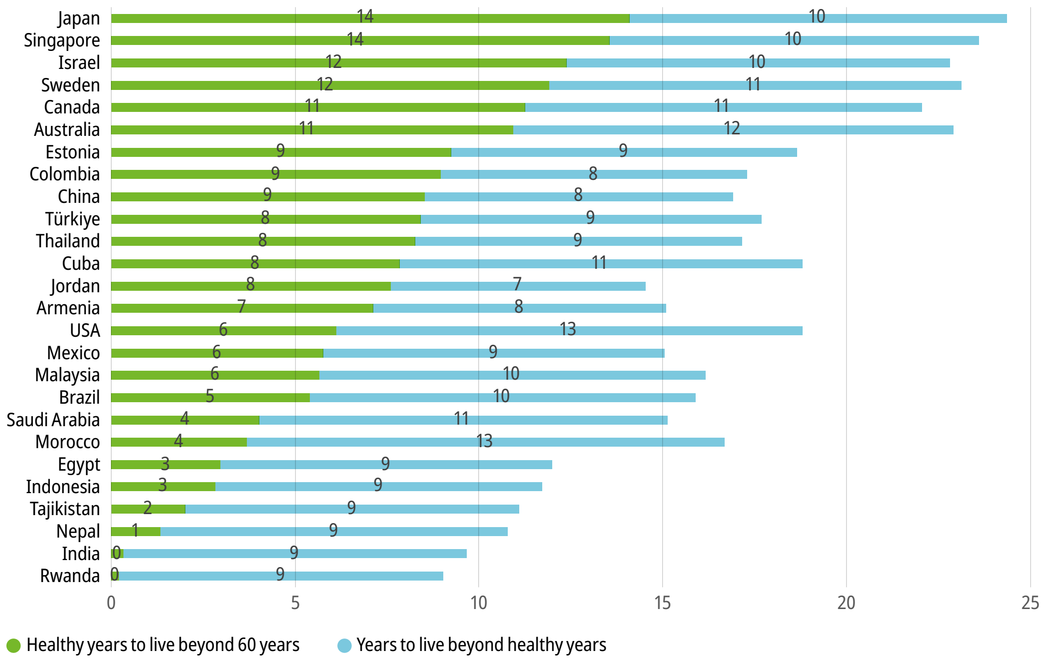
Examining well-being in aging and the role of innovation also involves reviewing the development of healthy life expectancy – an important measure of what people aspire to.[29] On average, healthy life stops about nine years before death. Figure 8 illustrates the relatively constant difference between the two concepts.

Figure 8 Life expectancy and healthy life expectancy, 2000–2019



Source: World Health Organization (WHO) Global Health Observatory Database.

Figure 9 Years of life beyond 60



Source: World Health Organization (WHO) Global Health Observatory Database.

Healthy life expectancy beyond 60 years of age is longest in Japan, with an additional 14 years of healthy living plus a further 10 years of less healthy living (see Figure 9). Some 30 countries (out of 183 covered) enjoy more than 10 years of healthy living beyond 60 years of age, while some 55 countries have a life expectancy of under 60 years.

Carbon dioxide emissions

Strict lockdowns and travel restrictions resulted in a significant reduction in global carbon dioxide (CO_2) emissions in 2020. Unfortunately, 2021 witnessed a notable rebound, with emissions increasing by 5.3 percent, more than reversing the pandemic-induced decline.

In 2022, the growth of CO_2 emissions slowed again to 1.7 percent growth over 2021 – which is still higher than the 10-year trend of 0.7 percent (see Dashboard). Comparing the first five months of 2023 to those of 2022, the increase in CO_2 emissions appears very modest, with a 0.3 percent growth, but data are provisional and growth is still positive with no global reductions of CO_2 emissions in sight.[30]

Conclusion

The GII's Global Innovation Tracker provides a data-driven perspective on the latest innovation trends and impacts. The main findings of the 2023 edition are as follows:

- After a boom in 2021, investments in science and innovation showed a more mixed performance in 2022. Scientific publications, R&D and venture capital deals continued to increase and are at historically high levels. Novel innovation waves offer unseen possibilities, and leading innovation nations and innovation-intensive firms are ramping up their innovation efforts. But growth was lower than the exceptional rates seen in 2021. In fact, the value of VC investment has declined, possibly foreshadowing how tighter monetary conditions might come to affect innovation finance, and making the outlook for 2023 and 2024 uncertain.
- A topical question is whether the pandemic and subsequent economic downturn will have lasting negative impacts on less mature innovation systems in middle- and low-income economies, as well as on emerging firms and start-ups. The 2021 and 2022 data necessary to answer this critical question is not as yet available in most cases.

- Judging from data available to the GII, technology adoption is growing. Yet penetration often remains low. As outlined in preceding GII reports, fostering adoption in some sectors, such as agri-food, green or medical innovations, poses a significant challenge. Novel, demand-led innovation approaches, plus new regulatory set-ups and other fresh efforts are required.
- Measures of the socioeconomic impact of innovation suggest weak, if not declining, progress in recent years. To a large extent, this reflects the impact of the COVID-19 pandemic. How strongly they will rebound, as once the impact of the pandemic recedes, remains an open question.

Notes

1 IMF, 2023.

2 Massimo and Verginer, 2022.

3 Among middle-income economies, next to China, Türkiye and Serbia registered unprecedented growth in R&D in 2021, with GERD increasing by 15.6 percent and 18.1 percent, respectively. Other middle-income economies that increased their total R&D in 2021 include Kazakhstan (+7.8 percent), Armenia (+4 percent), Egypt (+2.9 percent) and Uzbekistan (+2 percent).

4 Government R&D budget indicators for the OECD area present the amounts that governments agree to allocate to R&D as part of their budgetary processes, rather than actual expenditure reported by R&D performers. Notably, economies like Japan witnessed an impressive surge of 59 percent in 2020 in real terms, while Australia experienced a noteworthy increase of 18 percent. The Republic of Korea and the United Kingdom also demonstrated strong growth rates of 15 percent and 8 percent between 2019 and 2020, respectively, and the United States 12 percent.

5 OECD, 2023 notes that "data for 2021 indicate that the decline R&D budgets was principally explained by the readjustment to health R&D. This year marks the return to growth in undirected R&D funding (general university funds and other funding for the general advancement of knowledge)."

6 China Statistical Yearbook 2022, Table 20-1, Basic statistics on Scientific and Technological activities, www.stats.gov.cn/sj/ndsj/2022/indexeh.htm.

7 Grassano *et al.*, 2022.

8 Care should be taken when looking at nominal growth rates, as they have not yet been adjusted for inflation. Growth in R&D intensities can in that sense be more informative, as inflation is cancelled out.

9 Airbnb is also no longer considered in the Software and ICT services category but handled in Travel, leisure and personal goods in the 2023 June version of the BvD Orbis database.

10 See WIPO's GII Innovation Insight on "Growth in venture capital financing will decline in 2022 relative to the 2021 boom, but remains at historic levels," December 14, 2022. Available at: www.wipo.int/global_innovation_index/en/news/2022/news_0008.html (figures have been updated).

11 For assessments of how IP filings fared during this and previous crises see, WIPO, 2010; WIPO, 2022; and Fink *et al.*, 2022.

12 WIPO, 2023b.

13 Rotman, 2020.

14 Pollie, 2021; Wang *et al.*, 2023.

15 www.intel.com/content/dam/www/central-libraries/us/en/documents/what-does-it-take-to-build-a-fab.pdf and https://techcrunch.com/2022/03/15/intel-plans-to-build-a-19-billion-chip-plant-in-germany.

16 Available here: www.top500.org/statistics. The authors of TOP500 are Erich Strohmaier, Jack Dongarra, Horst Simon and Martin Meuer.

17 IRENA, 2022. Between January 2019 and May 2022, aluminum costs – which can account for as much as 10 percent of solar photovoltaic modules' costs – rose by 50 percent, while copper, which is used extensively in all electric power generation technology, experience a 55 percent price increase. Furthermore, iron ore prices increased by 87 percent in the same period, and the steel contained within it is an important component of wind turbine towers.

18 For full definitions, see www.genome.gov/about-genomics/fact-sheets/DNA-Sequencing-Costs-Data.

19 To sequence a large stretch of DNA using NGS (next-generation sequencing), such as a human genome, the strands have to be fragmented and amplified: https://frontlinegenomics.com/long-read-sequencing-vs-short-read-sequencing.

20 UNICEF and WHO, 2023; United Nations Children's Fund (UNICEF) and World Health Organization, 2019.

21 An individual may have more than one mobile broadband subscription.

22 International Telecommunication Union, 2022.

23 https://ifr.org/ifr-press-releases/news/top-5-robot-trends-2023.

24 Müller, 2022.

25 IEA, 2023.

26 www.nytimes.com/2021/03/02/climate/electric-vehicles-environment.html.

27 www.conference-board.org/data/economydatabase.

28 This topic was also discussed in the context of the GII 2022 theme in the webinar series "Exploring the Future of Innovation-driven Growth and the Role of Intellectual Property: U.S. Industry Experiences," co-organized by WIPO and the Intellectual Property Owners Association (IPO), January 18, 2023, see www.wipo.int/global_innovation_index/en/news/2023/news_0003.html and "Exploring the Future of Innovation-driven Growth and the Role of Intellectual Property: European Industry Experiences," WIPO and BusinessEurope, April 5, 2023, www.wipo.int/export/sites/www/global_innovation_index/en/docs/businesseurope-workshop.pdf.

29 Healthy life expectancy refers to the average number of years that a person can expect to live in "full health" by taking into account years lived in less than full health, because of disease and/or injury, see www.who.int/data/gho/data/indicators/indicator-details/GHO/gho-ghe-hale-healthy-life-expectancy-at-birth. See also "Do you really want to live to be 100?," by Sarah O'Connor, *Financial Times*, December 6, 2022.

30 Carbon Monitor, https://carbonmonitor.org, accessed June 15, 2023.

Data notes

Scientific publications captures the number of peer-reviewed articles published in the Social Sciences Citation Index (SSCI) and Science Citation Index Expanded (SCIE), excluding early access articles. Source: Web of Science (Clarivate), https://apps.webofknowledge.com.

R&D investments captures R&D expenditures worldwide in PPP-adjusted constant 2015 prices. The 2021 values were calculated using available real data of gross expenditure on R&D (GERD) and business enterprise expenditure on R&D (BERD) at the country level from the UNESCO Institute for Statistics (UIS) online database; the OECD's Main Science and Technology Indicators (MSTI) database (March 2023 update); Eurostat and the Ibero-American and Inter-American Network of Science and Technology Indicators (RICYT). For those countries for which data were unavailable for 2021, the 2021 data were estimated using the last observation carried forward (LOCF) method. The R&D section also includes data on government budget allocations for R&D between 2019 and 2022 sourced from the Joint OECD–Eurostat data collection on resources devoted to R&D, April 2023, with figures in current US dollars. Data for the top global R&D spenders, in turn, are derived using the top spenders compiled in the European Commission's 2022 EU Industrial R&D Investment Scoreboard as a starting point and WIPO calculations facilitated by the Bureau van Dijk (BvD) Orbis database, with all figures in current US dollars.

Venture capital (VC) deals refers to the absolute number of VC deals received by companies located in a region. VC value refers to the total amount of current US dollars invested – via venture capital – into companies located in a region. Source: Refinitiv Eikon data on private equity and venture capital, www.refinitiv.com/en/products/eikon-trading-software/private-equity-data.

International patent filings refers to the total number of patent applications filed through the WIPO-administered Patent Cooperation Treaty. Source: WIPO IP Statistics Data Center, www.wipo.int/ipstats.

Microchip transistor count (Moore's Law) refers to the number of transistors to be found on the most advanced, commercially available microchips in a given year. Source: Karl Rupp, https://github.com/karlrupp/microprocessor-trend-data.

Green supercomputers consists of a Green500 list of the most powerful, commercially available computer systems known, which are at the same time the most energy-efficient in terms of calculation capacity per energy invested (Gflops/Watts). Source: TOP500, www.top500.org/lists/green500.

Cost of renewable energy captures the global weighted average levelized cost of electricity (LCOE) generation of solar photovoltaics and onshore wind. Source: International Renewable Energy Agency (IRENA), www.irena.org/Publications/2022/Jul/Renewable-Power-Generation-Costs-in-2021.

Electric battery price refers to the average lithium-ion battery price (in 2022 USD, including the cell, module and pack), weighted by power capacity (MWh), across all sectors. Source: BloombergNEF (BNEF), https://about.bnef.com/blog/lithium-ion-battery-pack-prices-rise-for-first-time-to-an-average-of-151-kwh.

Cost of genome sequencing refers to the cost of sequencing the DNA of one human genome (in USD). Source: National Human Genome Research Institute (NHGRI), US National Institute of Health, Wetterstrand KA. DNA sequencing costs: data from the NHGRI Genome Sequencing Program (GSP), www.genome.gov/sequencingcostsdata.

Drug approvals refers to the number of new drugs approved by the U.S. Food & Drug Administration (FDA). Data include both small molecule drugs and biologics. Source: FDA, www.fda.gov/media/135307/download.

Safe sanitation refers to that proportion of the population that has access to a sanitation facility not shared with other households and where excreta are safely disposed of *in situ* or removed and treated off-site, including flush/pour toilets connected to piped sewerage systems; septic tanks or pit latrines; pit latrines with slabs; and composting toilets. Source: WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP), https://washdata.org.

Broadband penetration is equivalent to the number of fixed and (active) mobile broadband subscriptions, respectively, per 100 inhabitants. Source: International Telecommunication Union (ITU) World Telecommunication/ICT Indicators database, www.itu.int/en/ITU-D/Statistics/Pages/facts.

Robots is a measure of the number of robots currently deployed in industrial automation applications (also known as the operational stock of industrial robots). The stock is calculated assuming an average service life of 12 years with immediate withdrawal from service at the end of this period. Source: International Federation of Robotics (IFR), https://ifr.org/img/worldrobotics/Executive_Summary_WR_Industrial_Robots_2022.pdf.

Electric vehicles (EVs) stock share is the percentage of passenger cars worldwide that are battery electric vehicles (BEVs) or plug-in hybrid electric vehicles (PHEVs). Source: International Energy Agency (IEA), www.iea.org/articles/global-ev-data-explorer.

Cancer radiotherapy refers to the total number of linear accelerators per cancer cases requiring radiotherapy. Linear accelerators (LINACs) are devices for delivering high-energy x-rays or electrons to cancers for a therapeutic purpose. A higher ratio indicates a better-equipped health care system. Penetration rate refers to the number of countries that meet minimal radiotherapy resource requirements worldwide, based on a rough assumption that one in every two cancer cases requires radiotherapy and that one machine is needed for every 500 patients requiring radiotherapy. Source: Special tabulations by International Atomic Energy Agency's (IAEA) DIrectory of RAdiotherapy Centres (DIRAC) for the GII based on IAEA DIRAC (https://dirac.iaea.org) and IARC GLOBOCAN (https://gco.iarc.fr) databases.

Labor productivity refers to the world total of output per hour worked, as estimated by The Conference Board. Source: The Conference Board Total Economy Database™, April 2023, https://conference-board.org/data/economydatabase.

Life expectancy refers to the number of years a newborn infant could be expected to live, if patterns of mortality prevailing at the time of birth were to stay the same throughout its life. Source: World Development Indicators, https://databank.worldbank.org/source/world-development-indicators.

Carbon dioxide emissions refers to fossil emissions, excluding carbonation, for the world, measured in billion tonnes of CO_2 per year. Source: Global Carbon Project (2022). Supplemental data of Global Carbon Budget 2022 (Version 1.0), https://doi.org/10.18160/gcp-2022.

References

Fink, C., R. Lamb, B. Le Feuvre and H. Zhou (2022). How the COVID-19 crisis affected international intellectual property filings. In Fink, C., Y. Ménière, A. Toole and R. Veugelers. *Resilience and Ingenuity: Global Innovation Responses to Covid-19*. Center for European Policy Research. Available at: https://cepr.org/publications/books-and-reports/resilience-and-ingenuity-global-innovation-responses-covid-19.

Grassano, N., H. Hernandez Guevara, P. Fako, E. Nindl, A. Georgakaki, E. Ince, L. Napolitano, F. Rentocchini and A. Tübke (2022). *The 2022 EU Industrial R&D Investment Scoreboard*. Luxembourg: Publications Office of the European Union. Available at: https://iri.jrc.ec.europa.eu/scoreboard/2022-eu-industrial-rd-investment-scoreboard.

IEA (2023). *Global EV Outlook 2023: Catching Up with Climate Ambitions*. International Energy Agency. Available at: www.iea.org/reports/global-ev-outlook-2023.

IMF (2023). World Economic Outlook: A Rocky Recovery, April 2023. Washington, DC: International Monetary Fund. Available at: www.imf.org/en/Publications/WEO/Issues/2023/04/11/world-economic-outlook-april-2023.

International Telecommunication Union (2022). *Measuring Digital Development: Facts and Figures 2022*. Available at www.itu.int/itu-d/reports/statistics/facts-figures-2022.

IRENA (2022). *Renewable Power Generation Costs in 2021*. International Renewable Energy Agency, Abu Dhabi. Available at: www.irena.org/publications/2022/Jul/Renewable-Power-Generation-Costs-in-2021.

Massimo, R. and L. Verginer (2022). The impact of the COVID-19 pandemic on scientific research in the life sciences. *PLoS ONE*, 17(2), e0263001. Available at: https://doi.org/10.1371/journal.pone.0263001.

Müller, C. (2022). *World Robotics 2022 – Industrial Robots*. Frankfurt am Main: IFR Statistical Department, VDMA Services GmbH.

OECD (Organisation for Economic Co-operation and Development) (2023). *OECD Main Science and Technology Indicators: Highlights – March 2023*. OECD Directorate for Science, Technology and Innovation. Available at: www.oecd.org/sti/msti2023.pdf.

Pollie, R. (2021). Nanosheet chips poised to rescue Moore's Law. *Engineering*, 7(12), 1655–1656. Available at: https://doi.org/10.1016/j.eng.2021.11.008.

Rotman, D. (2020). We're not prepared for the end of Moore's Law: It has fueled prosperity of the last 50 years – But the end is now in sight. *MIT Technology Review*. Available at: www.technologyreview.com/2020/02/24/905789/were-not-prepared-for-the-end-of-moores-law.

UNICEF (United Nations Children's Fund) and WHO (World Health Organization) (2019). *Progress on Household Drinking Water, Sanitation and Hygiene 2000–2017: Special Focus on Inequalities*. Available at: https://data.unicef.org/wp-content/uploads/2019/06/JMP-2019-FINAL-high-res_compressed.pdf.

UNICEF and WHO (2023). *Progress on Household Drinking Water, Sanitation and Hygiene 2000–2022: Special Focus on Gender*. Available at: https://data.unicef.org/resources/jmp-report-2023.

Wang, X., L. Chi, W. Yuning, F. Shun, S. Dongming and C. Huiming (2023). Three-dimensional transistors and integration based on low-dimensional materials for the post-Moore's law era. *Materials Today*, 63, 170–187, ISSN 1369-7021. Available at: https://doi.org/10.1016/j.mattod.2022.11.023.

WIPO (2010). Special theme: The impact of the economic crisis and recovery on innovation. In *World Intellectual Property Indicators 2010*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/edocs/pubdocs/en/intproperty/941/wipo_pub_941_2010.pdf.

WIPO (2022). *World Intellectual Property Indicators 2022*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4632.

WIPO (2023a). *Madrid Yearly Review 2023: International Registration of Marks*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4660&plang=EN.

WIPO (2023b). *Patent Cooperation Treaty Yearly Review 2023: The International Patent System*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/edocs/pubdocs/en/wipo-pub-901-2023-en-patent-cooperation-treaty-yearly-review-2023.pdf.