innovation indicator

2024

INNOVATIONSINDIKATOR.DE

BDI
Bundesverband der Deutschen Industrie e.V.

Fraunhofer ISI

Roland Berger

ZEW

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.

innovationsindikator.de

CONTENT

EDITORIAL

Dear Reader,

Germany is sluggish, China remains dynamic. These are just two of the striking results of the new Innovation Indicator for 2024 – representative of the shifts in global innovation, in which traditional industrialized nations are facing ever greater challenges.

Growing trade and technology conflicts intensify this change. They present economies and the companies that operate within them with the task of surviving in a volatile market environment and adapting their strategies accordingly. Depending on their size and structure, companies have stronger or weaker ties to a particular location; yet, they all depend on local research and innovation policies. The importance of academic institutions in this geo-economic constellation is often underestimated. Global exchange in the area of cutting-edge research, the excellence of academic institutions and their attractiveness for talented individuals from all over the world are of fundamental importance. They are crucial for innovation, including the development of key technologies.

The Innovation Indicator 2024 is particularly revealing as a reflection of the innovation process activities on the global political stage. It backs up the success of innovative economies with figures based in science. It shows that today's positioning is a reflection of past decisions and investments. However, it is possible to shape the future – all the more so: without a change in behavior, there will not be the necessary momentum, and without changes in action, there will be no better results.

In this year's report, Germany slipped down two ranks compared wirth other economies. Switzerland and Singapore are smaller than Germany but have long been the most innovative countries in the world. Denmark has achieved an astonishing improvement in its innovation capability. Germany's innovation capability continues to decline: It is now ranked 12th out of 35, two places lower than in last year's rankings. It does better in the areas of key technologies and sustainability, maintaining seventh and third place respectively.

Germany, as a major European economic power, is at the center of global change. As publishers of the Innovation Indicator, we are convinced that only if Germany once again becomes an innovation nation – the #InnoNation, as we call it – will it master the challenges ahead. The Innovation Indicator provokes important questions: Do we want to reform the innovation system or do we believe we can sit out the change? Do

we focus on academic excellence or do we stick to our scattergun approach? Do we want to master key technologies or become even more dependent? In what direction should we drive the debate on dual-use research and what are the consequences for our innovation system?

For German policymakers, the results of our study can only mean one thing: They must pursue their research and innovation policy goals even more consistently. Despite the upcoming federal elections, a long-term perspective is needed to realize the objectives of strengthening technological sovereignty, promoting excellence, improving the transfer of research into applications, implementing goals in a targeted manner, eliminating funding contradictions and making financial support available.

For businesses, the most important thing is to make innovation-driven investment decisions despite uncertainties and to strengthen future competitiveness through active portfolio management. An open culture of innovation and R&D partnerships with other companies can make a significant contribution here.

Ultimately, everyone has to want innovation: It is the responsibility of us all, not the job of the few. Fear and reticence are poor counsellors. With the Innovation Indicator, we invite you to get involved. It's time to get started.

Siegfried Russwurm
President, BDI

Stefan Schaible
Global Managing Partner, Roland Berger

GERMANY'S RANKINGS AND TASKS

At a glance

TOP
3

INNOVATION CAPABILITY

RANK	COUNTRY	
1	SWITZERLAND	71
2	SINGAPORE	68
3	DENMARK	68

0 20 40 60 80 100

KEY TECHNOLOGIES

RANK	COUNTRY	
1	SINGAPORE	46
2	DENMARK	46
3	JAPAN	44

0 20 40 60 80 100

SUSTAINABILITY

RANK	COUNTRY	
1	DENMARK	67
2	FINLAND	60
3	GERMANY	48

0 20 40 60 80 100

RANK
12 ↘

Germany must ...

... step up its efforts to keep its innovation system open internationally.

... focus additional state R&D funding on areas of particular importance for its long-term innovation capability and the challenges ahead.

... ensure that more SMEs orient their business models towards innovation, new technologies and global marketing.

... finally start promoting top science and so create specific beacons of excellence with global visibility.

KEY TECHNOLOGIES

42 INDEX POINTS

RANK
7 →

Germany must …

… seek European collaboration and claim a stronger leadership role in science and research.

… rethink the separation between civilian and military research in order to create institutional synergies and allow innovations to spill over into civilian use.

… use existing competences and domain knowledge to apply AI in new and domain-specific contexts.

SUSTAINABILITY

48 INDEX POINTS

RANK
3 →

Germany must …

… broaden its funding programs to speed up the sustainability-oriented transformation of the economy and promote the emergence of new, circular business models.

… assign clear, transparent responsibilities in the administration of its innovation and technology policies and bring about a greater concentration of resources.

… create a stable and reliable environment for societal actors, especially with regard to innovations in climate and environmental protection.

More recommendations can be found at the end of each chapter.

GERMANY IS LOSING GROUND

Key results

- In our comparison of the innovation capability of 35 economies, **Germany's** position has eroded still further. The country is now ranked twelfth, having dropped two places compared to our previous report. Germany's indicator value has fallen slightly while, at the same time, other economies have increased their commitment to innovation.

- **Germany** has also lost ground in some key technologies but has managed to halt the downward trend in the general index covering all technologies. It remains in seventh place on technology. In the sustainability index, Germany ranks third, unchanged from last year's report.

- **Switzerland** has the highest innovation capability in the Innovation Indicator 2024. As in last year's report, it achieved a score of 71 points.

- **Denmark** is one of the most dynamic, innovative countries in the world. It has improved its performance significantly, along with its position in the international rankings. Denmark is also a leader in a number of key technologies. It ranks second in the overall index, just behind Singapore, and is the world leader in energy technologies and biotechnology.

- **Ireland** has continuously increased its focus on innovation, including by hosting branches of foreign technology companies, and has thus become the top location for the commercial exploitation of innovations in Europe. The country is investing more heavily in higher education and could climb further up the rankings in future by increasing its own innovative strength.

- With 48 points, **Belgium** has dropped six points and three places compared to last year. The country's ability to innovate was hard hit by the pandemic. Prior to this, Belgium had established a strong position, reflecting an impressive reorientation towards research and innovation. The country has increasingly specialized in innovation-oriented economic activities, as evidenced by the 3.41 % share of R&D expenditure in its 2022 GDP.

- In the **USA**, innovation performance has been falling slowly but steadily since in the mid-2000s. The country has only recently been able to keep its innovation capability stable, but it is one of the economies that was particularly affected by the pandemic.

- The top regions within the **USA** – Massachusetts and California – rank significantly higher than the country as a whole. In assessing the overall US position, it should therefore be remembered that the country has some specific highly innovative regions that are global beacons. At the same time, there is a whole series of US states (regions) that operate well below the level of the global leaders.

- The **USA** does not achieve a top 3 rank in the comparision of economies in any of the seven key technologies examined. In absolute terms, the USA is the leader in many areas, as reflected in the indicators and rankings. But in terms of breadth and standarized for size, the country. often only puts in a mediocre performance.

- Digital technologies, as well as other technology fields in which the **USA** has a strong absolute position (such as pharmaceuticals/biotechnology and aerospace), only form a small part of the US economy. There are also larger fields of technology (chemicals, mechanical engineering, automotive) in which the USA's position in global innovation competition has deteriorated.

- **Poland** has recorded the strongest growth since 2005 of all the Southern and Central European countries, reaching 22nd place in 2023. The country has improved its ranking because of its improved high-tech trade balance, increased scientific output and greater expenditure on academic research and tertiary education. In the area of key technologies, on the other hand, Poland remains fairly low in the international rankings, despite slight improvements in the recent past. It achieved its best position in the category Advanced Materials, where it ranks 8th.

- **China** is the only major economy whose innovation capability is developing at great speed. The country has moved up the innovation ranking each year: Overall, it now ranks 25th, ahead of Italy and Japan. However, there has been no further growth in its innovation index value since 2020, which can be explained by the coronavirus crisis and the extreme lockdown measures imposed in China.

OPENING UP LONG-TERM PROSPECTS

The Innovation Indicator

Since its first publication in 2005, the Innovation Indicator has provided a systematic measurement concept for recording the innovation capability of national economies. The strength of the measurement concept is based, among other things, on empirical and methodological expertise in the construction of composite indicators. The concept of National Innovation Systems (NIS) distinguishes between various subsystems whose organization significantly influences the innovation capability of an economy, focusing on its actors and their interconnections. In a national innovation system, these subsystems interact and so determine the innovation capability of national economies in different ways.

OUR APPROACH

The NIS approach has a long tradition in innovation research and has proven a fruitful starting point for the empirical analysis of innovation processes at the national level in the past. This is also demonstrated by the fact that the approach has been continuously refined in research over the last few decades in order to account for a changing environment, for example new societal challenges or the emergence of new technologies. In particular, the system-centered NIS approach has been expanded to include a functional perspective[1]. The focus of this so-called functional NIS approach is no longer on measuring ex ante defined systems (science, industry, state, society, education) and their actors, but on how certain functions relevant to innovation systems are performed. Building on the functional NIS approach, the Innovation Indicator takes up these findings from innovation research and translates them into an operationalized measurement concept that depicts the central challenges and functions facing modern innovation systems. Increasing technological competition in the course of geopolitical realignment, alongside the central challenges of decarbonization and the digitalization of the economy, academia, state and society, form the background for the Innovation Indicator 2024. Accordingly, the Innovation Indicator focuses on three "functions":

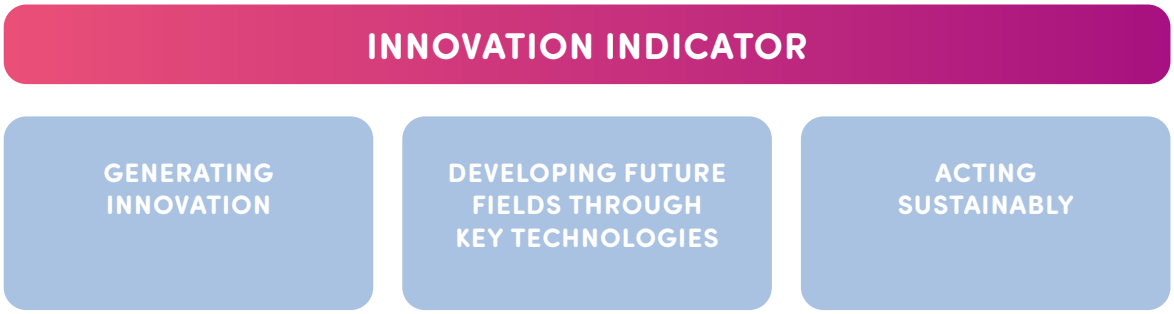
- **Generating innovation**
- **Developing future fields through key technologies**
- **Acting sustainably**

All three areas are regarded as independent target functions and are recorded within the Innovation Indicator concept in the form of independent composite indicators. The indicators assigned to these functions are not offset against each other.

The Innovation Indicator takes into account how future-oriented a country's positioning is. This is achieved first by analyzing how well the individual national economies perform in relation to important key technologies. Second, the Innovation Indicator considers how sustainable the economy and innovation processes are. For example, an economy can be successful in terms of innovation in the present moment but face strong barriers to innovation in the long term – if it does not invest sufficiently in the future key technologies that drive innovation across many sectors, say, or if the innovations do not comply with environmental and resource-related sustainability limits. In this sense, the methodological and conceptual framework of the Innovation Indicator aims to add a more long-term perspective on the innovation capability of individual economies.

INNOVATION SECURES THE FUTURE

With a view to the key technologies, seven technological areas are mapped that we consider to be particularly relevant for future competitiveness, not least because they are prerequisites for technological developments in other technology areas and for a large number of different industries:



- **Digital hardware**
- **Digital networks**
- **Advanced production technologies**
- **Energy technologies**
- **Advanced materials**
- **Biotechnology**
- **Circular economy**

The function "developing future fields through key technologies" focuses on the ability of an economy to independently produce innovations in specific areas of technology, defined in a general manner, and to utilize the resulting economic development potential. This approach is thus based on a long-term, technology-orientated competitive perspective.

The competition perspective is expanded by including the function "acting sustainably", which primarily refers to efforts to adhere to planetary limits. This function deals with the question of whether existing production and innovation processes are organized sustainably, and which scientific and technological prerequisites supporting the transformation of the economy and society exist in the country in question. The two perspectives – key technologies and sustainability – complement each other. For example, it is possible for a national economy to be a leader in the provision of energy technologies and also derive economic benefits from this, while at the same time its own production and innovation processes are not organized in a sufficiently sustainable manner. In this sense, the sustainability indicator in the Innovation Indicator provides a measurement of the extent to which national economies can maintain their production structures in the long term within a sustainable economic paradigm.

The Innovation Indicator pursues the overarching goal of measuring the extent to which various countries are securing their future viability with the help of innovation. The function "generating innovation", which was already included at least implicitly in previous years' Innovation Indicators, is now expanded to include a decidedly future-oriented perspective. In particular, the function "developing future fields through key technologies" better reflects the future technological competitiveness of individual national economies. On the other hand, the function "acting sustainably" is explicitly included in order to analyze whether and to what extent the innovation and production systems of the individual economies comply with planetary boundaries and can therefore be successful in the long term.

A list of the respective indicators can be found in the individual chapters and in the methodology report, available here:
innovationsindikator.de/methodik

SWITZERLAND REMAINS NUMBER ONE

Economies and their innovation capability

The aim of the Innovation Indicator is to measure the innovation capability of 35 economies. The 2024 Innovation Indicator uses the revised measurement method developed for last year's report. Based on a systemic understanding of innovation, it examines how innovations are generated, introduced and used productively. This requires the interaction of many players – companies, academia, politics, society – and the existence of an innovation-supporting infrastructure and an innovation-friendly environment.

The Innovation Indicator attempts to reflect the variety of influencing factors by referring to 23 individual indicators. To this end, four functions for generating innovations are considered:

- Knowledge creation
- Knowledge diffusion
- Converting knowledge into marketable innovation
- Turning innovation into revenue

When selecting the indicators, a balance is struck between indicators that measure a country's current innovation performance and forward-looking indicators that reflect future innovation capability. Current innovation performance is based on investments made in the past and therefore does not necessarily say anything about the potential that a country can exploit in the coming years. However, it is an important indicator because it shows how much innovation contributes to a society's current prosperity. At the same time, current innovation performance generates the income needed to invest in future innovation capability. These central factors for future innovation include for example the international orientation of the innovation system, the performance of the research system and the interaction between academia and industry.

All individual indicators in the Innovation Indicator are normalized to the size of the economy in question using its gross domestic product (GDP) or population size. This enables a direct comparison of innovative capability between countries of different sizes. However, it should be noted that small and large economies have different opportunities to focus on innovative activities (see box "On the comparison of large and small economies in the Innovation Indicator").

The values of the individual indicators are normalized to a value range between 0 and 100. For this purpose, the indicator value of an economy is compared to the indicator values of a reference group.[2] A value of 0 indicates that the indicator value of the country under consideration is equal to or lower than the lowest indicator value in the reference group, while a value of 100 indicates that the indicator value is equal to or higher than the highest value in the reference group. Values between 0 and 100 occur if the indicator value of a country lies within the value range of the reference group. The overall index for the Innovation Indicator corresponds to the mean value of the normalized individual indicators and lies between 0 and 100 points.

MAIN RESULTS

Switzerland is the country with the highest innovation capability in the Innovation Indicator 2024. As in last year's ranking, the country achieved a score of 71 points. Singapore is still slightly behind with 68 points, up 3 points compared to last year. Denmark, in third place, recorded an even higher increase of 8 points, also reaching 68 points. The positive development of Singapore and Denmark has brought the three top-ranked countries much closer together. The gap between these three and the next countries in the ranking has increased significantly.

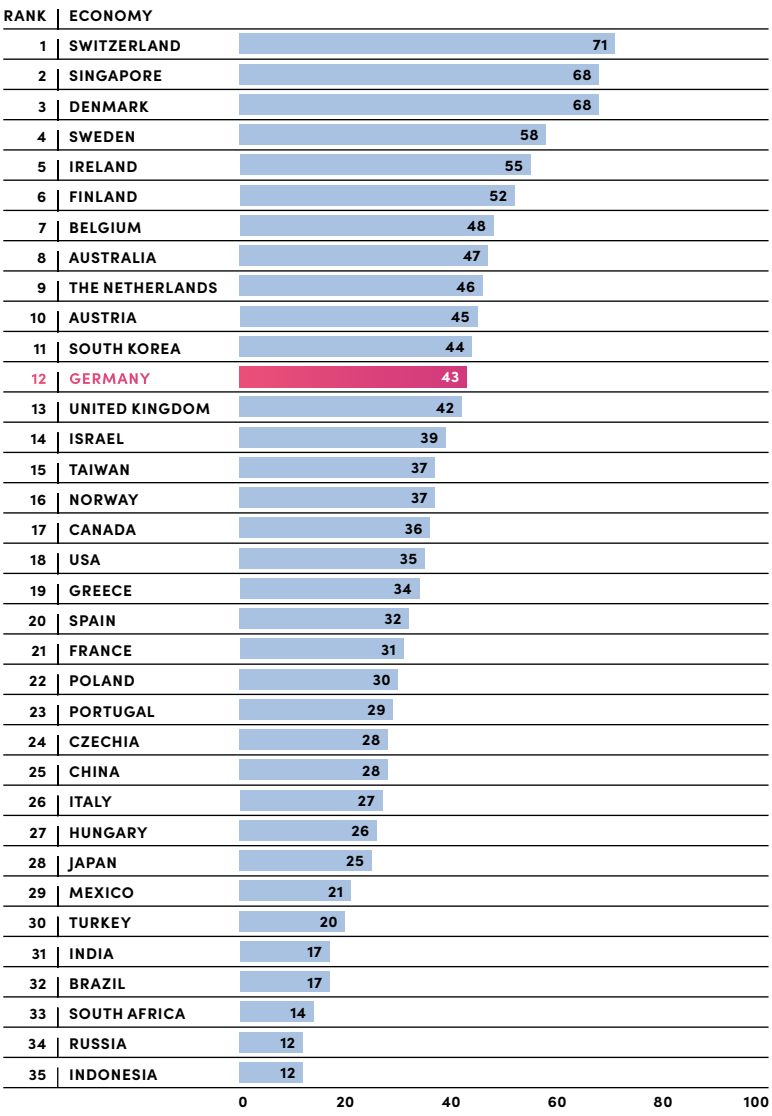
Sweden, Ireland and Finland came fourth, fifth and sixth in the ranking. Sweden improved by 8 points and moved up from sixth to fourth place, with 58 points. Ireland remained in fifth place despite a slight increase in points. Finland is in sixth place, with 52 points (up 3 points compared to last year). Belgium, on the other hand, has fallen behind, with 48 points, down 6 points and dropping three places on last year.

Belgium leads a group of seven countries with very similar innovation performances, each one point behind the country in front. In addition to Belgium, Australia, the Netherlands, Austria, South Korea and the UK, this group also includes Germany. With 43 points, Germany scored 2 points less than last year and dropped from tenth to twelfth place.

The rest of the midfield in the innovation ranking comprises a group of five economies that are quite close to each other, with scores between 39 and 35 points. These are Israel, Taiwan, Norway, France and the USA. The second part of the midfield is made up of eleven countries with between 34 and 25 points. They include larger economies (China, Japan, France, Italy) and also a number of small to medium-sized Southern and Central European countries (Greece, Spain, Poland, Portugal, Czechia, Hungary).

Japan brings up the rear in the broader midfield. The fact that Japan is so far down in the innovation ranking is primarily due to the indicators used to measure international networking, academic performance, the development of skilled workers and government support for R&D. Japan lags far behind in all of these indicators, so that even its top values for R&D activities, patents and high tech are not enough to move the country forward.

INNOVATION CAPABILITY: RANKING AND INDEX VALUES OF THE ECONOMIES



Source: Fraunhofer ISI calculations

At the bottom of the ranking are seven countries that can be described as emerging economies, including four of the five BRICS countries (Brazil, Russia, India, South Africa) as well as Turkey, Mexico and Indonesia. Their indicator values are between 21 and 12 points.

CHANGES DUE TO COVID-19, THE ENERGY CRISIS, INFLATION AND THE WAR IN UKRAINE

The results of the Innovation Indicator 2024 include the effects of the coronavirus pandemic, the rise in energy prices, the sharp increase in inflation since 2022 and the war in Ukraine. It should be noted that the individual indicators are influenced very differently by these crises and macroeconomic upheavals. Some indicators are very "crisis-resilient", as they reflect the fundamental structures of an innovation system, such as the qualifications of the workforce or employment in academia. Other indicators react much more strongly to the less favorable environment for research and innovation due to the crises. These include indicators for the international exchange of knowledge and technologies, investments in new technologies and the commercialization of innovations.

As a result, we see some significant shifts between the 2023 and 2024 Innovation Indicators, primarily due to the different effects of the crises mentioned. Owing to the delay in the availability of data for many indicators, the 2023 Innovation Indicator was only able to capture the initial effects of the coronavirus pandemic, but not the effects of the rise in energy prices, high inflation and the war in Ukraine.

A comparison of the change in scores between the two Innovation Indicators shows, first of all, that some of the countries lagging far behind in the rankings have made significant gains. This applies to Brazil, Indonesia, India, Mexico and South Africa. Second, two countries from the lower midfield have also improved their indicator values significantly (Poland, Greece). Third, some of the innovation-intensive economies managed to emerge stronger from the crisis, above all Denmark, Australia and Sweden, but also Singapore, Taiwan and Finland.

The latest gains in points in the emerging markets are primarily due to improved trade balances in high tech and increased numbers of international co-patents. In addition, the ratio of young to older university graduates

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

has risen due to demographic factors. India was also able to increase its output of highly-cited academic publications. Poland and Greece scored particularly well with their improved trade balance in high-tech goods, increased academic outputs, greater R&D expenditures in academia and in the area of tertiary education. The current momentum in innovation-intensive economies is due on the one hand to the number of academic publications, and on the other to better results in the implementation of knowledge (e.g., venture capital investments, trademark applications, business-science collaborations). Australia was also able to improve in the area of tertiary education.

By contrast, the position of several countries has deteriorated significantly in the current Innovation Indicator. This applies most of all to Russia. However, a number of countries that are generally strong in innovation have also suffered significant losses, including France, the USA, Norway, Belgium and Israel. The reasons for this vary from country to country, ranging from a decline in business R&D expenditure or the share of high-tech value added (Belgium, Norway, France) to less dynamic R&D activity in academia (USA, France) and lower R&D funding activities by the state (USA, Israel). Having lost two points, Germany also joins the group of countries with a currently declining innovation performance.

VERY HIGH VALUES AMONG SMALLER ECONOMIES

The high values for smaller economies in the Innovation Indicator show that it is easier for these countries to allocate a greater proportion of their available human and financial resources to the creation and economic exploitation of new knowledge. This is particularly true for the leading country, Switzerland. The Swiss Confederation is home to some of the most efficient academic institutions in the world, whose output per GDP is higher than in almost any other country. At the same time, the economy is concentrated on those fields for which new research findings are of particular importance, such as pharmaceuticals/biotechnology, electronics and automation. Close networks between academia and industry generate and productively utilize many innovation opportunities. The only weak points for Switzerland in the Innovation Indicator are the relatively low level of venture capital investments and the very low level of state R&D funding for companies. However, both of these points may also reflect the fact that research-intensive companies have sufficient internal resources and therefore do not depend on government support or external funding.

Singapore and Denmark follow a very similar approach to Switzerland. High investments in an efficient academic system create excellent local conditions for innovative and very internationally networked industries. In addition to high expenditures on higher education and excellent academic institutions, close cooperation between business and academia is an advantage of these countries.

» SOME COUNTRIES THAT IN PRINCIPLE ARE STRONG IN TERMS OF INNOVATION HAVE SUFFERED SIGNIFICANT LOSSES. “

The economies of both nations focus on pharmaceuticals/biotechnology and knowledge-intensive services.

The strong position of Belgium in the Innovation Indicator reflects an impressive change of orientation in research and innovation that has been underway in the country since the mid-2010s. In 2013, Belgium was still ranked in the middle of the Innovation Indicator, with an index value of 41 points. Since then, considerable investments have been made in developing the innovation system, particularly in academia and industry, and how they network with each other. This has been accompanied by an increasing specialization in particularly innovation-oriented economic activities. One indicator of this is the sharp rise in R&D expenditure, which in 2022 amounted to 3.41 % of GDP. This is the highest figure of all European countries, on a par with Sweden and ahead of Switzerland and Germany. By comparison, in 2010 Belgium’s R&D ratio was just 2.1 %. In the latest period, however, Belgium has not been able to continue this upward trend. The indicator value fell significantly in 2022 and only recovered slightly in 2023. It is not yet possible to say whether this is a trend reversal or just a short-term setback caused by the crisis.

Ireland has been increasing its focus on innovation, although it has chosen a different approach to the four countries ranked ahead of it in the Innovation Index. The Irish strategy relies heavily on attracting foreign technology corporations, for example through generous R&D funding, a large, English-speaking supply of skilled workers and access to the European single market. As a result, the country has become the top location for the economic exploitation of innovations in Europe. This is reflected in very high productivity, an enormous export surplus in the high-tech goods sector and the second highest GDP per capita in Europe after Luxembourg.

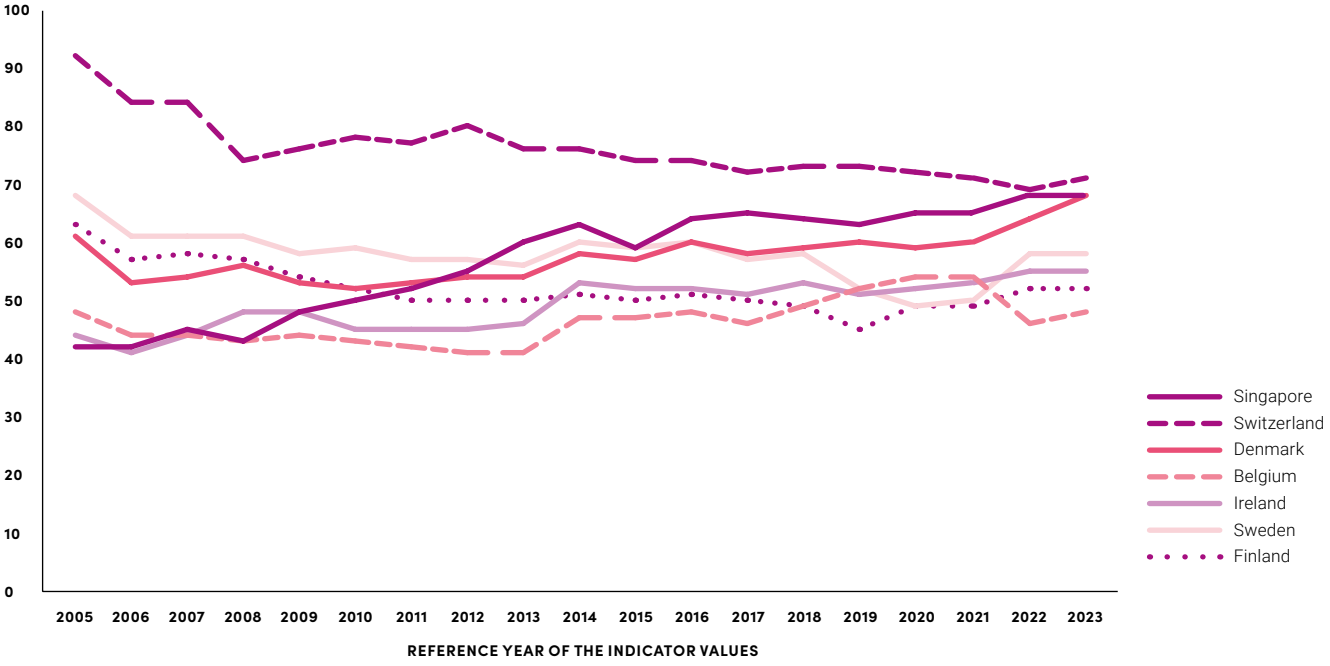
GERMANY CONTINUES TO LOSE MOMENTUM IN THE INTERNATIONAL INNOVATION RACE. “

INNOVATION CAPABILITY: OVERALL RANKING OF ECONOMIES

RANK	2005	2010	2015	2020	2023
1	SWITZERLAND	SWITZERLAND	SWITZERLAND	SWITZERLAND	SWITZERLAND
2	SWEDEN	SWEDEN	SWEDEN	SINGAPORE	SINGAPORE
3	FINLAND	DENMARK	SINGAPORE	DENMARK	DENMARK
4	DENMARK	FINLAND	DENMARK	BELGIUM	SWEDEN
5	USA	SINGAPORE	IRELAND	IRELAND	IRELAND
6	NORWAY	USA	FINLAND	SWEDEN	FINLAND
7	THE NETHERLANDS	AUSTRIA	BELGIUM	FINLAND	BELGIUM
8	AUSTRIA	IRELAND	ISRAEL	THE NETHERLANDS	AUSTRALIA
9	CANADA	GERMANY	THE NETHERLANDS	SOUTH KOREA	THE NETHERLANDS
10	BELGIUM	THE NETHERLANDS	AUSTRIA	GERMANY	AUSTRIA
11	GERMANY	BELGIUM	GERMANY	ISRAEL	SOUTH KOREA
12	UNITED KINGDOM	NORWAY	USA	NORWAY	GERMANY
13	IRELAND	CANADA	SOUTH KOREA	AUSTRIA	UNITED KINGDOM
14	ISRAEL	ISRAEL	NORWAY	USA	ISRAEL
15	SINGAPORE	FRANCE	UNITED KINGDOM	UNITED KINGDOM	TAIWAN
16	AUSTRALIA	SOUTH KOREA	CANADA	AUSTRALIA	NORWAY
17	FRANCE	UNITED KINGDOM	AUSTRALIA	CANADA	CANADA
18	SOUTH KOREA	AUSTRALIA	FRANCE	FRANCE	USA
19	JAPAN	JAPAN	SPAIN	TAIWAN	GREECE
20	SPAIN	SPAIN	HUNGARY	SPAIN	SPAIN
21	ITALY	TAIWAN	CZECHIA	HUNGARY	FRANCE
22	TAIWAN	HUNGARY	TAIWAN	ITALY	POLAND
23	RUSSIA	RUSSIA	JAPAN	GREECE	PORTUGAL
24	CZECHIA	ITALY	PORTUGAL	CHINA	CZECHIA
25	HUNGARY	CZECHIA	RUSSIA	CZECHIA	CHINA
26	GREECE	PORTUGAL	GREECE	PORTUGAL	ITALY
27	SOUTH AFRICA	GREECE	ITALY	JAPAN	HUNGARY
28	TURKEY	CHINA	POLAND	POLAND	JAPAN
29	PORTUGAL	POLAND	CHINA	RUSSIA	MEXICO
30	POLAND	SOUTH AFRICA	TURKEY	TURKEY	TURKEY
31	CHINA	INDONESIA	BRAZIL	MEXICO	INDIA
32	INDONESIA	MEXICO	MEXICO	SOUTH AFRICA	BRAZIL
33	MEXICO	TURKEY	SOUTH AFRICA	INDIA	SOUTH AFRICA
34	BRAZIL	BRAZIL	INDIA	BRAZIL	RUSSIA
35	INDIA	INDIA	INDONESIA	INDONESIA	INDONESIA

Source: Innovation Indicator

INNOVATION CAPABILITY: DEVELOPMENT OF SMALL ECONOMIES WITH VERY HIGH INDEX VALUES



Source: Fraunhofer ISI calculations

At the same time, there is also increased investment in higher education in order to meet the high demand for well-trained specialists.

However, not all small countries that previously embarked on a path of strong innovation orientation and achieved very high innovation index values have been able to maintain this high level in the long term. In the 2000s, Sweden and Finland were among the most innovative countries in the world, ranking second and third behind Switzerland. Sweden was able to maintain a high innovation index value until the mid-2010s, but then fell behind. The downward trend began earlier in Finland. The main reason for this decline in both countries is the strong focus of the national innovation system on digital technologies. In this highly dynamic field of technology, it is more difficult to maintain an innovative edge once it has been achieved than in other fields of technology. However, small countries cannot avoid focusing their relatively limited resources on a few innovation topics. They therefore run the constant risk of losing the innovation position they have achieved, for example if new technology and market trends are not anticipated quickly enough or if new competitors emerge with superior innovations or business models. At the same time, however, both countries are holding up well in the current difficult macroeconomic and global political situation. This reflects their ability to adapt quickly to unfavorable conditions.

A comparison of the innovation performance of small economies with very high index values for the four sub-processes distinguished in the Innovation Indicator – knowledge creation, knowledge diffusion, converting knowledge into marketable innovation, turning innovation into revenues – reveals some similarities. Innovation performance is particularly high in the area of creating new knowledge. This reflects the strategy of channeling as many economic resources as possible into knowledge-generating activities (academia, tertiary education, research-intensive industry, knowledge-intensive services). In the area of knowledge diffusion, the indicator values mostly are significantly lower. This indicates that a large proportion of the scientific knowledge generated in these countries does not remain in the country. Given the small size of the national economies and the need to specialize in relatively few economic activities, this is hardly possible in any other way. In the field of academia, the small countries also focus on the entire disciplinary breadth and cover all academic fields. The indicator values for the implementation of knowledge in innovations are also rather low. One factor here is the overall economic structure, which is more strongly oriented towards small and medium-sized enterprises. After all, in order to successfully implement innovations, it is important to market them worldwide. Countries with many globally active corporations often perform better here. One of the strengths of the small economies with a very high index value, at least for some of the countries, lies in their use of innovation for economic prosperity.

There are some interesting differences between the seven small economies with a very high index value. Ireland deviates from the general pattern in that it invests relatively little in the creation of new knowledge (apart from expanding higher education), but achieves a very high score in the economic use of innovations. Sweden, on

the other hand, stands out with a very low value for the diffusion of knowledge, while Switzerland is particularly strong here. Singapore stands out within this group due to its relatively good performance in the conversion of knowledge into innovations.

GERMANY IN SECOND PLACE AMONG THE MAJOR ECONOMIES

Germany ranks twelfth in the 2024 Innovation Indicator, putting it in second place behind South Korea among the major industrialized economies. The index value of Germany has been largely constant for many years, fluctuating around 45 points, which indicates a very stable innovation system overall. However, it fell to 42 points in 2022, followed by a slight increase to 43 points in 2023. Germany's strength lies in its relatively good performance in all four sub-processes of the creation and utilization of innovations, i.e., in a balanced system. The country has the lowest score in the sub-process of turning knowledge into innovation. The reasons for this lie, among others, in the unfavorable skilled labor situation, low venture capital investments and low government support for corporate R&D activities compared to other countries.

Germany achieved its highest score in the knowledge generation sub-process. This reflects the efforts made over the past two decades to increase the R&D ratio. With the target of investing 3.0 % of GDP in R&D achieved in 2017 and the announcement of a new target of 3.5 % for

COMPARISON OF LARGE AND SMALL ECONOMIES IN THE INNOVATION INDICATOR

Due to their limited resources, small economies can rarely produce all the goods that are in demand in a country. Rather, they must concentrate on certain economic activities in order to achieve a critical sitze, benefit from economies of scale and create a differentiated ecosystem. If small countries have favorable location conditions for innovative activities – such as an efficient academic community or a well-educated population – they particularly focus on innovation-oriented economic activities. Within these fields of specialization, significantly more goods are produced than are in demand in the country, which leads to a strong export orientation in these fields. At the same time, many other required goods are imported.

Large economies, on the other hand, usually have a very broad spectrum of economic activities because their production potential for one specific good would otherwise exceed global demand. For example, if the USA wanted to concentrate a large part of its economic resources on the production of cutting-edge technology goods such as semiconductors or pharmaceuticals, this would result in a production volume far in excess of global demand. At the same time, the demand for basic goods – from food to personal services – is so high in large economies that it is unrealistic to import the majority of these basic goods. This is why large economies have a more balanced economic structure in terms of highly innovative and less innovative activities than small economies.

As a result, innovation-oriented activities can account for a much higher proportion of all activities in small economies than in large ones. If indicators for measuring innovation performance are therefore normalized according to the size of the economies examined, then small countries often perform significantly better than large ones – although the absolute innovation contribution of small countries lags far behind that of large economies. In large economies, on the other hand, innovation activity is often heavily concentrated in certain sub-regions with particularly favorable conditions. If these sub-regions were considered separately, they would often have a significantly higher innovation capability than many of the highly innovative small economies. Combined with other sub-regions that specialize in non-innovative activities, however, the average measure of innovation capability is noticeably lower (see also the special evaluations for California, Massachusetts, Baden-Württemberg and Saxony).

GERMANY'S STRENGTH LIES IN ITS RELATIVELY GOOD PERFORMANCE IN ALL FOUR SUB-PROCESSES OF INNOVATION CREATION AND UTILIZATION. "

2025, this sub-process was and remains a key focus of German innovation policy. The introduction of tax incentives for R&D (the Forschungszulage or "research allowance") in 2020, which began to take effect in the 2022 financial year, provided further impetus for increasing R&D expenditure.

At the same time, Germany's innovation policy has recognized the deficits in other sub-processes, particularly with regard to the diffusion and implementation of new research results. The German Agency for Transfer and Innovation (DATI), newly established in 2023, and the Federal Agency for Disruptive Innovation (SPRIN-D), established in 2019, represent two new funding approaches to strengthen knowledge and technology transfer in Germany and the implementation of ideas into commercially successful innovations. However, there is still an investment backlog in many areas in Germany as a whole. Investments in knowledge and capital stock were, and still remain, too low. R&D expenditure has risen in relation to GDP and the new funding approaches mentioned above promise new opportunities. However, the public sector – above all the federal government – has reduced its financial commitment in real terms in recent years, undermining the previously agreed split of 2/3 private to 1/3 public expenditure on research and development. Only time will tell what this means for the R&D ratio in Germany as a whole. In any case, reducing investment in the knowledge base at a time when more and more countries are entering the innovation race is the wrong approach.

Infrastructure investments also remain necessary to a large extent. Not only railways, roads and bridges, but also communication, energy and charging infrastructure need to be renewed or completely rebuilt. Particularly in phases of transformation, such as those necessitated by the current social challenges, there is a massive need for investment. This should not be postponed if we seriously wish to tackle these transformations.

Germany is not the only major economy with a relatively stable innovation performance. The USA, Japan and France are also characterized by rather small changes in their innovation capability over time. One reason for this is that large economies are involved in a much larger number of technologies and innovation topics, so that abrupt changes in one area of technology do not have a strong influence on the overall ranking. Second, in large economies, considerably more financial and human resources need to be shifted in order to make a noticeable change to innovation performance. Against this backdrop, the high innovation momentum in South Korea between 2010 and 2015 is remarkable. During this period, the country benefitted from its strategy of focusing strongly on digital technologies and the digital economy. Since 2017, South Korea has been the most innovative of the major economies in the Innovation Indicator. After a significant slump in 2022, it recorded an increase again in 2023. Like Germany, South Korea scores highly thanks to its balanced overall innovation system. And like Germany, its greatest strengths lie in the area of knowledge creation and diffusion, while the implementation of knowledge in innovations is also the sub-process with the lowest indicator value in South Korea.

The dynamics of innovation capability in the United Kingdom are different. Starting from a high innovation index value in the mid-2000s on a similar level to Germany, the country has now lost much of its innovation capability, especially since the 2007/08 financial crisis. A slow but steady catch-up process has been taking place since 2012. Unlike Germany and South Korea, the UK's strength lies very clearly in the area of knowledge creation, and here again in the very efficient academic system. In contrast, the ability to innovate in the area of knowledge diffusion and the economic use of innovations is rather weak.

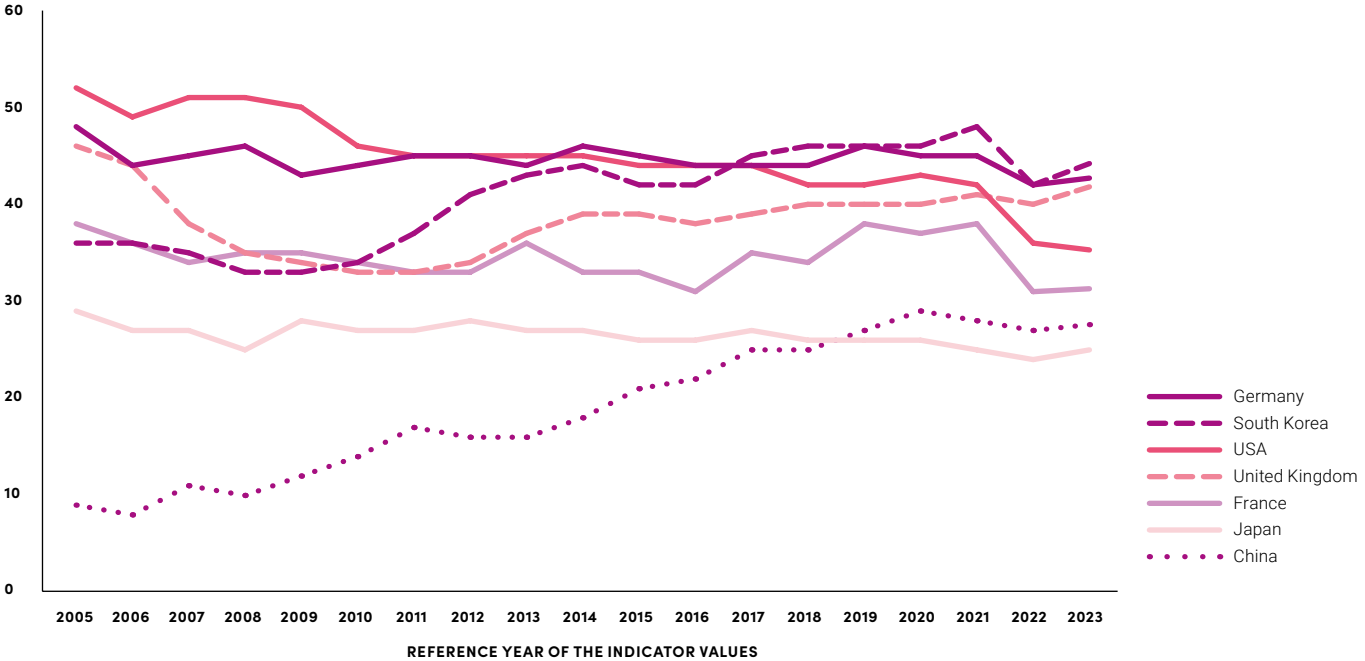
An upward trend since the end of the 2010s can also be observed for France. The high level of government investment in promoting R&D in industry in the form of tax incentives is one important reason for this. Weak points lie in the creation of new knowledge and the economic utilization of innovations. In 2022, however, there was a very sharp decline in the indicator value.

In the USA, the innovation index value fell slowly but steadily from the mid-2000s to the end of the 2010s. Only recently has the USA been able to maintain its innovation capability. At first glance, this development does not fit in with the great dominance of the USA in the digital economy, where US companies play a key role in both digital platforms and technology development in the field of microelectronics and digital devices. However, it should be borne in mind that digital technologies, like other technology fields in which the USA has a strong position (such as pharmaceuticals/biotechnology or aerospace), only represent a small part of the US economy. At the same time, there are major fields of technology in which the USA's position in global innovation competition has deteriorated over time. These include the chemical industry, mechanical engineering and – despite Tesla – the automotive industry. Finally, the positive development of the US domestic market leads to relatively strong growth in demand for standard products and simple services. As a result, a very high and positively developing innovation capability in individual subject areas is not enough to raise the economy as a whole to a significantly higher level of innovation.

China is the only major economy with a highly dynamic development of its innovation capability. In the innovation ranking, China was able to continuously improve and thus clearly set itself apart from other emerging markets. The initially very large gap to the leading major economies has more than halved since 2005. However, there has been no further growth in the innovation index value since 2020, which can be explained by the coronavirus crisis and the extreme lockdown measures imposed in China. China's strengths clearly lie on the input side of the innovation process, i.e., a lot is invested in the system and the result is a high innovation output, albeit with comparatively low productivity. However, this also shows that China still has a lot of potential in this respect and can therefore make further progress in the innovation system in the future and achieve a better position in the international rankings. In the sub-process of knowledge creation, China has an index value of 45, just 11 or 12 points less than Germany or the USA. This is backed by a sharp rise in R&D expenditure, which amounted to just under 2.5 % of GDP in 2022, well above the EU level (2.1 %). The index value in the area of diffusion of knowledge is also quite high (34 points, on a par with the UK); this is, among other factors, due to intensive R&D cooperation between academia and industry.

Japan plays a special role. The country lies well behind the other major economies over the entire period under review, with no noticeable improvement or deterioration in the index value. At first glance, this seems to contradict the strong innovation position of Japanese companies in many markets and fields of technology. However, Japan's position is based on structures and investments that were created a long time ago. In addition, the development of the competitive situation with China poses a particular challenge to Japan's traditional technology sectors

INNOVATION CAPABILITY: DEVELOPMENT OF LARGE ECONOMIES



Source: Fraunhofer ISI calculations

such as microelectronics and consumer electronics. Japan is finding it increasingly difficult to maintain the strong position it held in the 1980s and 1990s (see also the following chapter on key technologies). In the case of forward-looking indicators such as the performance of the academic system, the supply of skilled workers, the international orientation of the innovation system, the exchange of knowledge between academia and industry and venture capital investment, Japan is in a poor position. The country is well aware of the danger of insisting on established structures for too long – however, it has not yet found a way out of the dilemma of investing in new fields of technology without undermining the foundations of its currently still very high level of prosperity. The low economic momentum over the past three decades, the increasing shortage of skilled workers, and also strongly hierarchical decision-making mechanisms and a certain tendency towards isolation in Japanese society have created and continue to create difficult conditions for a fundamental change in the Japanese innovation system. The Innovation Indicator shows that this change has still not been set in motion.

UPPER MIDFIELD: A TREND TOWARDS CONVERGENCE

There are several small and medium-sized economies in the upper midfield of the Innovation Indicator whose innovation capability is at a very similar level. Looking at the medium-term development of the Innovation Indicator for this group of countries, it is noticeable that the innovation capability within this group has noticeably converged over time. This is due to the fact that the group includes economies with rising trends, namely the Netherlands, Taiwan and Australia. On the other hand, this group also includes an economy whose innovation performance is trending downwards from a relatively high level, namely Canada. Finally, Norway, Austria and Israel are three countries in the upper midfield of the Innovation Indicator for which the index values have changed very little over the past decade and a half.

What all seven economies in this group have in common is that the creation of new knowledge is the sub-process with the highest index value. In this respect, the innovation system is not very balanced. A sign of efficient knowledge transfer are medium to high values in the sub-processes creation, diffusion and implementation of knowledge. Finland, Australia, Austria and Norway rely particularly heavily on knowledge generation. The performance in the area of knowledge diffusion is rather weak in all seven countries. There are major differences when it comes to turning knowledge into innovations: Canada, Israel and Finland achieve higher index values here, while Australia and Taiwan have decreased sharply. Israel and Norway are characterized by relatively high values for the economic use of innovations.

The case of Canada is very ambivalent. Canada has a number of technological focal points in which it is particularly strong in knowledge production and also in implementation. This includes materials research in general (e.g. nanotechnologies) as well as battery and fuel cell research, and individual areas of energy technologies. At the same time, however, Canada is unable to advance beyond the midfield.

The border with the USA, the world's largest national market for high technologies, is both a blessing and a curse for Canada. The country's geographical and cultural proximity to the USA means that it is geared towards and has access to the US market. However, there is also a tendency for technology skills – both qualified employees, intellectual property and companies – to migrate from Canada to the USA, which makes it difficult for the innovation system to remain constant. Well-known examples include RIM (Blackberry) and Nortel; in the recent past, a number of companies in the early stages of their development have migrated to the USA or been bought up by US corporations. Overall, Canada's innovation performance is stable, although changes are occurring within the system. It will be interesting to observe further developments. Most recently, the share of R&D expenditure in GDP (R&D ratio) declined slightly – at approximately 1.7 % it was already well below the OECD average of 2.7 %. A strength in the implementation of innovations, as Canada has, is of little use if there is no knowledge and no ideas for implementation.

CHINA IS THE ONLY MAJOR ECONOMY WITH A HIGHLY DYNAMIC DEVELOPMENT OF ITS INNOVATION CAPABILITY. "

As the different strengths in the sub-components of the Innovation Indicator show, Canada is an ideal partner for Germany in science and technology, and also as a location for German companies in North America. The Comprehensive Economic and Trade Agreement (CETA) and the institutionalized scientific and technological cooperation (S&T Cooperation Agreement, 1971) between Germany and Canada are not the only examples of these partnerships. Both a continued greater cultural proximity to Europe and shared thematic interests and expertise are conducive to this.

SOUTHERN AND CENTRAL EUROPEAN COUNTRIES ARE CATCHING UP

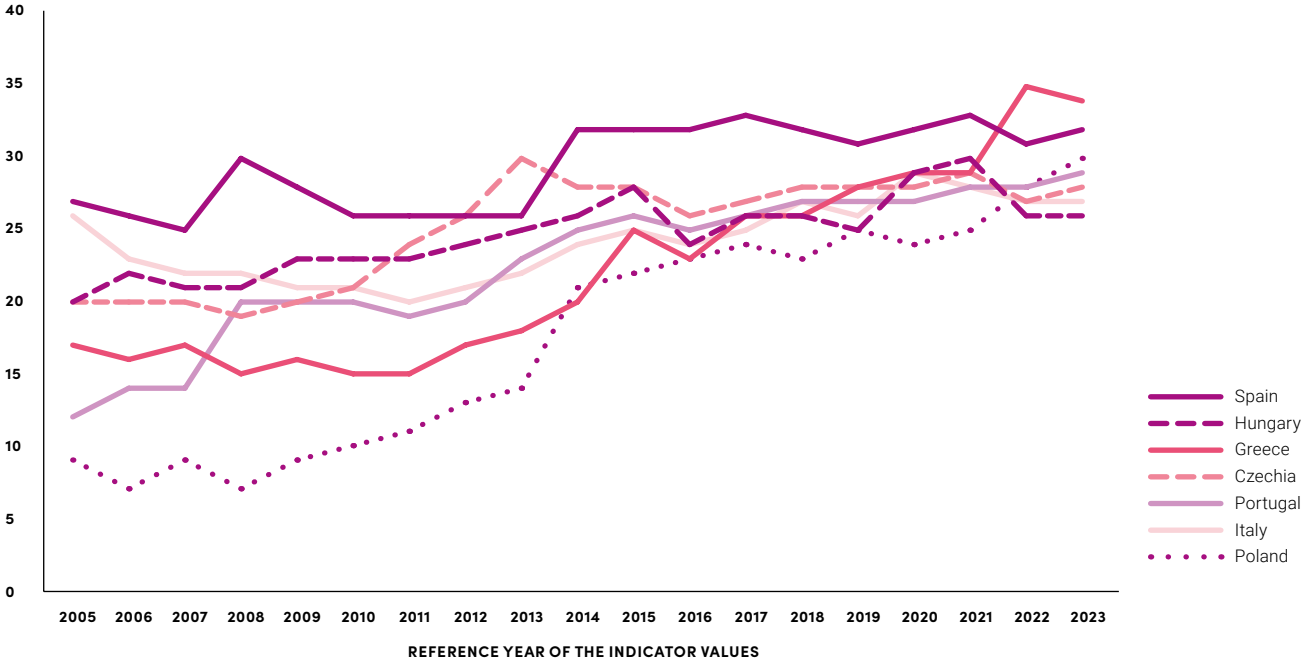
The Innovation Indicator maps the innovation capability of seven Southern and Central European countries. All seven economies are clearly catching up and at the same time converging in terms of innovation capability. The strongest growth in the period since 2005 was recorded by Poland, followed by Portugal and Greece. These countries more than doubled their index values of 15 points or less in the second half of the 2000s. It is interesting to note that Greece and Poland were able to make a significant upwards leap in 2022. It seems that it was possible to stimulate growth in the innovation system after the end of the coronavirus pandemic while avoiding the negative repercussions of the energy crisis and the war in Ukraine. The innovation capability of the Czechia, Hungary and Spain has risen less sharply, although they also started from a higher level before these crises. Italy shows the lowest growth over the entire period. However, it was able to halt the downward trend that was evident until the beginning of the 2010s and turn it into a positive dynamic. From 2011 to 2020, Italy's index value improved by 9 points to 29 points and has only fallen slightly since then.

Compared to the countries further ahead in the Innovation Indicator, the Southern and Central European countries have a significantly different focus in terms of their innovation capability. In most of the countries in this group, their strength lies in the conversion of knowledge into innovations. In many cases, this may not only be knowledge generated in the country itself, as performance in the creation of new knowledge is significantly worse and performance in the diffusion of knowledge is also very low. Investments from abroad could play a greater role, particularly in the high-tech sector. These ensure a high degree of innovation in the area of production and draw on knowledge that has often been developed in other countries. However, the networking of this part of the local economy with domestic knowledge producers is low, which may explain the low values for the diffusion of knowledge. Still, the strong implementation performance does not lead to correspondingly high economic returns from innovations. This is primarily due to the fact that high-tech activities resulting from foreign investments only represent a small part of the overall economy. On the other hand, only part of the innovation revenue is likely to remain in the country. The catching-up process in this group of countries also shows that further development towards innovation capability is possible on the basis of independent knowledge production. The Southern European countries and the Czechia in particular have already made further progress in this direction, as the relatively high values in the knowledge creation sub-process show.

CLEAR UPWARD TREND IN EMERGING MARKETS

At the bottom of the Innovation Indicator rankings are seven countries, all of which can be characterized as emerging markets. In these countries there are some globally networked and innovation-oriented activities, but the greater part of the economy is still in the process of focusing on economic activities with high value added potential. For a long time, these seven countries did not exhibit a uniform development and did not show a clear trend towards increasing innovation capability. However, since around 2018 this has been changing. Almost all of the emerging economies included in the index have been able to significantly increase their index value and are drawing closer to the group of Southern and Central European countries. This process is most advanced in Turkey and Mexico. Mexico has improved significantly, particularly in the latest period, after several years of little progress. India, South Africa, Brazil and Indonesia show very significant growth in some cases in 2022, albeit starting from an extremely low level. In all six countries, the focus of innovation capability is on the implementation of innovations. In addition to investments from abroad, efforts to develop independent technology sectors are also likely to play a role here. In Brazil, Turkey and Mexico, the ability to innovate has also improved in the area of knowledge diffusion, i.e. cooperation between academia and industry.

INNOVATION CAPABILITY: DEVELOPMENT OF THE SOUTHERN AND CENTRAL EUROPEAN COUNTRIES

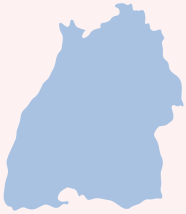


Source: Fraunhofer ISI calculations

Within this group, South Africa is the country that focuses most strongly on expanding its own knowledge base, achieving a comparatively high score of 26 points in the sub-process of creating new knowledge.

A special case in this group is Russia. The country started out from the highest level of all emerging countries included in the Innovation Indicator. However, it did not improve during the entire period under review. Since the first half of the 2010s, its innovation capability has tended to decline. In 2022, the indicator value fell sharply with the war of aggression against Ukraine. Russia fell behind almost all other countries and is now on a par with the bottom performer in the Innovation Indicator, Indonesia. It should be noted that the effects on Russia's innovation capability resulting from the conversion of the Russian economy to a war economy, the withdrawal of foreign investment and the lack of access to Western knowhow are only very incompletely reflected in this edition of the Innovation Indicator.

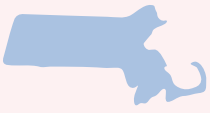
REGIONAL INNOVATION CAPABILITY



Baden-Württemberg

Saxony

California



Massachusetts

The size of an economy has a major influence on its scientific and technological specialization and its focus on innovation. Smaller countries must ultimately specialize in order to pool resources and expertise in a targeted manner and thus deploy them efficiently. Larger countries, on the other hand, have the opportunity to maintain a broad profile and thus achieve a critical mass in many areas. Conversely, larger units are also more heterogeneous, meaning certain activities are generally concentrated regionally. Although Germany as a whole specializes in automotive or mechanical engineering and plays a strong international role, this is not the same in all federal states or regions of the country. Strengths in individual fields are often based on regional strongholds – often in the form of clusters. Similarly, a country like the USA, for example, may have some hotspots or "beacons" that are internationally renowned and have a major impact on the overall economic and innovation performance of the USA. However, such strongholds do not exist everywhere; there are also numerous regions that are far removed from the international leaders in science, research and innovation. Two highly innovative regions from Germany and the USA – Baden-Württemberg and Saxony as well as California and Massachusetts – were selected as examples to examine the classification of these lighthouses. The individual indicators from the area of innovation capability were collected for these regions and condensed into a composite index, which was then classified in the ranking of the 35 economies examined in the Innovation Indicator.

REGIONS AHEAD OF THEIR COUNTRIES

Baden-Württemberg and the two US states mentioned above each ranked higher than their country in terms of innovation capability, Saxony one place behind the German average. If Baden-Württemberg were an economy in its own right, it would rank fourth in the world, behind Denmark and ahead of Sweden. Until the 2010s, it was even in third place – only Switzerland and Massachusetts were ahead of it. The index values for Baden-Württemberg declined slightly in the 2010s, and the trend was only reversed in the years years of the pandemic. Baden-Württemberg is particularly successful in terms of intellectual property rights (patents, trademarks), R&D expenditure by companies – both internal and external expenditure – and human capital resources, although the shortage of skilled workers is reflected in the number of vacancies and academically trained employees. This area is also largely responsible for the state's downward trend in international comparison. An unfavorable demographic situation, owing to the fact that a large number of highly qualified employees will retire in the coming years, as well as falling index values despite a slight increase in the proportion of tertiary educated employees pose challenges to maintaining the level achieved in terms of both GDP per capita and value added. This is clearly demonstrated by the indicators examined here.

Saxony, the second German state in our focus, has developed positively and was able to gradually increase its index value in the 2010s. It only suffered slight declines in the years 2021 to 2023. Saxony is in 16th place in the current ranking of 35 economies and four regions. Our figures show that it has a very competitive academic system which, thanks to strong public commitment to R&D, produces many highly-cited publications, a large number of patent applications and considerable achievements in the area of transfers. The corporate sector, on the other hand, is not among the best in the world: It has index values in the middle range for R&D expenditure and also top values for the share of value added in high technology, but its values for patents, trademarks and productivity are in the lower half.

The two focus regions in the USA are each well above the national average, demonstrating both the great regional heterogeneity within the USA and the strengths of the two states in question, which often characterize the image of the USA abroad. Massachusetts, which is home to the Boston region, with Harvard University, Boston University and MIT as well as a whole range of technology-oriented companies, ranks seventh in a global comparison, including the four regions under consideration. Massachusetts was in second place until 2017, directly behind Switzerland, but then lost significant index points

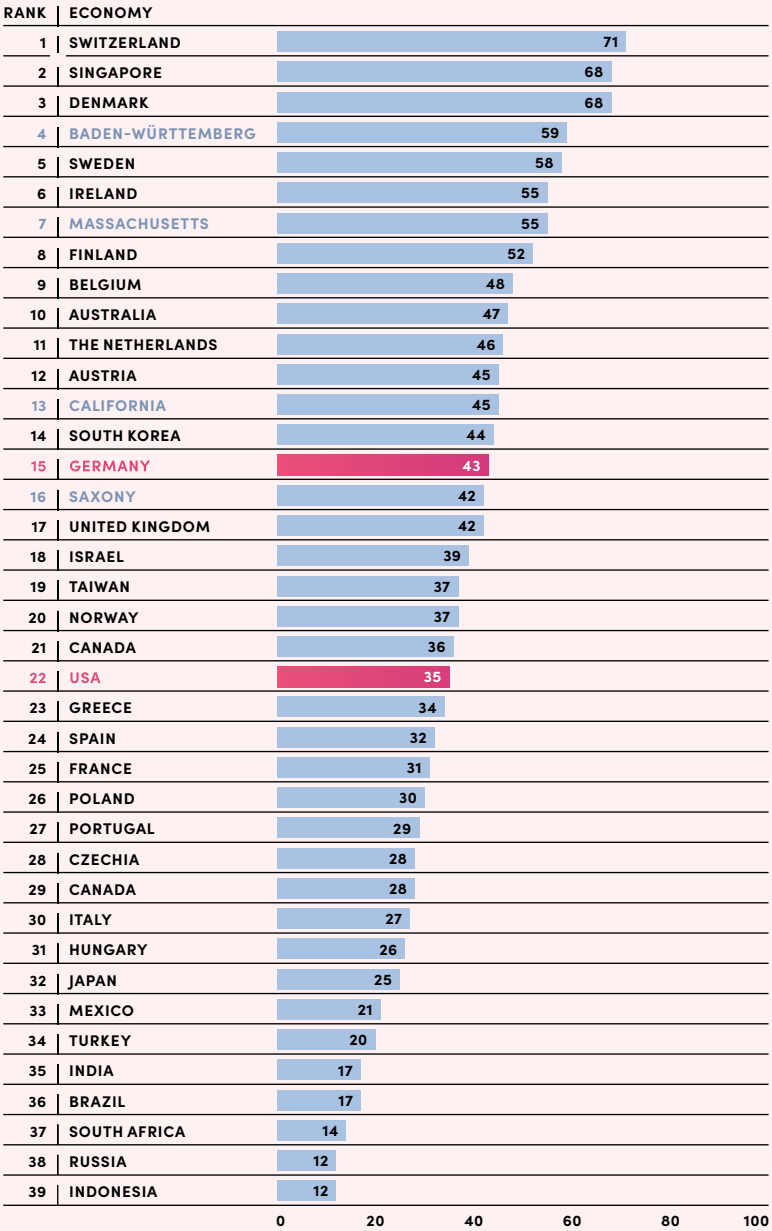
shortly before and during the pandemic, ranking behind Baden-Württemberg, Sweden and Ireland in 2023. Massachusetts can build on an extremely competitive innovation system in all areas, although there are clear challenges in terms of human capital in the business sector. The index values for academic employees and demographic development are at the lower end. All the indicators relating to academic publications and state R&D funding in public research institutions are among the best in the world. The number of patent applications per capita is also very high. The figures for GDP per capita and value added in high technology are likewise in the top range.

UNIVERSITIES STRONG ON PATENTS

California, with 39 million inhabitants more populous than the whole of Scandinavia, is home to the most patent-rich university association in the USA – the Universities of California – with members including Berkeley and UCLA. It is also home to the world's most spin-off-intensive research organization, the California Institute of Technology (CalTech), Stanford University and, of course, Silicon Valley with its now geographically far-reaching software and platform industry. While the USA occupies 22nd place in this extended ranking, California is much further ahead, in 13th place. However, the West Coast state has experienced a downward trend at times, particularly during the 2010s: from fourth place in 2006, just behind Massachusetts and Baden-Württemberg, to seventh place in 2015 and 11th place in 2020. It then remained in 11th place in 2023. In the almost two decades covered in our analysis, the index values have fallen from just over 60 to approximately 55 and most recently to 45.

California's strengths continue to lie – albeit with slightly falling index values – in the quality of its academic output, R&D expenditure by industry, patent applications and value creation in high tech. The main reasons for the decline in the index values and drop in the ranking can be found in GDP per capita, value added in the manufacturing industry and co-publications by academia and industry.

INNOVATION CAPABILITY: RANKING OF SELECTED REGIONS IN COMPARISON WITH THE NATIONAL ECONOMIES



Source: Fraunhofer ISI calculations

RECOMMENDATIONS

IMPROVE CONDITIONS FOR INTERNATIONALIZATION

International cooperation in research and innovation is a key determinant of the innovation capability of national economies. Drawing on globally available knowledge and utilizing this knowledge in as many regions as possible is a prerequisite for turning research and innovation into productivity and competitiveness. With the increase in international conflicts, and economic and technology policies in various countries that are more focused on national boundaries, the conditions for internationally open innovation strategies have deteriorated. German innovation policy must respond to this in two ways: First, efforts must be stepped up to keep the German innovation system open internationally and maintain international networks, for example by promoting international cooperation. Here, the reliability of partnerships should always be taken into account. Second, it must be ensured that independent technological sovereignty is maintained in Germany in all critical areas of the national economy, or developed if necessary.

PRIORITIZE R&D FUNDING

Given limited government R&D funding, it is important to focus the additional funds available for achieving the 3.5 % target on those areas that are particularly important for Germany's long-term innovative capacity and the economic and societal challenges that lie ahead. In academia, this means concentrating the increase in funding on topics and activities relevant to innovation and transformation. In addition to the broad-based funding (the Forschungszulage or "research allowance"), which is important for small and medium-sized enterprises (SMEs), the focus of business should be the major transformation topics of energy, sustainability, digitalization, safety and health.

FINANCE INNOVATIVE START-UPS

Growth-oriented start-ups are important for the dynamism of the innovation system. Particularly in newly emerging fields of technology such as AI (artificial intelligence), they provide much impetus for innovation. With its Startup Strategy of 2022, the German government has taken important steps in the right direction, but these measures have only partially taken effect due to the difficult overall economic situation. These steps should be continued over the long term, particularly the provision of venture capital for start-ups during their growth phase. At the same time, EU legal obstacles to the inclusion of venture capital-financed start-ups in research funding should be removed immediately. Due to their capital structure, VC-financed start-ups are often considered over-indebted according to the EU-criteria and are therefore excluded from funding.

BOOST INNOVATION BY SMES

Germany's innovative strength is largely based on large, globally active corporations. Overall, the small and medium-sized enterprise (SME) sector only makes a relatively small contribution to research and innovation. In order to broaden the country's innovation activities, it is necessary for more SMEs to focus their business models on innovation, new technologies and global marketing – and thus ensure the German success model of "hidden champions" for the next generation". The prerequisites for this are continuous R&D activities and a clear internationalization strategy. In the R&D sector, an important new instrument has been created in the form of tax incentives for R&D (the "research allowance"), which is increasingly being used to encourage more SMEs to make continuous, more intense R&D efforts. In addition to financial support, however, innovation-friendly framework conditions are also needed in all fields of technology and markets. The two most important issues at the moment are ensuring a sufficient supply of skilled workers as well as reducing bureaucracy and in many places an unnecessarily dense and detailed set of regulations. These are also important starting points for promoting the internationalization of SMEs. In addition, it is important to help SMEs develop current and new foreign markets given today's more difficult global and trade policy conditions, for example by providing more extensive export credit guarantees.

PURSUE QUALITY OVER QUANTITY IN ACADEMIA

The German academic system as a whole, while still above-average, is no longer one of the best in the world. Countries such as Singapore, Denmark, Belgium, Switzerland, the USA and also the UK have much more efficient systems that score higher on academic indicators (number of publications, citations, academic prizes, university rankings and so on). In addition, various studies show that it is not the average of the system, but the top group that significantly determines a country's innovation performance, because the truly radical, outstanding innovations usually originate not from the rank and file but from academic excellence.

Germany must continue to invest in academia and public research in order to create the basis for future innovative capacity. The Federal Ministry of Education and Research should receive more funding so it can continue with its "Pacts" and at the same time set real priorities in specific topics with achieving a critical mass and international competitiveness.

It is particularly important to promote cutting-edge science and create beacons of excellence on a global level. Germany's "Excellence Initiative" is far too fragmented for this and thus does not live up to its name. It is important to create a program and the right environment for individual institutions to catch up with the world's best. This means a departure from the principle of equality in the German academic landscape and a deliberate singling out of individual institutions from the rest. However, good research and teaching conditions must be maintained across the breadth of the research landscape – that is to say, more resources must become available in the system. This is the only way Germany can secure a competitive knowledge base in the long term.

SINGAPORE TAKES THE LEAD

Future technologies drive competitiveness

Not all technologies and technology fields are equally research-intensive and not all determine the current and future competitiveness of companies and economies in the same way. Within the group of research-intensive technologies, there are those that can reasonably be assumed to be of great importance for both the economic success and the technological sovereignty of a country. This applies in particular to those technologies that can be used in many areas of application (general purpose technologies) and that can be expected to make decisive contributions to solving major societal challenges (such as sustainability, health, communication, energy, mobility).

Such key technologies are usually particularly dynamic and contribute significantly to the global shift in technological competitiveness. In some cases, individual countries also pursue explicit strategies based on the development and dynamics of certain key technologies. This "leap-frogging" enables them to skip a technology level and come out at the top of the next level. Since the early 2010s, China's science and innovation policy strategies in the field of automotive engineering have been aimed not at trying to catch up with combustion vehicles, but at focusing directly on electromobility and then thinking systemically and systematically about all key parts of the value chain – from materials and vehicles to batteries, power electronics and charging infrastructures. In Germany, by contrast, the modern production and logistics systems known as "Industry 4.0" and renewable energy technologies are among the key technologies of particular importance.

The Innovation Indicator 2024 examines the scientific and technological performance and competitiveness of the 34 economies under review[3] in seven selected key technologies. These seven key technologies are:

- Digital hardware (micro- and nanoelectronic components, including computer chips and other integrated circuits)
- Digital networks and software-based applications (development of future-proof digital communication networks, for example semiconductors and semiconductor lasers, quantum technologies, artificial intelligence and cloud computing)
- Advanced production technologies (modern machines, facilities and their components and production processes, for example sensors, measuring devices, control systems, automation)
- Energy technologies (renewable energies, hydrogen, energy storage, energy efficiency)
- Advanced materials (lightweight construction, substitution of raw materials, material technology, for example composites, coatings or plastics, nanomaterials and their manufacturing processes)
- Biotechnology (enzymes, peptides, proteins and microorganisms and processes based on them as well as processing and measuring methods)
- Circular economy (technologies for returning materials to the materials cycle)

Below, we analyze, present and discuss each of the seven key technologies individually. In addition, all seven areas are summarized in a composite index that reflects the function "developing future fields through key technologies" in innovation systems.

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 academic publications in the area of the individual key technologies in all national publications
- Share of academic publications in the field of the individual key technologies among worldwide publications in the area of key technologies
- Share of transnational patent applications in the area of the individual key technologies among all transnational patent applications of a country
- Share of transnational patent applications in the area of the individual key technologies among all (global) transnational patent applications in the area of key technologies
- Balance of trade in the area of the individual key technologies in relation to the country's population
- Balance of trade in the area of the individual key technologies in relation to global exports in the field of the individual key technologies
- Trademark applications at the European Intellectual Property Office (EUIPO) in the area of the individual key technologies
- Venture capital deployed for the early stage (all VC investments, incl. Series C and D) in the individual key technologies as a share of GDP (only used for the integrated indicator, not for the calculation of the key figures in the individual key technologies)
- Share of computer-implemented inventions (software patents) in all inventions in the field of the key technology in question

FINLAND HAS LOST GROUND IN THE AREA OF KEY TECHNOLOGIES. “

KEY TECHNOLOGIES OVERALL: RANKING OF ECONOMIES 2007 TO 2023

RANK	2007	2010	2015	2020	2023
1	SWITZERLAND	SWITZERLAND	SWITZERLAND	FINLAND	SINGAPORE
2	JAPAN	JAPAN	FINLAND	JAPAN	DENMARK
3	USA	FINLAND	JAPAN	SWITZERLAND	JAPAN
4	GERMANY	GERMANY	GERMANY	SINGAPORE	SWITZERLAND
5	SINGAPORE	USA	USA	DENMARK	CHINA
6	SWEDEN	SINGAPORE	SINGAPORE	CHINA	FINLAND
7	DENMARK	SWEDEN	SWEDEN	GERMANY	GERMANY
8	FINLAND	DENMARK	DENMARK	SWEDEN	SOUTH KOREA
9	THE NETHERLANDS	THE NETHERLANDS	SOUTH KOREA	SOUTH KOREA	SWEDEN
10	IRELAND	IRELAND	IRELAND	USA	USA
11	AUSTRIA	AUSTRIA	THE NETHERLANDS	IRELAND	AUSTRIA
12	UNITED KINGDOM	UNITED KINGDOM	CHINA	THE NETHERLANDS	THE NETHERLANDS
13	ISRAEL	BELGIUM	AUSTRIA	UNITED KINGDOM	ITALY
14	BELGIUM	CHINA	UNITED KINGDOM	AUSTRIA	IRELAND
15	FRANCE	SOUTH KOREA	BELGIUM	ITALY	UNITED KINGDOM
16	CANADA	FRANCE	SPAIN	BELGIUM	GREECE
17	CHINA	NORWAY	FRANCE	ISRAEL	INDIA
18	NORWAY	ISRAEL	PORTUGAL	SPAIN	NORWAY
19	ITALY	PORTUGAL	ISRAEL	NORWAY	PORTUGAL
20	SPAIN	CANADA	CANADA	FRANCE	CZECHIA
21	SOUTH KOREA	SPAIN	NORWAY	AUSTRALIA	SPAIN
22	AUSTRALIA	AUSTRALIA	ITALY	INDIA	BELGIUM
23	INDIA	CZECHIA	HUNGARY	CZECHIA	FRANCE
24	GREECE	ITALY	AUSTRALIA	CANADA	AUSTRALIA
25	BRAZIL	GREECE	INDIA	PORTUGAL	HUNGARY
26	CZECHIA	BRAZIL	CZECHIA	POLAND	POLAND
27	POLAND	INDIA	MEXICO	HUNGARY	CANADA
28	RUSSIA	RUSSIA	POLAND	GREECE	ISRAEL
29	PORTUGAL	POLAND	BRAZIL	SOUTH AFRICA	INDONESIA
30	SOUTH AFRICA	SOUTH AFRICA	RUSSIA	RUSSIA	RUSSIA
31	HUNGARY	MEXICO	SOUTH AFRICA	INDONESIA	SOUTH AFRICA
32	TURKEY	HUNGARY	TURKEY	BRAZIL	MEXICO
33	MEXICO	TURKEY	GREECE	MEXICO	BRAZIL
34	INDONESIA	INDONESIA	INDONESIA	TURKEY	TURKEY

Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2024

OVERALL RANKING

The overall ranking of the economies considered here, across all key technologies, is led by Singapore (46 points), just ahead of Denmark (46) and Japan, Switzerland, China and Finland (44 points each). Germany is close behind with 42 points, resulting in the seventh place in the ranking. Five more economies (South Korea, Sweden, the USA, Austria and the Netherlands) follow with 40 to 33 points, putting them directly behind the group chasing the frontrunners. The broad midfield begins with Italy, which is already some distance behind at 29 points. The next two countries have index values that are only around half that of the leading country, Singapore, namely Canada (23) and Israel (22). At the bottom of the ranking are Russia (17), South Africa (17), Mexico (17), Brazil (16) and finally Turkey (14).

STRONG DYNAMICS

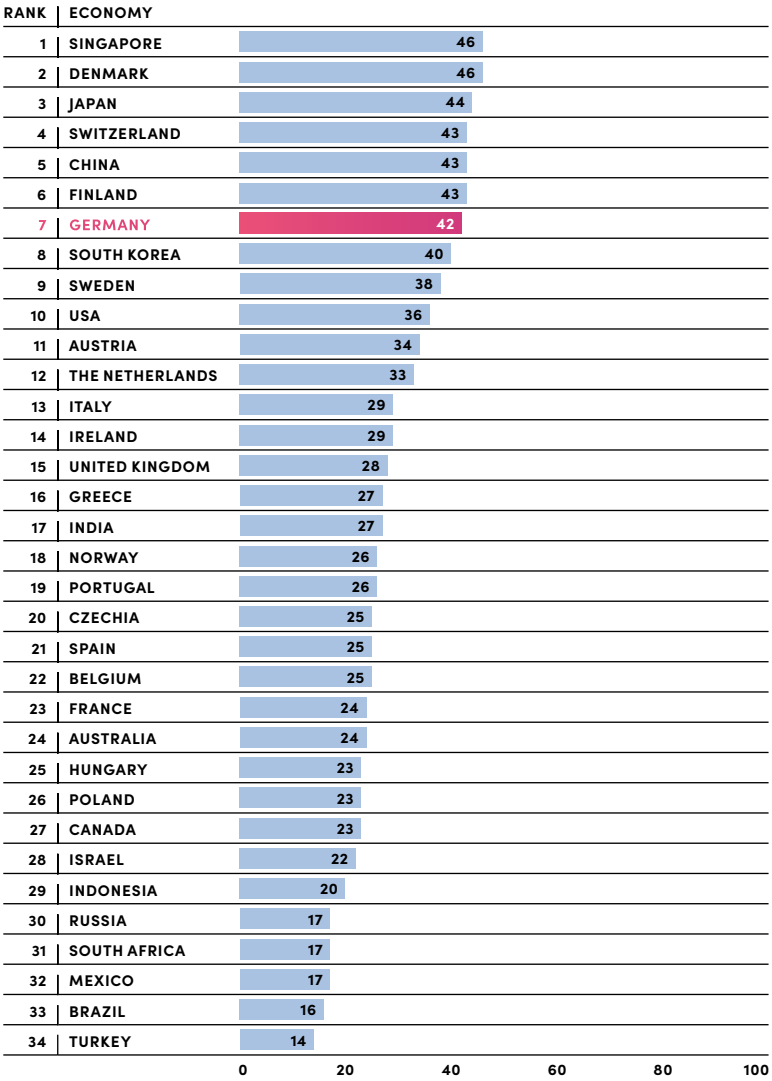
Over the past 15 years, the ranking of countries for key technologies has changed noticeably in some cases (see table). This applies in particular to the pandemic years and developments in the current period. However, Germany is one of the countries whose performance has not changed in terms of both ranking and index value. One of the countries that lost in the pandemic in the area of key technologies is Finland, whose index values are lower and which slipped further down the rankings due to deteriorating performances in the individual fields of publications, trademarks and software-based patents (computer-implemented inventions). Thus, it fell from first place in 2020 to sixth in 2023 in the overall ranking of key technologies. Singapore, on the other hand, was able to work its way up from fourth place to first, primarily thanks to better scores in almost all fields of technology in terms of patents, trademark applications and foreign trade. Singapore can boast top figures in the area of academic publications in all key technology fields with the exception of the circular economy.

The USA had already fallen back to tenth place in 2020 compared to its very good position in the 2000s and 2010s. The country was able to maintain this position in 2023. The index values for the USA recently fell by an average of three points across all fields, but this had no impact on the ranking. Only in the case of computer-implemented inventions did other countries develop more dynamically, although this was compensated for somewhat by gains in foreign trade in the areas of digital hardware, biotechnology and the circular economy. At this point, however, it should be emphasized that the USA is not among the top three economies in any of the seven key technologies examined – although, in absolute terms, the USA is the leader in many areas, which is also reflected in the indicators and rankings. The country is also in the top half of the distribution in most of the technologies considered here, but not No. 1 in any of them.

Austria was able to improve its ranking by three places, while Ireland dropped three places, also due to corresponding changes in the index values. Austria has made slight gains in academic publications per capita, foreign trade and trademark applications, and significant gains in venture capital in digital technologies and energy technologies. Losses can be seen in patents in relation to the population in some areas of technology.

Ireland achieves lower index values in most fields for foreign trade and for computer-implemented inventions, and has lost a great deal of ground in venture capital investments in particular.

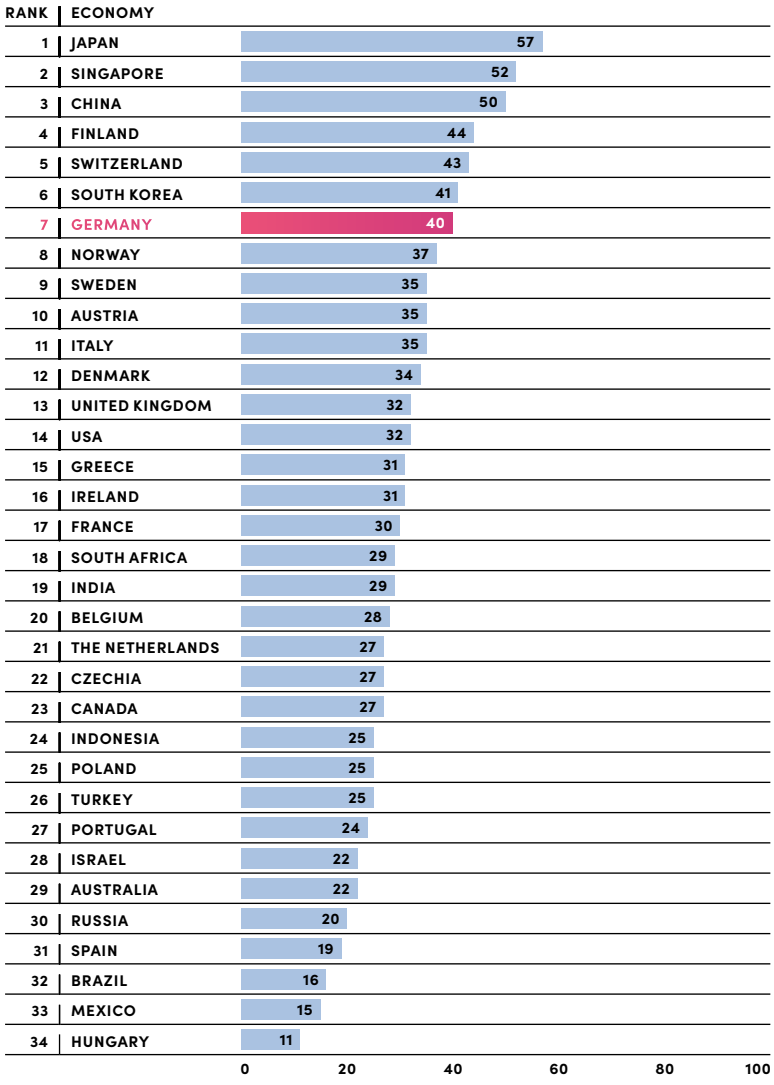
KEY TECHNOLOGIES OVERALL: RANKING AND INDEX VALUES OF ECONOMIES



Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2024

» THE USA IS NOT AMONG THE TOP THREE ECONOMIES IN ANY OF THE SEVEN KEY TECHNOLOGIES ANALYZED. “

DIGITAL HARDWARE: RANKING AND INDEX VALUES OF ECONOMIES



Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2024

Belgium ranks 22nd in 2023, significantly worse than in 2020, when it ranked 16th. The reasons for this are less to be found in a deterioration in its own performance than in the improvement of a number of economies operating at a similar index level. These include the Czechia (20th place) and India (17th place). The Czechia, for example, has increased venture capital in key digital technologies, as well as academic publications in all areas of technology. India has increased its foreign trade in numerous key technologies, as well as its share of global publications.

At the lower end of the tables there are only minor changes in rankings and index values. It is worth mentioning the slight increase of four points in the index values of Mexico, although this only leads to an improvement of one place in the ranking. As the innovation index has also improved, it will be interesting to see whether this trend continues and whether Mexico can now live up to its long-held expectations of catching up with the dynamically developing emerging markets.

DIGITAL HARDWARE

Digital hardware refers to micro- and nanoelectronic components, primarily computer chips, but also other integrated circuits. They form the basis for numerous applications ranging from consumer electronics, vehicles and machines to medical technology.

The ranking for digital hardware is led by a clear margin by Japan, with an index value of 57 points. Japan has held this position since the beginning of the analysis period in 2007. Japan is less strongly positioned in academic publications, but scores particularly well in patents and foreign trade. Singapore (52 points) caught up at the beginning of the current decade and is now in second place. The same applies to China (50 points) in third place.

Singapore is particularly strong in digital hardware in the area of academic publications, patents and trade. China scores highly on publications and patents purely due to its size, but it is also very well positioned in foreign trade with digital hardware. Finland (44 points) has moved up to fourth place in 2023 and Switzerland (43 points) is also keeping up with the leaders. South Korea (41 points) lost points in the digital hardware index during the pandemic years and has slipped from fourth to sixth place. Slight declines can be seen in almost all index values, which in turn can be attributed to actual declines in absolute data and not just to a relative decline due to improvements in other economies. Overall, the dominance of East Asian and Southeast Asian countries in this area is unmistakable. Countries such as Finland, Switzerland, Germany (40 points, 7th place), Norway (37 points), Sweden, Austria and Italy (35 points each) and Denmark (34 points) are at least keeping up with the group of countries that are chasing the leaders, although the gap between them and the leaders is obviously bigger. Germany improved slightly on almost all indicators compared to 2020, but still dropped one place in the ranking.

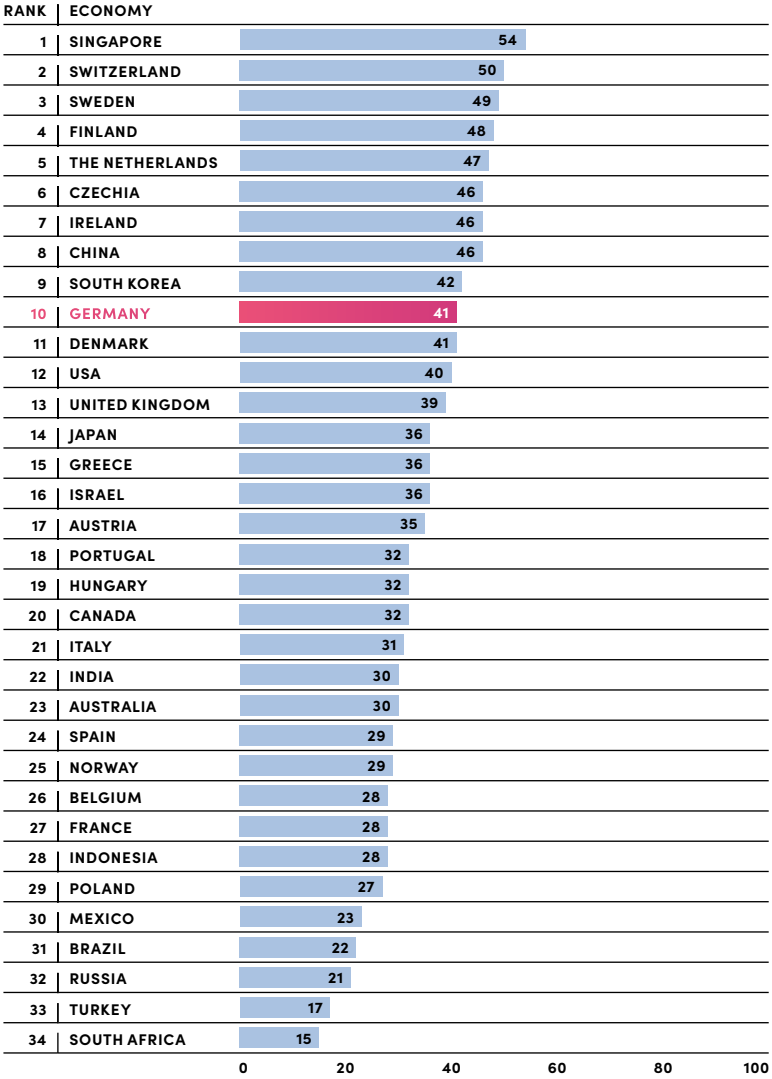
The middle of the field is led by the UK (32 points, 13th place), followed by the USA (32), Greece (31), Ireland (31), France (30) and the two newly industrializing countries of South Africa and India, with 29 points each, in 18th and 19th place. South Africa has thus been able to continue its upward trend during the pandemic. India has been at this level for some time now.

DIGITAL NETWORKS

Digital networks comprise technologies that are important for the development of future-proof digital communication networks. These are primarily semiconductors and semiconductor lasers, but also high-performance computers and even quantum computers. There are also software-based application areas such as artificial intelligence and cloud computing.

The ranking for digital networking is led by Singapore (54 points), as it has been since the mid-2010s. The country is at the top of the per capita indices for academic publications, patents and foreign trade. Switzerland has moved up to second place in the comparative ranking in 2023, just ahead of Sweden, while Finland has dropped from second to fourth place, although these three economies are close behind the leader with 48-50 points. The Netherlands (47), Czechia (46), Ireland (46) and China (46) follow in fifth to eighth place. South Korea (42), Germany (41), Denmark (41), the USA (40) and the UK (39) are chasing behind China. Germany scores highly on trade and trademark applications and is also comparatively well positioned in terms of patents in the field of digital networking. The other indicators in this area also place Germany in the lower midfield – and quite consistently so. Compared to 2020, venture capital investments have risen slightly, while the share of computer-implemented inventions in all patents in 2023 is slightly lower than in 2020. The USA only scores highly for digital networking in the areas of publications and patents, where its size makes a difference. The trade deficit in this technology sector, on the other hand, pulls the country down significantly in the rankings.

DIGITAL NETWORKS: RANKING AND INDEX VALUES OF ECONOMIES

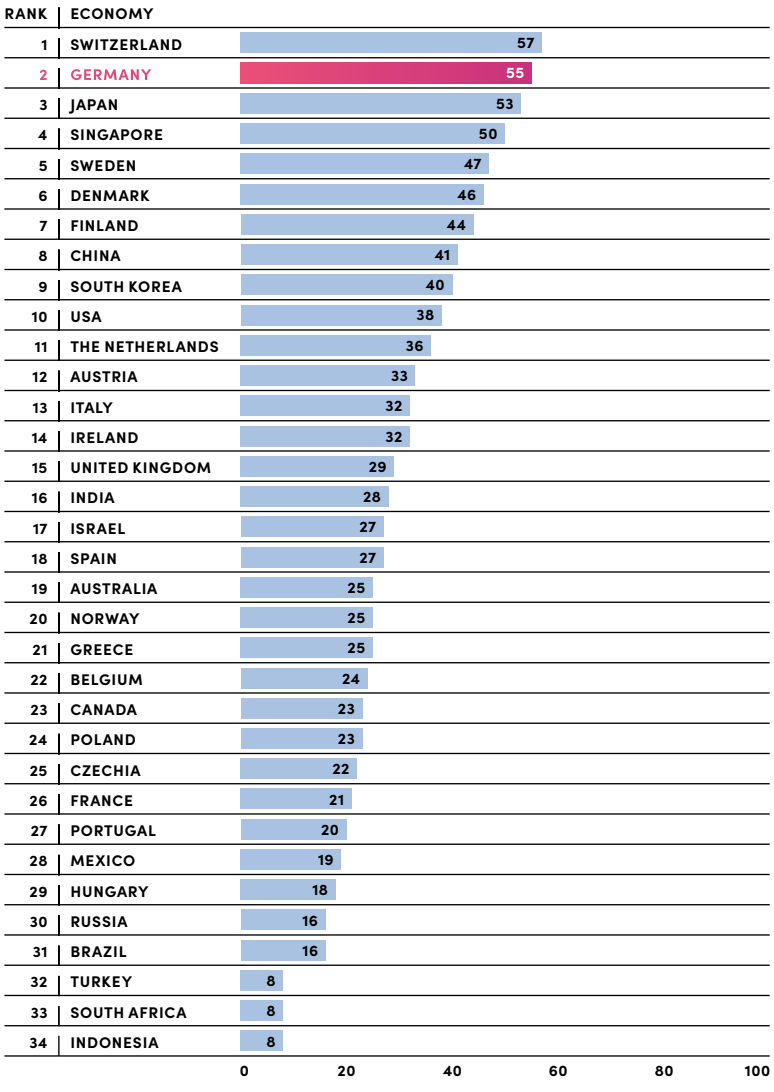


Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2024

ADVANCED PRODUCTION TECHNOLOGIES

The term "advanced production technologies" is closely related to the buzzword "Industry 4.0," although the latter defines a narrower field of technology than the one examined here and focuses on the networking and automation of production and logistics. The Innovation Indicator uses a broader definition of advanced production technologies. These can be modern machines and also entire systems or their components, from sensors and measuring devices to control systems and automated logistics. However, the production processes themselves are also included, such as joining (e.g., soldering, welding, gluing) or the pre-treatment of production equipment.

ADVANCED PRODUCTION TECHNOLOGIES: RANKING AND INDEX VALUES OF ECONOMIES



Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2024

In 2023, Switzerland overtook Germany at the top of the list, reaching 57 index points for advanced production technologies. Switzerland achieves the maximum number of points for publications, patents and foreign trade and also scores well on trademark applications and the proportion of computer-implemented inventions. This is enough to put it two index points ahead of Germany, which achieved the highest score in the global share of foreign trade. Germany is well behind Switzerland in terms of publications and computer-implemented inventions, but achieves high index values for intellectual property rights (patents and trademarks).

Japan (53 points) has been in third place throughout the observation period, and it remains so in 2023. Singapore (50), Sweden (47) and Denmark (46) complete the top 5 in the area of advanced production technologies. Finland (44), China (41), South Korea (40) and the USA (38) follow, ahead of the Netherlands (36), Austria (33), Italy (32) and Ireland, which comes in fourteenth. While China has steadily worked its way up over time to take eighth place in 2023, the USA has steadily declined to tenth place since the mid-2010s. Although the USA can exploit its economies of scale in terms of publications and patents and also achieves comparatively high scores for computer-implemented inventions, it places at the bottom for all other indicators in the area of advanced production technologies.

Since 2007, India has worked its way up from 24th place to 16th. Belgium (24) is at the lower end of the midfield for advanced production technologies, as are Canada (23), Poland (23), the Czechia (22) and France (21). France has continued to fall since 2010 and is in 26th place in 2023, with slight declines in almost all of the individual indicators considered. Only the share of global trade has increased significantly for France, since around the mid-2010s.

ENERGY TECHNOLOGIES

New energy technologies are the basic prerequisite for a climate-friendly energy supply and use, and thus for the energy transformation of the economy. In addition, new energy technologies offer the opportunity to increase independence from energy imports and hence the competitiveness of the respective business location. Energy technologies include technologies for the use of renewable energy sources (wind, solar, biomass, hydropower), the production, use and distribution of hydrogen as an energy carrier, technologies for storing energy and technologies for saving energy (energy efficiency).

In terms of energy technologies, Denmark (70 points) leads by a clear margin across the entire observation period. After taking second place in 2020, Germany (54 points) has now been pushed into third place by China (57 points). China has worked its way up continuously

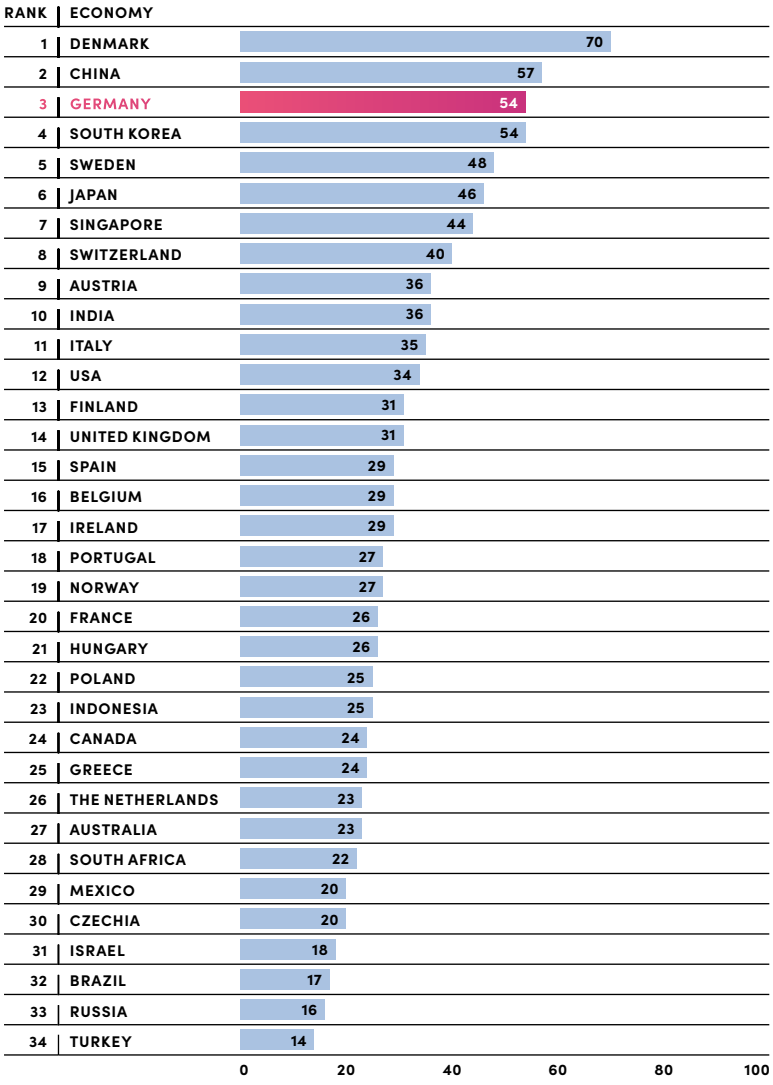
GERMANY'S GOOD POSITION IN ENERGY TECHNOLOGIES IS PARTLY DUE TO FOREIGN TRADE AND TRADEMARK APPLICATIONS. "

in this technology field since 2007. The country not only has a large and growing demand for energy, it has a wide range of expertise in various sub-sectors such as wind, solar and photovoltaics as well as energy storage, which it needs to meet this energy demand and which are reflected in its top index values in terms of global shares of publications, patents, foreign trade and computer-implemented inventions in this area. In relation to China's population, most of the key figures are still very low, but here too the trend is upwards; it is only a matter of time before China catches up with Denmark. Germany's continued strong position is based on a good performance in almost all indicators and very good index values for foreign trade, trademark applications and, most recently, venture capital.

South Korea (54) is tied with Germany in fourth place, followed at a considerable distance by Sweden (48), Japan (46) and Singapore (44). Switzerland is in eighth place, with 40 points. There is then a gap of four points to Austria (36) and India (36). They are followed by Italy (35), the USA (34), Finland (31), the UK and the three tied economies of Spain, Belgium and Ireland, with 29 points each. The USA has steadily dropped down the rankings over time, falling from sixth place in 2007 to 12th in 2023. The Inflation Reduction Act (IRA), which also provides massive investments in energy technologies, has not yet had a lasting impact on the energy technology indicators we consider here.

The bottom half of the peer group begins with Portugal (27) in 18th place and Norway, who are level on points. France (26) has no significant advantages in any of the indicators considered here. The French energy policy, which is strongly oriented towards nuclear power, is reflected negatively in the indicators for new energy technologies we consider here.

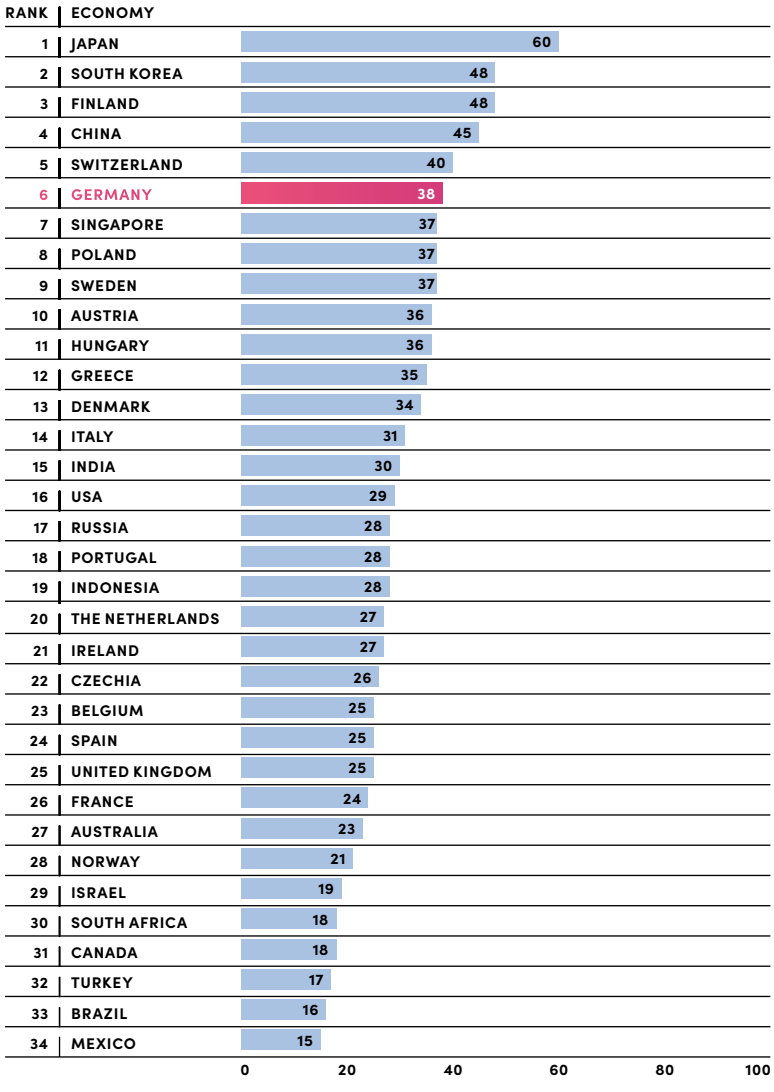
ENERGY TECHNOLOGIES: RANKING AND INDEX VALUES OF ECONOMIES



Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2024

JAPAN DOMINATES THE RANKING FOR ADVANCED MATERIALS, PARTLY DUE TO THE HIGHEST SCORES FOR PATENTS AND FOREIGN TRADE INDICATORS. “

ADVANCED MATERIALS: RANKING AND INDEX VALUES OF ECONOMIES



Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2024

ADVANCED MATERIALS

Advanced materials are the basis for numerous other developments and open up new possibilities, for example in lightweight construction. However, they also play an important role in the replacement of environmentally harmful raw materials and in the area of material efficiency. Material technologies such as coatings also enable improved product properties. This category therefore includes composite materials, coatings and plastics with special properties such as nanomaterials, as well as processes for their production and processing.

The ranking for advanced materials is led by Japan (60 points), which achieved the highest score for patents and foreign trade indicators. Japan is well ahead of South Korea (48) and Finland (48). China is in fourth place, five points ahead of fifth-placed Switzerland. In sixth place, with 38 points, comes Germany, which once again has a system that is well positioned in all indicators but does not achieve top scores in any of them. Where it does achieve scores in the upper range, this is most often for trademark applications.

Still above the middle of the range of scores is Russia (28), which can boast its best ranking in key technologies thanks to good index values for foreign trade and even academic publications, as well as a high proportion of computer-implemented inventions. The sanctions against Russia are only reflected to a very limited extent in the estimates of trade data available here and could therefore result in an overestimation of Russia’s performance in the most recent period.

The bottom half of the ranking begins with Portugal, which also has 28 points and is in 18th place, just ahead of Indonesia, which again has 28 points. Australia is in 27th place with 23 points. Together with Norway (21 points) it is still slightly ahead of the final group, which

starts with Israel. At the lower end of the chart are a number of economies, including Canada, whose poor performance in advanced materials may come as something of a surprise. With the exception of foreign trade, Canada's indicators show hardly any significant variance across the board. Patent applications targeting global markets are particularly low.

BIOTECHNOLOGY

Biotechnology refers to the scientific and technological utilization of living organisms and biological processes. The definition used here covers all areas of biotechnology and its applications in health, industry, the environment and food production. In addition to enzymes, peptides, proteins and microorganisms, and the processes based on them, processing and measuring methods are also included.

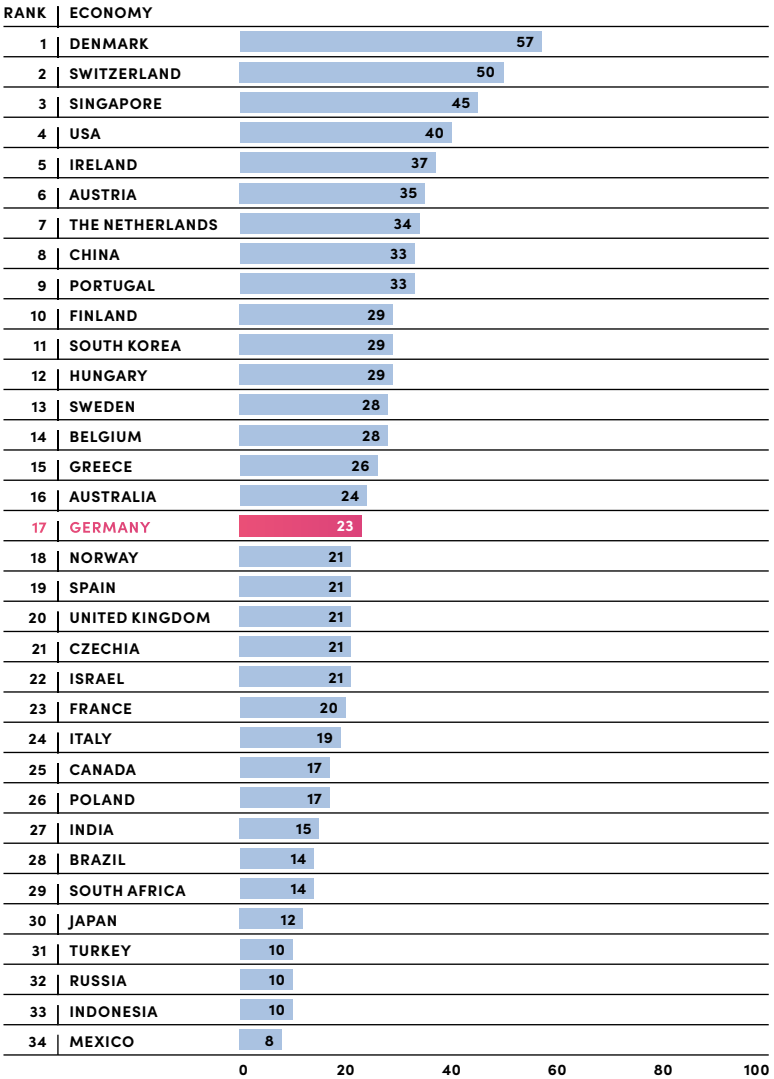
The key technology biotechnology has been led for several years by Denmark (57 points), which achieves top values for almost all indicators normalized for population size considered here and has only recently recorded a downward trend in patents. Due to the size of the country it is not in a position to score highly in terms of its global share of publications and patents, but it still achieves the top position overall. The country's good performance can be attributed to its strong academic system, but also to an established pharmaceutical and biotech sector, which includes numerous small and medium-sized companies as well as some large global companies. Alongside energy technologies, the pharmaceutical and biotechnology sector is the second strong pillar of the Danish innovation system.

Denmark is followed by Switzerland (50 points), Singapore (45) and the USA (40), which with fourth place achieves its best ranking in biotechnology among the key technologies examined here. The fact that the USA has the highest share of publications and patents worldwide form one of the foundations of its good ranking, but its strong global trade shares are also reflected in the index value. The indicators normalized for population size also contribute to the USA's index value of 40 points, but they also show that other economies are more committed to the field of biotechnology. However, the dominance of the USA on the global markets for biotechnology products (particularly for pharmaceutical applications) is unmistakable in the key figures. If this dominance did not exist, the USA would only be average worldwide in this key technology.

In fifth place comes Ireland (37), which has high index values for publications, trademark applications and foreign trade and is therefore not only a popular location for multinational companies in the biotechnology sector, but has also developed its own capacities and expertise. Austria follows in sixth place (35), just ahead of the Netherlands (34), China (33) and Portugal (33). Portugal achieves its best ranking here among all key technologies, which is due to several individual indicators with remarkable results, namely publications, foreign trade, trademarks and also its share of computer-implemented inventions, essentially bioinformatics. However, it should be mentioned here that the absolute number of patents from Portugal as a whole, and thus also in bioinformatics, is rather low.

With a gap of four index points to Portugal, Finland (29) is in tenth place in the biotechnology benchmarking, tied on points with South Korea and Hungary, and just ahead of Sweden (28) and Belgium (28). Greece (26), Australia (24) and Germany (23) take the remaining places. This means that Germany is merely average in the key technology biotechnology. Despite strengths in the pharmaceutical sector and a number of large as well as small and medi-

BIOTECHNOLOGY: RANKING AND INDEX VALUES OF ECONOMIES



Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2024

um-sized companies in this sector, the country does not hold a strong global position in biotechnology. This is partly due to a trade deficit in biotechnology goods. Germany also lags far behind others in terms of publications and patents. The absolute figures are not really declining – apart from pandemic-related fluctuations – but other countries have simply developed much more dynamically in many indicators in this area.

Norway is in 18th place, with 21 points, heading the bottom half of the ranking. France, from which one might also have expected a better performance due to its strong pharmaceutical sector, comes in 23rd place, with 20 index points. India – despite its strong pharmaceutical sector, which is geared more towards traditional pharmaceutical products and individual special technologies outside of biotechnology – does not perform particularly well in any of the indicators considered, with the exception of its share of global publications. In terms of foreign trade, the pandemic appears to have hit India harder than many other economies that are active in biotech products, and the index values have fallen significantly in the current period.

Japan (12) puts in its worst performance of all the key technologies in biotechnology, which may be surprising given the strong chemical and pharmaceutical sector in the Asia-Pacific region, which is strong in both traditional and modern pharmaceutical technologies (e.g. mRNA). Japan evidently does not have any strong competences in biotechnology.

CIRCULAR ECONOMY

Circular economy technologies encompass various approaches to the long-term use of materials and products. In its broadest definition, this includes processes for the shared use of products (a sharing economy), for the reuse of products by third parties or through improved repair options. This field of technology also includes recycling processes that begin with the development and production of products and, for example, the selection of materials. In the Innovation Indicator, however, we use a narrower definition and essentially just look at recycling technologies for returning materials to the material cycle.

The ranking for the key technology circular economy is led by Germany (46 points), which can be explained by the country's good index values for almost all indicators – in other words, Germany is able to operate a competitive innovation ecosystem across all dimensions of the circular economy. The country's patents, trademarks and foreign trade are competitive worldwide. In the area of academic publications and computer-implemented inventions, i.e. software-based control of processes and

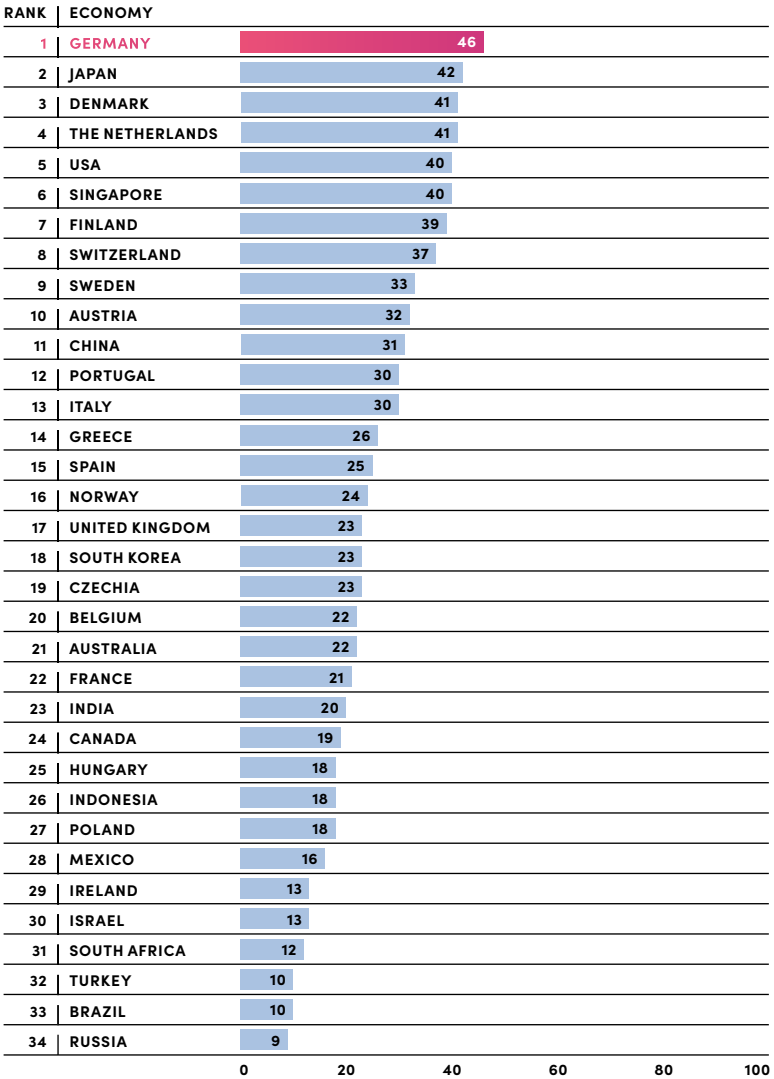
REGARDING THE CIRCULAR ECONOMY, GERMANY IS IN A POSITION TO OPERATE AN INNOVATION SYSTEM THAT IS COMPETITIVE IN ALL DIMENSIONS. “

technologies, some other countries are better positioned than Germany. Basic research and the greater automation and optimization of processes therefore still offer Germany opportunities for improvement, despite its leading position.

Japan comes in second place (42), followed by Denmark (41), the Netherlands (41) and, in the fifth place, the USA (40). The USA's good performance is once again due to economies of scale, which result in an absolute top position in terms of global publications and patents. The USA also performs well in foreign trade and computer-implemented inventions.

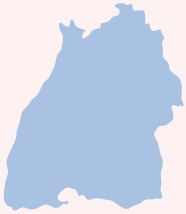
France (21) is in 22nd place, having fallen significantly behind since the mid-2010s. This is mainly due to a decline in foreign trade and computer-implemented inventions. At the same time, France has been able to maintain its position – albeit not a particularly strong one – in terms of academic publications and patents.

CIRCULAR ECONOMY: RANKING AND INDEX VALUES OF ECONOMIES



Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2024

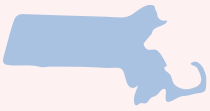
KEY TECHNOLOGIES IN THE REGIONS



Baden-Württemberg

Saxony

California



Massachusetts

The current strengths of regional innovation systems are mostly based on past and established structures and technologies. An internationally well-connected and competitive academic system, high R&D expenditure and the constant implementation of new knowledge in new applications are an expression of a well-developed system.

CONTINUOUS DEVELOPMENT NECESSARY

Technological advancements, changes in innovation cycles and shifts in global value chains and foreign trade relations constantly pose new challenges for regional innovation systems and require continuous attention and, if necessary, a change of direction or realignment. In order to assess the ability of national economies and regions to develop their technological performance and future competitiveness, the Innovation Indicator collects and analyzes key figures that cover particularly relevant key technologies: These are technologies that are either relevant for several economic sectors and thus have a cross-sectoral character, or are of particular importance for addressing global societal challenges. The seven key technologies considered here range from digitalization, energy and sustainability to production processes and biotechnology.

The classification of the four selected regions from Germany and the USA – Baden-Württemberg, Saxony, Massachusetts and California – is based on the indicators that are also used to evaluate the economies considered in the Innovation Indicator. The overall result of the composite indicator for all seven key technologies is presented and discussed in this chapter. The results are based on the individual indicators, which were determined separately for each of the seven technologies.

Our analysis shows that across all key technologies the values of the regions are below the respective national values. This is in essence due to the fact that the regions in question maintain a more specialized profile – similar to that of smaller countries – than their country (Germany, the USA) as a whole. In other words, the regions are only specialized in individual key technologies, while the country's economy as a whole may well be specialized in several fields.

Baden-Württemberg holds eighth place in the current ranking of key technologies of the 38 economies and regions considered here, just behind Germany as a whole. Over time, it has fallen from its best ranking – fourth place in the years 2012–15 – to eighth place, but it has remained among the top 10 throughout the entire period of observation. Although Baden-Württemberg achieves second place worldwide in the fields of advanced production technologies, energy and the circular economy, it lags slightly behind in digital technologies. The gap between Baden-Württemberg and the top region is particularly clear in advanced materials, and even more so in biotechnology.

In terms of key technologies, Saxony is placed in the front midfield worldwide, ranking 11th. Its ranking has remained fairly stable over time: its worst position was 16th place in 2013 and its best position its current 11th place, which was also achieved in 2015 and 2017. Key technologies in Saxony focus on digital hardware, energy technologies and advanced materials. It achieves its lowest rankings in the individual key technologies in digital networking (20th place) and biotechnology (18th place).

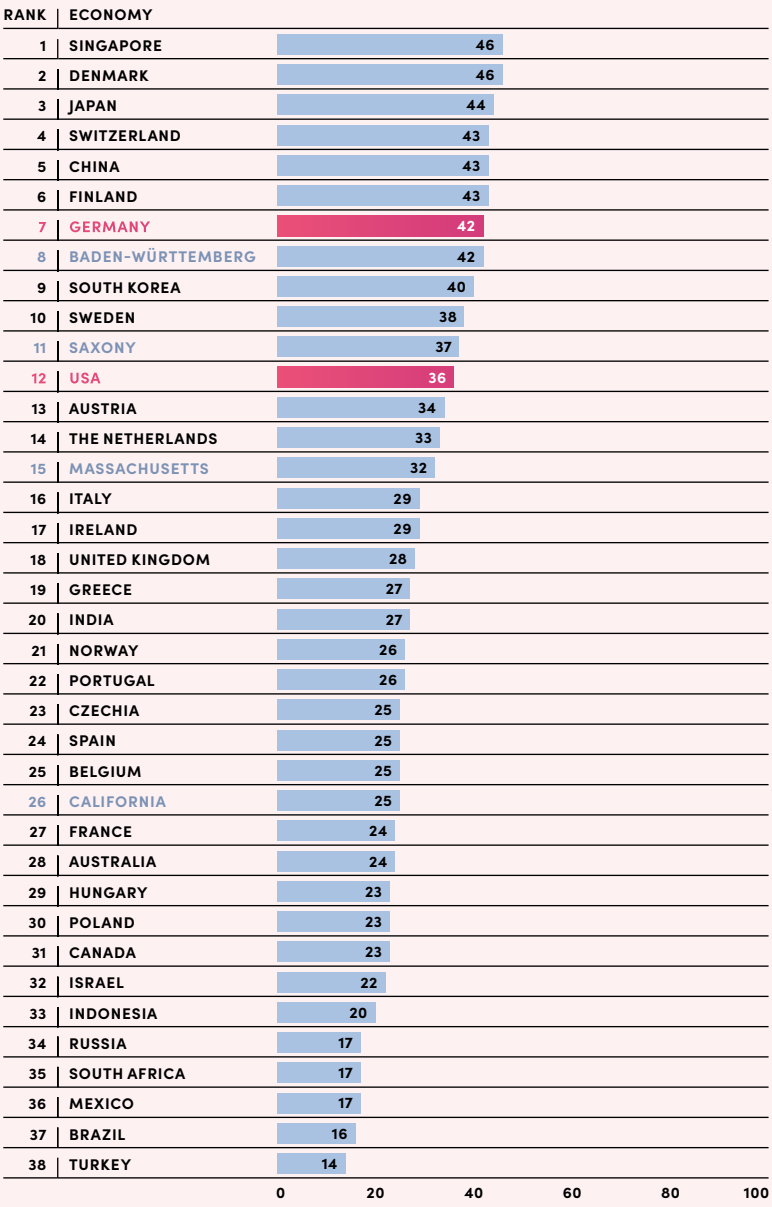
Massachusetts has also fallen behind over time in key technologies – as in innovation capability – and was ranked 15th out of 38 in 2023. Since around the second half of the 2010s, it has hovered between 16th and 13th place. In the ten years before that, it was ranked between 8th and 12th place and thus further up the rankings. Biotechnology is one of Massachusetts' distinct strengths, and it also achieves low double-digit rankings in the circular economy and advanced production technologies. In the field of digital technologies and energy technologies, on the other hand, it performs poorly in an international comparison, ranked below 20th place – which ultimately also explains its overall mid-table position.

CALIFORNIA IS LOSING GROUND

In the overall analysis of all the key technologies, California lags far behind the USA, in 26th place compared to the USA's 12th place. This puts it just behind the Czechia, Spain and Belgium, but ahead of France and Australia. The trend for California is clearly downwards over time.

From its 14th place ranking in 2007, California plummeted to around 20th place. It then stabilized and it was not until the current year that it fell again significantly in the ranking, despite only a slight fall in its index value. This can be explained by the dynamism of the other nearby economies. Its only pronounced strength is in biotechnology, as is the case for the USA as a whole. In terms of digital technologies, by contrast, California is not far ahead internationally. Although it achieves the highest score for patents in digital networking technologies and its index values for computer-implemented inventions (software patents) are quite pronounced across almost all fields of technology, this cannot compensate for its weaknesses in academic publications and, above all, balance of trade. However, it should be noted that license revenues and value added at the level of key technologies cannot be collected and that California generates significant revenues and thus contributions to GDP per capita through the software and movie industries. There is also no data on venture capital at the level of the individual key technologies and this is therefore not included in our analysis.

KEY TECHNOLOGIES: RANKING OF SELECTED REGIONS IN COMPARISON WITH THE NATIONAL ECONOMIES



Source: Fraunhofer ISI calculations

RECOMMEN-DATIONS

1

USE ARTIFICIAL INTELLIGENCE AND DIGITAL PLATFORMS AS ENABLERS

Information and communication technologies (ICT) have long played an important role in numerous industries and sectors as a cross-sectional technology. Artificial intelligence (AI) and platform-based business models have given rise to new technologies and applications based on this, which are also considered to be of far-reaching importance – as well as being disruptive. Germany's real position in this area might be better thant suggested by its reputation when it comes to ICT technologies: It ranks in the top 10 internationally for digital hardware and digital networks. This means that the basics are in place, at least.

With AI it is less important that a country comes up with the large language models itself, as long as various models from different providers are available and domestic providers have mastered the technology and can successfully develop innovative solutions based on it and place them on the market. It is important to promote the targeted application of AI in the country's own areas of specialization and competencies. At the same time, AI can be expanded in domain-specific contexts through in-house knowledge, thus ensuring a differatiation of the AI applications and enhancing competitiveness. However, the availability and provision of data also represent major hurdles here. Germany has taken an important step forward with the establishment of the NFDI (National Research Data Infrastructure). Players within the industry have formed partnerships with each other and with the academic community to develop specific data spaces and data ecosystems. Projects such as Gaia-X, Catena-X, Manufacturing-X and Transfer-X are good starting points, but they still need to be brought to a successful conclusion.

Two main challenges arise with digital platforms. First, interoperability is of crucial importance, which means that fragmentation into separate solutions must be avoided. Second, digital business models must be developed and implemented. It is essential not only to digitalize existing business models but also to develop entirely new business models on a digital basis.

RETHINK THE SEPARATION BETWEEN CIVILIAN AND MILITARY RESEARCH

The Russian invasion of Ukraine and the turnaround in defense policy have pushed one topic to a more central position on the innovation policy agenda: the dual use of new technologies for military and civilian purposes.

Various synergy and efficiency potentials exist with regard to the coming growth in research expenditure in the area of defense. Increased defense research should be systematically examined to determine whether and to what extent it could have broader social and economic benefits via spillovers into civilian use. Germany has a number of institutional and structural factors that restrict such synergies. In the USA, for instance, DARPA systematically examines possible crossover applications; SPRIN-D does not have this task in Germany. Furthermore, in Germany, the permeability of defense research and civil research only exists through individual institutes within the Fraunhofer-Gesellschaft and the German Aerospace Center DLR. In addition, Germany's "Civil Clause" – a commitment by academic institutions not to engage in military research – has a restrictive effect in many universities. Significant potential in dual use areas is not being exploited here, particularly in the realm of civil security, such as for IT security or the protection of critical infrastructure.

To leverage the potential synergies between defense and civilian research, Germany needs a broad debate about academic policy with regard to the framework conditions for academic institutions, and in part a cultural change. This debate should cover the application of the Civil Clause in German universities as well as the widespread systemic and organizational separation of civilian and defense research. Improved organizational permeability, allowing both research funders and those carrying out research to conduct both civilian and defense research, would enable dual-use spillovers and synergies between civilian and military research.

SEEK EUROPEAN SOLIDARITY

When it comes to comprehensively researching, implementing and diffusing most key technologies, Germany is too small on its own to generate sufficient critical mass. Critical mass plays a decisive role in research because, among other things, the complexity of current issues has increased enormously in many areas and because the speed with which results are achieved has become a much more decisive criterion for success. New findings require a great willingness to invest and efficient transfer structures to implement them, and lead markets today primarily dependent on their size in order to be able to scale quickly and in a targeted manner.

Other countries, particularly the USA and China, are able and above all willing to make massive investments in science and research. Germany can therefore only be successful if it joins forces with other countries in Europe, supporting the European Research Area (ERA) and seeking cooperation with the best in Europe. At the same time, Germany should take a stronger leadership role in science and research in Europe and thus, together with its European partners, define the research agenda. The ERA offers a suitable framework for this. European scientific and research cooperations are also essential for Germany's technological sovereignty.

NORTHERN EUROPE WITH STRONG RESULTS

Economic transformation for people and the environment

Starting with the Innovation Indicator 2023, we explicitly track sustainability in a separate indicator. Sustainability is not only a task of particular importance for the economy: It must be supported by society as a whole. It aims to meet the economic and social needs of the current generation without compromising the opportunities of future generations. Sustainability is important at a macroeconomic level, as long-term economic success and social prosperity are only possible by respecting planetary boundaries. Civil society, academia, the government and businesses must work together to create sustainable innovation systems. Sustainability, as it is understood in the Innovation Indicator, therefore aims at the socio-ecological transformation of the economic system while at the same time taking economic competitiveness into account.

Business plays a dual role: It is both the cause of environmental pollution and, through its ability to produce environmental innovation, it can contribute to reducing negative environmental impacts through newer manufacturing and production methods. This in turn can generate considerable economic added value, which is also reflected in increased prosperity.

The opportunities arising from a switch to the circular economy are particularly significant here. A circular economy is crucial for sustainable development as it focuses on conserving resources. Unlike the linear economy, which extracts, processes and disposes of raw materials, the circular economy aims to design products that can be produced in a resource-efficient way, used for a long time and recycled at the end of their lifecycle.

In the recommendations on sustainable management in last year's Innovation Indicator, we particularly emphasized the importance of politics. The role of politics is to support the development of a sustainable economy and society through legislation and funding programs. Examples include the promotion of renewable energies and energy efficiency through subsidies and incentives. Regulations and taxes can effectively control environmentally harmful behavior. Public procurement is a particularly promising approach, as it has an enormous economic leverage effect and can also be designed in compliance with laws on state subsidies, outside of innovation projects, in such a way that it remains largely competition-neutral.

In addition to the economy and academia, consumers play a central role. Environmentally conscious consumer behavior reduces environmental impact and creates incentives for companies to offer sustainable products and services. Consumers also influence the sustainability of the transportation system, which is responsible for around 20 % of CO_2 emissions. To achieve changes in consumption and mobility patterns, society needs to be made more aware of sustainability.

The Innovation Indicator reflects these various aspects in the sustainability indicator, which consists of 11 individual indicators. These cover not only environmental technologies and their application, but also key areas of the environmental innovation system in relation to business, academia, governments and civil society. The aim here is to assess the orientation of national economies towards sustainability innovations. The same economies are considered as for innovation and key technologies, and all indicators are normalized to avoid distortions due to differences in size.

CENTRAL RESULTS

As last year, the ranking of the indicator "Acting sustainably" is led by Denmark, which achieved 66 points (down two points on 2023). In second place is Finland, with 60 points, significantly closing the gap to Denmark compared to last year. Germany and South Korea tied with 48 points, coming third and fourth respectively. In 5th and 6th place are the UK (46 points) and the Netherlands (45 points). Austria (44), Sweden (44), Japan (43) and France (43) follow in 7th to 10th place.

The sustainability ranking is dominated by European economies. With Finland and Denmark in strong positions, two Northern European nations are once again well ahead. For Switzerland and Singapore, the leading nations in the indicator "Innovation capability", sustainability scores of 34 points for Switzerland (15th place) and 21 points for Singapore (24th place) put them far behind the top group.

The broader midfield includes Portugal, Belgium and Italy, as well as other European countries such as the Czechia (34), Hungary (29) and Spain (29). Countries such as Australia (26), China (25) and Canada (25) are also in this group.

The performance of the USA, which scored 17 points, remains poor. This is unchanged compared to previous years, so it may be concluded that the Inflation Reduction Act (IRA), which is strongly geared towards sustainability, has not yet had any measurable effect on the economy as a whole. Emerging countries such as Mexico (19 points) and South Africa (15) are in a similarly poor position. Ireland and Israel are two other established industrialized countries that also perform poorly, with 14 and 12 points respectively. Russia remains at the bottom of the table, with zero points.

SPECIFIC INDICATORS FOR MEASURING SUSTAINABILITY AND THEIR SOURCES

- R&D in renewable energies and energy efficiency as a share of GDP (IEA)
- Green early-stage investments (EU and OECD)
- State R&D support, environment and energy (OECD)
- Attitude towards environmental issues, preference environment versus economy (World Values Survey)
- Environmentally relevant academic publications per capita of the 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 inhabitant (PATSTAT)
- ISO 14001 certifications (ISO-Survey)
- Environmental taxes (OECD)

To provide a detailed picture of the individual countries, we examine their development over time and their positions with regard to the individual indicators more closely below. As in the chapter on innovation capability, we group similar countries together (leading countries, large economies, Southern and Central Europe, emerging economies) and discuss those groups in turn.

DENMARK ENJOYS A STABLE LEAD

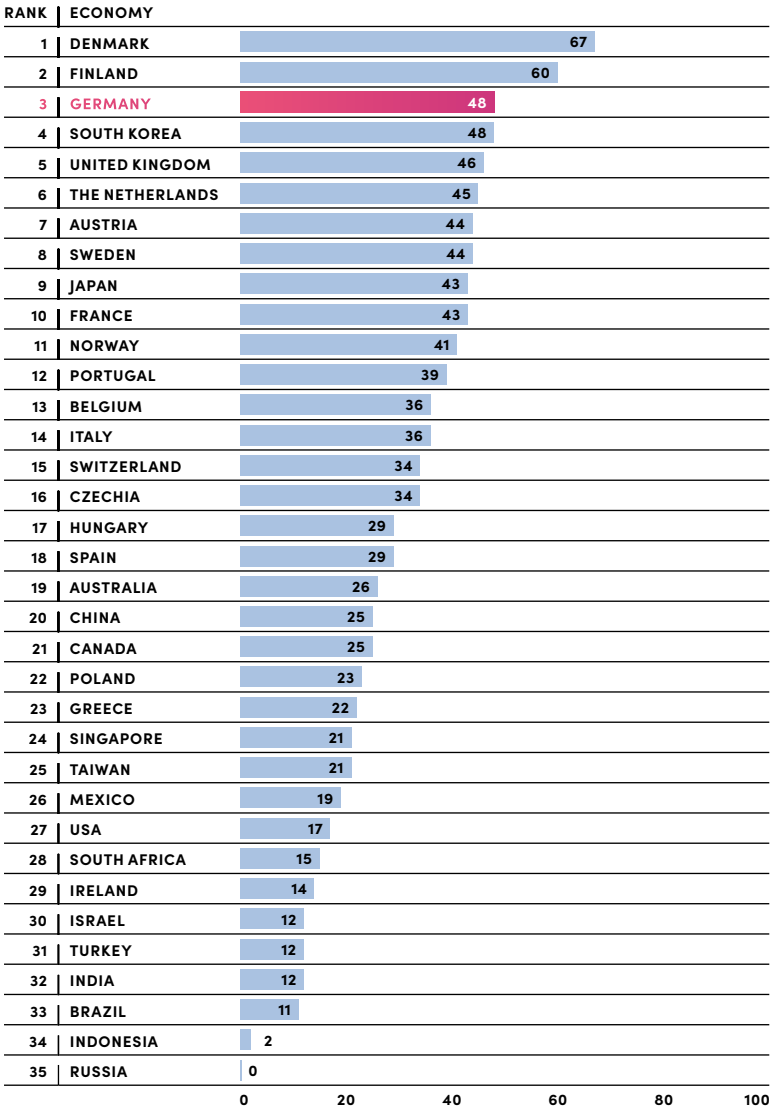
The scores for most of the leading economies in the sustainability indicator are relatively stable over time, with minor fluctuations. For example, Denmark already achieved a score of 66 points in 2005. This roughly corresponds to the current value. However, it should be noted that Denmark achieved values above 70 points in the past, particularly between 2010 and 2015. It has now partially lost this very clear lead. Major changes are rare in the top group of leading countries, and only occur in specific time periods, if at all. The only exception is Germany, which increased its score from 37 to 48 points between 2010 and 2023. Since 2020, however, a stagnating trend seems to have prevailed here, too.

A look at the characteristics of the individual indicators reveals clear profiles of strengths and weaknesses. Denmark performs well above all with its relatively high number of environment-related academic publications, environmental innovations by companies and environmentally relevant patents, in each of which areas it achieves the highest score, that is, 100 points. However, it has pronounced weaknesses in ISO certifications, where it scores zero points. Denmark shares this weakness with most of the other countries in the leading group, with the exception of Germany, which has 50 points. Germany achieves a very good score of 99 points for the export of sustainable goods, but otherwise fails to take the top position anywhere. Nevertheless, it achieves solid scores for government funding for environmentally relevant R&D (79 points) and for green early-stage investments (74). Germany's overall good performance can be explained by the fact that it does not have any particularly pronounced weaknesses; almost all indicators are in the midfield. This underlines the fact that the German system is broadly geared towards sustainability issues, but there is still potential for development. It should also be noted that for key performance indicators such as environmental innovations (45 points), R&D in renewable energies (34) and patents (35), Germany's values tend to be below average. There were no changes here compared to last year.

South Korea, which was not in the group of leading nations last year, has a similar profile to Germany, with neither pronounced strengths nor weaknesses. Unlike Germany, however, it achieves comparatively high values primarily through its good positioning in the economic sector, e.g. in environmentally relevant patents (79 points). It also enjoys a strong position on environmental taxes (64) and state subsidies for the environment and energy (77). The country's clear improvement in the international ranking is thanks in particular to its indicator values for the share of R&D expenditure in key energy fields and environmentally relevant patents. The Netherlands, which is also new to this group, has strengths in consumer purchasing behavior (100) and environmental taxes. In terms of environmental innovations, however, it only scores a modest 21 points.

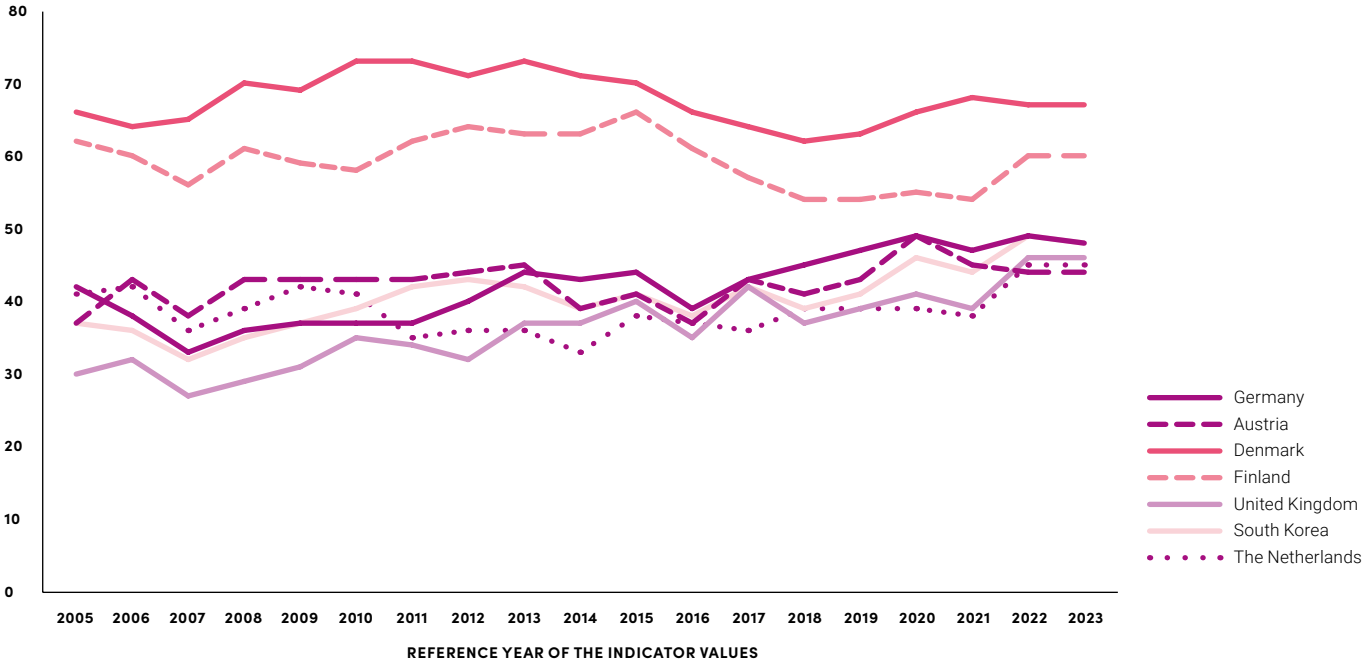
The UK, which, like the Netherlands, has strong scores for environmentally friendly purchasing behavior (79), achieves a good position in ISO 14001 certifications. But it performs very poorly in the area of environmentally relevant patents, scoring just 7 points. It is also not well positioned in terms of environmental innovations, with 32 points. The UK thus has weaknesses in the area of green inventiveness and innovation.

SUSTAINABILITY: RANKING AND INDEX VALUES OF THE ECONOMIES



Source: Innovation Indicator 2024

SUSTAINABILITY: DEVELOPMENT OF ECONOMIES WITH A HIGH INDEX VALUE



Source: Fraunhofer ISI calculations

LARGE ECONOMIES

Within the group of major economies, the UK and South Korea in particular have recently moved up the rankings. The same applies to China and France, although both recently lost ground again. China only scored 14 points at the start of the reporting period; In 2022, it had already reached 31 points, although the gains since 2010 have been rather modest. In the current reporting year, China only scored 25 points. The Chinese government has been focusing on sustainable energy supply and environmental innovations since the mid-2000s, during the period of emerging economic development, a trend that has intensified in more recent periods. However, critics saw this in many areas as nothing more than greenwashing research, innovation and economic policy, primarily because the traditional energy supply – mainly coal-fired power generation – was maintained. At the same time, the Chinese government not only focused on renewable energies but also invested heavily in nuclear energy. The main reason given for the continued energy mix was that the rapidly increasing demand for energy in China could not otherwise be met. During the coronavirus pandemic, it appears that the Chinese government's efforts to expand sustainable energy technologies fell behind in relation to the overall economic development and compared to the efforts of other countries. A final assessment of this phase will only be possible in years to come.

China's strengths in the indicator "Acting sustainably" lie in its ISO certifications (100 points), as was the case in the past. However, the country is clearly lagging behind in other indicators. This also applies to the government, which was not particularly active either in terms of environmental taxes (0 points) or environmental regulation (27 points), despite public policy statements suggesting otherwise.

Japan has lost ground. At the beginning of the observation period, it was still at 50 points or more; in 2023 it only achieved 43 points. The country's main strengths are ISO certifications (100) and state promotion of the environment and energy (75 points). Japan is weak in terms of environmentally relevant academic publications (0) and exports of sustainable goods (7).

» THE GERMAN SYSTEM IS BROADLY GEARED TOWARDS SUSTAINABILITY AND DOES NOT HAVE ANY SIGNIFICANT WEAKNESSES. "

FRANCE'S DISTINCTIVE STRENGTHS LIE IN ITS ENVIRONMENTAL REGULATIONS. "

SUSTAINABILITY: OVERALL RANKING OF ECONOMIES

RANK	2005	2010	2015	2020	2023
1	DENMARK	DENMARK	DENMARK	DENMARK	DENMARK
2	FINLAND	FINLAND	FINLAND	FINLAND	FINLAND
3	JAPAN	NORWAY	ITALY	NORWAY	GERMANY
4	HUNGARY	SWEDEN	SWEDEN	GERMANY	SOUTH KOREA
5	SWEDEN	AUSTRIA	NORWAY	AUSTRIA	UNITED KINGDOM
6	SWITZERLAND	THE NETHERLANDS	JAPAN	ITALY	THE NETHERLANDS
7	GERMANY	HUNGARY	GERMANY	FRANCE	AUSTRIA
8	THE NETHERLANDS	CANADA	FRANCE	SWEDEN	SWEDEN
9	BELGIUM	CZECHIA	SWITZERLAND	SOUTH KOREA	JAPAN
10	NORWAY	SWITZERLAND	SOUTH KOREA	UNITED KINGDOM	FRANCE
11	AUSTRIA	SOUTH KOREA	AUSTRIA	JAPAN	NORWAY
12	SOUTH KOREA	JAPAN	UNITED KINGDOM	SWITZERLAND	PORTUGAL
13	CZECHIA	GERMANY	THE NETHERLANDS	CZECHIA	BELGIUM
14	AUSTRALIA	ITALY	TAIWAN	THE NETHERLANDS	ITALY
15	FRANCE	AUSTRALIA	AUSTRALIA	TAIWAN	SWITZERLAND
16	CANADA	UNITED KINGDOM	CANADA	CANADA	CZECHIA
17	ITALY	FRANCE	BELGIUM	BELGIUM	HUNGARY
18	UNITED KINGDOM	SPAIN	PORTUGAL	PORTUGAL	SPAIN
19	MEXICO	TAIWAN	CZECHIA	AUSTRALIA	AUSTRALIA
20	SPAIN	CHINA	POLAND	CHINA	CHINA
21	PORTUGAL	BELGIUM	CHINA	HUNGARY	CANADA
22	GREECE	MEXICO	HUNGARY	GREECE	POLAND
23	SINGAPORE	PORTUGAL	SPAIN	SPAIN	GREECE
24	POLAND	POLAND	GREECE	SINGAPORE	SINGAPORE
25	SOUTH AFRICA	SINGAPORE	MEXICO	MEXICO	TAIWAN
26	IRELAND	TURKEY	SINGAPORE	POLAND	MEXICO
27	ISRAEL	GREECE	TURKEY	INDIA	USA
28	TURKEY	IRELAND	SOUTH AFRICA	USA	SOUTH AFRICA
29	USA	ISRAEL	BRAZIL	TURKEY	IRELAND
30	CHINA	USA	INDIA	BRAZIL	ISRAEL
31	TAIWAN	BRAZIL	IRELAND	INDONESIA	TURKEY
32	RUSSIA	SOUTH AFRICA	USA	SOUTH AFRICA	INDIA
33	INDIA	RUSSIA	ISRAEL	ISRAEL	BRAZIL
34	BRAZIL	INDIA	INDONESIA	IRELAND	INDONESIA
35	INDONESIA	INDONESIA	RUSSIA	RUSSIA	RUSSIA

Source: Innovation Indicator 2024

Among the major economies, the USA, which most recently scored 17 points, is still in a weak position, achieving a very similar result to last year. It remains problematic that the USA performs below average in almost all indicators. The country scores zero points for the export of sustainable goods and for environmental taxes. In view of the low export success, these results clearly show that there are also economic costs associated with a low focus on sustainability. Decent values are achieved for R&D in renewable energies (37 points) and promotion of the environment and energy (38), although the country remains below average here.

France's most pronounced strength lies in environmental regulations, where it achieves the best possible score of 100 points. However, it is poorly positioned in terms of environment-related patents (2 points) and publications (14). Japan and South Korea share many of the same strengths. Thus, both nations are characterized by a pronounced promotion of R&D in the fields of environment and energy. Accordingly, both countries also score well in terms of R&D expenditure on renewable energies and energy efficiency – and both have weaknesses in exports of sustainable goods.

POSITIVE TREND IN SOUTHERN AND CENTRAL EUROPE

In the group of Southern and Central European countries, Italy was unable to continue its positive trend of previous years. While it still reached 47 points in 2020, it had fallen to 36 points by 2023. Hungary, which was originally very far ahead, with 48 points, has also fallen back considerably, scoring just 29 points in 2022. Hungary recorded significant declines in R&D expenditure in key energy fields and in the environmental index. In contrast, Portugal was able to increase its score by 13 points, to 39 points, between 2005 and 2023. Most other countries in Southern and Central Europe changed their scores only slightly. This also applies to Spain, which recently reached 29 points (up two points compared to 2005).

It is worth noting that almost all economies in Southern and Central Europe share one particular strength and one particular weakness. With the exception of Spain (35), all of the countries surveyed are well ahead in terms of environmental taxes in relation to total tax revenue. Greece even scores 100 points here. All other countries score more than 50 points. By contrast, no country in this group scored even as much as 10 points for environmental patents – which can at least partly be explained by the generally below-average patenting activities in these countries. There are some other interesting aspects of these countries' performances. Italy, which is otherwise considered to be less founder-friendly, still scores 53 points for green early-stage investments. The country's sharp drop compared to 2021 can be attributed, among other things, to a massive deterioration in its ISO 14001 certification: Italy scored 84 points before, but now only scores 13.

Almost all countries in this group are characterized by a fairly high level of state support for R&D in the environment and energy sector. Hungary now leads the group

SUSTAINABILITY: DEVELOPMENT OF MAJOR ECONOMIES

Source: Fraunhofer ISI calculations

with the best possible score of 100 points (81 in 2021). The downward outlier is Poland, which traditionally relies heavily on fossil fuels (coal). Nevertheless, Poland was able to increase its value slightly from zero to 11 points compared to 2021. In Portugal, state support is also having an effect, the country scoring 67 points for R&D activities in the field of renewable energies – an increase of one point on last year. The Czechia is in second place, with an unchanged 40 points. Like last year, Spain (12 points) and Greece (zero) achieved poor results here.

Economic successes in terms of a positive trade balance with sustainable goods can be seen above all in the Czechia (100 points) and Hungary (86); in other words, these countries export significantly more of these goods than they import. Portugal has strengths in the area of knowledge generation, scoring 67 points for environmental publications. Overall, the picture that emerges for Portugal is one of specialization in the area of sustainability, which is primarily the result of state support for sustainable economic activities. However, as with most other countries in this group, there is still potential for expansion by companies.

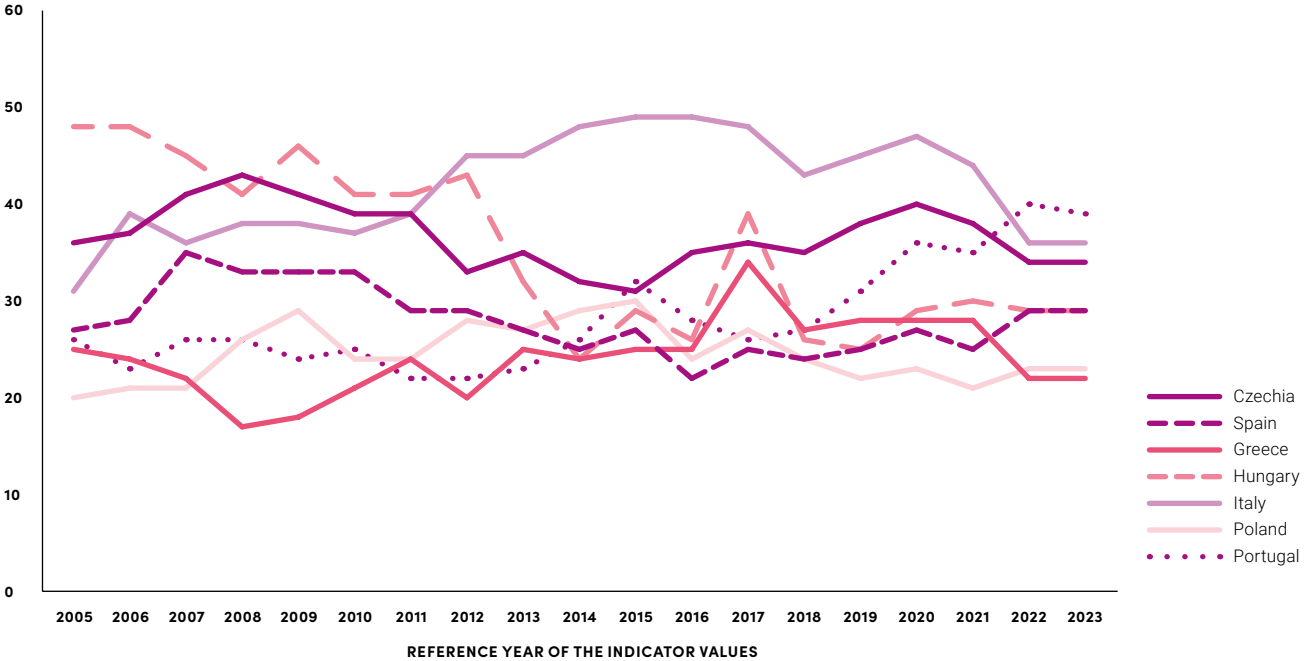
EMERGING MARKETS

There are both winners and losers in the group of emerging markets. For example, Russia has lost considerable ground since 2005. At the beginning of the observation period, it scored up to 15 points, but it has recently fallen to zero points according to our calculations. It achieves the minimum value for almost all indicators, including the development of environmental innovation in companies as a proportion of all innovations (2 points). Losses were also recorded for Mexico (19 points in 2023 compared to 28 in 2005) and South Africa (15 points in 2023 compared to 19 in 2005). Turkey has also lost ground, recently scoring 12 points (down 5 points on 2005). Gains were made by India and Brazil: India has increased its score from 7 points in 2005 to 12 today, while Brazil increased its score from 7 to 11 points.

All emerging countries are characterized by very low values in the area of environmentally relevant publications and patents. This reflects a general weakness on the part of these nations in producing patents and publications. In addition, all emerging economies show weaknesses in the area of environmental regulation. Turkey achieves the highest score here, with 16 points, followed by India, with 14 points. Brazil, Indonesia, Mexico, Russia and South Africa have zero points. Exports of sustainable goods are also low in most countries. Mexico and Turkey are at a comparatively high level, with 19 points, while South Africa has 7 points and all other countries zero.

Data on R&D funding and R&D activities in environmentally relevant areas is incomplete for this group. It is interesting to note, however, that Mexico – unusually for emerging economies – scores 100 points for state R&D funding in the environment and energy sector. Equally encouraging is the fact that South Africa and Brazil are two of the emerging economies with the highest levels of environmental innovation in companies, scoring 27 and 28 points respectively; admittedly, these are not top scores,

SUSTAINABILITY: DEVELOPMENT OF ECONOMIES IN SOUTHERN AND CENTRAL EUROPE



Source: Fraunhofer ISI calculations

SUSTAINABILITY: DEVELOPMENT OF ECONOMIES IN EMERGING MARKETS

Source: Fraunhofer ISI calculations

but they are still solid. This puts these two countries well ahead of many Southern and Central European countries in terms of this indicator. In addition, both Turkey and South Africa achieve high results for environmental taxes, Turkey scoring 63 points and South Africa 73.

» THE EMERGING MARKETS SHOW WEAKNESSES IN PRODUCING PATENTS AND PUBLICATIONS. “

RECOMMEN-DATIONS

STRENGTHEN THE TRANSPARENCY AND STRATEGIC CAPABILITY OF INNOVATION AND TECHNOLOGY POLICY

Innovation and technology policy has become much more directional thanks to its stronger mission orientation. Its objectives are typically multidimensional: In addition to economic objectives and goals related to competition policy, sustainability-oriented objectives now also play a major role. A sustainability-oriented technology and innovation policy comes with the hope of achieving a double return – the creation of new markets, and simultaneously an improvement in sustainable economic activity. For this to be possible, however, the economic and environmental objectives must be carefully balanced and harmonized with each other, and that calls for great strategic ability and planning. Policy approaches that attempt to shape the world around them often have the problem that the political decisions involved are strongly influenced by vested interests, something that must be avoided as far as possible. To create sufficient strategic capability, the organization of innovation and technology policy must be fundamentally rethought. An important starting point is the assignment of clear, transparent responsibilities in the administration in order to ensure coordination of policies across departmental boundaries.

Unfortunately, the processes involved in German innovation and technology policy are currently characterized by a fragmentation of responsibilities. The problem here is not just the often unclear departmental demarcation of different responsibilities, but also the creation of new organizations and agencies, frequently with narrowly defined areas of activity. This makes political processes less transparent and so increases the risk of political appropriation. Furthermore, it often leads to a lack of strategic prioritization and thus to insufficient resources in individual policy areas. A good starting point is thus to establish a stronger concentration of resources and responsibilities in the innovation and technology policy.

CREATE STABLE AND RELIABLE FRAMEWORK CONDITIONS FOR SOCIAL PLAYERS

Processes of social transformation often incorporate disruptive elements. However, due to their systemic nature, they also have long implementation periods. At the same time, they require a high level of concentrated investment by the players involved – for example, in the case of the research and implementation of new, environmentally friendly technologies, by the business world. An important task of German innovation policy is to contribute to planning security by creating long-term, reliable and above all stringent framework conditions.

This applies in particular to innovations in the area of climate and environmental protection. Here, innovation, energy and environmental policy must work hand-in-hand. European emissions trading and binding emissions targets play an important role in mitigating climate change. To achieve innovation, Germany must continue along its agreed targets and emission paths. At the same time, new instruments such as the calls for proposals for the European Innovation Fund (for example for energy-intensive industrial processes) and the climate protection agreements already introduced in Germany are expected to have an impact on innovation. Both these instruments consolidate the effect of emissions trading. In other areas of environmental policy it is necessary to first create or adapt the corresponding framework conditions, for example amending the wastewater levy or orienting water protection policy towards new challenges. At the same time, sectoral coordination problems, which typically arise as costly infrastructures are created, must be solved. These infrastructures create the conditions for the broad diffusion of new technological solutions, but they also require a clear idea of which technologies will prevail, and how quickly. Typical examples are the building of electric charging infratructure and hydrogen networks. Policymakers must help to resolve these coordination problems by establishing communication and coordination processes and developing supporting measures.

PROMOTE THE CREATION OF CIRCULAR BUSINESS MODELS

Innovation funding in the EU has traditionally been strongly geared towards the development of new technologies. There is no doubt that new, disruptive technologies play an important role in overcoming sustainability-related challenges. However, this focus obscures the fact that a socio-economic transformation of the economy is often primarily dependent on the development of new circular business models. Although these models can be based on new technologies, they also require the transformation of entire value chains. One particularly important example is the recycling of raw materials, such as rare earths for battery production. This not only enables sustainability gains to be made, but also reduces dependence on raw material suppliers, which ultimately strengthens the technological sovereignty of the domestic economy.

Research has shown that even using existing technologies to achieve a higher level of sustainability is not easy, as the established business models often make transformative changes appear economically unattractive, at least in the short term. In order to speed up the sustainability-oriented transformation of the economy, funding programs should be broadened so that they also promote the emergence of new circular business models. The necessary legal framework must be created for this.

CONCEPTUAL FRAMEWORK

Methodology of the Innovation Indicator

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 normed 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 innovation
- 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.[4]

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 individual 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 UK, Ireland, Italy, Japan, the Netherlands, Austria, Poland, Portugal, Sweden, Switzerland, Spain, the Czechia and the USA. 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 2023 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 2023. The following rules were applied: In the case of patent data, the data for 2022 was estimated per country and field/technology based on the data available in the databases for the first five months of 2022 and compared with the proportion of patent applications in the first five months of 2021 in relation to all patent applications in 2021. The patent figures calculated in this way were then extrapolated to the year 2023. Data series ending in 2021 or earlier were estimated forward for one year using time series analysis. The data was then extrapolated up to 2023. Data up to 2023 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 2022 and 2023 could now be provided compared to the 2023 Innovation Indicator, published in spring 2023, which covered data up to 2021. 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 (2022): 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 Ct. 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 comprises all countries in the Innovation Indicator for which values are available for as many years as possible and for as many individual indicators as possible. These are Austria, Belgium, the Czechia, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, the Netherlands, Poland, Portugal, Spain, Sweden, Switzerland, the United Kingdom and the USA.

3 As some data is not available for Taiwan (in particular foreign trade data), only 34 economies rather than the full 35 are examined in the analyses of key technologies.

4 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.

PROJECT PARTNERS

BDI
Bundesverband der Deutschen Industrie e.V.

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.
bdi.eu

Roland Berger

Roland Berger is one of the world's leading strategy consultancies with a wide-ranging service portfolio for all relevant industries and business functions. Founded in 1967, Roland Berger is headquartered in Munich. Renowned for its expertise in transformation, innovation across all industries and performance improvement, the consultancy has set itself the goal of embedding sustainability in all its projects. Roland Berger revenues stood at more than 1 billion euros in 2023.
rolandberger.com

Fraunhofer ISI

The Fraunhofer Institute for Systems and Innovation Research ISI conducts research in seven Competence Centers with a total of 28 business areas for practical applications and sees itself as an independent pioneer for society, politics, and business. Our competence in the field of innovation research is based on the synergy of knowledge in the fields of technology, economics, and social sciences which our staff members possess. In our work, we not only apply a wide range of advanced scientific theories, models, methods, and social science measurement tools, but also continuously further develop them using empirical findings from the research projects we conduct.
isi.fraunhofer.de/en.html

ZEW

The ZEW – Leibniz Centre for European Economic Research in Mannheim is a non-profit and independent institute with the legal form of a limited liability company (GmbH). ZEW is a member of the Leibniz Association. Founded in 1990 on the basis of a public-private initiative in the Federal State of Baden-Württemberg in co-operation with the University of Mannheim, ZEW is one of Germany's leading economic research institutes, and enjoys a strong reputation throughout Europe.
zew.de/en

EDITORIAL INFORMATON

PUBLISHER

Federation of German Industries (BDI)
Breite Straße 29
10178 Berlin, Germany

Roland Berger Holding GmbH & Co. KGaA
Sederanger 1
80538 Munich, Germany

AUTHORS

Rainer Frietsch, Christian Rammer, Torben Schubert,
Cecilia Garcia Chavez, Sonia Gruber, Valeria Maruseva,
Rainer Walz

RESPONSIBLE

Iris Plöger (BDI, Member of the Executive Board),
Stefan Schaible (Roland Berger, Global Managing Partner)

EDITORS

Dr. Rainer Frietsch (Fraunhofer ISI), Prof. Dr. Torben Schubert
(Fraunhofer ISI), Dr. Christian Rammer (ZEW), Dr. Carsten Wehmeyer (BDI),
Laura Biehn (Roland Berger), Dr. David Born (Roland Berger)

GRAPHICS AND LAYOUT

SeitenPlan GmbH, Dortmund, Germany

STATUS

September 2024

COPYRIGHT

Federation of German Industries (BDI), Roland Berger

»

EVERYONE HAS TO WANT INNOVATION: IT IS THE RESPONSIBILITY OF US ALL, NOT THE JOB OF THE FEW. “