innovation indicator

2025

INNOVATIONSINDIKATOR.DE

BDI Bundesverband der Deutschen Industrie e.V.
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All results and analyses of the Innovation Indicator, as well as further background material and a detailed methodological report in English, can be found on the German-language website. There, you can also use "My Indicator" to compare economies individually.

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CONTENTS

EDITORIAL

Dear Reader,

We are in the midst of an epochal change: Our economic success in recent decades has been based on a model of globalization founded on the Bretton Woods institutions and supported by the United States as a global protective power. With the shift in globalization toward more regionalized value creation and the danger of a hegemonic division of the global economy, even proven innovation approaches are coming under pressure. Tariffs, the relocation of value chains, and high uncertainty are increasing cost pressure on companies. And the justified expansion of defense budgets is limiting the financial leeway of governments.

Against this backdrop, the Innovation Indicator 2025 focuses on two new special topics: the efficiency and openness of innovation systems. The respective analyses provide answers to two crucial questions: How efficiently do economies use their resources to generate and commercialize new knowledge? And to what extent do countries rely on exchange and cooperation to strengthen their innovative capacity?

The results show that Germany efficiently generates new knowledge but is significantly less successful at commercializing it — that is, transferring inventions into innovations. Numerous adjustments can be made, not all of which require financial resources. For instance, existing funding programs should accelerate their processes so companies can bring their innovations to market more quickly. Start-ups must be given easier access to venture capital and simpler spin-off rules, while existing companies must be supported by faster government processes and more targeted funding programs.

At the same time, Germany's innovation system is also coming under pressure due to the increased focus on national security interests. This is because innovation depends crucially on cooperation and collaboration between countries. The necessary openness is coming under pressure worldwide, and in Germany, too, questions about research security and technological sovereignty are increasingly being asked. Despite all legitimate security interests, one thing is clear: Germany must continue to focus on openness and exchange if we do not want to give up our claim to technological leadership. In concrete terms, this means improving intra-European cooperation through a stronger single market while at the same time establishing and strengthening partnerships outside Europe.

The overall assessment of innovative capability clearly shows one thing: Germany is living off its past successes. As in the previous year, Germany ranks 12th in the international comparison. This is no cause for celebration, especially when looking at the details. Germany is falling behind in terms of the innovative performance of its companies. Research and development in the field of digitalization are particularly affected.

In terms of sustainability, however, Germany has fallen significantly, dropping from third to seventh place. The reasons for this are wide-ranging but can be summarized by the fact that sustainability goals have not been sufficiently reconciled with economic success in the recent past.

All in all, the same applies to Germany's innovation system as to the economy as a whole: Past successes will become less and less effective in a dynamic competitive environment. We must change: less regulation, a more efficient public administration, investment in innovation and digital technologies. We must pursue our security interests with confidence. At the same time, we must show more pragmatism in international partnerships and a stronger commitment to the European single market. Or to put it bluntly: We need to roll up our sleeves and get to work.

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1 — SUMMARY

INNOVATION OPENNESS UNDER PRESSURE

GENERATING INNOVATIONS

- Switzerland remains the most innovative country, followed by Singapore and Denmark. These three countries managed to continuously keep up their innovation capability. Meanwhile, countries from the midfield of the ranking such as the United States, the United Kingdom, France and Canada are improving their innovation capability.

- Smaller countries such as Sweden (ranked 4th), Finland (5) and Belgium (7) perform better in this year's rankings, mainly thanks to their high level of specialization and strong international cooperation. These countries make effective use of their resources to advance innovation activities.

- China (30), Taiwan (19) and Australia (13) have seen their innovation capability decline, partly due to their dependence on international markets. Poland (27), Turkey (34), Italy (29) and Israel (17) are also experiencing declining innovation capability, in this case due to specific national factors.

- Germany maintains its 12th place in the innovation ranking but has lost ground on key indicators such as R&D expenditures and transnational patents. The innovation performance of German companies has deteriorated, particularly in digitalization, transnational patents and high-tech value creation – a development that threatens the country's competitiveness. Germany also failed to achieve any significant improvement in its scientific performance, as reflected in unchanged publication and patent numbers compared to more dynamic countries. This stagnation could prove problematic in the long term.

- Japan (28) once again performs poorly, largely due to low output from the science system and very low international integration of R&D activities.

- Russia has advanced considerably in the innovation ranking and now holds 23rd place. It has achieved this by stepping up investment in emerging technologies following the country's transition to a war-focused economy. Whether this progress is sustainable remains unclear.

- Geopolitical tensions have changed governments' roles in innovation systems, particularly regarding technologies pertinent to national security. This could have long-term impacts on innovation capabilities across the globe.

DEVELOPING FUTURE FIELDS THROUGH KEY TECHNOLOGIES

- Cross-cutting technologies such as microelectronics and AI are already having a major impact on various industries, while other technologies – in the energy industry, for example – are primarily driving efficiency gains.
- The Innovation Indicator examines seven key technologies for an economy's competitiveness. These include digital hardware, digital networks, advanced production technologies, energy technologies, advanced materials, biotechnology and the circular economy.
- The ranking of economies in the field of key technologies is relatively stable over time, with Denmark, Switzerland and South Korea occupying top positions. These countries have strong national innovation systems focused on science and technology.
- Germany (ranked 4th) achieves good positions in many key technologies, particularly in the circular economy. However, the country lags behind when it comes to the digitalization of goods and services, resulting in a decline of competitiveness.
- Japan (6) enjoys a strong position in several key technologies but has weaknesses in the science system.
- China (9) has made progress in recent years, particularly in biotechnology and new energy technologies.
- The United States (11) performs well in biotechnology but has a trade deficit across all key technologies, which impairs its overall performance in key technologies.
- Many European economies, including France and Italy, do not focus on key technologies, and consequently hold positions in the lower part of the ranking. Strengthening their innovation systems is essential if they are to regain global competitiveness.
- While some European countries perform well on specific key technologies, better coordination and cooperation within the European Union is needed to boost competitiveness and secure technological sovereignty. The European Research Area and public-private partnerships could help overcome challenges, but fragmentation of the internal market remains an obstacle to developing and scaling key technologies.

ACTING SUSTAINABLY

- Public policies – through the legal frameworks and support measures they create – play a crucial role in promoting sustainable practices. Incentives for renewable energy and the regulation of environmentally harmful behavior are important for building an environmentally friendly economy.
- Many countries that previously led on sustainability have dropped down the rankings this year. This is partly due to catch-up by countries such as China (ranked 5th this year, compared to 20th in 2020). The two leading countries, Denmark (1) and Finland (2), also score lower than in previous years.
- Germany has lost considerable ground in the sustainability index, falling to seventh place. Despite a strong political focus on sustainability, the country has shortcomings in innovation capability and spending on environmentally friendly technologies.
- China has improved significantly in the ranking, rising to 5th place. This achievement is primarily due to progress on environmental innovations – despite external criticism of possible greenwashing and continued high dependence on coal power.
- Norway (3) shows strengths in environmentally focused publications and environmentally friendly purchasing behavior, while other countries like Austria (6) and the United Kingdom (8) demonstrate specific strengths in green investments and certifications.
- Countries such as the United States (29), Turkey (30) and Brazil (31) are lower down the sustainability index. Indonesia (27) has achieved the largest gains, while Israel (32) and Ireland (33) round out the ranking.

INNOVATION EFFICIENCY

- Innovation processes are both costly and risky. Additionally, the complexity and knowledge required for new innovations have increased in recent years. This leads to a decrease in the marginal effects of innovation expenditure and pushes companies to work more efficiently. At the same time, public and private research budgets are under pressure.
- With this in mind, this year's Innovation Indicator also analyzes the efficiency of national innovation systems. The results show that many countries, particularly in Europe, exhibit a discrepancy between high knowledge generation efficiency and low commercialization efficiency, illustrating the so-called European paradox.
- System efficiency, resulting from the combination of knowledge generation and commercialization, varies significantly between countries. Austria, Denmark and Germany show high knowledge generation efficiency but face difficulties in commercialization.
- Resource deployment and innovation output in the United States are relatively low, given the size of the economy. The country therefore performs rather poorly in the overall ranking of innovation capability. However, it is one of the most efficient countries when it comes to innovation systems, in both knowledge generation and commercialization.

OPEN SCIENCE AND INNOVATION

- Openness in science and innovation systems has gained importance over the past decades. However, geopolitical tensions and protectionist policies have led to a reorientation in recent years, making research security and technological sovereignty matters of high priority.
- Because restrictions on openness can potentially increase innovation costs and impair innovation system efficiency, it is important for economies to strike the right balance between enabling openness in innovation and strengthening national security.
- Our analyses show that the openness of innovation systems has been stable over past decades. However, since 2020 the openness of innovation systems has been declining. The main reasons for this are the COVID-19 pandemic, geopolitical tensions, increased protectionism and a focus on technological sovereignty.
- Switzerland leads the Openness Index with 72 points, followed by Denmark (2) and a group of smaller countries including the Netherlands (3) and Singapore (4). Smaller countries tend to perform better as they often engage in international cooperation to find suitable partners.
- Germany (13) has an open science and economic system, though societal openness is comparatively low.
- Japan (23) has a science system with little international integration, and private research and development have a strong national orientation; only trade in goods and financial flows can be considered internationally open.
- The United States (28) does not have an open innovation system. The country's science system is only moderately internationally cooperative, as indicated by its low share of open-access publications, co-publications and foreign master's students. By contrast, its R&D system is strongly internationally integrated. The changes seen in this area over time are striking: Openness generally declined after 2005, but it increased between 2017 and 2019 thanks to investments, open-source software repositories, an influx of students from abroad and the growth of libertarian social values.
- Some countries are highly open when it comes to foreign direct investments, foreign R&D and scientific collaboration. They include the Czech Republic, which has made significant progress over time and holds seventh place this year.
- There is a positive correlation between the openness of national systems and their innovation capability, though this correlation has slightly weakened since 2020. While some countries show high innovation capability combined with comparatively low openness, others, like Denmark and the Netherlands, are more open than the correlation would suggest.

BOOSTING INNOVATION

Multiple crises, greater security needs, the goal of greater technological sovereignty, global power shifts, more intense international competition and protectionist policies are having a significant impact on the innovation systems of individual countries. Various key technologies make a special contribution to both securing technological sovereignty and maintaining competitiveness. Addressing societal challenges and focusing on social and sustainable development goals, including climate and environmental protection in particular, are currently posing additional challenges for national economies. Building, maintaining and expanding skills and capacities in these areas is the focus of science and innovation policy in many countries.

The findings of the **Innovation Indicator 2025** on the innovative capacity of economies, their performance in key technologies and sustainability, and the openness and efficiency of innovation systems provide a wealth of insights into how countries can secure and improve their innovation and competitiveness and allow the following recommendations to be made:

The generation of knowledge is crucial for innovation and technological sovereignty. Additional investment in research and development is therefore essential.

- To ensure a focus on current issues and challenges and to achieve new insights at the respective frontiers of knowledge, investment in the science system and an expansion of R&D in public organizations and private companies are urgently recommended. This can be achieved through direct or indirect research funding. In Europe, the 3% target still applies. China and the United States have already achieved this target or are on their way to doing so. Individual countries within and outside Europe are significantly above this target, driven by a corresponding technology portfolio and specialization in cutting-edge technologies. These countries will set the pace for research and innovation even more in the future, which will increase the pressure on others.

In many countries, however, public budgets offer little scope for additional investment, especially as competition between different policy areas for scarce resources is fierce. It is therefore crucial to organize the innovation system as efficiently as possible.

- Public funds must be used in such a way that they generate maximum social benefit. This requires prioritizing strategic issues, stricter evaluation criteria, better coordination and shared infrastructure to avoid duplication of work.
- Open science, standardized data formats and digital processes improve reusability and reduce overheads. Reducing bureaucracy and targeted public-private partnerships mobilize additional resources.
- Results-oriented funding models and clear impact metrics steer research toward application-relevant solutions, maintain excellence and increase the return on public investment.

Openness and innovation go hand in hand – a realignment of global cooperation in science and research is essential due to new requirements.

- International cooperation in science, research and new technologies is undergoing radical change, and a new global system has yet to be established. For individual countries, this means developing and communicating clear strategies for international cooperation. New requirements in terms of research security and technological sovereignty necessitate a reorientation but must not lead to isolationism. Openness can only be expected if it is also adopted as a guiding principle.
- In Europe, the European Research Area (ERA) provides a political and programmatic framework that helps to deepen cooperation and bring together the specializations of individual countries in a synergistic way. The new policy agenda has been adapted to current requirements and challenges. The task now is to improve the resources and organizational conditions, both nationally and through the upcoming Research Framework Programme (from 2027), in order to achieve the ambitious goals of the ERA. The importance of the new Research Framework Programme for science, research and competitiveness, as well as for Europe's technological sovereignty, justifies an expansion of the budgetary framework. However, when allocating these funds, even more attention must be paid to excellence criteria and the promotion

of specialization than in the past, as this is the only way to ensure not only the effectiveness but also the efficiency of the European Research Area.

- Openness of innovation systems also means creating the right conditions for companies to be able to use knowledge internationally and, at the same time, integrate internationally available knowledge into the national context, especially within companies at different locations. Since specific government objectives and regulations can restrict these knowledge flows, the costs must never exceed the benefits, neither from a government nor a business perspective.

The capabilities for knowledge transfer, implementation and diffusion must be addressed in a targeted manner in modern research, technology and innovation policy.

- To advance the implementation of knowledge into innovations, cooperation between industry and science must first be further expanded. Especially in the case of emerging topics and technologies, rapid commercialization and scaling of innovations within an ecosystem must be established. This requires transfer incentives in science, venture capital and market-oriented IP regulations.

- New topics and technologies – from security technologies to technologies for coping with climate change – require additional research and innovation capacities in industry and science.

- In the business sector, market-based instruments are particularly effective. To support the diffusion of new technologies and achieve acceleration, especially in early market phases, public procurement and government R&D contracts should be awarded in a targeted manner.

Key technologies make a decisive contribution to competitiveness and technological sovereignty.

- To drive forward the development of key technologies, a fundamental build-up of expertise is necessary, which should be embedded in international cooperation. In Europe, this should take place within the framework of the ERA. However, care must be taken to ensure that these programs are less bureaucratic to make them more agile and flexible. In addition, Important Projects of Common European Interest (IPCEI) offer a rapid expansion of the scientific base and ensure critical masses that individual countries in Europe would not normally achieve. The comprehensive involvement of companies means that implementation and market orientation are already taken into account. Further specialized IPCEIs should be considered.

The transformation to a sustainable industry can only be achieved through ambitious packages of measures, but it also offers great economic opportunities.

- Measures that use market-based mechanisms, such as emissions trading, are particularly effective, as they generally provide optimal incentive control. Additional regulatory support measures (e.g., feed-in tariffs) have proven to be very effective, especially in the diffusion of climate- and energy-friendly technologies.

- In the field of energy generation and distribution, digitalization plays a key role in increasing cost efficiency and security of supply. For example, the use of smart metering and control systems enables real-time monitoring and control, early detection of faults and improved load flow control. The creation of technical and regulatory frameworks, including those relating to cybersecurity and data protection, is important for digitalization in this context.

- For reasons of state aid law, innovation funding in the EU has focused heavily on the development of new technologies. To accelerate the sustainable transformation of the economy, funding programs should be designed to be more comprehensive so that they specifically support the development of new circular business models. This requires an appropriate legal framework. Synergies in the member states with European funding and programs related to the circular economy coordinated through the European Circular Economy Stakeholder Platform can support the achievement of these goals.

3 — INTRODUCTION

FOCUS ON EFFICIENCY AND OPENNESS

The publication of the Innovation Indicator 2025 comes at a time of significant economic uncertainty. Forecasts for this year and next predict only minimal growth, both in Germany and many other European countries. Budgetary constraints leave little room for maneuver, which also impacts public investment in the innovation system. Although strengthening science and research remains a key goal of German policy, the country risks falling behind in technological performance and consequently suffering in terms of medium-term competitiveness – especially in light of the investments that other countries are making in these areas. Germany's off-budget "special funds" (Sondervermögen) are stimulating the economy through increased government demand, but it remains unclear when and where these resources will be deployed and whether they will ultimately boost the country's innovation capacity.

In addition, geopolitical developments and military conflicts are creating uncertainty and additional costs worldwide, including for Germany's export-oriented economy. Trade barriers such as tariffs and other protectionist measures are affecting international trade in goods and services, often leading to higher costs and reduced sales in foreign markets for export-focused companies. At the same time, public budgets around the globe are feeling the aftermath of past crises and high expenditure on welfare systems. As a result, both businesses and governments are increasingly reliant on the efficient use of scarce resources. With this in mind, this year's Innovation Indicator not only evaluates the innovation capacity of the countries examined but also looks at the efficiency of their systems, across various dimensions.

Another critical aspect is the openness of innovation systems – now under greater threat than ever due to the shifting geopolitical landscape. We dedicate a special chapter to this topic, focusing on the networks and relationships between science, business and society, and linking these findings to the innovation capacity discussed in the first chapter.

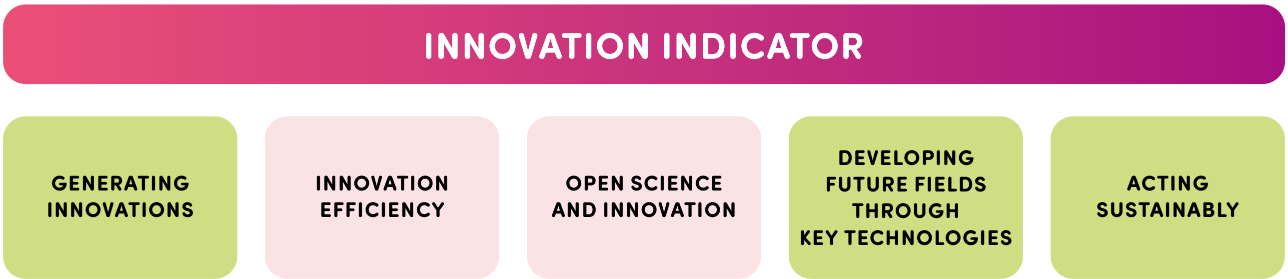
Key technologies not only shape the current competitive landscape but also provide a forward-looking perspective on future competitiveness and capabilities across various technological domains. We therefore devote another chapter to an examination of seven selected key technologies. We then address the sustainability of knowledge utilization and industrial production, before concluding with a short explanation of our methodology.

OBJECTIVES AND METHODOLOGY

The Innovation Indicator 2025 describes the state and development of 35 knowledge- and innovation-oriented economies worldwide. It is based on the concept of National Innovation Systems (NIS), which distinguishes between various subsystems whose design significantly influences a country's innovation capacity. The NIS approach has a long tradition in innovation research and has proven a fruitful foundation for the empirical analysis of national innovation processes. Recent refinements of the approach place a stronger emphasis on functions within the system.[1] The Innovation Indicator builds on these findings from innovation research and translates them into an operationalized measurement concept. Increasing technological competition driven by geopolitical realignment and the critical challenges of decarbonizing and digitalizing the economy, science, government and society form the backdrop to our analysis. Accordingly, the Innovation Indicator places the following three aspects at the forefront:

- **Generating innovations**
- **Developing future fields through key technologies**
- **Acting sustainably**

Each of these functions is treated as an independent objective and represented within the Innovation Indicator framework by a separate indicator. The indicators assigned to these functions are not combined into a single score.



GENERATING INNOVATIONS

The Innovation Indicator assesses how well positioned a country is for the future. It does so in the first place by analyzing how effectively individual economies perform in critical key technologies. But it also evaluates how sustainably both the economy and innovation processes are structured. For example, an economy might be currently successful in innovation but face significant long-term barriers if it fails to invest sufficiently in the emerging technologies that drive innovation across multiple industries, or if its innovations fail to adhere to environmental and resource-related sustainability limits. In this sense, the methodological framework of the Innovation Indicator provides a longer-term perspective on the innovation capacity of individual economies.

KEY TECHNOLOGIES

Seven key technologies are particularly relevant for future competitiveness – not least because they are the prerequisites for technological development in other domains and across multiple industries. They are:

- **Digital hardware**
- **Digital networks**
- **Advanced production technologies**
- **Energy technologies**
- **New and advanced materials**
- **Biotechnology**
- **The circular economy**

The function "Developing future fields through key technologies" focuses on an economy's ability to independently generate innovations in specific, broadly defined technological areas and to harness the resulting economic development potential. This approach is based on a long-term, technology-oriented competitive perspective.

ACTING SUSTAINABLY

The competitive perspective is expanded to include the "Acting sustainably" function, which primarily aims to ensure compliance with planetary boundaries. This function addresses the question of whether existing production and innovation processes are organized sustainably and what scientific and technological capacities countries possess to support the transformation of their economies and societies.

Indicators are listed in the individual chapters and also in the methodology report, available here: innovationsindikator.de/methodik

NO CHANGE AT THE TOP

The global changes taking place in recent years are reflected in the Innovation Indicator. True, there has been no change at the top: Switzerland remains the country with the highest innovation capacity in this year's Innovation Indicator, with Singapore and Denmark following. But there has been movement in the middle- and lower-ranked countries. For example, the United States, United Kingdom, France and Canada have all shown noticeable improvement. The most significant advance has been made by Russia, which moves from second-to-last place to 23rd in the ranking. The transition to a wartime economy and countermeasures against economic sanctions have led to substantial additional investment in new technology. However, this highlights the double-edged nature of input-based indicators: While Russia's increased investments in technology are reflected in the ranking, they are unlikely to enhance the productivity of the Russian economy or improve the country's overall prosperity.

Several economies whose technological development depends heavily on the international integration of their economies, such as China, Taiwan and Australia, have slipped down the ranks. Similarly, Poland, Turkey, Italy and Israel have moved down, driven primarily by economy-specific factors.

Germany has managed to maintain its position in this challenging global environment, still in 12th place. It ranks behind other major economies such as the United Kingdom and South Korea but ahead of the United States, France and Japan. In general, smaller countries tend to perform better in the ranking. Thus, following the top three countries, the next six spots are occupied by Sweden, Finland, Ireland, Belgium, the Netherlands and Austria – countries that in terms of gross domestic product (GDP) are relatively small. The stronger performance of these smaller countries is partly due to the significant weight that the Innovation Indicator places on international collaboration in science, research and technology utilization, considered a critical factor for long-term innovation capacity: Smaller economies are typically more internationally oriented than larger ones (see box on page 20).

The Innovation Indicator also reveals that more and more economies traditionally considered laggards in innovation are advancing toward the middle ranks. For instance, Hungary, the Czech Republic, Mexico and Poland now show indicator values similar to those of the larger Southern European countries – Italy and Spain. Japan's poor performance is noteworthy; this was also evident in previous years' Innovation Indicators. The main reason for this is the relatively low output of Japan's scientific system compared to the country's size, as well as the very limited internationalization of its innovation system – apart from the export of technological goods (see Openness chapter). Japan's ranking is further driven down by its aging population and severe shortage of skilled workers.

China likewise finds itself in the lower ranks of the Innovation Indicator and has recently experienced a decline in its position. Its overall position is mainly due to the fact that, measured against the country's enormous size, China's innovation performance remains modest in many areas – for example, the commercialization of research (patent and trademark applications) and many human capital indicators. Nevertheless, in absolute terms, China represents one of the largest global innovation hubs.

Two developments have significantly shaped the changes in countries' innovation capacity in recent years:

- The environment for innovation approaches focused on collaboration and international exchange has become increasingly challenging. This shift began with the COVID-19 pandemic, which significantly disrupted exchange due to contact and travel restrictions. Additionally, there were interruptions in international supply chains, with effects that persisted long after the pandemic ended. Armed conflicts and populist, increasingly protectionist economic policies have further compounded these restrictions. In the Innovation Indicator 2025, the impacts of these developments are only visible up to the end of 2024; changes in international business activity that occurred in 2025, such as those driven by US tariff policies, are not yet reflected in the data.

- At the same time, changes to the international security landscape since the start of Russia's war on Ukraine have affected the role of the state in national innovation systems. The focus on strengthening research and technological development for military capabilities and critical infrastructure has led to a shift in priorities. While these initiatives initially require large, often state-funded investments, the medium- to long-term consequences for innovation, productivity and prosperity remain uncertain.

Countries' different exposure and responses to these developments can lead to changes in their relative innovation capacity. The Innovation Indicator inevitably produces both winners and losers, as it is a relative measure indicating how a country performs in relation to a reference group.

INNOVATION CAPABILITY: RANKING AND INDEX VALUES OF THE ECONOMIES

RANK	ECONOMY	Index value (0–100)	Change
1	SWITZERLAND	71	→ 0
2	SINGAPORE	64	→ 0
3	DENMARK	59	→ 0
4	SWEDEN	56	→ 0
5	FINLAND	56	↗ 1
6	IRELAND	54	↘ -1
7	BELGIUM	48	→ 0
8	NETHERLANDS	48	↗ 1
9	AUSTRIA	48	↗ 1
10	UNITED KINGDOM	46	↗ 3
11	SOUTH KOREA	43	→ 0
12	GERMANY	42	→ 0
13	AUSTRALIA	39	↘ -5
14	CANADA	38	↗ 3
15	USA	38	↗ 3
16	NORWAY	38	→ 0
17	ISRAEL	37	↘ -3
18	FRANCE	34	↗ 3
19	TAIWAN	33	↘ -4
20	GREECE	31	↘ -1
21	PORTUGAL	31	↗ 2
22	SPAIN	31	↘ -2
23	RUSSIA	30	↗ 11
24	HUNGARY	29	↗ 3
25	CZECHIA	29	↘ -1
26	MEXICO	25	↗ 3
27	POLAND	25	↘ -5
28	JAPAN	25	→ 0
29	ITALY	25	↘ -3
30	CHINA	24	↘ -5
31	INDIA	22	→ 0
32	SOUTH AFRICA	18	↗ 1
33	BRAZIL	17	↘ -1
34	TURKEY	17	↘ -4
35	INDONESIA	11	→ 0

Changes in ranking positions versus 2024 are shown on the right.
Source: Innovation Indicator 2025

A CHALLENGING ENVIRONMENT FOR COLLABORATION AND INTERNATIONAL EXCHANGE

For the five indicators in the Innovation Indicator that reflect different aspects of exchange within and between innovation systems – what we call "exchange-related indicators" – significant changes have occurred between 2018 and 2024. The greatest improvements have been made by Finland and Taiwan. Taiwan primarily expanded R&D collaborations between companies and academia within Taiwan itself. This development could be a consequence of the uncertain international situation, prompting Taiwan's technology leaders, particularly in the area of semiconductors, to rely more heavily on domestic scientific cooperation. Finland, Canada and India benefited from an increase in international cooperation over patent applications. Conversely, the same indicator is largely responsible for the significant deterioration in exchange-related indicators for Indonesia, Russia and Brazil. South Korea shows an unfavorable trend in its balance of trade for high-tech goods.

In Germany, exchange-related indicators have changed little over the past six years. Improvements in co-patents between science and industry are offset by a decline in the trade balance for high-tech goods. Other major economies also show stability in exchange-related indicators. In the United States and Japan, both of which exhibit low values overall for these indicators, hardly any changes took place. Japan's slight loss of points is attributed to a decline in its trade surplus for high-tech goods. In China, whose innovation system is somewhat more focused on collaboration, there has also been little change in exchange-related indicators. By contrast, the United Kingdom and France show positive developments – in the United Kingdom due to small improvements in most of the indicators (R&D collaboration between science and industry, co-patents, co-publications, international co-patents), in France due to notable improvements in R&D collaborations and co-patents.

INDICATORS MEASURING ECONOMIES' INNOVATION CAPABILITIES

Knowledge creation
- Share of doctoral degree holders
- University (level) education expenditure per student
- Industry R&D expenditure per GDP
- Science R&D expenditure per GDP
- Scientific and technical publications per capita
- Citations per scientific and technical publication
- Share of frequently cited scientific and technical publications

Knowledge diffusion
- Ratio of young to older university graduates
- Share of industry-funded R&D expenditures of science
- Transnational patent applications per capita
- Patents from science per capita
- Co-patents science-industry per capita
- Co-publications science-industry per capita

Converting knowledge into innovation
- Share of employees with a university degree
- Supply of skilled workers: share of vacancies (indicator included in the overall index with weight -1, i.e., a high indicator value indicates a low innovation capability)
- Venture capital per GDP
- Share of international co-patents
- Share of government-funded business R&D expenditure
- Trademark applications per capita

Turning innovation into revenue
- Share of high-tech industries in GDP
- GDP per capita
- Value added per hour worked in manufacturing
- Balance of trade in high-tech goods

GOVERNMENT ENGAGEMENT IN TIMES OF CHANGE

A second major shift in the international innovation landscape concerns government engagement. Since Russia's war on Ukraine and the increasing tensions in the Middle East, the issue of security – both in terms of essential infrastructure and military capabilities – has become critical. This has necessitated additional efforts to develop and disseminate security-related technology. Shifting priorities continue to drive the trend toward a mission-oriented innovation policy, which had already been observed in the previous decade as a response to major challenges such as demographic change, climate change and sustainable development.

In the Innovation Indicator, these shifts are reflected in the indicators heavily influenced by government actions. These are mainly indicators related to the human capital base for innovation systems, as governments play a key role in setting the framework here through their funding and regulation of education and research systems. Additionally, governments influence the development and implementation of new technologies by supporting companies' R&D activities. Over the past six years, the largest increase in these indicators has been seen in Russia, driven by higher government spending on technology development. Other countries with large increases include Brazil, Greece and South Africa. The increases are primarily due to government efforts to strengthen national education and research systems, with the aim of expanding the supply of well-educated workers and enhancing research at universities. The strategy focuses on fostering innovation in the economy through increased public research – an approach particularly common in emerging economies such as India and Indonesia.

Contrasting this, in most industrialized countries – including Germany – indicators influenced by government actions have deteriorated in the last six years. This is primarily due to the fact that countries with the highest indicator values have often improved their scores more significantly than most other countries, causing the latter to fall behind in relative terms. In Germany, this trend is evident in several areas, including the indicators related to the academic system, the supply of university graduates, and government support for R&D in companies – although for the last of these, an improvement in Germany's score is expected in the coming years as the R&D funding (Forschungszulage) introduced in 2020 begins to take financial effect, along with the increases to it that were approved for 2024 and 2025.

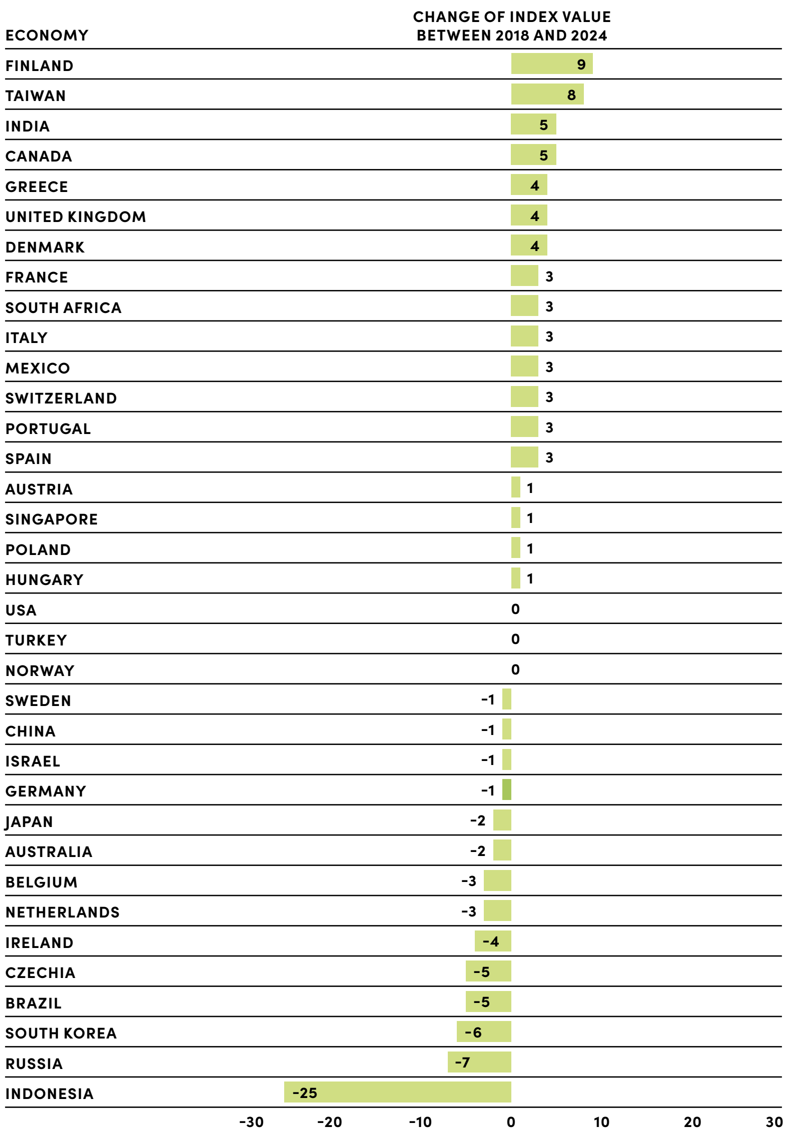
CORPORATE INNOVATION

A key area covered by the Innovation Indicator is companies' performance in terms of innovation. The Innovation Indicator measures companies' investments in the development of new knowledge and technology, and also how they implement it in the market. Over the past six years, South Korea has shown the most significant improvement in this area. At the same time, some countries with historically weaker corporate innovation have made substantial progress, including Poland, Portugal, Greece and the Czech Republic. Additionally, some of the countries traditionally leading the pack in corporate innovation have managed to improve further still, particularly Sweden and Denmark.

» COUNTRIES WITH HISTORICALLY WEAKER CORPORATE INNOVATION HAVE MADE SUBSTANTIAL PROGRESS. «

Germany, on the other hand, has fallen noticeably behind here. One reason is that corporate R&D expenditure has grown less dynamically than in other countries. In particular, German businesses have struggled to keep up with countries like the United States or China in R&D related to digitalization. Germany has also seen a relative decline in transnational patent applications and the value-added share of high-tech industries, although the latter remains very high in international terms. However, some other countries are rapidly catching up in these areas. The strong negative trend in China is primarily due to the significant decline in venture capital (VC) investments compared to the late 2010s. At the same time, despite high R&D expenditure by Chinese companies, the number of transnational patent applications remains modest.

CHANGES IN EXCHANGE-RELATED INDICATORS



Exchange-related indicators: R&D collaborations, patent collaborations, publication collaborations, patent internationalization, trade balance.
Source: Innovation Indicator 2025

RESEARCH AND ACADEMIA – NO IMPROVEMENT IN GERMANY

The Innovation Indicator measures the performance of the academic sector by using three publication indicators and one patent indicator. The publication indicators reflect the number of scientific publications per capita, the number of citations per publication (citation rate) and the share of highly cited publications (top publications, excellence rate). Additionally, the Innovation Indicator considers the number of scientific patent applications by academic institutions per capita. Germany ranks in the middle for these indicators, achieving less than half the value of the two leading countries, Switzerland and Denmark. Over the past six years, Germany has not shown any improvement. Its slightly higher share of top publications is offset by somewhat lower patent activity.

The strongest improvement for this indicator is seen in China, followed by India, South Korea and Taiwan, all four countries having significantly increased their academic output over the past six years. Major improvements have also occurred in Turkey, Poland, South Africa, Greece, the Czech Republic and Portugal – all countries that were at a very low level at the end of the 2010s. Among historically strong performers, Australia made the most significant increase. Notable positive developments were also seen in Norway, Ireland, Austria, Belgium and the Netherlands. Switzerland was unable to improve its position, as it already achieves the maximum values for most of its indicators.

The United States shows the most unfavorable trend in academic output. At first glance, this result is surprising, but it reflects the relatively low number of scientific publications compared to the country's size and the slight decline in this number over time. The United States' citation rate and share of top publications also fell during the period, albeit from a relatively high starting point.

SMALLER ECONOMIES LEAD THE WAY

Eight of the nine countries at the top of the Innovation Indicator 2025 are relatively small economies, with populations of up to ten million. Their high scores demonstrate that smaller economies are often better able to allocate a significant portion of their human and financial resources to creating and using new knowledge (see box on page 20). The strength of these countries lies in their specialization in specific topics and technologies, supported by highly effective sectoral innovation systems that seamlessly integrate knowledge generation, knowledge diffusion, innovation implementation and the broader economic utilization of innovations (see also Innovation Efficiency chapter). A key prerequisite of this approach to innovation is having a high degree of openness in the innovation systems. Another critical factor is the strong

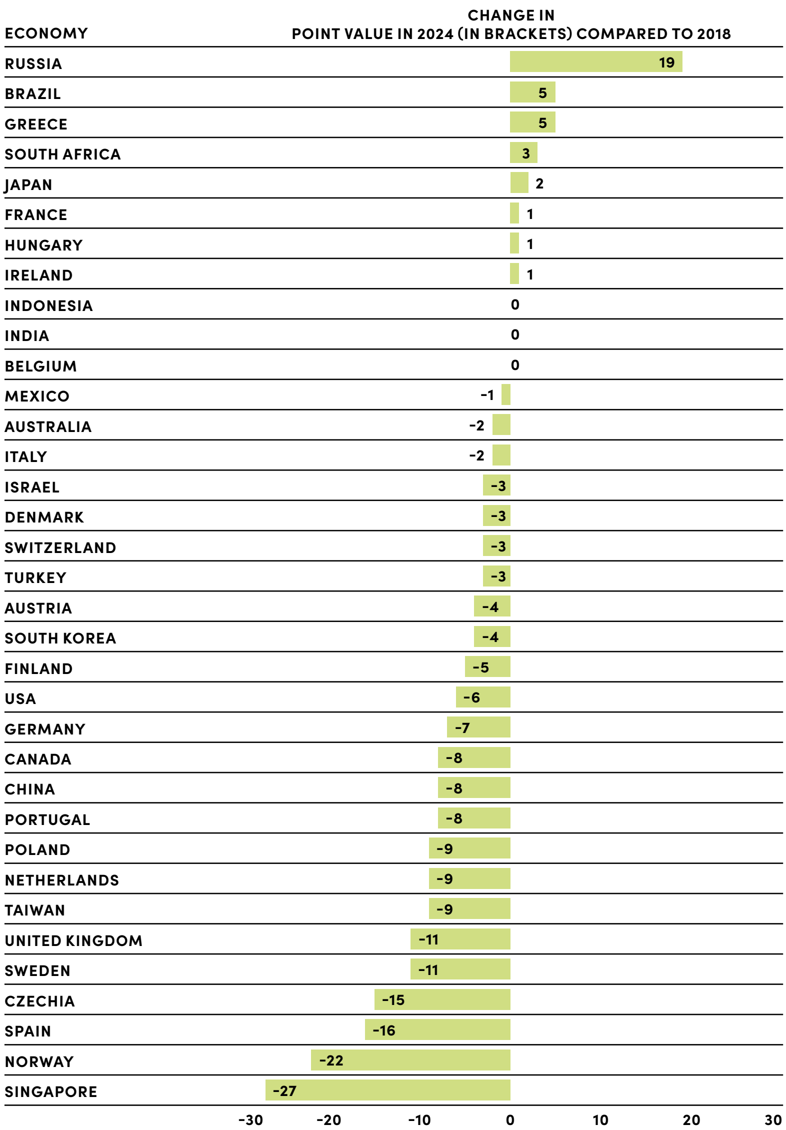
» SMALLER ECONOMIES ARE OFTEN BETTER ABLE TO ALLOCATE A SIGNIFICANT PORTION OF THEIR HUMAN AND FINANCIAL RESOURCES TO CREATING AND USING NEW KNOWLEDGE. «

internationalization of the economy, enabling innovations to be converted into domestic value creation through global market access. At the same time, these countries can source knowledge and technology in non-specialized areas from other countries.

An excellent example of this approach is Switzerland. The Swiss innovation system is highly focused on a few industrial sectors – primarily pharmaceuticals and chemicals, mechanical engineering, and instruments – plus financial services. At the same time, Switzerland has one of the most efficient academic systems in the world, strongly interconnected both with the domestic economy and international markets, and serving as a hub for knowledge transfer.

Over the past two decades, Denmark and Belgium have followed in Switzerland's footsteps, developing and expanding their innovation systems on the basis of a highly efficient and transfer-oriented academic sector and a focus on a few, globally leading industrial innovation fields. However, Sweden and Finland demonstrate the risks of pursuing such a strategy. These two countries implemented this strategy as early as the 1980s and 1990s, putting a strong emphasis on digital technologies – and then saw a sharp decline in their global position due to disruptive innovations in their areas of specialization. Nevertheless, in recent years both countries have been able to develop or strengthen new focus areas, particularly in production technologies and digital services, leading to an improvement in their positions in the Innovation Indicator.

CHANGES IN INDICATORS STRONGLY INFLUENCED BY GOVERNMENT ACTIONS



Indicators heavily influenced by government actions: doctorates, higher education expenditure, R&D in academia, graduate supply and R&D funding.
Source: Innovation Indicator 2025

A SLIGHT DOWNWARD TREND IN GERMANY

In the Innovation Indicator 2025, Germany comes in 12th place, as in the previous year. Of the large industrialized economies, Germany is on a par with South Korea but behind the United Kingdom, which moves up due to favorable developments in its number of highly skilled workers and improvements in its trade balance. Germany's score has remained relatively stable in past years, hovering around 45 points. However, since 2018, a downward trend has been seen. This reflects the increasingly challenging international environment for Germany's innovation system. Compared to 2018, Germany's index values have significantly declined for nine indicators relative to developments in its reference countries. These include input-oriented factors, such as R&D expenditure in business and science, transnational patent applications, and government R&D support for companies, as well as indicators related to the economic utilization of innovations, namely the share of high-tech industries, industrial productivity and the trade balance. Additionally, the central macroeconomic output measure – societal prosperity, or GDP per capita – has developed less favorably than in the reference countries. One driver of this trend is the increasing challenges in international competition, which in recent years have slowed down some of Germany's key industries: automotive, mechanical engineering and chemicals. Other contributing factors include more difficult access to sales markets, higher energy and material costs, and rapid technological advances by competitors – often overtaking Germany – in critical future technologies such as e-mobility and artificial intelligence (AI).

The United States and France have been able to increase their index scores after the significant declines seen in 2022, which were partly due to the lingering effects of the COVID-19 pandemic. In the United States, stronger VC investment, an increase in the proportion of university graduates and a favorable balance between the influx of new graduates and the retirement of older professionals contributed to this improvement. In France, human capital-related factors also played a key role, along with

COMPARING LARGE AND SMALL ECONOMIES IN THE INNOVATION INDICATOR

Small economies, with their limited resources, are rarely able to produce all the goods needed internally; instead, they focus on specific economic activities, achieving critical mass in those areas and developing a well-structured ecosystem. If they enjoy favorable conditions for innovative activities – such as a strong scientific base or a well-educated population – they often focus on innovation-driven economic activities. Within these areas of specialization, they produce significantly more goods than are needed domestically, leading to a strong export orientation. At the same time, they import many other necessary goods.

In contrast, large economies typically engage in a much broader range of economic activities, as their production potential would otherwise exceed global demand. For example, if the United States were to concentrate a significant portion of its economic resources on the production of high-tech goods such as semiconductors or pharmaceuticals, it would result in production volumes far in excess of global needs. At the same time, demand for basic goods – from food to personal services – is so high in large economies that relying predominantly on imports for these basic goods would be unrealistic. As a result, they tend to have a more balanced economic structure than smaller countries, encompassing both highly innovative and less innovative activities.

Innovation-driven activities thus account for a significantly higher proportion of all activities in small economies than in large ones. If we adjust the indicators measuring innovation performance for the size of the economy in question, small countries often perform much better than large ones – despite the fact that their absolute contribution to global innovation lags far behind that of large economies.

In large economies, innovation activities are often highly concentrated in specific regions where there are particularly favorable conditions. If these regions were analyzed separately, they would often demonstrate a much higher level of innovation capacity than many of the small, innovation-strong economies. However, when combined with other regions that specialize in non-innovative activities, the average for the whole country is significantly lower.

increased academic output (citation rate, top publications). For its part, Japan has maintained a very stable index score over time, whereas China has been unable to continue its rapid catch-up process after 2020. Indeed, in 2024 China's index score saw a notable decline due to weaker VC investment and reduced higher education expenditure per student.

DIFFERENT FOCUS AREAS OF INNOVATION SYSTEMS

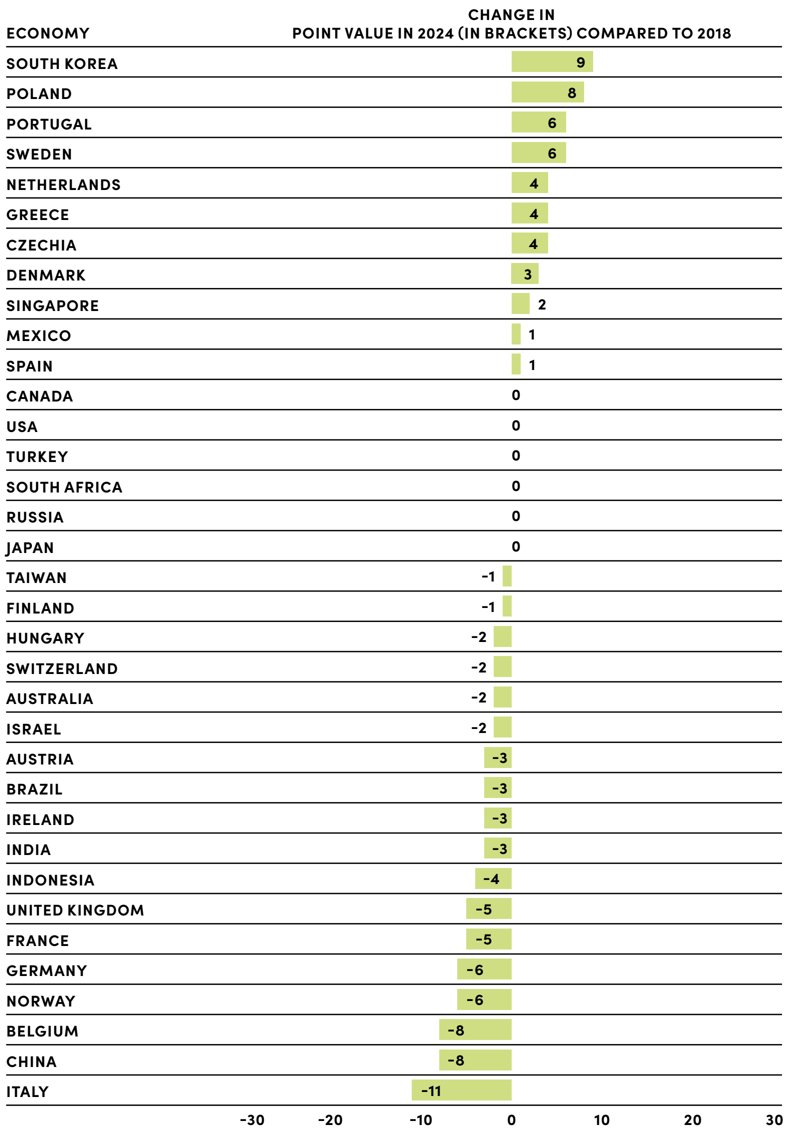
The selection of indicators for the Innovation Indicator follow a process-oriented approach. It begins with metrics that capture the creation of knowledge, followed by a second set that measures its diffusion. A third process covers the transformation of knowledge into innovations, and a fourth reflects the broader economic utilization of innovations (see "Methodology" below). A comparison of the focus areas of countries across these four subprocesses reveals clear differences in the priorities of individual national innovation systems, which in turn influence the innovation policies of these countries. We distinguish five different groups of countries:

- Countries with a **balanced innovation system** and high scores across all four subprocesses. This group includes smaller economies that rank at the top of the Innovation Indicator. They have successfully established coordinated and interconnected innovation processes that ensure the continuous creation, dissemination, implementation and utilization of new knowledge. These systems are based on very high inputs into the innovation process from both the business and academic sectors, which are converted into innovations and value creation through well-developed transfer systems and highly innovative industrial clusters. The challenge for innovation policy in these countries is to maintain this balance while adapting the individual subprocesses to external shocks, such as technological disruption. Sweden and Finland demonstrate that such adjustments are possible – but require a certain amount of time.

  This group also includes some countries with medium or relatively low overall indicator scores, such as Norway, Portugal, Spain and Italy. These countries should focus on evenly developing their existing innovation potential to advance their innovation systems toward more sophisticated innovations and to improve their ability to quickly adopt new technological trends. Norway has made the most progress here, continuously rising in the rankings since around 2010, although it recently experienced a setback. By contrast, Southern European countries still have a long journey ahead of them.

- Countries with **input- and diffusion-oriented innovation systems**. This includes most of the nations in the middle ranks of the Innovation Indicator. These countries are characterized by strong academic and research systems and well-developed structures for transferring knowledge between different actors. Some are also strong in implementation, meaning they successfully translate new knowledge into innovations – Belgium, the United Kingdom, Canada and Israel, for example. Others lag behind in implementation – particularly Taiwan, China and to some extent South Korea, Australia and France. Importantly, there are often long time lags between investment in new knowledge and its widespread diffusion, especially

CHANGES IN INDICATORS REFLECTING CORPORATE INNOVATION PERFORMANCE



Indicators reflecting corporate innovation performance: R&D in business, patents, venture capital investments, trademarks, and high technology.
Source: Innovation Indicator 2025

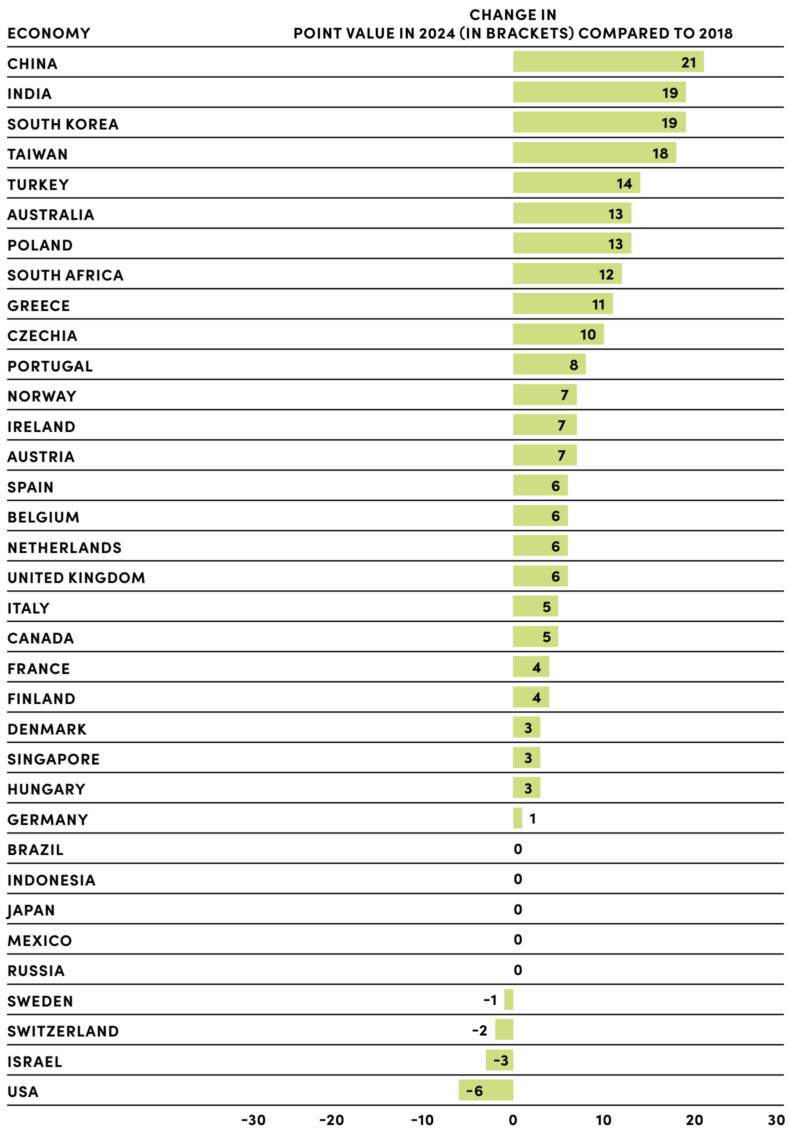
where the focus is on radical innovations or entirely new technologies. Overall, this group puts in a below-average performance in the fourth subprocess, the broader economic utilization of innovations. Policy in these countries should focus on leveraging their strong innovation hubs and clusters to generate greater economic returns at a national level.

- Countries that excel in the **broader economic utilization of innovations**. This group includes Germany, the Netherlands, Austria, the Czech Republic and Japan. These countries generally achieve relatively high scores in the subprocesses of knowledge creation and diffusion, but tend to score lower in economic implementation of innovations. A key task in these countries is to address the implementation weakness of the innovation system and to ensure that the strong existing potential for knowledge generation and diffusion translates into a continuous flow of innovations – sustaining the currently high economy-wide returns generated from this knowledge. This is crucial, as part of the strong performance in the economic utilization of innovations still stems from research successes achieved some time ago.

- Countries with **implementation-oriented innovation systems** that have only limited capacity for knowledge creation and diffusion. Many of the innovation successes in these countries rely on the import of knowledge and technology, often through foreign direct investment (FDI). This group includes four countries in the lower-middle ranks of the innovation rankings: Greece, Hungary, Mexico and Poland. Innovation policy in these countries should focus on developing independent academic and research capacities.

- Countries with **diffusion-oriented innovation systems** that generate almost no broad economic returns from innovations and have very limited capacity for knowledge creation. This group includes Russia, India, South Africa, Turkey and Indonesia, which typically come at the bottom of the Innovation Indicator. Their strength in the subprocess "knowledge diffusion" often stems from their education and higher education systems, which transform external knowledge into workforce qualifications. However, due to a lack of industrial innovation capacity, this human capital can only be used to a limited extent for the economic implementation of innovations. Innovation policy in these countries faces the challenging task of strengthening both the input and implementation sides, without being able to rely on economic returns from innovations. Russia and Brazil occupy a somewhat unique position within this group, as they are significantly better positioned in the area of implementation. Brazil has explicitly stated in its innovation strategy that strengthening academia and research, as well as building industrial clusters based on domestic innovations, is key to advancing the country. However, Brazil's indicator score is still low, and the road ahead is a long one.

CHANGES IN INDICATORS REFLECTING ACADEMIC RESEARCH



Indicators reflecting academic research: publications, citation rate, top publications and scientific patents.
Source: Innovation Indicator 2025

METHODOLOGY

The Innovation Indicator aims to measure the innovation capacity of 35 economies. Building on a systemic understanding of innovation, it captures how innovations are generated, introduced and utilized productively. This requires the collaboration of various actors – businesses, academia, government and society – as well as the presence of innovation-supporting infrastructure and favorable framework conditions.

The Innovation Indicator seeks to capture this diversity of influencing factors in its 23 different indicators. These cover four dimensions:

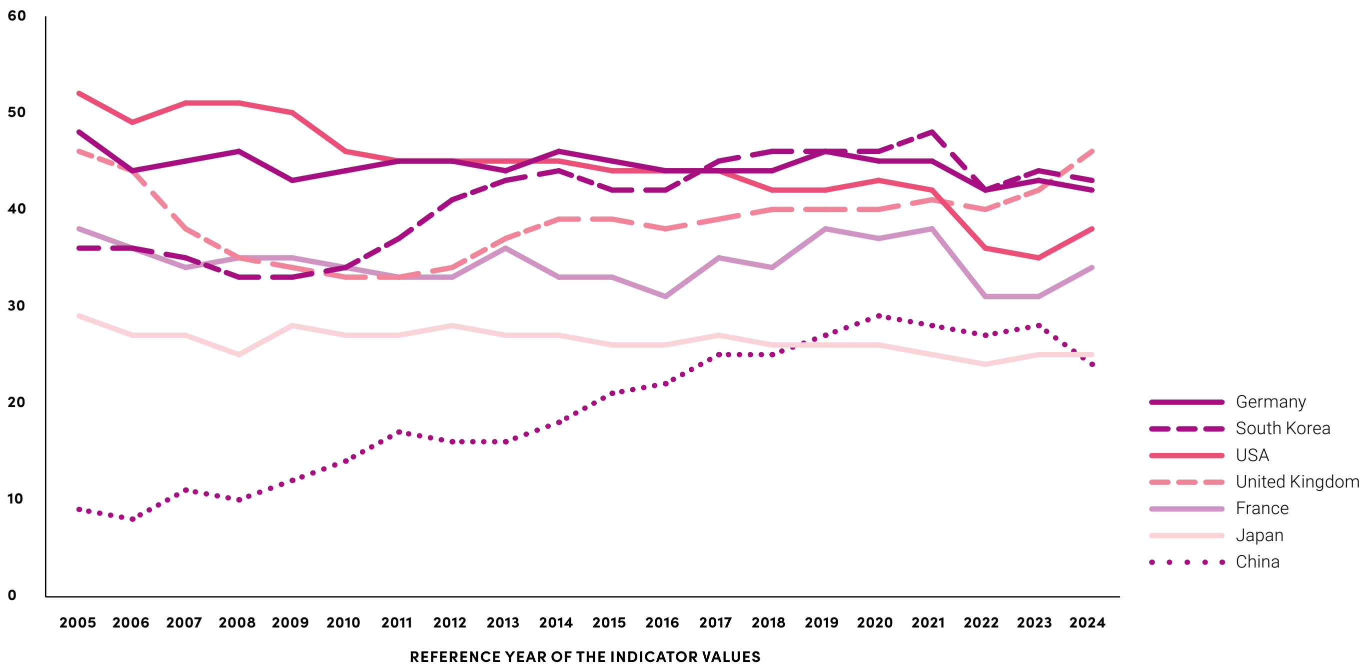
- Creating knowledge
- Diffusing knowledge
- Converting knowledge into marketable innovation
- Turning innovation into revenue

The selection of indicators aims to balance those that measure a country's current innovation performance with forward-looking indicators that reflect its future innovation capacity. Current innovation performance is based on past investments and so does not necessarily indicate a country's potential in the coming years. However, it remains an important metric as it shows how much innovation contributes to the present prosperity of a society. Moreover, a country's current innovation performance generates the returns it needs for investments in future innovation capacity. For a country's future innovation capacity, the factors that are gaining in importance for innovation capacity play a particularly crucial role. These include, for example, the international orientation of the innovation system, the performance of the research system, and the interaction between science and industry.

All the individual indicators in the Innovation Indicator are normalized to the size of each economy (GDP or population). This allows for a direct comparison of innovation capacity between countries of different sizes. However, it should be noted that small and large economies differ in their ability to focus on innovative activities (see box on page 20).

The values of the individual indicators are normalized to a scale from 0 to 100. To achieve this, each country's indicator value is compared with the corresponding values within a reference group.[2] A value of 0 indicates that the country's score is equal to or lower than the lowest value in the reference group, while a value of 100 means that the country's score equals or exceeds the highest value in the group. Values between 0 and 100 occur when a country's indicator lies within the range of the reference group. The overall Innovation Indicator index is calculated as the average of all normalized indicators and therefore also ranges between 0 and 100 points.

INNOVATION CAPABILITY: INDEX SCORE FOR SEVEN MAJOR COUNTRIES, 2005–24



Source: Innovation Indicator 2025

5 — FOCUS 1: INNOVATION EFFICIENCY

WHO GETS MOST BANG FOR THE BUCK?

Innovation processes are costly and complex, and they are associated with high levels of risk and uncertainty regarding their eventual success. This uncertainty extends from the technical solution or idea and its implementation, to market development and commercialization. At any stage, the process can fail and the investment yield no return.

The complexity of technological innovation – and the amount and specialization of knowledge required to innovate successfully – has increased significantly in recent years. As a result, the marginal returns on innovation spending have declined; in simpler terms, each additional euro invested in innovation now yields less effect than the one invested before it. Adding to this are intensified competition in many industries and technology fields, as well as shorter innovation cycles, leaving less time overall for recouping innovation expenditures.

Since the start of the COVID-19 pandemic, and further exacerbated by the costs of military conflicts, rising energy prices, transformation costs, increasing expenses in other policy areas (for example, those linked to demographic changes) and a generally challenging economic situation, public budgets for science, research and innovation are unlikely to grow significantly in many countries over the coming years. The changing nature of innovation processes, the greater effort required to achieve their goals and increasing competition in many areas are also putting pressure on corporate R&D budgets. Overall, this means that in most countries, both public and private R&D budgets are unlikely to grow and may even decline; there is no chance of universal expansion. In terms of scientific and technological competitiveness, this means that most countries will either become less innovative or must use their resources as efficiently as possible to maintain their current innovation capacity.

Against this backdrop, which countries make the most effective use of the resources available? This chapter seeks to answer that question using the data provided by the Innovation Indicator.

MEASURING THE TRANSFORMATION FROM INPUTS TO OUTPUTS

The methodology used here differs from that of the main Innovation Indicator, which is based on composite indicators – that is, the weighted or unweighted aggregations of individual indicators into an overall indicator. The Innovation Indicator includes both input-oriented indicators, such as R&D expenditure or the number of employees with university degrees, and output-oriented indicators, which measure tangible results such as patents or value creation in high-tech industries. In other words, the Innovation Indicator treats both inputs and outputs as positive contributions to a country's measured innovation capacity. Although composite indicators are well established in innovation measurement, they have methodological drawbacks. In particular, they can result in double counting of inputs and outputs, especially when an input is successfully transformed into an output. In such cases, the Innovation Indicator captures both the input and the resulting output.

For this reason, some have proposed measuring only outputs – that is, actual results achieved.[3] However, this approach also has its limitations, as it tends to undervalue emerging economies whose innovation systems are still developing. These countries, especially those pursuing technology-push strategies, often show high input levels but, due to time lags, still low output levels. As a result, they would be ranked similarly to countries making minimal investments.

A more meaningful approach is therefore to measure both input levels and the efficiency of transforming inputs into outputs. Efficiencies can be captured only to a very limited extent through composite indicators. A more suitable approach is provided by efficiency analysis methods based on the Data Envelopment Analysis (DEA) framework. The core idea of this method is to use the best-performing observations in the sample to estimate a theoretically possible production function that serves as a benchmark. The distance of each observation in the sample from this benchmark function can then be interpreted as a measure of inefficiency. In other words, observations that reach the benchmark are classified as efficient, while those that do not exhibit varying degrees of inefficiency. The DEA analysis – basic concept methods box illustrates this efficiency concept using a simple example.

In this chapter, we apply an enhanced version of the original DEA methodology, specifically adapted for measuring innovation efficiencies.[4] This approach is conceptually compatible with the functional understanding of innovation systems used in the Innovation Indicator and distinguishes between two interrelated core functions of the innovation system. First, the knowledge-generation function, through which new academic and technological knowledge is created from various inputs. Second, the goods provision or commercialization function, through which final goods and services are produced. These outputs are generated, on the one hand, using standard production factors, particularly labor, and, on the other hand, by applying the technological knowledge generated in the first function. This model structure is illustrated in the figure on page 28.

Within this model structure, it is possible to distinguish three different types of efficiency: a) the efficiency with which a country generates new knowledge, b) the efficiency with which a country uses this knowledge to produce goods and services – that is to say, its commercialization, c) the efficiency of the overall system, which results from the interaction between knowledge generation and commercialization.[5]

» IN MOST COUNTRIES, BOTH PUBLIC AND PRIVATE R&D BUDGETS ARE UNLIKELY TO GROW. «

DEA ANALYSIS – BASIC CONCEPT

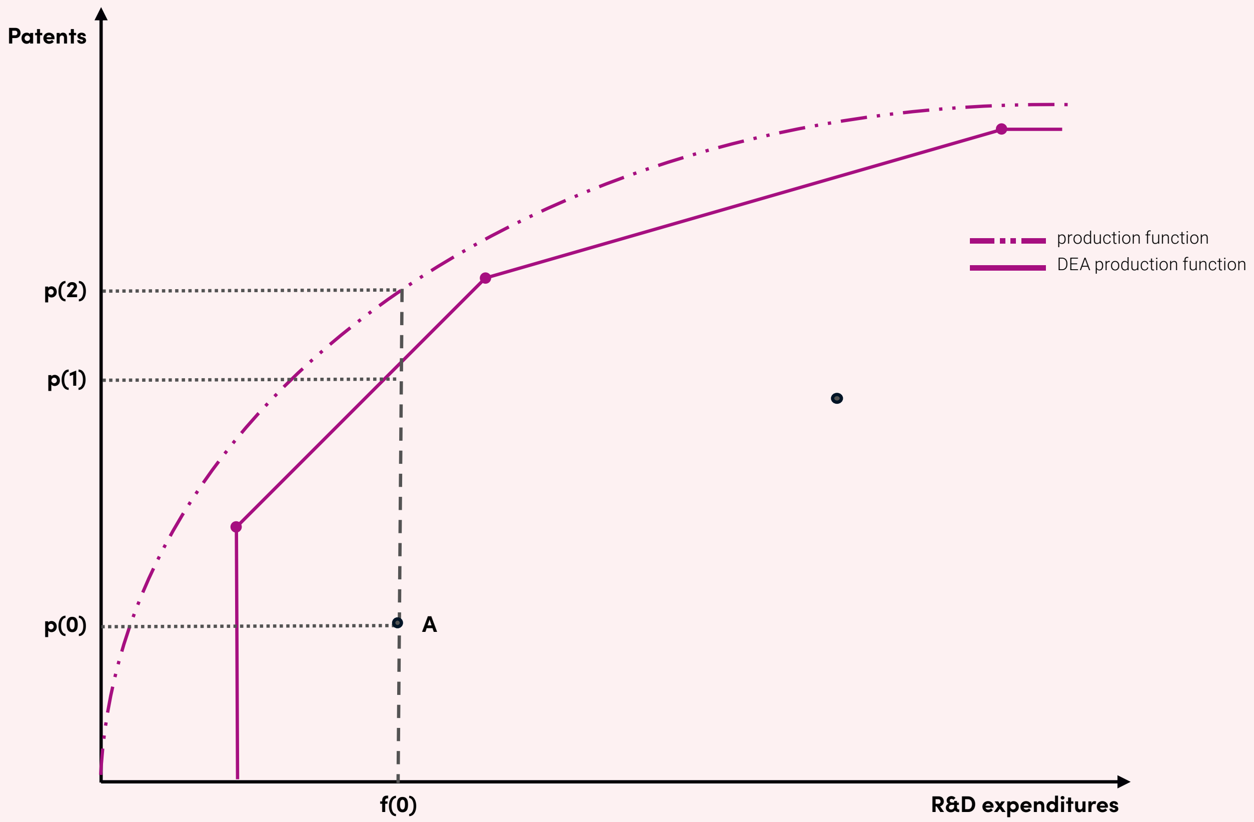
To illustrate the basic idea of Data Envelopment Analysis (DEA), let us assume that an innovation system produces only one innovation output (patents) using one innovation input (R&D expenditure). In DEA analysis, the production function is defined as the production maximum. In other words, it shows how much output can be achieved at each input level under ideal efficiency conditions. This production function is represented by the dotted curve. A country can lie on or below this curve. If it lies on the production function, it is efficient; if it lies below, it exhibits inefficiency. If this production function were known, efficiency could easily be calculated. For example, consider Country A, which produces p(0) patents with R&D expenditure f(0). According to the production function, it could produce p(2) patents with the same level of input. The efficiency measure of country A is thus given by its relative distance from the production frontier: Efficiency = p(0) / p(2) < 1 – that is, the number of actual patents registered ("produced") divided by the number of patents that could be registered ("produced") if the country were operating efficiently.

However, the true production function is typically not known, meaning that the efficiency of Country A or any other country cannot be directly determined. DEA addresses this by estimating the production function based on empirical observations. Suppose we have data from additional countries, each represented as a point in Figure 1. The highly flexible Variable Returns to Scale (VRS) DEA estimator then constructs an estimate of the unknown production function by forming the convex hull of these data points. Essentially, it creates a piecewise linear function supported only by observed countries but lying as close as possible to the true, unobserved function. This estimated DEA production function is shown by the solid line.

Under this estimated function, the efficiency of Country A is measured as p(0) / p(1). While the estimated efficiency is not exactly equal to the true value, the accuracy improves as the number of observed countries increases. With many data points, it becomes very likely that several observations lie close to the true production function, yielding highly accurate efficiency estimates.

In this chapter, we employ more complex DEA estimators that, first, consider multiple inputs and outputs simultaneously and, second, differentiate between subsystems within the innovation process. Despite this added complexity, the underlying efficiency-theoretical principles remain the same.

SCHEMATIC REPRESENTATION OF DEA ANALYSIS WITH ONE INPUT AND ONE OUTPUT



SOLID RESULTS FOR ESTABLISHED INNOVATION NATIONS

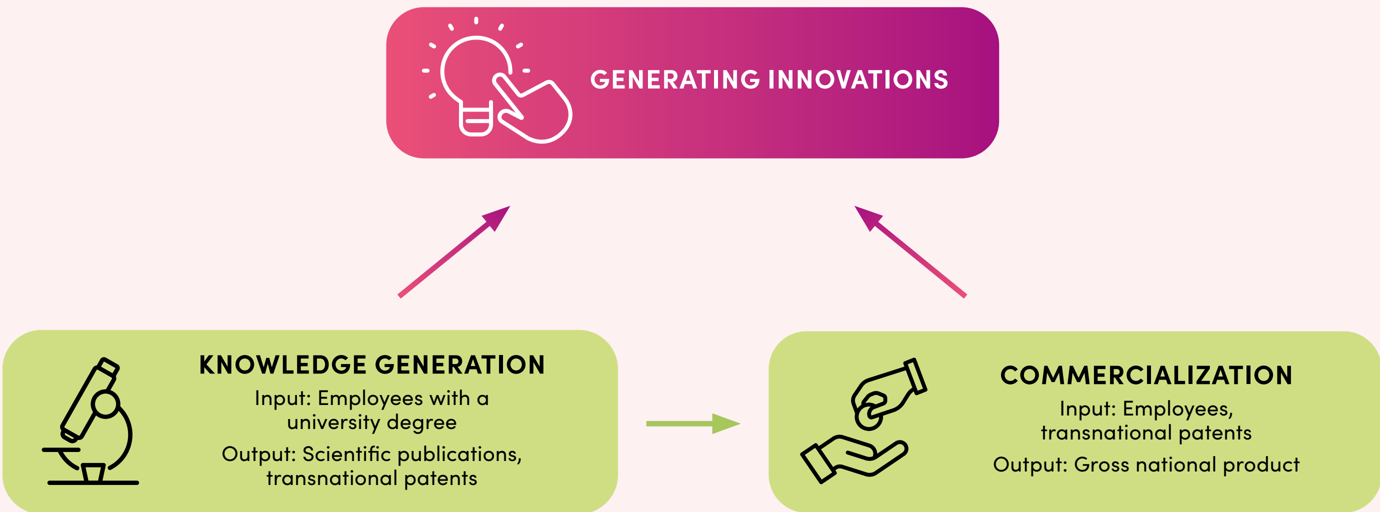
The results of applying this approach to the Innovation Indicator are shown in the figures on pages 28 and 29. Looking first at knowledge-generation efficiency – that is, how efficiently a country produces new knowledge – it becomes evident that some of the top performers in this area are not necessarily those that hold the highest overall ranks in the Innovation Indicator. These include the United States, Italy, Denmark, Austria, United Kingdom and Germany. This illustrates that efficiency in resource utilization is not directly equivalent to the Innovation Indicator's implicit measurement concept, which treats inputs and outputs simultaneously as positive contributions to a country's innovation performance.

The highest-ranked countries in the Innovation Indicator show varied results. Switzerland, which leads the rankings, does not quite reach the top in terms of knowledge-generation efficiency but it is very well positioned, with a score of 91%. This is not the case for Singapore, ranked second in the Innovation Indicator; its knowledge-generation efficiency is just 32%. Relative to its size, Singapore delivers excellent results, but it requires too much input to achieve them. Singapore's rise began in the 1990s, so the question arises as to whether this is the result of a natural time lag or if there are systemic inefficiencies that the country should actively address through appropriate measures.

Most nations with established innovation systems show solid results in terms of knowledge-generation efficiency. They include Australia (98%), Norway (90%), South Korea (90%), Ireland (84%), France (79%) and Spain (73%). The middle tier covers several Southeast European countries, such as Hungary (69%), while Greece scores 65% and Portugal 64%. Israel (57%) and Japan (60%) also fall into this group. Japan's relatively modest performance in knowledge generation likely has multiple causes, including the limited international orientation of its academic system. Most emerging economies lag far behind the others – for example, Turkey (10%), Russia (6%) and Mexico (5%).

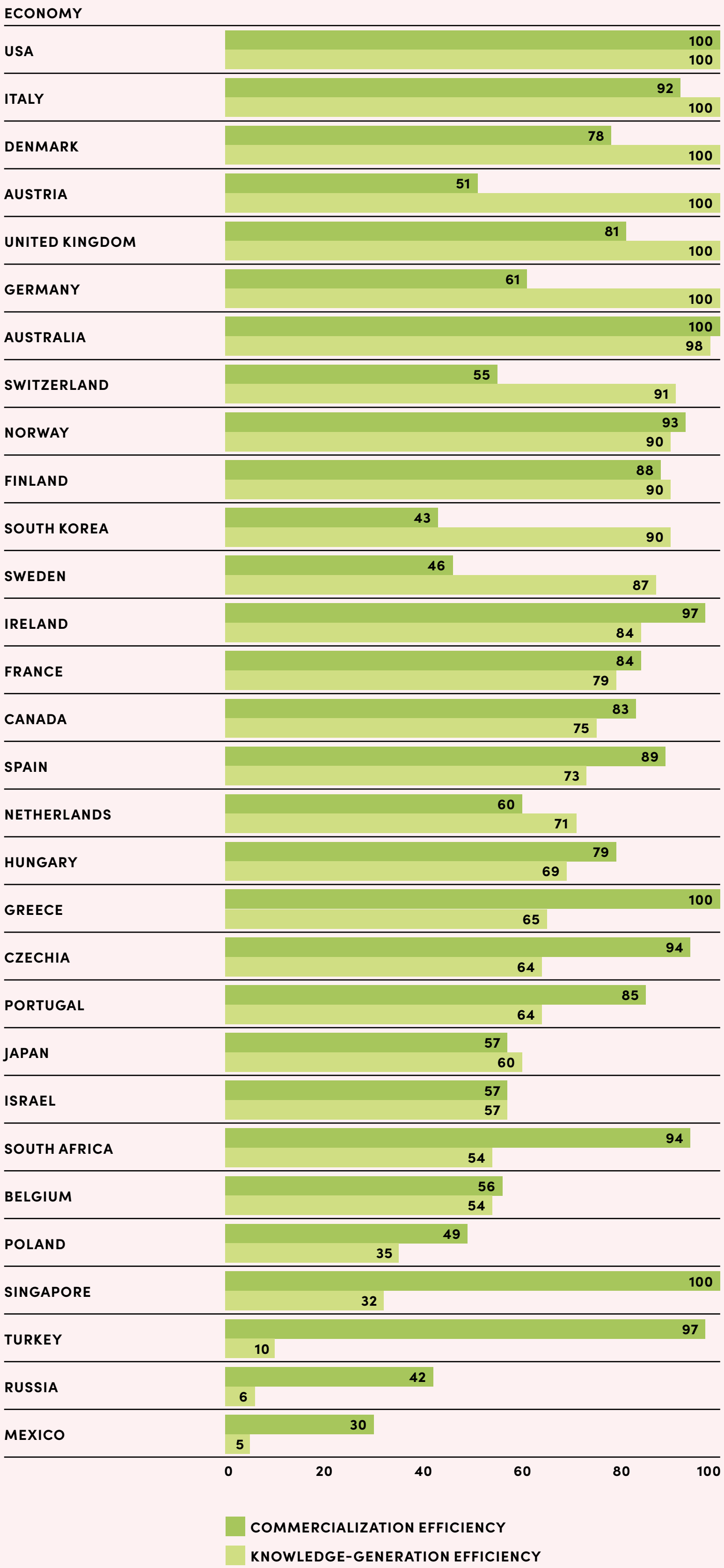
Despite many similarities between the two areas, some countries differ in their scores for commercialization efficiency and knowledge-generation efficiency. The United States, Singapore and Australia lead on commercialization efficiency, with scores of 100%. In the case of Singapore, this compensates for its weakness in knowledge generation, while the United States and Australia are strong in both areas. Notably, many countries that perform well in knowledge generation, particularly those in Europe, fall behind on commercialization efficiency. For example, Germany scores only 61% on commercialization, Denmark 78% and Sweden 46% – in Sweden's case despite a knowledge-generation efficiency score of 87%. A similar pattern is found for Switzerland, which scores just 55% in commercialization efficiency. Other countries, including some in Europe, show similar results in both knowledge-generation and commercialization efficiency; for instance, Finland scores 88% for commercialization efficiency and 90% for knowledge-generation efficiency. Belgium is in the lower-middle range for both dimensions, scoring 53% for knowledge-generation efficiency and 56% for commercialization efficiency. Spain performs slightly better in commercialization efficiency (89%) compared to its knowledge-generation efficiency (73%), and the same applies to Portugal (85% vs. 64%).

STRUCTURAL MODEL OF INNOVATION GENERATION



Source: Innovation Indicator 2025

KNOWLEDGE-GENERATION AND COMMERCIALIZATION EFFICIENCY



Source: Innovation Indicator 2025

These observations have significant implications for the economics of innovation, particularly with regard to the so-called European paradox – the idea that Europe's weakness lies not in knowledge generation but in commercialization. Interestingly, the countries where commercialization efficiency is significantly lower than knowledge-generation efficiency are indeed all in Europe: Germany, Sweden, Switzerland, Denmark, Austria and the United Kingdom. This suggests that the European paradox does exist. However, there are two important caveats. First, the majority of European countries are not affected by this phenomenon; many other European countries, including France, Spain and Hungary, systematically achieve better results in commercialization efficiency than in knowledge-generation efficiency. Second, the small group of countries that do show signs of the European paradox are all economic leaders. Despite their inefficiency in commercialization, they are still able to achieve high levels of prosperity, thanks to their strong performance in knowledge generation, at least at present. By contrast, those European countries that show no signs of the European paradox tend to lag behind in economic performance.

However, the commercialization weakness observed in Europe's leading economies is not a general feature of economically advanced countries. As noted earlier, countries such as Australia, the United States, Japan (which lies in the middle range) and Singapore are not affected by this issue. A likely explanation is that these countries have well-developed knowledge-transfer systems. In the United States, for example, the widespread availability of venture capital supports the rapid commercial scaling of key innovations. With the exception of South Korea, none of the non-European countries studied have significantly lower knowledge-generation efficiency than commercialization efficiency – indeed, in many emerging economies the opposite is the case. Countries such as Turkey, South Africa and Russia achieve at least moderate commercialization efficiency despite very low efficiency in knowledge generation. Our data therefore provides evidence for the existence of a European paradox, but this phenomenon appears to be limited to the leading European economies of Central and Northern Europe.

Looking finally at overall system efficiency, we see that in some cases the system efficiency lies roughly midway between knowledge-generation efficiency and commercialization efficiency. This is the case, for example, for Germany, which has a system efficiency of 84%. This figure falls between its knowledge-generation efficiency of 100% and its commercialization efficiency of 61%. The country's strong scientific base therefore partially compensates for its commercialization inefficiencies. However, commercialization continues to constrain the overall system, preventing Germany from achieving full efficiency. Accordingly, Germany would need to strengthen its capacity to convert knowledge into economic value. Potential approaches include enhancing the transfer of knowledge from universities to industry and improving the availability of venture capital for scaling innovative technologies.

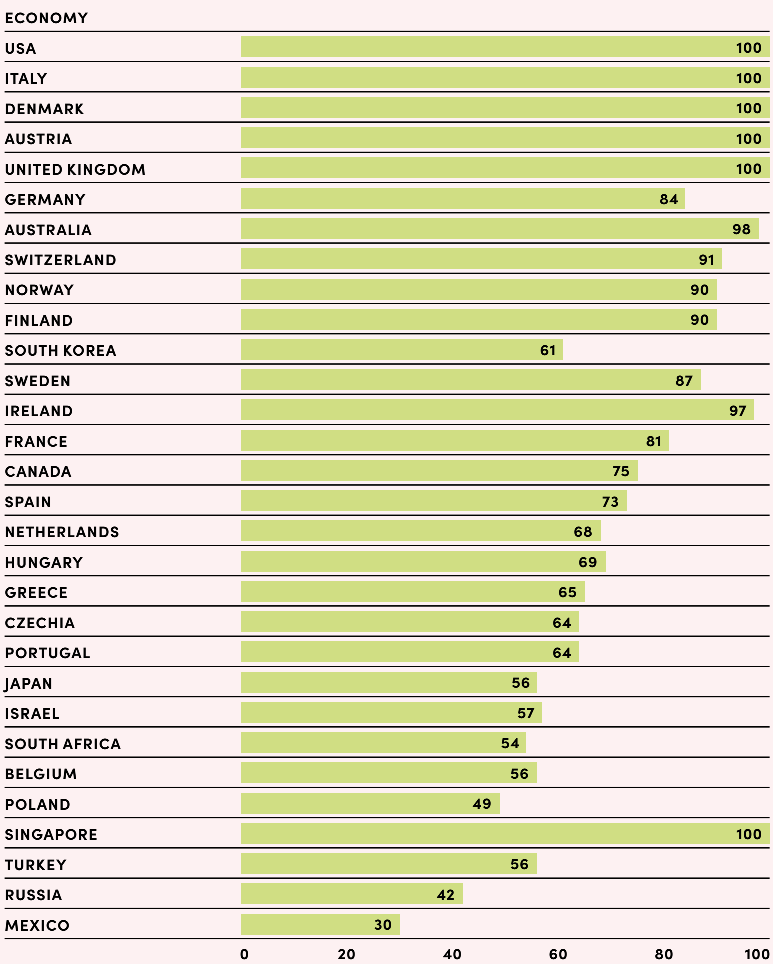
SHADES OF EFFICIENCY

We also find cases where inefficiencies in one area can be completely compensated for by strengths in the other. Italy, for example, achieves the maximum in system efficiency despite showing slight inefficiencies in commercialization, with a score of 92%. In other countries, efficiencies are aligned in both subsystems. For example, the United States achieves full efficiency in both knowledge generation and commercialization, resulting in a system efficiency of 100%. Does this mean that Italy is as productive as the United States? In fact, both countries are fully efficient, but at very different absolute output levels. As discussed in the DEA analysis – basic concept box, technical efficiency as estimated by DEA does not indicate whether a country invests enough or scales sufficiently; it only reflects the distance from the production function given the inputs. Thus, countries with very limited inputs can still be technically efficient if they use their inputs efficiently – although their absolute performance level remains low because they invest too little. This is likely the case for Italy: Overall, Italy allocates too few resources, such as funding for its academic system, as shown in the main Innovation Indicator ranking, yet it achieves good results from the limited investments that it does make.

Several other observations are also noteworthy. Switzerland achieves 91% system efficiency, compensating for its weakness in commercialization with its relatively strong scientific system. However, as Switzerland is not absolutely efficient in either subsystem, further improvement would likely require strengthening both its scientific system and its commercialization capabilities. Austria, on the other hand, achieves full system efficiency at 100%, despite weaknesses in commercialization efficiency (51%). It performs exceptionally well in knowledge-generation efficiency (100%), so in this case fully compensates for its weaknesses in one area with strengths in another – a pattern also observed in Singapore. In countries such as South Africa, by contrast, the reverse pattern can be seen: Weaknesses in one subsystem carry through to the system as a whole. South Africa scores 94% for commercialization but only 54% for knowledge generation, resulting in an overall system efficiency that likewise amounts to 54%. Here, the bottleneck lies in knowledge generation – a pattern that appears to varying degrees across nearly all emerging economies covered by the Innovation Indicator.

Overall, our efficiency analysis provides important insights into how efficiently countries utilize their resources. It also highlights whether their strengths or weaknesses lie more in knowledge generation or in commercialization. However, this analysis should be understood as complementary to the Innovation Indicator: Its findings focus solely on the efficiency of resource utilization and do not indicate whether countries are investing sufficiently. For that purpose, the Innovation Indicator and its individual components offer a better perspective.

SYSTEM EFFICIENCY



Source: Innovation Indicator 2025

6 — FOCUS 2: OPEN SCIENCE AND INNOVATION

HOW OPEN ARE INNOVATION SYSTEMS?

Knowledge is the foundation of all innovation, whether product, process, service or business model innovation. The complexity and volume of knowledge required for innovation are rising sharply – in some scientific and technological fields even exponentially. Yet, as individual companies and research institutions often lack both the necessary depth of current knowledge and the disciplinary diversity required for groundbreaking innovations, collaboration and knowledge exchange with other organizations have become essential.

The openness of science and innovation systems was already promoted in the 1990s and early 2000s. The concepts introduced by Chesbrough (2003)[6] and von Hippel (1998)[7] gained both recognition and implementation, prompting many companies and research institutions to rethink their cooperative activities with the aim of becoming more open and better connected. These ideas emerged during the era of globalization and primarily promised rapid progress through cooperation and the free flow of knowledge. While the core principles remain valid, protectionist policies, the end of globalization and growing geopolitical tensions over the past decade have reshaped international scientific cooperation. New priorities now include research security and technological sovereignty, forcing many countries to adjust their strategies accordingly.

Research security focuses on safeguarding knowledge, preventing the intentional manipulation or misuse of research results, avoiding unwanted knowledge leaks through espionage or theft, and protecting competitiveness – particularly, though not exclusively, in the area of what are known as dual-use technologies, meaning those that can be used for both civilian and military purposes (Kroll 2025).[8] Many countries, including Germany, have introduced or already implemented corresponding policy measures.[9]

The second dimension is technological sovereignty, which refers to the ability to act independently in key governmental and societal areas such as healthcare, energy supply, communication, mobility and both military and civilian security. Ultimately, it is about avoiding one-sided dependencies, building or maintaining domestic capabilities and ensuring reliability, predictability and trustworthiness (Edler et al. 2020).[10]

A CORPORATE PERSPECTIVE

These dimensions are also highly relevant for companies. In addition, however, there is a cost dimension. In recent years, cost pressure on R&D activities has risen sharply, particularly in Europe. At the same time, European companies are facing growing innovation pressure, driven in part by the rapid strengthening of China's innovation system. Companies are responding by improving efficiency and relocating R&D centers to countries with lower wage levels. Market proximity and access to relevant technology clusters also play a role in such relocation decisions.

Given the growing influence of (geo)political considerations on corporate strategy, there are signs of a partial reverse trend, with some firms "reshoring" research activities. However, this is not a general trend, as both cost pressure and the attractiveness of foreign markets remain very high. Moreover, relocating R&D as part of a local-for-local strategy can help diversify risks.

Companies therefore rely on maintaining open information flows across borders within their organizations. Partnership-based and open-innovation approaches are also used to achieve better and faster innovation, even though they carry the risk of unintentional technology transfer. It is therefore crucial to strike a careful balance between openness and research security. Restricting openness may entail higher costs – both for ensuring research security protection and for establishing new, trustworthy technology partnerships. As a result, innovation costs rise and the overall efficiency of the innovation system declines, as achieving the same outputs may require greater input in knowledge generation or commercialization.

THE EU PERSPECTIVE

The EU Compass Strategy, released in 2025 in response to the 2024 Draghi Report, emphasizes enhanced collaboration and calls for technological sovereignty in Europe. “Trade with third countries is a key driver of Europe’s prosperity. ... A high degree of trade openness is therefore crucial, not only for sustaining Europe’s prosperity, but also for enhancing its resilience” (European Commission 2025; own translation).[11]

In his 2024 statement accompanying the publication of the report on the future of European competitiveness,[12] Mario Draghi, chair of the expert group, highlighted the EU’s and its member states’ openness – and, at the same time, their dependency on certain foreign technologies, particularly in the field of digital technology. Against the backdrop of a changing global landscape, where established business models sometimes no longer function and geopolitical challenges are redefining economic dependencies, a new perspective is need – one that reconsiders both Europe’s internal goals and the nature of its openness and cooperation frameworks.

OPENNESS INDEX

RANK	ECONOMY	
1	SWITZERLAND	72
2	DENMARK	65
3	NETHERLANDS	60
4	SINGAPORE	60
5	AUSTRIA	59
6	IRELAND	58
7	CZECHIA	57
8	FINLAND	57
9	SWEDEN	56
10	AUSTRALIA	53
11	CANADA	51
12	UNITED KINGDOM	47
13	GERMANY	47
14	PORTUGAL	46
15	BELGIUM	43
16	HUNGARY	43
17	ISRAEL	41
18	NORWAY	39
19	FRANCE	38
20	SPAIN	35
21	POLAND	34
22	SOUTH KOREA	33
23	JAPAN	32
24	GREECE	32
25	INDONESIA	32
26	SOUTH AFRICA	30
27	RUSSIA	30
28	USA	30
29	ITALY	29
30	INDIA	28
31	CHINA	24
32	TURKEY	23
33	MEXICO	21
34	BRAZIL	21

0 20 40 60 80 100

Unfortunately, the available data does not allow for the calculation of index values for Taiwan.
Source: Innovation Indicator 2025

OPENNESS TODAY

Openness in science, research and innovation today primarily means targeted and deliberate openness. This approach explicitly incorporates both research security and technological sovereignty. The stated goal is not simply to be as open as possible, but at the same time as closed as necessary. It must always be remembered, however, that openness and cooperation imply a two-way exchange. Those who expect open systems but remain closed themselves are unlikely to achieve long-term success.

Various policy measures and approaches have been introduced that reflect these two additional dimensions. At the start of this decade, the German government, as part of its so-called de-risking strategy – a critical review of relevant topics and partner countries – took action to secure and strengthen the country's technological sovereignty. With the European Research Area (ERA), originally launched in the mid-2000s but given a new direction and visibility through the 2021 agenda, the European Union likewise aims to foster cooperation among member states as well as with associated countries (European Commission 2021).[13] The first objective of the ERA policy agenda adopted in 2021 accordingly addresses open knowledge exchange and the use of research results within the ERA.

On the scientific side, open science instruments primarily include open access – meaning free access for readers to scientific journal publications – and open data, which refers both to the documentation of data used in scientific publications and, more broadly, to providing wide access to research-relevant data.

The openness of science and innovation systems is not an end in itself but serves scientific progress and technological performance. The dimensions of openness extend from scientific exchange and R&D processes to the diffusion of innovations and their economic impact. We have compiled four groups of indicators to compare the openness of the countries covered by the Innovation Indicator and to track their development over time: scientific exchange, technological exchange, cross-border trade and financial flows, and societal openness including mobility (see box).

RESULTS

As with the Innovation Indicator, Switzerland also leads the Openness Index with 72 points, followed by Denmark with 65 points. Next is a group of countries consisting of the Netherlands, Singapore, Austria, Ireland, the Czech Republic, Finland and Sweden.[14] The reasons for the strong performance of these countries vary significantly. In addition to structural and contextual factors, smaller countries tend to perform better on the Openness Index. This is partly because organizations in smaller countries are more likely to collaborate internationally, as suitable partners are often hard to find domestically (see box in Innovation Capability chapter). That said, this chapter does not seek to determine the optimal degree of openness for each country, but rather evaluates countries on the basis of the intensity of their openness.

» THE OPENNESS OF SCIENCE AND INNOVATION SYSTEMS IS NOT AN END IN ITSELF BUT SERVES SCIENTIFIC PROGRESS AND TECHNOLOGICAL PERFORMANCE. «

INDICATORS USED FOR THE INTERNATIONAL COMPARISON OF OPENNESS IN SCIENCE AND INNOVATION SYSTEMS

Scientific exchange

1 Share of national and international co-publications in all scientific and technical articles (Source: Elsevier – Scopus)
2 Share of open-access publications in all publications of a country (Source: Elsevier – Scopus)
3 Share of international students in total student enrollment (Source: OECD – EAC)

Technological exchange

4 Foreign-funded R&D expenditure (% of GDP) (Source: OECD – MSTI)
5 R&D by foreign subsidiaries (% of GDP) (Source: OECD – DSD_SBRD)
6 Share of international co-patents in all transnational patent applications (Source: EPO – PATSTAT)
7 Share of international PCT patent applications in all national patent applications of a country (Source: EPO – PATSTAT)
8 IPR payments (% of GDP) (Source: World Bank)
9 IPR revenues (% of GDP) (Source: World Bank)
10 GitHub repositories per capita (Source: GitHub)

Cross-border trade and financial flows

11 Foreign direct investment, net inflows (% of GDP) (Source: World Bank)
12 Foreign direct investment, net outflows (% of GDP) (Source: World Bank)
13 Balance of payments (% of GDP) (Source: OECD)
14 Net foreign assets (% of GDP) (Source: World Bank)
15 Import share (% of GDP) (Source: UN – COMTRADE)
16 Applied tariff rate, weighted mean, all products (%) (Source: World Bank)

Societal openness and mobility

17 Rule of law (Source: World Bank)
18 Labor market participation of foreign-born individuals as a percentage of the population in the same subgroup (Source: OECD)
19 Inbound mobility rate (Source: UIS UNESCO)
20 Influx of foreign population (Source: OECD)
21 Would not like to have as neighbors (groups such as people of different origin; immigrants/guest workers; homosexuals; people of another religion; people who speak another language) (Source: World Values Survey)

In Switzerland, the Netherlands, Austria, Denmark and Sweden, the respective scientific systems are strongly internationally connected. In Switzerland, Ireland, Finland, Sweden and Denmark, a highly internationalized R&D system further contributes to their strong performance. In addition, Denmark, the Netherlands, Switzerland and Sweden benefit from highly integrated trade and financial flows.

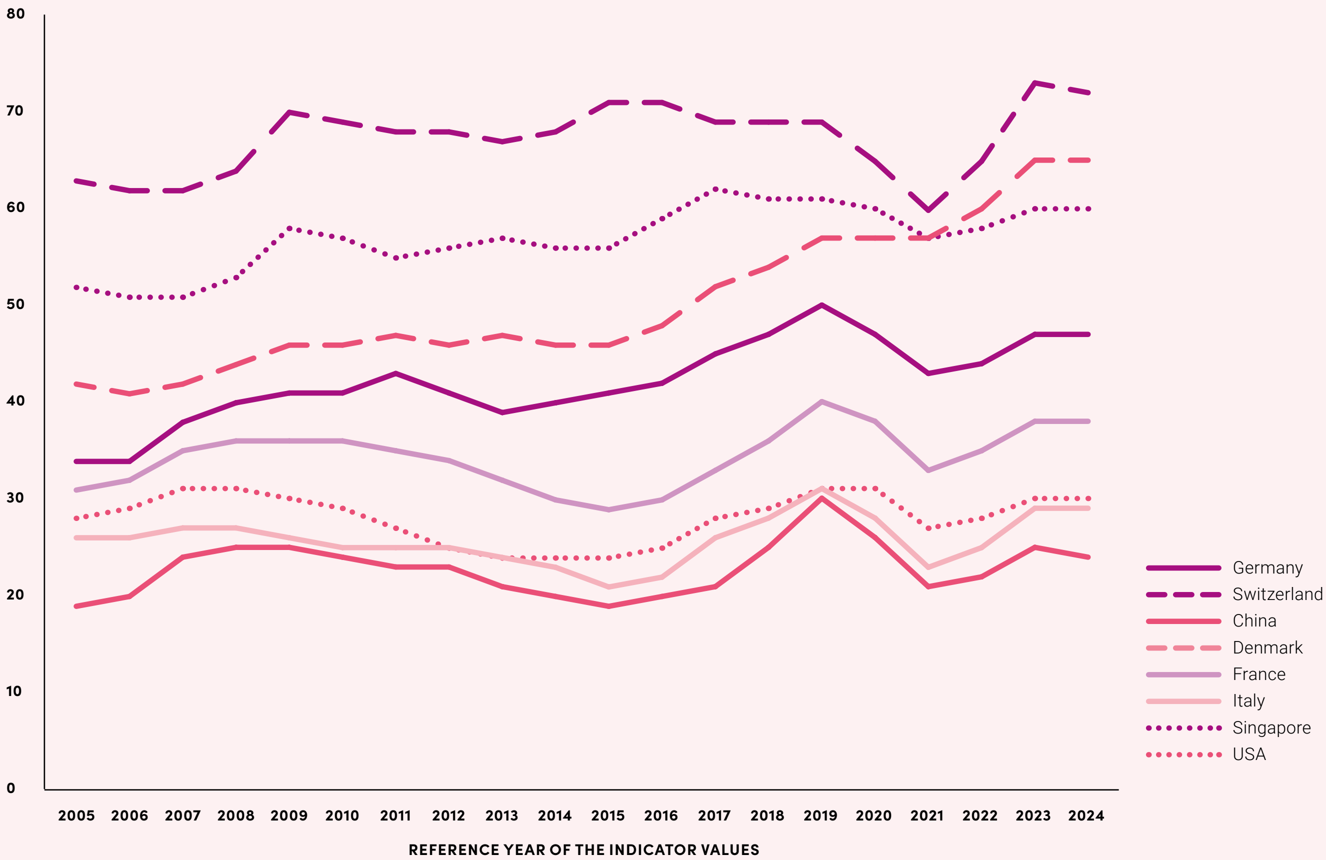
Singapore achieves mid-level rankings in the openness of science and research – it has a high share of international co-publications but publishes relatively few articles in open-access journals. Nevertheless, it leads our comparison in trade and financial flows as well as societal openness. The country is truly multicultural and serves as a regional hub for many multinational companies targeting Asian markets. The Czech Republic scores well due to strong FDI and internationally funded and conducted R&D.

A broad midfield follows, including Australia, Canada, the United Kingdom, Germany in 13th place, as well as Portugal, Belgium, Hungary and Israel. The United Kingdom performs well on societal openness but achieves only average scores for the openness of science and R&D systems, and slightly below-average results for trade and financial flows – despite serving as a bridgehead for US companies entering the European market. Ireland now performs significantly better in this regard.

Germany, on the other hand, has a particularly internationally oriented economic system (in terms of trade and financial flows) and a relatively open science system, yet performs weakly on societal indicators. While the rule of law is rated highly, Germany scores poorly in other dimensions, particularly on cultural openness.

Belgium, which ranks in the upper midfield of the Innovation Index, places only 15th in the Openness Index.

OPENNESS INDEX FOR SELECTED COUNTRIES, THREE-YEAR MOVING AVERAGES, 2005-24



Source: Innovation Indicator 2025

» CHINA CONTINUES TO SHOW SIGNIFICANT DEFICITS IN THE INTERNATIONAL INTEGRATION OF ITS RESEARCH SYSTEM AS WELL AS IN SOCIETAL OPENNESS. «

This is due to average scores in the openness of science, R&D, and trade and financial flows, while its economic structure and societal indicators rank in the lower range. Although Belgium's science system is well connected internationally, the share of open-access publications and foreign students remains comparatively low. Similarly, the labor market participation of foreign nationals and recent immigration from abroad are among the lowest of the countries surveyed.

Norway, France, Spain, Poland and South Korea achieve between 39 and 33 points, ranking 18th to 22nd. In 2024, Poland shows average societal openness and a slightly above-average degree of international economic integration, primarily due to strong FDI and favorable tariff conditions. Its science and research systems, however, show little international integration.

Japan follows in 23rd place with 32 index points. Japan has a moderately open society, achieving very high scores for openness toward minorities in neighborhoods (World Values Survey) and on the rule of law. However, it performs poorly in integrating its science and R&D systems internationally. Multinational companies remain hesitant to conduct R&D in Japan. While Japan's inward and outward investment levels are relatively high, its scores for other trade and financial indicators are only average or below average in international comparison.

Greece and Indonesia follow in the next two places, ahead of a group tied at 30 points – South Africa, Russia, the United States and Italy – with India slightly behind at 28 points, occupying ranks 26 to 30. The United States can no longer be classified among the upper midfield; with 30 points, it ranks only 28th in the Openness Index.

According to our analysis, the US scientific system can only be considered moderately international in its cooperation. In terms of co-publications – both international and domestic – the United States ranks in the middle, while the share of open-access publications remains very low. The proportion of foreign students is also low, particularly for bachelor's and master's degrees, likely due in large part to the high tuition fees. By contrast, a significant proportion of PhD students in the United States come from abroad. It is well known that foreign doctoral candidates have long played, and continue to play, a substantial role in US research output.

The US R&D system as a whole remains internationally integrated, not least because many multinational companies operate research facilities in the United States. However, in terms of trade and financial flows, based on the indicators used here, the United States ranks in the lower range of countries. While inward and outward FDI are both high, the balance of payments, import ratio (imports as a share of GDP) and net foreign assets are relatively low compared to other countries in this study. These are GDP-normalized indicators and therefore partly offset by the United States' exceptionally large economy.

At the lower end of the rankings is a group of four countries led by China, followed by Turkey, Mexico and, in last place, Brazil. China performs well in terms of international co-publications but ranks at the lower end of the scale for open-access publications. It also continues to show significant deficits in the international integration of its research system as well as in societal openness. International trade and financial flows contribute positively to China's overall Openness Index score. However, this is primarily driven by FDI, with some support from the balance of payments and net foreign assets. By contrast, both the import ratio and tariff levels weigh on China's overall score.

While the relative positions of countries in the Openness Index have remained fairly stable over time, there are still several trends that are worth noting. If openness or connectedness were analyzed based on trends within each country rather than normalized for international comparison, that data would show a peak in the first half of the 2010s – driven by intensive trade linkages, investments and foreign assets. This peak coincides with the height of globalization, which can also be dated to the beginning of the last decade.

Following the 2007-08 financial crisis, the world economy entered a phase of dynamic growth based on specialization and intensive international trade. This period also marked the start of China's rapid growth, built on deep integration in global value chains – as the so-called "workbench of the world" – combined with a deliberate technological catch-up strategy. At the same time, scientific and technological advancements were increasingly driven by emerging economies such as India and Brazil, as well as advanced economies such as Singapore and South Korea, rather than being exclusively led by the West. Consequently, multinational companies and research institutions expanded their international partnerships in various ways. Companies in particular sought to avoid missing technological trends, leading to an expansion of knowledge sourcing and broader adoption of open innovation, while the increasing complexity and cost of innovation processes created a greater need for collaboration, both between firms and research institutions and among research institutions themselves. Up until the onset of the COVID-19 pandemic and the start of the new decade, index values – and thus the intensity of openness and connectivity – remained relatively stable. However, with the beginning of the 2020s, openness began to decline more sharply, driven by the pandemic, increased protectionism and the push for technological sovereignty. Nevertheless, ensuring exchange between locations remains critical for multinational companies,

INNOVATION AND OPENNESS INDEX SCORES, 2024

AT = Austria, AU = Australia, BE = Belgium, BR = Brazil, CA = Canada, CH = Switzerland, CN = China, CZ = Czechia, DE = Germany, DK = Denmark, ES = Spain, FI = Finland, FR = France, GB = United Kingdom, GR = Greece, HU = Hungary, ID = Indonesia, IE = Ireland, IL = Israel, IN = India, IT = Italy, JP = Japan, KR = South Korea, MX = Mexico, NL = Netherlands, NO = Norway, PL = Poland, PT = Portugal, RU = Russia, SE = Sweden, SG = Singapore, TR = Turkey, US = USA, ZA = South Africa

Unfortunately, the available data does not allow for the calculation of index values for Taiwan.
Source: Innovation Indicator 2025

especially those with R&D capacities abroad. National policy goals such as technological sovereignty and regulatory measures – with China's Cybersecurity Law[15] as an extreme example – pose major challenges and, above all, are significant cost drivers.

To evaluate the development of countries independently of globalization cycles or broader effects impacting international exchange, we apply a normalized comparison. The core question is therefore not whether a country has become more or less open over time, but whether, relative to global trends, there are signs of intensifying (or declining) openness. Based on this systemic perspective – meaning, in this case, a multidimensional assessment based on several indicators – the overall trends remain remarkably stable over time. However, some countries have deviated from these general trends and exhibit distinct developments that warrant special attention. Compared to 2005, the Czech Republic records the strongest increase in Openness Index values. While nearly all individual indicators demonstrate rising trends in openness, FDI, foreign-funded R&D expenditure and R&D activities conducted by multinational companies have been particularly instrumental in boosting the Czech Republic's Openness Index, placing it seventh in the 2024 ranking.

Denmark has also made significant progress over time, managing even to increase its level of openness during the COVID-19 crisis. The steady upward trajectory, particularly since the mid-2010s, has been driven by greater scientific integration (international co-publications), rising FDI and higher labor-market participation among foreign-born residents.

The development of the United States is also noteworthy. Between 2008 and 2016, the country experienced declining index values, but from 2017 to 2019 – during the first term of President Donald Trump – they increased again, before the onset of a clear COVID dip. Both inward and outward FDI played a key role in this positive trend, as did open-source software repositories, the number of international students and libertarian societal values.

Germany's Openness Index developed positively over much of the observation period, until the effects of the COVID-19 pandemic became particularly evident in 2020 and 2021. This development has been strongly influenced by FDI flows into and out of Germany. At the same time, notable changes can also be seen within the scientific system that align with new political and strategic initiatives. For example, in 2017 the German government renewed its Internationalization Strategy for Science and Research, aiming to strengthen international collaboration. With the High-Tech Strategy launched in 2018, the concept of Open Science was explicitly introduced for the first time, laying the foundation for the ongoing national efforts in open access and open data.

When comparing the openness of national science and innovation systems, as illustrated here, with innovation capacity as presented in the first part of this report, a clear positive relationship emerges. The more open and internationally integrated a country is, the greater its innovation capacity. While the correlations shown here do not imply causation, the relationship is unmistakable and fully consistent with the conceptual considerations outlined at the beginning of this report.

Over time, however, changes have also emerged.[16] While the relationship between openness and innovation capacity increased steadily from the start of the observation period in 2005, it began to reverse around 2020 – although it remains high overall. This supports the assumption that during the era of globalization, international networking and system openness made a strong and growing contribution to innovation success, whereas in recent years new perspectives have taken hold. Conceptually, the additional dimensions of research security and technological sovereignty have reshaped openness and cooperation in many places. The data appears to support this shift. The correlation between openness and innovation capacity has slightly declined but remains strong, although the effects of the pandemic and geopolitical crises have also played a role.

If a linear trendline were drawn through the data points, countries such as Singapore, Sweden, Finland, the United Kingdom, Germany, Israel, France, Spain and Japan would lie on or close to that line. Countries below the line achieve high levels of innovation capacity despite relatively lower engagement in openness and exchange – including Belgium, South Korea, China, Mexico and the United States. Conversely, countries such as Denmark, the Netherlands, Austria, Australia, Canada and the Czech Republic exhibit high levels of openness but are unable to translate it into corresponding innovation performance.

In summary, there is a clear correlation between openness – as measured in this analysis – and countries' innovation capacity. However, both the conditions and the objectives of international cooperation in science, research, business and society have evolved over time. While the 2000s and 2010s were largely characterized by the opportunities arising from globalization, since the COVID-19 pandemic and the geopolitical disruptions of recent years, security and sovereignty considerations have increasingly shaped political and strategic thinking. In the future, all countries are likely to maintain openness and international exchange, but such engagement will no longer be based solely on opportunity management. Instead, it will be more strongly guided by clear objectives and contributions to sovereignty than in previous years.

DENMARK TAKES THE LEAD

Not all technologies and technological domains are equal in their economic or scientific importance. In today's environment, key technologies play a distinctive role in shaping both economic performance and societal progress. An established way of defining key technologies focuses on their cross-sectoral character and their disruptive potential for individual industries and markets.[17] On the one hand, there are key technologies that are of general benefit to a wide range of industries or for other technology fields – that is, cross-cutting technologies with an enabling character (General Purpose Technologies). Established cross-cutting technologies such as microelectronics and medical biotechnology already offer many mature solutions, yet they continue to evolve dynamically. One of the most dynamic cross-cutting technologies is artificial intelligence (AI). It is penetrating almost all areas of activity and already shows concrete competitive relevance for many small and medium-sized enterprises (SMEs). This technology is extremely diverse and developing at high speed, supported by a wide range of use cases.

On the other hand, there are key technologies that are primarily associated with major economic potential and the opening up of new markets. These include, for example, energy technologies, sustainability technologies and advanced production technologies (Industry 4.0). While the first type of key technologies already permeates economic and social life in numerous areas and has concrete competitive relevance, the second group currently possesses above all the potential to deliver improvements and efficiency gains to solutions that are already mature in many fields. For both types of technology, markets and economic effects from technological applications already exist. In some classifications, a third group is also counted among the key technologies – those that have the potential to create entirely new markets or to transform existing ones in the future. Examples include quantum technologies and the so-called cold fusion.

This section of the Innovation Indicator examines the capacity of countries to develop key technologies that enhance competitiveness and generate economic impact. The focus here is therefore on the first two types of key technologies discussed above, while those that are expected to become broadly market-relevant only in the future are excluded at this stage. In total, we consider seven technologies or technology fields that play a key role within specific industries or across several sectors. These have been selected on the basis of a long-term perspective and with particular relevance for Germany and the European Union. The selection follows the conceptual criteria outlined above regarding the nature of key technologies. The technology fields covered in the Innovation Indicator are: digital hardware, digital networks, advanced production technologies, energy technologies, advanced materials, biotechnology, and the circular economy, which is represented here primarily through recycling technologies. The following section first reports and discusses the index values of the countries analyzed across all seven areas before each technology is examined individually in the subsequent sections.

INDEX OF OVERALL PERFORMANCE IN KEY TECHNOLOGIES

When the results across the seven key technologies are combined, a largely stable ranking emerges over time, with only minor shifts among individual countries. However, the pandemic has left very different marks on national innovation systems, and geopolitical tensions together with global economic uncertainty have contributed to stronger movements, especially in trade and the exchange of goods. In addition, many countries are now trying – albeit with different orientations and priorities – to position and develop these key technologies within their national innovation systems. This first section of the chapter presents an overall assessment, providing a broad evaluation of countries' strategic focus on key technologies.

INDICATORS FOR MEASURING KEY TECHNOLOGIES

For all seven key technologies, we collected the following indicators and combined them to form both an index for each key technology and an overall index for all seven key technologies.

- Share of scientific publications in each key technology as a proportion of all national publications
- Share of scientific publications in each key technology as a proportion of global publications in the respective technology area
- Share of transnational patent applications in each key technology as a proportion of all transnational patent applications from a given country
- Share of transnational patent applications in each key technology as a proportion of all transnational patent applications worldwide in the respective technology area
- Trade balance in each key technology relative to the country's population
- Trade balance in each key technology relative to global exports in the respective technology area
- Trademark applications filed with the European Intellectual Property Office (EUIPO) in each key technology
- Venture capital invested in the early phase (including Series C and D) in each key technology as a proportion of GDP (used only for the integrated index, not for calculating the indicators within individual key technologies)
- Share of computer-implemented inventions (software patents) among all inventions in the respective key technology

»

GERMANY IS ONE OF THE TOP FIVE COUNTRIES IN FOUR OF THE SEVEN TECHNOLOGY FIELDS. «

KEY TECHNOLOGIES OVERALL: RANKING OF ECONOMIES 2007 TO 2024

RANK	2007	2010	2015	2020	2024
1	SWITZERLAND	SWITZERLAND	SWITZERLAND	FINLAND	DENMARK
2	JAPAN	JAPAN	FINLAND	JAPAN	SWITZERLAND
3	USA	FINLAND	JAPAN	SWITZERLAND	SOUTH KOREA
4	GERMANY	GERMANY	GERMANY	SINGAPORE	GERMANY
5	SINGAPORE	USA	USA	DENMARK	SWEDEN
6	SWEDEN	SINGAPORE	SINGAPORE	CHINA	JAPAN
7	DENMARK	SWEDEN	SWEDEN	GERMANY	SINGAPORE
8	FINLAND	DENMARK	DENMARK	SWEDEN	FINLAND
9	NETHERLANDS	NETHERLANDS	SOUTH KOREA	SOUTH KOREA	CHINA
10	IRELAND	IRELAND	IRELAND	USA	NETHERLANDS
11	AUSTRIA	AUSTRIA	NETHERLANDS	IRELAND	USA
12	UNITED KINGDOM	UNITED KINGDOM	CHINA	NETHERLANDS	AUSTRIA
13	ISRAEL	BELGIUM	AUSTRIA	UNITED KINGDOM	UNITED KINGDOM
14	BELGIUM	CHINA	UNITED KINGDOM	AUSTRIA	IRELAND
15	FRANCE	SOUTH KOREA	BELGIUM	ITALY	ITALY
16	CANADA	FRANCE	SPAIN	BELGIUM	NORWAY
17	CHINA	NORWAY	FRANCE	ISRAEL	INDIA
18	NORWAY	ISRAEL	PORTUGAL	SPAIN	GREECE
19	ITALY	PORTUGAL	ISRAEL	NORWAY	BELGIUM
20	SPAIN	CANADA	CANADA	FRANCE	FRANCE
21	SOUTH KOREA	SPAIN	NORWAY	AUSTRALIA	SPAIN
22	AUSTRALIA	AUSTRALIA	ITALY	INDIA	ISRAEL
23	INDIA	CZECHIA	HUNGARY	CZECHIA	CZECHIA
24	GREECE	ITALY	AUSTRALIA	CANADA	AUSTRALIA
25	BRAZIL	GREECE	INDIA	PORTUGAL	PORTUGAL
26	CZECHIA	BRAZIL	CZECHIA	POLAND	POLAND
27	POLAND	INDIA	MEXICO	HUNGARY	CANADA
28	RUSSIA	RUSSIA	POLAND	GREECE	BRAZIL
29	PORTUGAL	POLAND	BRAZIL	SOUTH AFRICA	HUNGARY
30	SOUTH AFRICA	SOUTH AFRICA	RUSSIA	RUSSIA	INDONESIA
31	HUNGARY	MEXICO	SOUTH AFRICA	INDONESIA	SOUTH AFRICA
32	TURKEY	HUNGARY	TURKEY	BRAZIL	RUSSIA
33	MEXICO	TURKEY	GREECE	MEXICO	TURKEY
34	INDONESIA	INDONESIA	INDONESIA	TURKEY	MEXICO

Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2025

Denmark takes first place for the first time. It ranks first in two of the seven key technologies – energy technologies and biotechnology – and among the top ten countries in three others in our comparison. In digital hardware and advanced materials, however, Denmark lies only slightly above the midpoint of the 34 comparison countries. From a strong position – sixth place in 2018 – it has worked its way to the top. Denmark thus demonstrates a national innovation system that is particularly oriented toward key technologies and well integrated across the stages of innovation. The system is primarily based on a strong and broad-based science sector, combined with focused investments in several core areas.

Switzerland ranks second, only narrowly behind Denmark. This year, Switzerland does not lead in any of the key technologies – last year it ranked first in advanced production technologies – but remains among the top eight countries across all seven technologies. As in Denmark, Switzerland's success rests largely on an excellent science system combined with an industrial base capable of translating scientific and research excellence into competitive outcomes. Given the small population of Switzerland (and likewise Denmark), a broad technology profile would not be expected due to the need to specialize and focus resources. Switzerland's strong performance in key technologies underlines its clear orientation toward high technology and innovation, while low-tech segments play virtually no role in its profile.

South Korea ranks third with 44 index points. It leads in digital hardware and is among the top eight countries in all seven technologies except the circular economy. South Korea consistently records high patent numbers and a large share of computer-implemented inventions, underlining its strong orientation toward digital processes.

A group of countries follows with identical index scores (differing only in the decimals), including Germany, Sweden, Japan, Singapore and Finland. Germany ranks among the top five countries in four of the seven technology fields and even takes first place in circular economy. Only in biotechnology does Germany perform at a mid-range level. The reasons for this become apparent along the entire innovation chain (see illustration in chapter 1). Overall, Germany's strong export orientation is reflected in generally positive trade balances. Distinct patent and trademark profiles further support this focus on international markets. At the same time, the digitalization of German goods and services lags behind that of many other countries, as shown, for example, by the share of computer-implemented inventions (software patents). This lag also threatens to undermine Germany's traditional strengths, such as in advanced production technologies, where this year for the first time it no longer ranks among the top three. While this decline is partly attributable to trade barriers and the global economic situation in the short term, linked to Germany's international exposure, it may in the longer term be reinforced by the comparatively slow diffusion of digital processes.

Japan performs less well in innovation capacity (as outlined in the previous chapter) but demonstrates a solid position in key technologies, underlining its strong focus on several of today's cross-cutting technologies. Only in biotechnology and digital networks – mainly communication technologies – does Japan not rank among the top seven countries in our comparison. One of the general weaknesses of its system is a science base that performs poorly by international standards, while patents and foreign trade continue to support its technological strengths. Japan plays a leading role particularly in advanced materials (including batteries), advanced production technologies and digital hardware (microelectronics). Overall, however, Japan faces the challenge of strengthening its innovation capacity in key technologies to remain globally competitive.

KEY TECHNOLOGIES OVERALL: RANKING AND INDEX VALUES OF ECONOMIES

RANK	ECONOMY	Index value (scale 0–100)
1	DENMARK	47
2	SWITZERLAND	45
3	SOUTH KOREA	44
4	GERMANY	43
5	SWEDEN	43
6	JAPAN	43
7	SINGAPORE	43
8	FINLAND	43
9	CHINA	40
10	NETHERLANDS	38
11	USA	38
12	AUSTRIA	35
13	UNITED KINGDOM	33
14	IRELAND	32
15	ITALY	30
16	NORWAY	27
17	INDIA	27
18	GREECE	26
19	BELGIUM	26
20	FRANCE	26
21	SPAIN	26
22	ISRAEL	26
23	CZECHIA	26
24	AUSTRALIA	26
25	PORTUGAL	25
26	POLAND	24
27	CANADA	24
28	BRAZIL	21
29	HUNGARY	21
30	INDONESIA	20
31	SOUTH AFRICA	19
32	RUSSIA	17
33	TURKEY	17
34	MEXICO	15

Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2025

Singapore, which held first place in 2022 and 2023, has now fallen back, even below its pre-pandemic level. The main reasons for this decline – beyond the narrow margins between top performers – lie in its trade balance in the areas of advanced materials, biotechnology and the circular economy, while Singapore was able to make modest gains in patents and publications across several key technologies.

China ranks ninth, just behind the group of countries mentioned above. Its overall momentum over time is also evident in the combined performance across the seven key technologies, although in recent years the pandemic and global economic conditions have caused strong fluctuations. In digital hardware (mainly semiconductors) and advanced production technologies, China is not among the top ten countries, but it now ranks third in energy technologies and advanced materials, and fifth in biotechnology, among the 34 countries compared. In absolute terms, China's scientific output in all these key technologies is the highest in the world, indicating that its science system is strongly focused on applied disciplines and can boast critical masses of research capacities in every field. The country's pronounced export orientation is based on access to numerous international markets, supported not only by cost advantages but increasingly by a strong competence profile. In most of the technology fields considered here, China has thus already completed the transition to an innovation-driven economy.

The Netherlands rank eleventh, level with the United States. The United States places second in biotechnology and fifth in the circular economy, but in the other key technologies considered here it does not rank among the top ten countries. This is partly because, in our analyses, licensing revenues from intellectual property cannot be allocated at the level of individual technologies. As a result, the performance of the United States, especially in digital technologies, is likely somewhat underestimated. Nevertheless, the data on key technologies also shows that the US science system as a whole lacks a strong focus and, when normalized for the country's size, does not demonstrate particularly high overall performance. Yes, there are universities that are particularly strong in research and transfer, and of course the Big Tech companies. But compared to other countries, knowledge production in the United States is excellent at the top but below average in breadth. Added to this is the country's large trade deficit, which is evident in almost all of the technologies considered here. This means that the United States has a higher demand for these technologies than it is able to produce domestically. On the one hand, this creates dependencies – among others, on China – and on the other hand, it leads to payments abroad, meaning that value creation is effectively financed elsewhere.

The upper half of the ranking is completed by Austria, the United Kingdom, Ireland and Italy. Italy manages to place among the top ten in only two of the seven technologies – advanced materials and the circular economy – and ranks below the top 20 in two others, digital networks and biotechnology. Taken together, this indicates no clear national focus on key technologies. In some areas, scientific activity can be identified that aligns with the technologies considered here, but neither a relative nor an absolute strategic orientation toward them is evident in Italy.

Norway leads a large group of countries with very similar scores, ranging from 24 to 27 points and covering positions 16 through 27. This group includes India, Greece, Belgium, France, Spain, Israel, the Czech Republic, Australia, Portugal, Poland and, finally, Canada.

France, much like Italy, has no clear orientation toward the key technologies examined here, either scientifically or technologically. The France 2030 investment strategy, published in mid-2024, addresses a number of infrastructure projects as well as some innovation-related priorities, including the development of biomedicine and the decarbonization of industry. A central component of the decarbonization effort is the production of hydrogen using nuclear energy, while parallel investments are planned

» WITHIN THE EU, COORDINATION AND COOPERATION ARE ESSENTIAL TO ACHIEVING BOTH COMPETITIVENESS AND TECHNOLOGICAL SOVEREIGNTY. «

in renewable energy. The impact of this strategy cannot yet be anticipated, and a shift in focus toward the key technologies considered here is also not apparent.

In most areas, France records a trade deficit, which means that the country remains heavily dependent on foreign capabilities in key technologies and lacks both domestic competencies and production capacities. France's best performance is a tenth-place ranking in digital hardware, reflecting a partial continuation of its earlier strengths in microelectronics during the 1980s and 1990s. Across all other technologies, France ranks clearly in the lower part of the country comparison, and over time it has also lost significant ground in the overall assessment of key technologies.

At the lower end of the ranking are primarily the countries that are catching up, such as Brazil, South Africa and Hungary, as well as countries that have not yet developed a broad innovation system. These include Indonesia, Russia, Turkey and Mexico. Hungary thus lags behind the other EU countries considered here in terms of overall performance, but it manages to reach a mid-range position in several technology fields, including digital networks, energy technologies, advanced materials and biotechnology. Although Hungary has not yet been able to build a strong base in knowledge and technology generation – its publication and patent activity remain below international standards – it has achieved some success as a production location in several of these technologies. If it succeeds in linking production with knowledge creation, a corresponding innovation dynamic could also emerge in Hungary.

Some of the European countries perform quite well in individual key technologies, indicating that the European Union as a whole possesses a solid technological foundation across the areas considered. However, the countries that stand out are often few in number and, in terms of population and overall economic weight, relatively small within Europe. In the field of digital technologies – both hardware and networks – these include, for example, Ireland, Austria, Finland and Sweden, and to some extent also Denmark. Countries such as France and Italy score at best in the upper-middle range for individual key technologies, but generally rank considerably lower. Germany is the only country able to hold its own in certain technologies, securing places near the top or even among the leading group. Only in biotechnology and the digital technologies does Germany rank in the middle or slightly below.

With regard to the key technologies considered here, it should be possible, given sufficient coordination and cooperation within the European Union as a whole, to both enhance the EU's competitiveness and secure its technological sovereignty. The European Research Area, along with public-private partnerships in individual technology domains – the so-called Important Projects of Common European Interest (IPCEIs) – are intended to help achieve these goals. However, the fragmentation of the European single market remains an obstacle, as critical mass, market development and scaling are crucial for maintaining competitiveness. The European Commission has recognized these challenges, but so far has not been able to generate broad impact, even though the policy approaches mentioned above appear promising.

DIGITAL HARDWARE

Digital hardware includes micro- and nano-electronic components – primarily computer chips, but also other integrated circuits. They form the basis for numerous applications, ranging from consumer electronics and vehicles to machinery and medical technology, while also serving as essential inputs for other key technology fields such as digital networks and, in particular, artificial intelligence. Beyond chip performance itself, recent years have highlighted additional challenges, especially in cooling and, as a result, in managing the energy consumption of chips, both of which have become critical factors.

In 2024, South Korea narrowly moved to the top position in digital hardware, ahead of the previous leader Japan – an improvement of five places compared to the previous year.[18] Singapore also advanced ahead of Japan to take second place. For South Korea, slight improvements can be seen across all indicators year on year, but the trade balance and the share of computer-implemented inventions were the decisive factors behind its rise to the top. Singapore has almost identical values to the previous year, while Japan lost index points in its trade balance but otherwise remained stable, allowing Singapore to move ahead. However, only one point separates the three leading countries.

At a slight distance but still within reach of the leading group, Ireland follows ahead of a somewhat underperforming cluster consisting of Switzerland, Austria and Germany. Austria maintains its strong individual values across several indicators and achieves further gains in patents and, above all, in publications, while showing a slight decline in venture capital. Overall, this results in a five-point improvement and a rise of four places in the ranking. Switzerland and Germany each maintain their previous positions.

Almost tied, Sweden, Finland, France and Israel take positions eight through 11. These countries display distinctly different profiles across the underlying indicators. Sweden performs very well in scientific publications, while France and Israel record positive trade balances. Israel also scores strongly on computer-implemented inventions, and Finland stands out from the other three countries with a somewhat stronger position in venture capital.

The next group of countries, with index scores between 35 and 32 points, includes the Netherlands, Italy, Denmark, the United States, the United Kingdom, Greece and

China. Despite similar overall scores, these results reflect very different national profiles. Denmark is strong in science, the Netherlands in patents and trademark applications, and Greece achieves high values for computer-implemented inventions. The United States benefits from its market size and scale effects, yet its publication output relative to population remains comparatively low.

Norway and South Africa lead the lower mid-range, followed by Australia, Portugal, Canada and the Czech Republic. Australia and the Czech Republic achieve respectable results in scientific publications but do not stand out in any of the other indicators. Slightly behind the lower mid-field, with 23 points, are Poland, Belgium and India, followed by Spain, Turkey, Indonesia and Russia. Brazil and Hungary narrowly avoid the bottom position, which is held by Mexico.

Overall, many European countries appear in the lower mid-range and at the end of the ranking – among them Portugal, the Czech Republic, Poland, Belgium and Spain – highlighting Europe's oft-lamented technological lag and its dependence on technology imports from other countries, which is critical for both current and future applications. In terms of capacity, however, many still fall far behind the leading Asian countries. The EU Chips Act, introduced in mid-2023 to expand production capacity in Europe through additional investment and thereby strengthen supply security and technological sovereignty, has yet to achieve tangible results. The collapse of plans to establish semiconductor production sites in Germany has significantly delayed progress, both nationally and at the European level.

DIGITAL HARDWARE: RANKING AND INDEX VALUES OF ECONOMIES

RANK	ECONOMY	Index value (0–100)
1	SOUTH KOREA	54
2	SINGAPORE	54
3	JAPAN	53
4	IRELAND	50
5	SWITZERLAND	44
6	AUSTRIA	40
7	GERMANY	40
8	SWEDEN	37
9	FINLAND	37
10	FRANCE	37
11	ISRAEL	36
12	NETHERLANDS	35
13	ITALY	34
14	DENMARK	34
15	USA	33
16	UNITED KINGDOM	32
17	GREECE	32
18	CHINA	32
19	NORWAY	30
20	SOUTH AFRICA	29
21	AUSTRALIA	28
22	PORTUGAL	27
23	CANADA	27
24	CZECHIA	26
25	POLAND	23
26	BELGIUM	23
27	INDIA	23
28	SPAIN	21
29	TURKEY	21
30	INDONESIA	20
31	RUSSIA	19
32	BRAZIL	14
33	HUNGARY	9
34	MEXICO	7

Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2025

DIGITAL NETWORKS

Digital networks comprise technologies that are essential for the development of future-proof digital communication infrastructures. These include, above all, semiconductors and semiconductor lasers, as well as high-performance computers and even quantum computers. Software-based application areas such as elements of artificial intelligence and cloud computing also form part of this domain.

Singapore has led the country rankings in digital networks for several years. This top position is once again the result of a strong science system and, in this case, also of strong performances in patent applications and trade balance – evidence of the effective application of scientific and technological capabilities. Sweden and Finland share second and third place, separated only by the decimals. Both Scandinavian countries have a long tradition in communication technologies, even though mobile phones have long ceased to be part of their product portfolios. They are strong in both publications and patents, maintain an almost balanced trade position, and perform particularly well in trademark registrations. Overall, Sweden and Finland are thus well positioned along the entire innovation chain, from science to the market.

Switzerland follows in fourth place (previous year: second), having fallen behind particularly in global trade related to digital network technologies, which also led to its lower ranking. It is followed by the Netherlands (48 points) and, with equal scores, Denmark, Ireland and South Korea in eighth place. Since 2007, South Korea had steadily advanced from 23rd place to near the top of the ranking by the beginning of this decade. Last year, the East Asian country occupied a similar position – ninth place – in digital networks, but in 2024 it improved across all indicators considered here and thus moved further up.

An OECD report identifies South Korea as having an innovation ecosystem strongly oriented toward digital technologies.[19] This is the result of long-term and consistent government policies to foster digital development. As early as the 2000s, significant investments were made in education and knowledge building. Under the so-called Digital New Deal, total investments of around USD 37 billion were allocated for the period 2020 to 2025 to strengthen data infrastructure and artificial intelligence, including AI research. In addition to research funding, the diffusion of digital services and business models – particularly among small and medium-sized enterprises (SMEs) – has also been actively supported.

China ranks ninth in this key technology with 44 index points. In tenth place, with 42 points, Germany stands slightly ahead of Austria, the United Kingdom, Norway and the United States. In digital networks, Germany does not stand out scientifically and performs only moderately on the other indicators, though it reaches the upper quartile in venture capital. The share of software patents in Germany is rather low compared to other countries in this part of the ranking. As with patents as a whole, there remains considerable room for improvement in digital networks. Germany's tenth-place position is thus largely due to its broad-based, technology-specific innovation system that performs consistently but without particular strengths.

Both the United States and China score poorly on population-adjusted indicators for patents and publications but achieve top positions on global, absolute measures. While the United States is a significant net importer in trade involving these technologies, China, as a producer and exporter, achieves the highest score. However, the United States should be considered somewhat underestimated in this area, as the analysis does not account for licensing revenues, which – given its strong position in technology development and provision, particularly in digital networks – are likely to be significant compared with those of most other countries in the study.

In contrast to its strong performance in digital hardware, Japan shows less scientific and technological expertise in digital networks and records a slightly negative trade balance, placing it 15th in this field. Behind Japan, with index scores between 37 and 32 points, are Hungary, Israel, Greece, Portugal, the Czech Republic, Italy, Canada, India and Spain. The similar overall scores of these countries result from very different profiles: Greece and Portugal have high scientific output in this technology field, the Czech Republic and Hungary show positive trade balances, Israel and India perform well in patents, while Italy and Spain achieve moderate results across all indicators.

Further down the ranking are Indonesia, Poland, Australia, France, Belgium, Brazil, Mexico, Russia, Turkey and South Africa. None of these countries stand out on any of the indicators considered for digital networks. Australia performs somewhat better in scientific publications but, like France and Belgium, has a distinctly negative trade balance. Interestingly, Mexico has a very positive trade balance in this field, which moves it slightly ahead of the bottom group, although it remains well behind on all other indicators. This underscores Mexico's role as an extended manufacturing base for the United States.

DIGITAL NETWORKS: RANKING AND INDEX VALUES OF ECONOMIES

RANK	ECONOMY	
1	SINGAPORE	57
2	SWEDEN	51
3	FINLAND	51
4	SWITZERLAND	49
5	NETHERLANDS	48
6	DENMARK	47
7	IRELAND	47
8	SOUTH KOREA	47
9	CHINA	44
10	GERMANY	42
11	AUSTRIA	42
12	UNITED KINGDOM	40
13	NORWAY	39
14	USA	39
15	JAPAN	37
16	HUNGARY	37
17	ISRAEL	37
18	GREECE	36
19	PORTUGAL	35
20	CZECHIA	34
21	ITALY	33
22	CANADA	32
23	INDIA	32
24	SPAIN	32
25	INDONESIA	30
26	POLAND	29
27	AUSTRALIA	29
28	FRANCE	28
29	BELGIUM	28
30	BRAZIL	24
31	MEXICO	23
32	RUSSIA	19
33	TURKEY	19
34	TAIWAN	17

Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2025

ADVANCED PRODUCTION TECHNOLOGIES

The term advanced production technologies is closely related to the concept of Industry 4.0. However, the latter defines a narrower field and focuses primarily on the networking and automation of production and logistics. The Innovation Indicator uses a broader definition of advanced production technologies. It includes modern machinery as well as complete systems and their components, ranging from sensors and measuring devices to controls and automated logistics. Also included are the production processes themselves, such as joining (soldering, welding, bonding) or the pre-treatment of production materials.

In 2024, Singapore also took the lead here, exchanging positions with Switzerland, which fell back to second place. The reason for this change lies in their respective trade balances. Singapore achieved the highest trade surplus as a share of GDP in advanced production technologies. Although Switzerland also maintains a positive balance, its volume has declined significantly.

The Netherlands made the greatest leap forward, rising from eleventh to third place. The country improved in scientific publications and venture capital, but once again its trade surplus proved decisive. This result is likely influenced by special effects in the field of lithography equipment for printed circuits, where the world market leader is based in the Netherlands. Exports from the Netherlands to China in this segment increased roughly fivefold between 2023 and 2024. Japan, in fourth place, remains very stable across all parts of its innovation system, showing only minor changes in its trade balance index values.

Germany follows Japan in fifth place. Having already fallen from first to second place in the previous reporting year, it lost further ground in 2024. The main reason again lies in the trade balance. Although still positive, its share of GDP has declined, while other countries such as Singapore, the Netherlands, Israel and Japan have posted much stronger results. Germany slightly improved its index values for scientific publications and venture capital in the field of advanced production technologies, but these gains could not compensate for the decline in the trade balance.

For Germany, this has two main implications in a competence area so fundamental to its economy. First, global economic disruptions and structural shifts in the German machinery and plant engineering sectors have left clear marks. Second, many other countries have expanded both their capabilities and capacities – among them China and South Korea, but also long-established players such as Italy and Japan. Together, they have further intensified competitive pressure, especially through greater digitalization of their technologies and products.

Overall, the countries in the top five positions are very close to each other, while from sixth place onward the differences become more pronounced, especially from eighth place. Finland, with 48 index points, is two points behind Germany and is followed by Sweden, Denmark, South Korea and Austria. Sweden dropped two places despite slightly improved index scores, South Korea maintained its position, and Denmark lost three index points and three ranks. Austria, by contrast, improved by eight index points and two places.

The United States has fallen by one place compared to the previous year and now ranks eleventh in advanced production technologies. The slight decline in its index value is primarily due to minor decreases in the indicators for publications and patents. Italy has remained stable in

ADVANCED PRODUCTION TECHNOLOGIES: RANKING AND INDEX VALUES OF ECONOMIES

RANK	ECONOMY	INDEX VALUE (0–100)
1	SINGAPORE	53
2	SWITZERLAND	51
3	NETHERLANDS	51
4	JAPAN	50
5	GERMANY	50
6	FINLAND	48
7	SWEDEN	47
8	DENMARK	43
9	SOUTH KOREA	42
10	AUSTRIA	41
11	USA	38
12	ITALY	35
13	UNITED KINGDOM	32
14	CANADA	32
15	ISRAEL	32
16	CHINA	32
17	GREECE	32
18	IRELAND	30
19	AUSTRALIA	30
20	INDIA	29
21	NORWAY	29
22	CZECHIA	26
23	SPAIN	26
24	POLAND	24
25	BRAZIL	24
26	PORTUGAL	23
27	BELGIUM	22
28	RUSSIA	22
29	FRANCE	22
30	TURKEY	21
31	HUNGARY	16
32	INDONESIA	12
33	MEXICO	12
34	SOUTH AFRICA	11

Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2025

this part of the ranking for several years, followed by the United Kingdom, Canada, Israel, China and Greece. For China, 16th place represents a significant drop of eight places and an interruption of the upward trend seen in previous years. The sole reason lies in its trade balance, which in recent years has been only moderately negative but now shows a deficit of almost 0.5 percent of GDP – a consequence of the pandemic and global economic turbulence.

Ireland follows in 18th place and, unlike in previous years, has not continued to improve. It achieved slightly higher index values for scientific publications, patents and trade balance, while showing small declines in the share of computer-implemented inventions and trademark applications.

Australia, India and Norway occupy the next positions, still maintaining index values close to the middle of the field. The Czech Republic, Spain, Poland, Brazil, Portugal, Belgium, Russia, France and Turkey, with index scores between 26 and 21, already lag behind. Hungary, Indonesia, Mexico and South Africa form the tail end of the ranking, remaining well behind the main field.

ENERGY TECHNOLOGIES

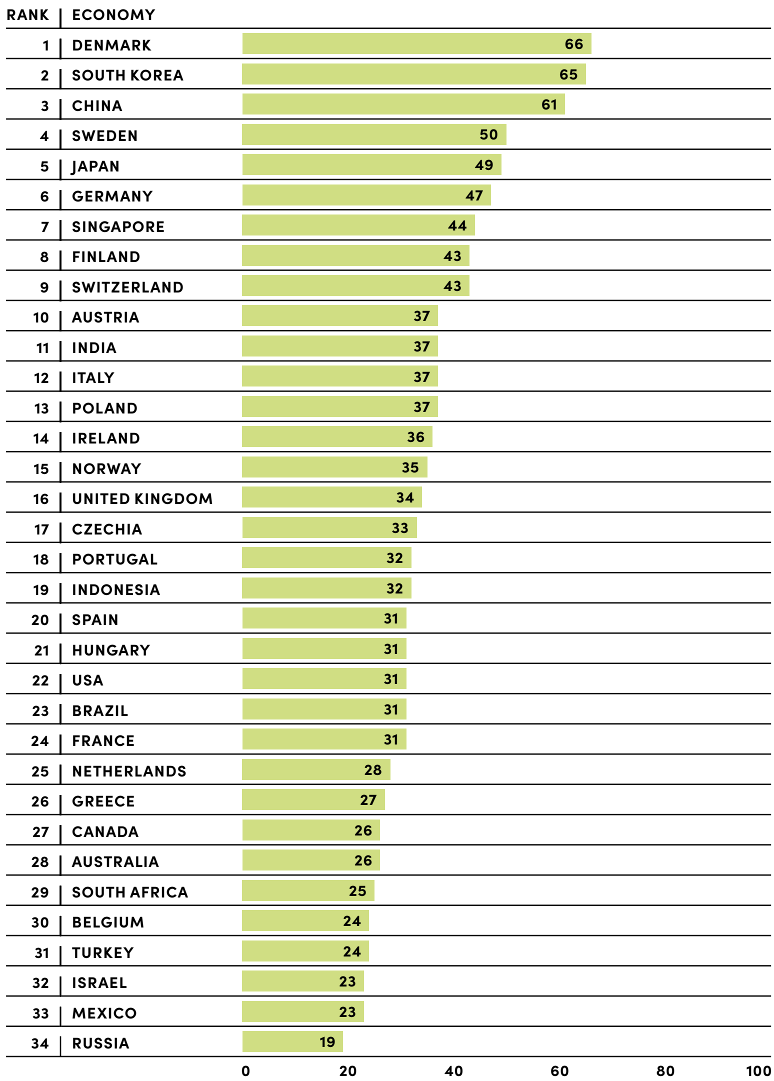
New energy technologies are a fundamental prerequisite for climate-friendly energy supply and use, and thus for the energy transition of both the economy and society. In addition, they offer the opportunity to increase independence from energy imports and thereby strengthen the competitiveness of economies. Energy technologies include technologies for harnessing renewable energy sources (wind, solar, biomass and hydropower), the production, use and distribution of hydrogen as an energy carrier, as well as technologies for energy storage and energy savings (energy efficiency).

In energy technologies, Denmark (66 points) has consistently led by a wide margin throughout the entire observation period, although it lost four index points in 2024. Denmark has been a global leader in wind energy technologies for decades and achieves top scores across all indicators analyzed here, with the only exception being the share of software patents, where it lags behind. It is followed by South Korea and China, both of which hold strong global positions in battery storage technologies. China has also developed significant expertise and capacity in renewable energy technologies, particularly in wind and photovoltaics. Only in trademark applications and computer-implemented inventions (software patents) do both countries show comparatively low values.

Germany ranks sixth, nine index points behind the leader, and closes a small group of followers that also includes Sweden and Japan. Despite a slightly negative trade balance, Germany performs well in this field, supported by high index values for trademark applications. On the other indicators, Germany ranks in the middle range. Sweden achieves high scores in publications, trademarks and venture capital and performs well overall despite a negative trade balance. The reason is that the United States sets the lower benchmark in this field, recording a pronounced trade deficit of nearly 3.5 percent of GDP in energy technologies. Accordingly, all other countries appear comparatively stronger in their trade balance results.

Singapore, Finland and Switzerland follow at some distance in seventh to ninth place. In the case of Singapore, scientific publications and computer-implemented inventions are the main factors driving its strong result. Switzerland records high values not just in science but also in trademark applications and venture capital. The same applies, in a different mix, to Finland, which improved its position by five places in 2024 compared to 2023.

ENERGY TECHNOLOGIES: RANKING AND INDEX VALUES OF ECONOMIES

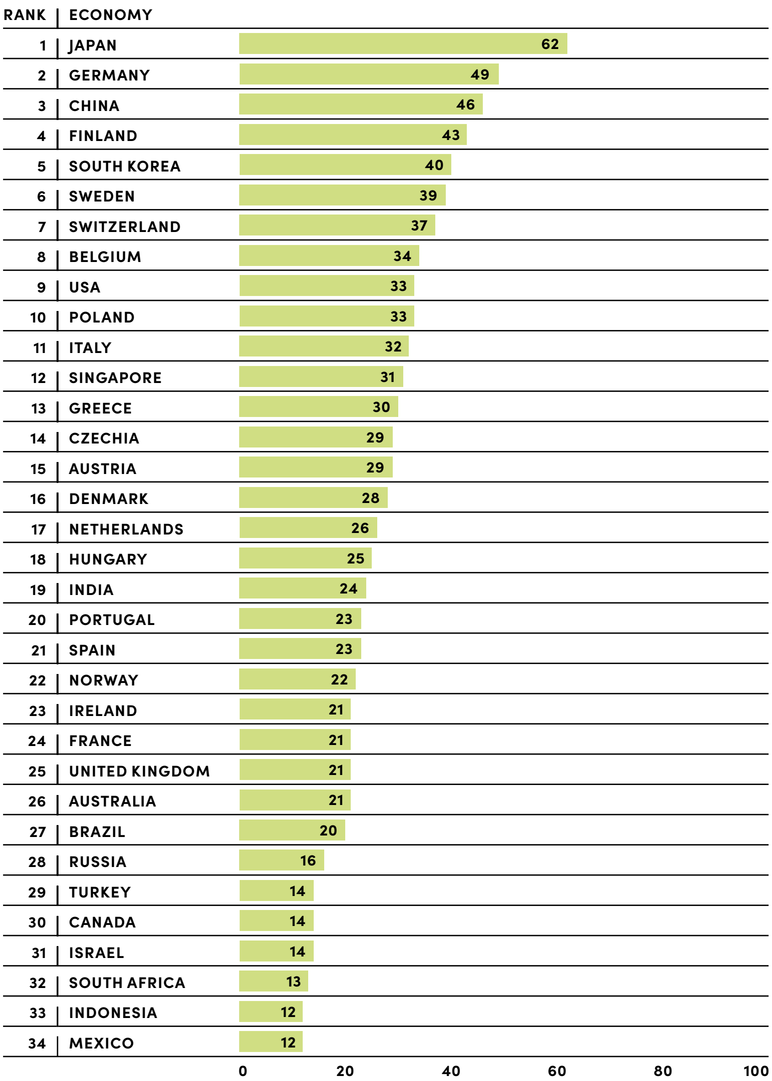


Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2025

With 37 to 36 points – well behind Switzerland's 43 – Austria, India, Italy, Poland and Ireland occupy the next positions. While the first three countries achieve similar rankings to those of 2023, Ireland moves up four places thanks to higher scores in venture capital and software patents. Poland made a notable jump from 22nd to 13th place, driven by its stronger trade balance results. It remains to be seen how substantial this improvement will prove to be.

The following ranks, from 15 to 24, are held by Norway, the United Kingdom, the Czech Republic, Portugal, Indonesia, Spain, Hungary, the United States, Brazil and France, with index scores between 35 and 31. As noted earlier, the United States has a pronounced trade deficit in energy technologies, which significantly drags down its performance in this field. Although the United States leads in the absolute number of scientific publications and patents, it scores low on the other indicators.

ADVANCED MATERIALS: RANKING AND INDEX VALUES OF ECONOMIES



Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2025

In France, none of the indicators considered here show a pronounced upward swing. This reflects France's strategic focus on nuclear energy. Although the European Commission has classified nuclear power as a CO2-neutral technology, it is not included in our definition of energy technologies, as from a German perspective nuclear power is not counted among green energy technologies.

Behind France are the Netherlands, Greece, Canada, Australia, South Africa, Belgium, Turkey, Israel, Mexico and, finally, Russia. Canada has lost ranking positions throughout the observation period, mainly because other countries have invested heavily in new energy technologies, while Canada shows only limited activity in publications and almost none in patents.

ADVANCED MATERIALS

Advanced materials with special properties form the basis for numerous other technological developments and open up new possibilities, for example in lightweight construction. They also play an important role in replacing environmentally harmful raw materials and improving material efficiency. Material technologies such as coatings further enhance the properties of products. This category therefore includes composite materials, coatings and plastics with special characteristics such as nanomaterials, as well as the processes involved in their manufacture and refinement.

Japan leads this key technology by a wide margin and has maintained its first-place position unchallenged throughout the entire analysis period. In patents – both in absolute terms and relative to population – Japan is the most active nation, and it also achieves the maximum score for trade balance. Although the contribution of advanced materials to Japan's GDP is modest at 0.07 percent, it is the highest value among all countries considered. Japan records mid-range scores for scientific publications and software patents.

Germany moved up to second place in 2024 for the first time. Until the mid-2010s, it ranked third, then dropped two places and, during the pandemic, fell as low as tenth. Germany has a positive trade balance in advanced materials and a comparatively high number of trademark applications, while patents and publications contribute moderately to its strong overall position. The decline in 2021-22 was driven by a slump in exports, resulting in a negative trade balance, and by a sharp decrease in computer-implemented inventions. The recovery to second place in 2024 was made possible by higher index values for trade and, to a lesser extent, computer-implemented inventions, while the other indicators remained stable. Several countries that ranked ahead of Germany in 2023 simultaneously experienced declines in certain indicators, especially in trade balance performance.

China ranks third with 46 index points, followed by Finland, South Korea and Sweden with scores ranging from 43 to 39 points. These countries also have a positive trade balance. Finland and Sweden rank high in publications relative to population and in trademark applications, while China achieves the highest score for the absolute number of publications. Finland also performs strongly in venture capital. South Korea has fallen from second to fifth place because the trade balance has deteriorated here as well, although its index values for publications and patents have risen slightly.

The next positions are held by Switzerland, Belgium, the United States, Poland and Italy, with scores between 37 and 32 points. Belgium made the biggest leap forward between 2023 and 2024, moving from 24th to eighth place. This improvement – from an index value of 25 to 34 – is entirely attributable to a positive trade balance, which had been negative the previous year. In Belgium, advanced materials contribute 0.06 percent of GDP.

Behind Italy are Singapore, Greece, the Czech Republic, Austria, Denmark, the Netherlands and Hungary, in 12th to 18th place. Among these countries, Austria has the relatively weakest trade balance: Imports of advanced materials amount to roughly 0.11 percent of its GDP. Publications, patents and trademarks contribute positively to Austria's position in the upper half of the ranking. The Czech Republic, which had fallen sharply during the pandemic years 2022 and 2023, regained several positions in 2024.

Ranks 19 to 28 in advanced materials are occupied by India, Portugal, Spain, Norway, Ireland, France, the United Kingdom, Australia and Brazil. The indicator values for these countries do not show any major fluctuations, meaning their national innovation systems are not geared toward advanced materials. Australia and Portugal have notable index figures for publications relative to population, while India performs well in absolute publication numbers.

At the lower end of the ranking are Russia, followed by Turkey, Canada, Israel, South Africa, Indonesia and, finally, Mexico.

BIOTECHNOLOGY

Biotechnology refers to the scientific and technological use of living organisms or biological processes. The definition used here covers all areas of biotechnology and their applications in health, industry, the environment and food production. In addition to enzymes, peptides, proteins and microorganisms and the processes based on them, it also includes processing and measurement techniques. Biotechnology thus encompasses a wide range of applications, and not all countries are equally specialized across all fields. It should be noted, however, that health-related biotechnology represents by far the largest segment, both economically and scientifically.

» JAPAN IS THE UNDISPUTED LEADER IN ADVANCED MATERIALS. «

The key technology biotechnology is once again led by Denmark (65 points), which has further strengthened its leading position. Denmark achieves top scores in almost all population-adjusted indicators considered here. With a clear margin, and tied with Switzerland, the United States follows in second place, having moved up two positions in 2024 to achieve its best result over the entire observation period. The United States' strong ranking is driven less by scientific publications – although it leads in absolute publication numbers – and more by the patent applications and a positive trade balance. Its dominance in the global markets for biotechnology products, especially in pharmaceutical applications, is unmistakable in the data. The foundation for this was laid largely by the National Institutes of Health (NIH) in the 1990s through a massive R&D funding program, which implemented a coordinated and focused policy approach for the first time. In addition to scientific and research excellence, this created a large number of companies and built the skilled workforce that continues to sustain biomedical and biotechnological research in the United States today.

With a ten-point gap to Switzerland, the Netherlands ranks fourth – a rise of three places – followed by China in fifth, which also improved by three positions. China has thus continued its upward trajectory in biotechnology after a slowdown during the pandemic years. A broad midfield follows, led by Austria with 31 points and extending down to South Africa in 22nd place with 21 points. This group includes Sweden, South Korea, Singapore, Belgium, Finland and Spain. Also part of the midfield are Hungary, Greece, Germany, Israel, Ireland, Australia, Portugal, France and the United Kingdom.

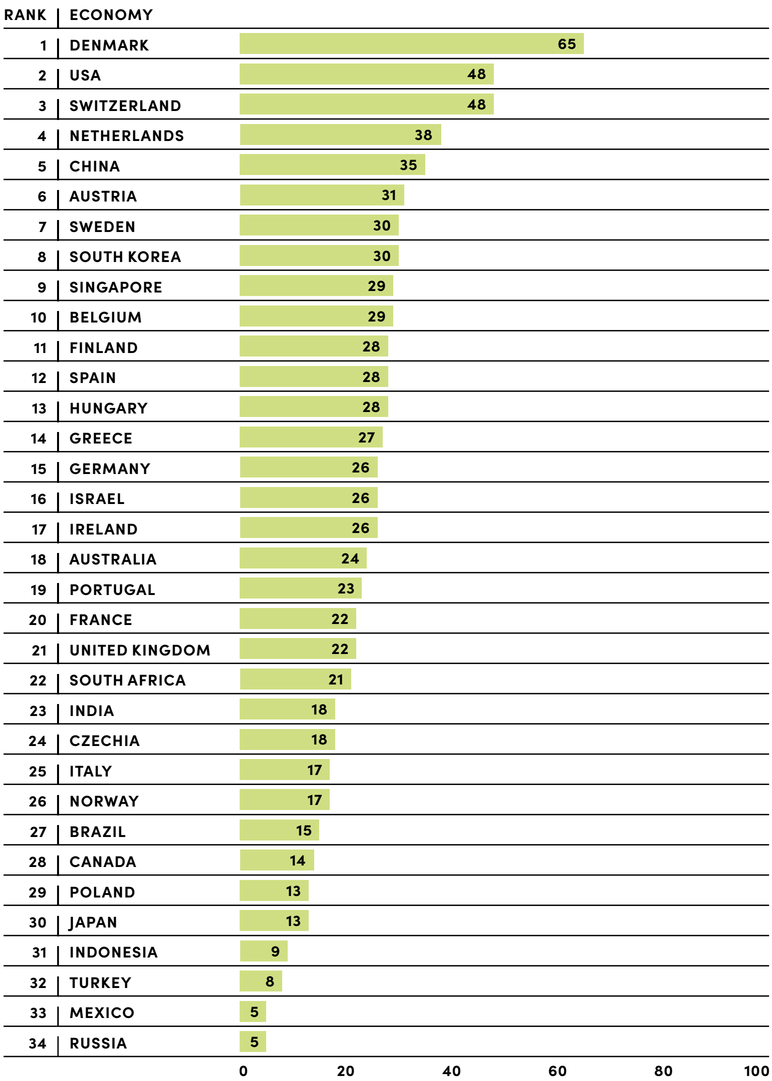
Hungary had benefited during the pandemic years from the weaknesses of similarly ranked countries and temporarily moved up, but in 2024 it lost some ground again. Interestingly, its trade balance remains the second highest among the countries considered, exceeded only by that of the leader, Denmark.

Germany, in 26th place, has returned roughly to its pre-pandemic position. It does not stand out in any of the indicators we consider here. Biotechnology funding programs have been in place in Germany since the 1990s. With the BioRegio program, launched in the second half of that decade to promote regional networks, Germany not only intensified its biotechnology support but also pioneered new approaches to cooperation and knowledge transfer. Since then, biotechnology-related funding programs have continued at both the federal and state levels.

The New Economy crisis in the early 2000s hit German biotechnology hard. The gap with the United States and other countries in red biotechnology (health-related applications) could not be closed after that. In the bioeconomy, however, Germany has achieved a stronger position thanks to its solid industrial base and dedicated funding – for example, it is particularly well positioned in biomaterials.

At the lower end of the ranking is a group of countries led by India, followed by the Czech Republic, Italy, Norway, Brazil, Canada, Poland and Japan. A further step down are four countries – Indonesia, Turkey, Mexico and, at the very bottom, Russia.

BIOTECHNOLOGY: RANKING AND INDEX VALUES OF ECONOMIES



Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2025

CIRCULAR ECONOMY

The circular economy encompasses various approaches aimed at the long-term use of materials and products. In its broadest definition, this includes processes such as product sharing (the sharing economy), reuse by third parties, and improved repairability. Recycling processes that begin already in product development and production – for example, in material selection – also belong in this technology field. In the Innovation Indicator, however, we apply a narrower definition, focusing essentially on recycling technologies that return materials into the production cycle.

As in the previous year, Germany clearly leads among the comparison countries in this key technology, ahead of Finland, Sweden and Denmark. Germany generates a strong trade surplus and performs well in intellectual property rights (patents and trademarks) but does not reach top scores in the other indicators. Process engineering, which forms the disciplinary foundation of the circular economy, has traditionally been highly application-oriented in Germany, with expertise concentrated in industry and universities of applied sciences, which generally have low publication intensity. As a result, while Germany has a solid scientific foundation, the decisive knowledge is concentrated more on the processes themselves, making German research comparatively underrepresented in international publication output. Finland, by contrast, is very well positioned in terms of scientific publications and patents. Sweden achieves high but not top scores across most indicators, yet it ranks highest in computer-implemented inventions (software patents).

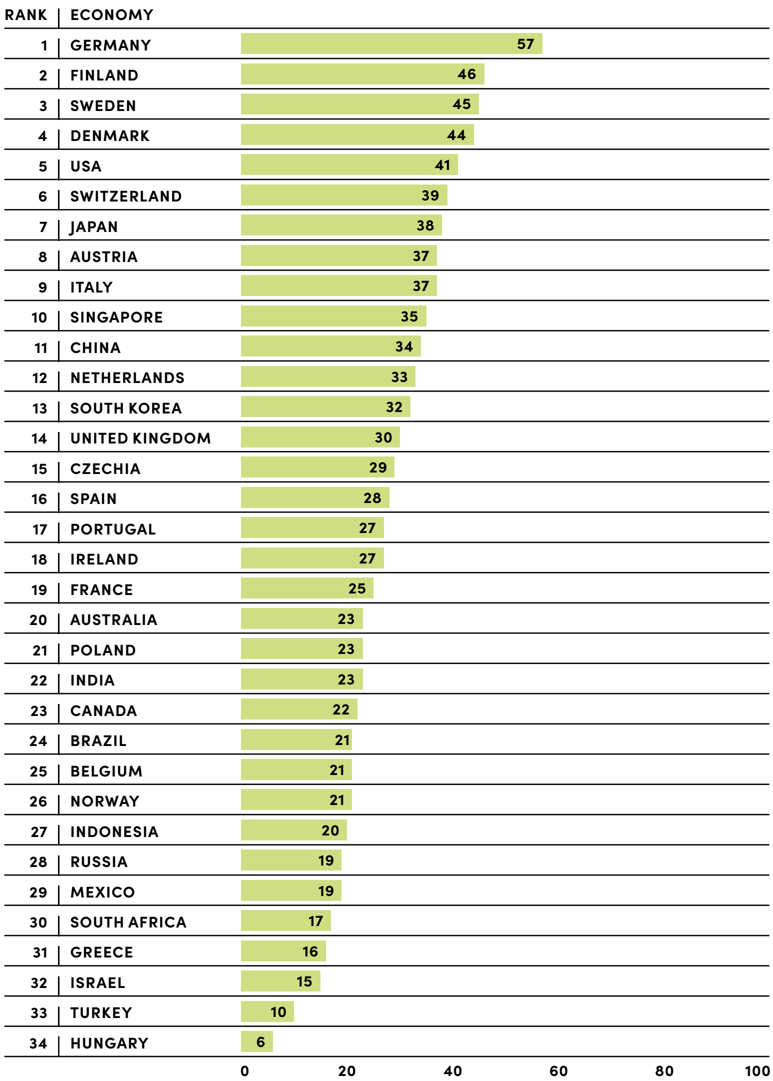
The United States retained its fifth place from the previous year, while Switzerland moved up two places to sixth. Japan, Austria and Italy follow with 37 and 38 points, respectively. Like Germany, Switzerland's strong position is based on application-oriented expertise in process engineering, although it is more firmly rooted in scientific research at universities and public research institutes.

Behind these come Singapore, China and South Korea, together with the Netherlands, in positions 10 through 13. China has made significant progress in circular economy technologies over the past 15 years, rising from 24th place in 2008 to 11th place in the current ranking. Since the early 2010s, China has achieved the highest score in absolute publication numbers, and from around 2017 onward, it has also climbed in patent rankings. Its trade balance has also improved, albeit with some delay, and while still far below the benchmark – Germany – it now shows a clear upward trend.

The next positions are occupied by the United Kingdom, the Czech Republic, Spain, Portugal and Ireland, with scores between 30 and 27. The lower midfield is led by France, in 19th place with 25 points, followed by Australia, Poland, India, Canada, Brazil, Belgium and Norway. France's position had steadily declined over time, particularly from 2018 through the pandemic years. Whether being ranked 19th marks a reversal of this trend remains to be seen. France scores across all indicators but does not stand out in any. Its publication indicators are very low, and it shows no comparative strength in patents. Overall, the data suggests that while the circular economy is present on France's policy agenda, it is not pursued with notable intensity or commitment. Moreover, without a strong foundation in science and research, a substantial and lasting improvement in technological performance appears unlikely. Norway, which also belongs to this lower mid-range group, performs slightly better than France, at least in terms of scientific publications.

A separate group of five countries follows at some distance, with scores between 19 and 15 points: Russia, Mexico, South Africa, Greece and Israel. At the bottom of the ranking, Turkey holds the second-to-last place, while Hungary trails far behind, with only six points.

CIRCULAR ECONOMY: RANKING AND INDEX VALUES OF ECONOMIES



Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2025

CHINA ON THE RISE

Sustainability is a societal challenge that extends beyond the economy. Its goal is to meet the needs of the population without jeopardizing the livelihood of future generations. For a future-proof economy, adhering to planetary boundaries is essential to ensure long-term prosperity. Close collaboration between civil society, academia, politics and business is therefore crucial to promote innovative approaches to sustainable development. The Innovation Indicator focuses on the socio-ecological transformation of the economic system while safeguarding competitiveness.

The economy affects sustainability in two ways: On the one hand, economic activities often place a strain on natural systems, whether through emissions or the consumption of natural resources. On the other hand, the economy can contribute to sustainability through sustainable innovation that helps reduce negative environmental impacts and promotes more sustainable production and use of goods and services.

A particularly important aspect is the transition to a circular economy. This economic model emphasizes the efficient use of natural resources. Unlike the traditional linear economy, which extracts raw materials, processes them and ultimately disposes of them, the circular economy aims to design products that are resource-efficient, durable and recyclable at the end of their lifecycle. One example is cradle-to-cradle design, which also enables the development of new, environmentally friendly business models.

The recommendations of the Innovation Indicator emphasize the importance of political frameworks for sustainable economic practices. Through legislation and targeted funding programs, policymakers can accelerate the transition to an environmentally friendly economy. This includes incentives for renewable energy and energy efficiency. Regulations and tax measures can help curb environmentally harmful behavior. Public procurement is viewed as an effective lever, given its substantial economic impact and its potential to be designed in a competition-neutral way.

Alongside business and research, consumer behavior plays a crucial role. Environmentally conscious consumption reduces environmental impact and encourages companies to offer sustainable products. Consumer decisions significantly influence sectors responsible for a large share of greenhouse gas emissions, such as transportation, food and construction. To bring about changes in consumption and mobility patterns, it is essential to raise public awareness of sustainability.

The Innovation Indicator incorporates all these aspects into the Acting Sustainably Index, which consists of 11 individual indicators. These indicators capture both the use of environmental technology and key elements of the environmental innovation system across business, research, government and civil society. The goal is to evaluate the progress of national economies toward sustainability-oriented innovation. The same set of countries is considered as in the chapters on innovation capacity and key technologies. All indicators are normalized to account for the differences in country size.

KEY FINDINGS

Many of the countries that previously led in sustainability have lost ground in this year's Acting Sustainably Index. This is partly due to the strong catch-up performance of countries such as China, which gained 16 points and thereby shifted the overall benchmark. However, in many cases the decline also reflects deteriorating performance in sustainability-related indicators.

This applies, for example, to Denmark, which topped last year's sustainability ranking with 67 points. Although it managed to retain its first-place position, it scored only 59 points this year. Finland remains in second place but also saw a significant decline, scoring 53 points (–7 compared with the previous year). The newly third-ranked Norway (45 points) replaces Germany, which dropped to 41 points (–7 points) and thus fell to seventh place. Given the recent strong policy focus on sustainability in Germany, this is a sobering result. As shown below, Germany's decline is mainly linked to weaker performance on indicators reflecting innovation strength in sustainability-related areas.

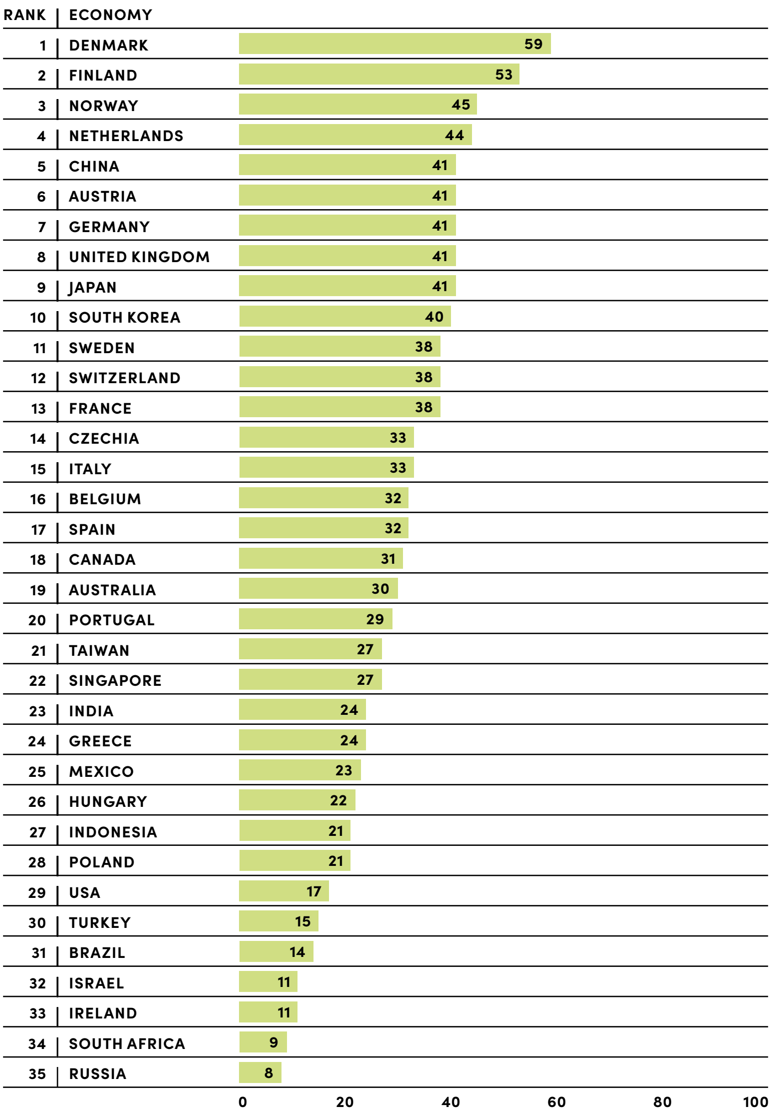
Ahead of Germany now rank the Netherlands in fourth place and Austria in sixth. China, meanwhile, made a remarkable leap forward, gaining 16 points to reach fifth

ACTING SUSTAINABLY INDEX – INDIVIDUAL INDICATORS

- R&D in renewable energy and energy efficiency as a share of GDP (IEA)
- Green early-stage investments (EU and OECD)
- Government R&D funding for environment & energy (OECD)
- Environmentally friendly consumer behavior (World Values Survey)
- Environmentally relevant scientific publications per capita of population (Scopus)
- Exports of sustainable goods as a share of GDP (Comtrade)
- Environmental innovation in companies (OECD)
- Environmental policy stringency index (OECD)
- Environmentally relevant patents per capita (PATSTAT)
- ISO 14001 certifications (ISO Survey)
- Environmental taxes (OECD)

» INCREASED BUREAUCRACY AND HIGHER ENERGY COSTS PLACE ADDITIONAL BURDENS ON BUSINESS ACTIVITIES. «

COUNTRY RANKING IN THE ACTING SUSTAINABLY INDEX



Source: Innovation Indicator 2025

place. It should be noted, however, that China does not provide data for some of the core indicators, which may influence the result – including green early-stage capital and R&D funding for green technologies. Real improvements are primarily driven by one indicator: environmental innovation by companies. Nevertheless, China's strengths are well documented: Multiple sources highlight its continued expansion of investment in green technologies. As early as the 12th Five-Year Plan (2011–15), China set a strategic course toward renewable energy,[20] not least to meet the increasing energy demand driven by its dynamic economic growth. This course has been pursued vigorously in subsequent plans. In recent years, China has not only met its own technological and capacity needs for renewable energy but has also become a major global player – most notably in wind and photovoltaic technologies.

Following Germany, the next positions – eighth to eleventh – are held by the United Kingdom, Japan, South Korea and Sweden. Switzerland improved by four points to reach 38 points, securing 12th place. Tied with Switzerland is France, which, however, lost six points compared to the previous year. Belgium ranks significantly lower, in 16th place, followed by Spain in 17th place with 32 points – an improvement of three points year on year. Despite a strong showing in the Innovation Indicator, Singapore remains far behind in the Acting Sustainably Index, in 22nd place even after a gain of six points.

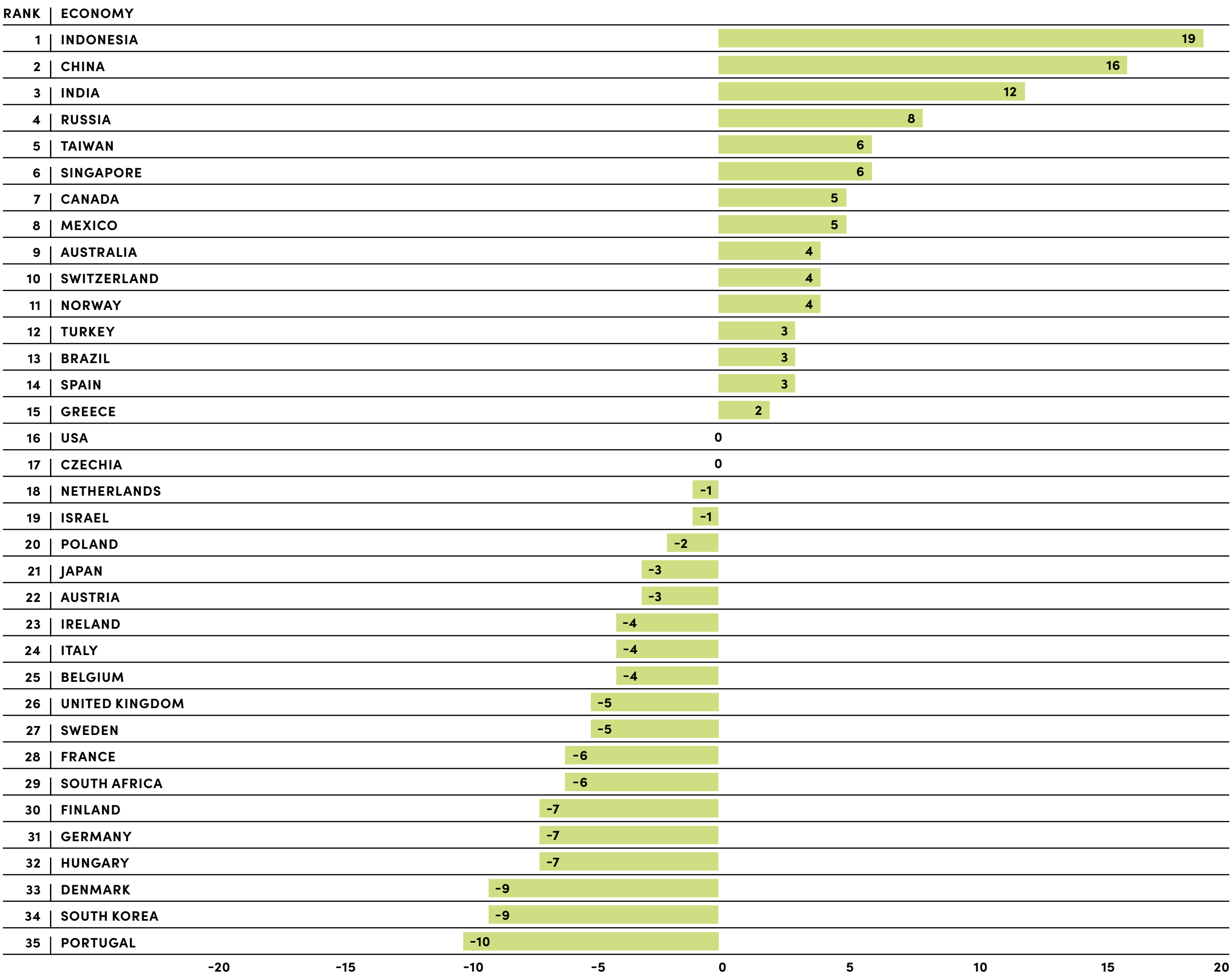
The United States has traditionally ranked near the bottom of the Acting Sustainably Index. Following the Inflation Reduction Act, which strongly promoted green investments, the country was able to achieve slight improvements in some indicators, albeit temporarily. However, no further progress has been made since, leaving the US score unchanged at 17 points, putting it in 28th place. Given the Trump administration's policy shift away from sustainability-focused economic policies, a reversal of this trend appears unlikely in the near term.

Emerging economies such as Turkey (15 points) and Brazil (14 points) perform similarly poorly. Indonesia, however, achieved the largest gains in this year's Acting Sustainably Index and now ranks ahead of the United States. At the bottom of the rankings are Ireland and Israel, both established industrialized nations, followed by South Africa (nine points) and Russia (eight points) in the final positions.

GERMANY LOSING GROUND IN SUSTAINABILITY

Germany's noticeably weaker performance in the latest edition of the Acting Sustainably Index may seem surprising at first glance, given the strong emphasis that the previous red-green-yellow coalition government has placed on socio-ecological transformation. However, it can be argued that many of its measures have also placed additional burdens on business performance – through increased bureaucracy (for example, the Supply Chain Due Diligence Act) or higher energy costs. In contrast, the green growth approach stresses that successful sustainability transitions must align economic, social and environmental goals by leveraging innovation potential and strengthening green innovation. Ideally, a focus on green innovation should not only improve the environmental footprint of the economy but also open up new markets.

CHANGES IN THE ACTING SUSTAINABLY INDEX COMPARED TO THE PREVIOUS YEAR



Source: Innovation Indicator 2025

To achieve this, strengthening market-based incentive mechanisms that operate through the price system is crucial.

This dynamic is clearly reflected in the Acting Sustainably Index. In the previous Innovation Indicator, Germany achieved 99 points – nearly the benchmark – for exports of sustainable goods. Now it scores only 63, a worrying result given the economy's dependence on exports. The country has also lost ground in energy-related R&D spending, dropping from 34 points to a mere eight points. Similarly, it has seen a sharp decline in support for environmentally friendly technologies, falling from 79 points to 55 points. Germany's weaker overall performance is therefore not limited to a few volatile trade indicators, but reflects a broader deterioration across multiple dimensions.

Otherwise, the strengths and weaknesses of countries across the individual indicators remain relatively stable. The leading country, Denmark, scores particularly high for the number of environmental scientific publications, environmental innovations by companies and environmentally relevant patents – achieving the maximum of 100 points in each category. Its most pronounced weakness lies in ISO 14001 certifications, where it scores zero. These certifications reflect the establishment of standardized environmental management systems and thus represent systematic corporate efforts to mitigate negative environmental impacts. ISO 14001 aims to embed a continuous improvement process within companies and thus acts as a dynamic management approach. However, the diffusion of ISO 14001 varies significantly between countries, with Japan, the United Kingdom and China leading the way, while many European countries remain more hesitant. Norway, Finland and Austria, for instance, record only low values. The reasons for these varying levels of adoption are not entirely clear, though research suggests that both institutional incentive mechanisms and bilateral trade relationships play a key role in shaping the diffusion of ISO 14001.

Norway, which was not among the leading nations in the Acting Sustainably Index last year, shows similar strengths to those of Denmark, particularly in environmental scientific publications. It also stands out for environmentally friendly consumer behavior, where it reaches the benchmark, and shows strong results in the implementation dimension – notably 83 points in corporate environmental innovation and strong performance in energy-related research and development. Austria, which ranks a solid sixth, excels in green early-stage investments, where it achieves the maximum score of 100 points. It also performs well in green exports (60 points) and reaches mid-range values for green innovations and environmentally relevant publications.

AMONG THE MAJOR ECONOMIES, CHINA IS GAINING GROUND

Within the group of large economies, the past year saw countries such as the United Kingdom and South Korea improve their positions in the ranking. This year, however, many major economies have lost ground – with the notable exception of China, which now reaches 41 points. In the mid-2000s, it stood at just 15 points, marking a significant leap forward. This progress highlights China's political commitment to making its economy not only more competitive but also more sustainable.

» CHINA DISPLAYS STRONG POLITICAL COMMITMENT TO MAKING ITS ECONOMY NOT ONLY MORE COMPETITIVE BUT ALSO MORE SUSTAINABLE. «

Critics, however, have often described this shift as "greenwashing" in research, innovation and economic policy, arguing that the country continues to rely heavily on conventional energy generation, particularly coal. At the same time, the Chinese government has invested not only in renewable energy but also heavily in nuclear energy. The government justifies this diversified energy mix by citing the need to meet the country's rapidly growing energy demand. Nevertheless, China's approach has proven successful in many areas of green energy technology, where it now competes internationally by exporting complete technologies, rather than merely low-cost components.

China's strengths in the Acting Sustainably Index remain largely consistent with previous years, most notably its ISO certifications (100 points). Its rise in the rankings is primarily due to progress in companies with environmental innovations, where China now sets the benchmark. In most other indicators, however, China still lags behind. This includes the public sector, which remains weak on environmental taxes (0 points) and environmental regulation (27 points), despite strong rhetorical commitments to sustainability.

South Korea, which was previously among the leading nations but has now fallen behind, has a similar profile to Germany, with no pronounced strengths or weaknesses. Unlike Germany, however, it achieves relatively high scores in the business dimension – particularly in environmentally relevant patents (53 points) – and shows strength in environmental taxation (70 points). It ranks lower in energy-related R&D and green exports.

France has notable strengths in environmental regulations, where it achieves the top score of 100 points. However, it is poorly positioned in environmentally relevant publications (14 points) and the share of companies with environmental innovations (11 points). On a positive note, France has slightly improved in environmentally relevant patents, now scoring 19 points.

The United Kingdom presents an interesting profile: It achieves a strong result in ISO 14001 certifications, where it sets the benchmark – a clear distinction from many other European countries that perform poorly in this area. It also achieves moderately good scores in environmental regulation (47 points) but performs very poorly in environmentally relevant patents, scoring just 11 points.

CONCEPTUAL FRAMEWORK

Since last year, the Innovation Indicator has taken a more functional perspective, enabling it to better capture the change in innovation processes and dynamics within the systems. In addition, it is now more able to take into account factors and technologies that are relevant for future innovation capability. The functional perspective focuses more strongly on the functions to be fulfilled and the interaction of different groups of actors within the innovation systems of the countries. On the one hand, this change reflects recent research findings in the field of innovation systems theory. On the other, the functional perspective allows closer integration with current topics and discussions in innovation policy. The purpose of the analyses is thus to compare the performance of the countries in question with regard to these functions.

Composite indicators such as the Innovation Indicator are weighted averages of individual indicators, which have to be normalized before they are aggregated. The Innovation Indicator records three functions of innovation systems using three separately calculated composite indicators. All three functions are recorded empirically and analyzed as independent target functions. The functions are:

- Generating innovations
- Developing future fields through key technologies
- Acting sustainably

The calculation of composite indicators takes place in three main stages, namely selection of the indicators, normalization of the values, and aggregation of the individual values into an index.[21]

SELECTION OF INDICATORS

The list of indicators used to calculate the index values for the three functions can be found in the relevant chapters. We chose the specific indicators in a three-stage selection process. First, we drew up a list of indicators that frequently appear in conceptual studies in innovation research and in sets of empirical innovation indicators. We then assigned the various indicators to the different stages in the innovation process, from inputs and throughputs to outputs, making sure the different stages were evenly represented. Finally, we carried out a statistical analysis of the individual indicators to identify indicators with high relevance for innovation and low redundancy with other included indicators. Correlation and factor analyses were used for this purpose. Indicators with very low coverage and a large overlap in the variance were removed from the selection set to create a model that is as economical as possible in a statistical sense.

NORMALIZATION

Normalizing is necessary in order to make the individual indicators independent of their original measurement units and to be able to subsequently offset them against each other. For this purpose, an indicator value of a country is set in relation to the indicator value of a comparison group. The following countries serve as a comparison group: Belgium, Denmark, Germany, Finland, France, Greece, the United Kingdom, Ireland, Italy, Japan, the Netherlands, Austria, Poland, Portugal, Sweden, Switzerland, Spain, the Czech Republic and the United States. The selected countries were those for which measured values were available for almost all individual indicators, for as many years as possible. The countries in the benchmark group are expected to display stable values or stable trends, ensuring the stability of the benchmark over time. If the benchmark were to change massively each year, the values of the individual countries would also change, possibly even without a de facto change in the original values of the economy in question. For this reason, we do not include catch-up economies or newly industrializing economies in the benchmark group.

The 19 countries listed above form the benchmark for each of the selected individual indicators. Their index values each define the rescaling range from zero (the minimum value) to 100 (the maximum value). The values of all other economies are aligned with this, with economies that perform worse than the worst country or better than the best country in the benchmark group set to the minimum (0) or maximum value (100), i.e., there are no negative values and no values greater than 100. In other words, the values of the individual indicators are each set to zero or 100 for extreme values outside the benchmark group of 19 countries.

AGGREGATION

How the different indicators are aggregated is of crucial importance for the resulting index. All selected indicators are given the same weight in the Innovation Indicator, i.e., there is no additional weighting of individual indicators in the offsetting. Within the three target functions, the respective overall indicators are therefore calculated as equally weighted mean values of the respective individual indicators. The reason for this equal weighting is easier communication and transparency. At the same time, both the theoretical conceptual framework and the empirically guided selection of individual indicators ensure that we only consider indicators that are relevant for the function in question. Likewise, there are no redundant indicators in the set. So there is also no indirect weighting through multiple mapping of a dimension due to several indicators measuring the same thing.

SELECTION OF ECONOMIES

Thirty-five economies are analyzed and compared in the Innovation Indicator. They include established industrialized nations, which are highly innovation-oriented and generally also highly active in the exchange of knowledge-intensive and technology-intensive goods and services on global markets. Emerging economies and newly industrializing countries are also included in the analysis. These include the BRICS group (Brazil, Russia, India, China, South Africa), which are interesting for international comparisons not only because of their current or expected dynamics, but also because of their economic size. We also include in the Innovation Indicator countries that have formulated significant development aspirations in terms of either their academic or innovation policy (e.g., Central European countries) or which, due to the size of their population, can be expected to have significant absolute numbers (e.g., Indonesia, Turkey, Mexico).

EXTRAPOLATION OF ANNUAL VALUES FOR THE CURRENT PERIOD

Statistical data up to the current reporting year 2024 is not available for all indicators. There are various reasons for this. In the case of patents, for example, there is an 18-month publication period. Some data is not collected annually and other statistics simply take longer to process and provide than half a calendar year. Data from the previous year is not yet available in the middle of the current year. In order to provide as up-to-date a picture as possible of the three functional dimensions, in this year we therefore extrapolate from certain raw data up to 2024. The following rules were applied: In the case of patent data, the data for 2023 was estimated per country and field/technology based on the data available in the databases for the first five months of 2023 and compared with the proportion of patent applications in the first five months of 2022 in relation to all patent applications in 2022. The patent figures calculated in this way were then extrapolated to the year 2024. Data series ending in 2022 or earlier were estimated forward for one year using time series analysis. The data was then extrapolated up to 2024. Data up to 2024 was available for a number of indicators and could therefore be used directly. All indicators were normalized and aggregated in accordance with the above-mentioned procedures. Thus, additional analyses for the years 2023 and 2024 could now be provided compared to the 2023 Innovation Indicator, published in spring 2024, which covered data up to 2023. During the coronavirus pandemic, the data in the statistics in some countries was subject to unusual and sometimes significant changes. For this reason, we only used time series analysis to estimate one year (2023): The uncertainty for longer estimate series increases sharply where there are significant changes over time, and we wished to avoid this. Nevertheless, some of the indicators are based on estimates or projections and may differ from the actual figures for the respective year, which will be published in the future. We are confident that we have made the best possible estimate with the chosen method and under the given circumstances.

Further details on the methodology can be found in the methodology document:
innovationsindikator.de/methodik

ENDNOTES

1 See Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S. & Rickne, A. (2008): Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Research Policy, 37(3), 407–429.

2 The reference group includes all economies in the Innovation Indicator for which measurement values are available, for as many individual indicators and years as possible. These countries are Belgium, Denmark, Germany, Finland, France, Greece, the United Kingdom, Ireland, Italy, Japan, the Netherlands, Austria, Poland, Portugal, Sweden, Switzerland, Spain, the Czech Republic and the United States.

3 See Janger, J., Schubert, T., Andries, P., Rammer, C. & Hoskens, M. (2017). The EU 2020 innovation indicator: A step forward in measuring innovation outputs and outcomes? Research policy, 46(1), 30–42.

4 Guan, J. & Chen, K. (2012). Modeling the relative efficiency of national innovation systems. Research policy, 41(1), 102–115.

5 System efficiency is not necessarily calculated as the average of knowledge-generation and commercialization efficiency; rather, it results from the specific interplay of input, output and scale configurations within each country. Accordingly, the overall system efficiency may numerically fall between the two subsystem efficiencies – but it may also be dominated by one of the two. In such cases, the respective subsystem should be understood as the limiting factor in the country's innovation system.

6 Chesbrough, H. W. (2003): Open innovation: The new imperative for creating and profiting from technology, Boston: Harvard Business School Press.

7 Hippel, E. von (1998): The sources of innovation, Oxford: Oxford University Press; Hippel, E. von; Krogh, G. (2011): Open innovation and the private-collective model for innovation incentives, In: Dreyfuss, R. & Strandburg, K. (ed.): The Law and Theory of Trade Secrecy: A Handbook of Contemporary Research, Cheltenham: Edward Elgar, 201–221.

8 Kroll, H. (2025): Governance internationaler Zusammenarbeit in Forschung und Technologie, Stiftung für den Maschinenbau, den Anlagenbau und die Informationstechnik, Frankfurt: Stiftung Impuls; https://impuls-stiftung.de/wp-content/uploads/2025/07/2025-06_IMPULS_FhG_ISI_Governance-internationaler-Zusammenarbeit.pdf.

9 Edler, J., Blind, K., Frietsch, R., Kimpeler, S., Kroll, H., Lerch, C. et al. (2020): Technologiesouveränität. Von der Forderung zum Konzept. Fraunhofer ISI. Karlsruhe.

10 https://www.bmftr.bund.de/SharedDocs/Downloads/DE/2024/positionspapier-forschungssicherheit.pdf?__blob=publicationFile&v=4

11 European Commission (2025): A Competitiveness Compass for the EU. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, Brussels.

12 European Union (2024): The future of European competitiveness. Part A: A competitiveness strategy for Europe, Luxembourg: Publications Office of the European Union.

13 European Commission (2021): European Research Area Policy Agenda – Overview of actions for the period 2022-2024, Brussels, European Commission; https://commission.europa.eu/system/files/2021-11/ec_rtd_era-policy-agenda-2021.pdf

14 Although there are a few indicators that are used for both innovation capability and openness, the differences are significant. Of the 21 indicators related to openness, only two (the proportion of international co-publications and co-patents) are also found in the context of innovation capability. Openness broadly aims at exchange, which is not directly taken into account in innovation capability.

15 https://www.investmentplattformchina.de/grenzueberschreitender-datentransfer-von-china-ins-ausland/

16 The correlation between innovation capability and openness increases over time, then slightly declines in the year 2020.

17 Kroll, H., Berghäuser, H., Blind, K., Neuhäusler, P., Scheifele, F., Thielmann, A. & Wydra, S. (2022): Key Technologies. EFI Office. Berlin; EFI – Expert Commission for Research and Innovation (2022): Annual Report on Research, Innovation and Technological Performance in Germany 2022. Berlin.

18 It is important to emphasize that Taiwan is not included in the set for key technologies due to the absence of foreign trade data. Nevertheless, Taiwan ranks among the world's leading economies in both chip design and chip production.

19 https://www.oecd.org/content/dam/oecd/en/publications/reports/2023/07/oecd-reviews-of-innovation-policy-korea-2023_6517d469/bdcf9685-en.pdf

20 https://www.iea.org/reports/world-energy-investment-2025/china; https://www.weforum.org/stories/2025/07/chinas-green-transformation/

21 See, for example: Nardo, M., Saisana, M., Saltelli, A., Tarantola, S., Hoffmann, A. & Giovanni, E. (2005): Handbook on Constructing Composite Indicators: Methodology and User Guide, OECD Statistics Working Paper STD/DOC(2005)3, Paris: OECD.

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The BDI is the umbrella organization of German industry and industry-related service providers. 39 industry associations, 15 state representations and more than 100,000 companies with around eight million employees make the association the voice of German industry. The BDI works for a modern, sustainable and successful industry in Germany, Europe and the world.
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Jana Legler (p. 5, left), Roland Berger (p. 5, right)

STATUS
November 2025

» PAST SUCCESSES WILL BECOME LESS AND LESS EFFECTIVE. WE MUST CHANGE. «