innovation indicator

2023

INNOVATIONSINDIKATOR.DE

BDI The Voice of German Industry

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,

Modern, knowledge-based societies need innovation to generate growth. This is particularly true for Germany, as – due to demographic pressures – productivity improvements through innovative technologies are required. At the same time, innovation is the key to solving essential future tasks such as the decarbonization of our industrial nation.

Switzerland, Singapore, and Denmark occupy the top three places in the new Innovation Indicator 2023. Germany follows at a considerable distance in tenth place. "There are no signs of catching up with the top group or of continuous improvement", the team of authors, scientists from the Fraunhofer Institute for Systems and Innovation Research and the Leibniz Centre for European Economic Research (ZEW) judges. This continues a trend for Germany that highlights our weaknesses all too clearly compared to our competitors: deficits that have been known for a long time are not addressed or are addressed too slowly, and opportunities are not sufficiently exploited. Industry has long suffered from a shortage of skilled labor, which is a drag on both innovation power and prosperity. One can only hope that the German government will take a true step forward with the implementation of the Immigration Act for Skilled Workers. Germany's future is at stake. The global challenges posed by climate change and multiple crises are enormous. Without radical transformation and consistent innovation, we will be unable to maintain our competitiveness. Now, what can policymakers and companies do?

Companies must tackle transformation boldly and courageously, while policymakers must become faster and more flexible. There is no shortage of initiatives and expertise in the German government, from the Future Strategy to the Future Council and the Start-up Strategy to the Alliance for Transformation – to name just a few. They all need to take effect now and implement measures that address our weaknesses, accelerate necessary change, and grasp opportunities. This is also what the Innovation Indicator 2023 clearly highlights: Germany is particularly strong across the future-oriented fields, spearheading "advanced production technologies" and ranking second and third for the key categories of "circular economy" and "energy technologies", respectively. Unsurprisingly, we are not performing as well in areas of digital networks and hardware. But this is what the business model for Germany as an industrial location must now focus on: building competence and expanding sovereignty in key technologies that are critical for our country.

Here, closer cooperation between policymakers and business will be crucial to create competitive regulatory frameworks for innovation that are close to the market. What is more, innovation must foster a sustainable transformation of society and economy. And actually, we are beating expectations in this regard: Germany ranks third behind Denmark and Finland in the sustainability indicator, and interest from venture capital investors in early-stage green investments has been roused, and is likely to increase as a result of the German government's DeepTech & Climate Fund.

Finally, the partners Roland Berger and the Federation of German Industries (BDI) also want to contribute to more innovative research regarding innovation by refocussing the Innovation Indicator on the key topics "generating innovation", "developing future fields through key technologies" and "acting sustainably". By revising the methodology and perspective on Germany's innovation capability, with the Innovation Indicator 2023 we are able to present a series of fresh results and findings that should invite discussion.

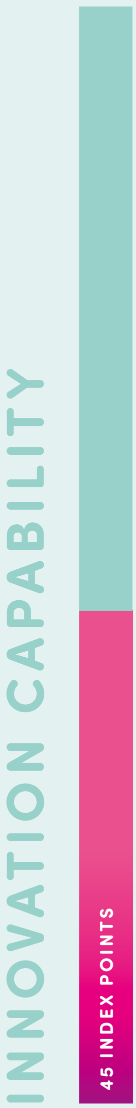
We wish you a stimulating read.

Siegfried Russwurm
President, BDI

Stefan Schaible
Global Managing Partner, Roland Berger

GERMANY'S RANKINGS AND TASKS

At a glance



RANK
10 →

TOP
3

INNOVATION CAPABILITY

RANK	COUNTRY	INDEX (0–100)
1	SWITZERLAND	71
2	SINGAPORE	65
3	DENMARK	60

KEY TECHNOLOGIES

RANK	COUNTRY	INDEX (0–100)
1	FINLAND	47
2	SWITZERLAND	45
3	JAPAN	45

SUSTAINABILITY

RANK	COUNTRY	INDEX (0–100)
1	DENMARK	68
2	FINLAND	54
3	GERMANY	47

Germany must ...

... mobilize the existing potential of skilled labor and speed up the immigration of skilled workers.

... further increase investment in innovative start-ups by expanding venture capital and exit channels.

... foster knowledge and technology transfer through greater flexibili-ty in IP management and spin-offs.

KEY TECHNOLOGIES

43 INDEX POINTS

RANK

7 →

Germany must ...

... increase its technological sovereignty in key technologies by extending its own competencies across the board and establishing differentiated value creation networks.

... expand its investments in key technologies across the board and intensify them in highly relevant areas. This can best be achieved together with European partners.

... prioritize selected fields of technology and deploy resources in a more targeted manner. This requires close interaction between basic scientific research and industrial application-oriented research.

SUSTAINABILITY

47 INDEX POINTS

RANK

3 ↗

Germany must ...

... develop new, circular business models and redesign value creation chains.

... take greater account of the potential of start-ups when supporting sustainable technologies.

... integrate sustainability goals consistently into procurements for the public sector.

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

GERMANY: STUCK IN THE MIDDLE

Key findings

INNOVATION CAPABILITY

- In 2021, Germany ranks tenth compared with 34 industrialized and emerging economies in terms of its ability to produce innovation. The gap to the top is significant. It is mainly smaller economies with a strong specialization in innovation that are at the top here. Among the larger economies, Germany ranks second behind South Korea.

- Germany's position has remained fairly constant over the entire observation period (i.e. since 2005). Neither a catching up with the top group nor a continuous improvement in innovation capability can be observed. The good news is that Germany has been able to maintain its innovation capability in a rapidly changing global environment marked by various crises. The bad news is that undynamic structures result in obstacles when larger adjustments become necessary.

- Germany's strengths are evident in its R&D activities in industry and science. For example, corporate R&D spending is high by international standards, as is company-funded R&D in science. Germany's focus on research-intensive goods is clearly shown in numerous indicators. In addition to the demographic challenge (shortage of skilled workers), Germany's weaknesses in the international comparison include continued low venture capital investment (although this has recently increased significantly) and a declining balance of trade in high-tech goods.

- The ranking of innovation capability is led by Switzerland, followed by Singapore and Denmark. These countries invest heavily in high-performance science systems and ensure close cooperations between science and business. This provides excellent location conditions for innovative and internationally highly networked industries.

- The USA ranks behind Germany, as do the UK and France. The USA's position has been eroding over time, which is among others due to the continued negative balance of trade in high-tech goods and a comparatively low intensity of cooperation between science and industry. In the overall assessment, it should be noted that the innovation performance of the USA is more concentrated in relatively few highly innovative sub-regions than in most other economies. In the USA, less innovation-oriented economic activities (for example, in the energy sector or consumer-oriented services) have grown more strongly in the past decade, while in many fields of innovation there have been relocation processes to lower-cost locations abroad.

- Over the past decade, China has worked its way up into the midfield. However, the effects of the Corona pandemic are glaring in China. In 2021, for the first time since 2013, no increase in the index value could be observed. China's strengths lie on the input side, i.e. high R&D spending by industry and a scientific community becoming ever more productive. On the implementation side, the strongly positive trade balance in the area of high-tech goods stands out.

KEY TECHNOLOGIES

- Germany is ranked seventh overall in key technologies. It has dropped a few places in the rankings over time but has been able to keep the average index score across all key technologies largely constant. However, it is in danger of falling behind in some of the technologies due to other countries investing more heavily and becoming more involved. Germany, on the other hand, is at best following the general trends there. This applies to digital hardware and new materials.

- Germany's strengths lie in production technologies, energy technologies and circular economy technologies. As far as digital networks and biotechnology are concerned, Germany only ever places in the middle of the comparison countries over the entire analysis period.

- Finland ranks first in key technologies. The Scandinavian country is at the top of most technology fields. Its position is particularly strong in digital networks, advanced materials, and the circular economy.

- Since 2007 the USA has also been gradually sliding down the ranks in key technologies – the same as regarding the innovation capability index and currently ranks only tenth. Although the USA was able to maintain its score, it was overtaken by several other countries.

- China has caught up in all fields of technology and has thus also steadily moved up from a mid-table position toward the top group to fifth place in the overall ranking of key technologies.

SUSTAINABILITY

- Germany ranks third among the 35 economies in terms of acting sustainably. It was able to improve its index score from 42 to 47 points in the period from 2005 to 2021.

- Germany shows high index scores in government funding for environmentally relevant R&D, environmental attitudes, and green early-stage investments. Overall, the German system is shown to be across the board focused on sustainability issues, even if it lags somewhat in key indicators of economic success, such as environmental innovation, R&D in renewable energy and patents.

- Denmark ranks first by a clear margin in the sustainability index throughout the entire observation period. A high number of environment-related scientific publications, environmental innovation by companies and environment-related patents are the particular strengths.

- China is in twentieth place. An improvement in its position from 2010 onwards is conspicuous and could be an effect of the increasing focus on sustainable energy supply and environmental innovation. The Chinese government sees sustainability not only as a necessity for preserving the environment, but always also as an opportunity for economic success and greater competitiveness.

- The USA has so far only achieved noteworthy index scores for a few factors as far as acting sustainably is concerned. Overall, it ranks 28th and is thus one of the lowest-ranking countries. No positive development can be derived from the data. It remains to be seen whether the Inflation Reduction Act can give a boost to clean technologies in the USA.

PAVING THE WAY FOR LONG-TERM PROSPECTS

The new Innovation Indicator

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

NEW ALIGNMENT

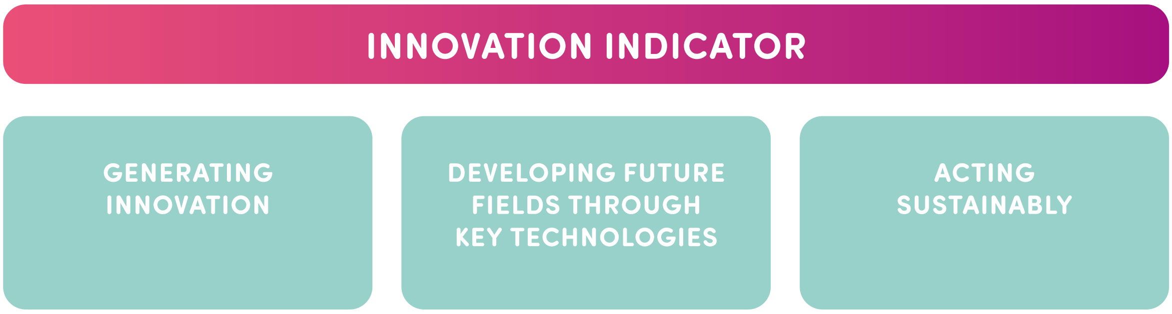
The NIS approach has a long tradition in innovation research and has in the past proven to be a fruitful starting point for the empirical analysis of innovation processes at the national level. This is also reflected in the fact that the approach in research has been continuously developed over the past decades. This was done in order to account for changing framework conditions, for example new societal challenges or the emergence of new technologies. In particular, the system-centric NIS approach has increasingly been extended to include a functional perspective.[1] The focus of this so-called functional NIS approach is no longer on capturing 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 2023 takes up these findings of innovation research and translates them into an operationalized measurement concept that maps key challenges and functions facing modern innovation systems. The increasing technology competition in the course of geopolitical realignment as well as the central challenges of decarbonization and digitalization of industry, science, state, and society are to be understood as the background of the Innovation Indicator 2023. For this reason, the Innovation Indicator focuses on the following three aspects:

- **generating innovation;**
- **developing future fields through key technologies;**
- **acting sustainably.**

All three functions 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 new methodologies of the Innovation Indicator 2023 imply deviations in the results compared to previous editions of the Innovation Indicator, so that a direct comparison is not possible. However, these adjustments seem unavoidable against the backdrop of radically changing innovation processes[2] as a result of crisis-ridden developments (Covid-19, Ukraine war), intensifying innovation competition especially in the area of new key technologies[3] and the increasingly materializing effects of climate change.

The Innovation Indicator 2023 takes into account how sustainable a country's positioning is. This is achieved firstly by analyzing how well the individual economies perform in relation to significant key technologies. Secondly, the Innovation Indicator 2023 considers how sustainably the economy as well as the innovation processes are designed. For example, an economy may be currently successful at generating innovation but face strong barriers to innovation in the long term if it does not invest sufficiently in technologies that will be significant in the future and that drive innovation across many industries. Or if the innovation do not comply with environmental and resource-related sustainability limits. In this sense, the methodological-conceptual innovation of the Inno-



vation Indicator 2023 pursue the goal of developing a more long-term perspective on the innovative capacity of individual economies.

INNOVATION DEFINES 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 innovation in specific, generally defined technology areas and to exploit the resulting economic development potential. This approach is thus based on a long-term, technology-oriented competitive perspective.

This competition perspective is expanded by including the function "acting sustainably," which primarily aims at adhering to planetary limits. This function is concerned with the question of whether existing production and innovation processes are organized sustainably and which scientific and technological prerequisites exist in the countries to support the transformations of industry and society. Both perspectives – that of key technologies and that of sustainability – complement each other. For example, it is possible for an economy to be a leader in the provision of energy technologies and to be able to 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 2023 provides a measurement concept to capture to which extent national economies can maintain their production structures over the long term even within a sustainable economic paradigm.

The reorientation of the Innovation Indicator 2023 pursues the overarching goal of measuring the extent to which various countries secure their future viability with the help of innovation. In doing so, the function "generating innovation", which was already well represented at least implicitly in previous editions of the Innovation Indicator, is expanded to include a decidedly future-oriented perspective. In particular, the function "developing future fields through key technologies" better displays the future technological competitiveness of the individual economies. Additionally, 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 limits and thus are able to be successful in the long term. A list of the respective indicators can be found in the respective chapters.

SWITZERLAND MAINTAINS TOP POSITION

Generating innovation

The Innovation Indicator 2023 presents a new approach to measuring the innovation capability of 35 economies. The indicator aims to display how innovation are generated, introduced, and used productively, and to make the results comparable. To this end, 23 individual indicators measure four sub-processes:

- knowledge creation;
- knowledge diffusion;
- converting knowledge into marketable innovation;
- turning innovation into revenue.

The indicator selection combines measures of an economy's current innovation performance, which is based on past investments, with measures of activities that relate to a country's future innovation capability. In particular, the Innovation Indicator takes into account those factors that will gain in importance for innovation performance. These include, for example, the international orientation of the innovation system and the interaction between science and industry (see info box on page 14).

All individual indicators of the innovation ranking are standardized to the size of a national economy (gross domestic product [GDP] or population size). This enables a direct comparison of innovation capability between countries of different sizes. However, it should be kept in mind that small and large economies have different opportunities to focus on innovative activities.

Due to their limited resources small economies can rarely produce all the goods for which there is demand in a country. Rather, they have to concentrate on certain economic activities in order to achieve a critical size for these and create a differentiated ecosystem. If small countries possess favorable conditions for innovation – such as an efficient scientific community or a well-educated population – they will focus on innovation-oriented activities. Within these areas of specialization, significantly more goods are produced than are needed to satisfy demand within the country, which leads to a strong export orientation in these fields. At the same time, many other required goods are imported.

In contrast, large economies usually have a very broad spectrum of economic activities because the production potential otherwise exceeds global demand. If, for example, the USA were to concentrate a large part of its economic resources on the production of high-tech goods such as semiconductors or pharmaceuticals, this would result in a production volume far in excess of global need. At the same time, demand for basic goods – from food to personal services – is so high in large economies that it is unrealistic to import most of these basic goods. Therefore, large economies have a more balanced economic structure in terms of very innovative and less innovative activities than small economies.

As a result, innovation-oriented activities can account for a much higher share of all activities in small economies than in large ones. Thus, when indicators for measuring innovation performance are normalized according to the size of the economies studied, small countries often perform significantly better than large ones – although the absolute innovation contribution of small countries pales in comparison to large economies. In large economies, on the other hand, innovation is often strongly concentrated in certain sub-regions with particularly favorable conditions. If these sub-regions were considered separately, they would often show a significantly higher innovation capability than many of the highly innovative small economies.[4] Combined with other sub-regions that specialize in non-innovative activities, however, the average measure of innovation capability is noticeably lower.

MAIN FINDINGS

Switzerland, once again, ranks as the country with the highest capability to innovate in our 2023 assessment. It achieved 71 out of a possible 100 points. Singapore follows with 65 points and Denmark is in third place with 60 points. Ranked fourth to seventh are Belgium (54 points), Ireland (53), Sweden (50) and Finland (49), four other rather small economies. The first larger economy to be found is South Korea (48), only in nineth place, behind the Netherlands. Germany ranks tenth with 45 points, making it the second most innovative country among the larger economies. With 42 points, the USA lies behind Germany, as do the UK (41) and France (38).

The high scores of smaller economies show that they find it easier to allocate a larger share of the available human and financial resources to the creation and economic exploitation of new knowledge. Singapore is an outstanding example of this. The city-state with less than 6 million people on an area smaller than the urban area of Berlin has long relied on new technologies and innovation-oriented economic sectors – from microelectronics and biotechnology to the digital economy, the financial sector and innovative logistics. To this end, the country invests both in excellent science and a very well-educated population, as well as in the establishment and growth of innovative industries. At the same time, there is strong international networking and intensive exchange between science and industry. With this strategy, Singapore has gradually worked its way up from a mid-table position since the mid-2000s and has been at the top for around ten years.

In Europe, Switzerland and Denmark follow a very similar approach to Singapore. Large investments in a capable science system create excellent conditions for innovative and internationally highly networked industries. In addition to high spending on university level education and excellent science, close cooperations between industry and science are a locational advantage. As far as industries are concerned, both countries focus on pharmaceuticals/

INNOVATION CAPABILITY: RANKING AND INDEX VALUES OF THE ECONOMIES

RANK	ECONOMY	Index value (0–100)
1	SWITZERLAND	71
2	SINGAPORE	65
3	DENMARK	60
4	BELGIUM	54
5	IRELAND	53
6	SWEDEN	50
7	FINLAND	49
8	THE NETHERLANDS	48
9	SOUTH KOREA	48
10	GERMANY	45
11	ISRAEL	44
12	NORWAY	44
13	AUSTRIA	44
14	USA	42
15	UNITED KINGDOM	41
16	CANADA	40
17	AUSTRALIA	39
18	FRANCE	38
19	TAIWAN	34
20	SPAIN	33
21	HUNGARY	30
22	GREECE	29
23	CZECHIA	29
24	PORTUGAL	28
25	ITALY	28
26	CHINA	28
27	JAPAN	25
28	POLAND	25
29	RUSSIA	20
30	TURKEY	19
31	MEXICO	14
32	INDIA	9
33	SOUTH AFRICA	8
34	BRAZIL	6
35	INDONESIA	1

Source: Fraunhofer ISI calculations

biotechnology and mechanical engineering. Denmark also has a highly developed knowledge-intensive service sector.

Belgium has also increasingly followed a path of specialization in particularly innovation-oriented activities over the past decade. This is reflected in a strong increase in R&D spending. In 2020, R&D expenditure by Belgian business and science reached a share of 3.4 percent of the country's GDP. This is the second-highest figure among all European countries – just behind Sweden, but still ahead of Switzerland and Germany. In 2010, by contrast, Belgium's R&D ratio was only 2.1 percent. Ireland has also continuously been strengthening its focus on innovation, although the Emerald Isle chose a different approach than the four countries ranked ahead of it. The Irish strategy has so far relied heavily on the establishment of foreign technology corporations, including generous R&D funding, a large (English-speaking) skilled workforce and access to the European single market. By contrast, investments in science remain low, but the focus on excellence and cooperation in the relatively small domestic science sector has been greatly increased.

But not all small countries that have followed a path of strong innovation orientation and achieved very high index scores have been able to maintain this high level in the long run. In the 2000s, Sweden and Finland were among the most innovative countries in the world. Sweden was able to maintain a high index value until the mid-2010s, but then fell back. In Finland, a downward trend began earlier. The reason for this in both countries is the strong concentration of the national innovation system on digital technologies. In this highly dynamic field of technology, it is more difficult to maintain innovation leads once gained than in other technology areas. However, small economies cannot avoid focusing their relatively small amount of resources on a few innovation topics. They therefore always run the 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 innovation or business models.

From a long-term perspective, Switzerland's current top position is also less clear-cut than a mere glance at its ranking would suggest. In the mid-2000s, Switzerland

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 enters the overall index with a weighting of -1, i.e. a high indicator value indicates a high capacity for innovation).
- 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

still had a significantly higher level of innovation capability relative to its competitors. The index value declined until 2008 but remained constant thereafter. Since the mid-2010s, however, there has been a slight downward trend again, meaning that other countries are catching up faster. However, this need not be a disadvantage per se for Switzerland, because its specific competitive advantages in education and knowledge generation, as well as Switzerland's specific technological focus (mechanical engineering, high-tech instruments, pharmaceuticals, chemicals, medical technology) differs from that of other countries at the top.

The example of Singapore shows that small countries can succeed relatively quickly in catching up with the top nations, but that it is difficult to continue to increase innovation capability from the top. In Singapore, the dynamic process towards ever greater innovation orientation seems to have come to a standstill in the second half of the 2010s. Belgium, which started the catching-up process later, shows a dynamic development up to the present time.

» IN EUROPE, SWITZERLAND AND DENMARK FOLLOW A SIMILAR APPROACH TO SINGAPORE. «

GERMANY: SECOND AMONG THE MAJOR ECONOMIES

Large economies, on the other hand, tend to show a more stable development of their innovation capability. On the one hand, this is because they cover a much larger number of technologies and innovation topics, so that abrupt changes in one technology area do not have a strong impact on the overall ranking. On the other hand, large economies would have to shift considerably more financial and human resources in order to change innovation performance noticeably. Against this background, the large innovation momentum in South Korea between 2010 and 2015 is remarkable. During this period, the country benefited from its strategy towards information technologies and digital economy. Since 2017, South Korea has been the most innovative of the major economies in the Innovation Indicator. South Korea scores high due to high R&D spending in business and science, a well-educated population, and efficient translation of innovation into economic returns. This indicates high efficiency in the transformation of inputs into outputs.

Compared with South Korea, Germany shows much lower dynamics. The index value has hardly changed over the past 15 years. This indicates a stable innovation system that has been able to defend its locational advantages in a rapidly changing global environment characterized by various crises but has developed little momentum. Germany's strength lies in its good performance in all four processes of innovation creation and use, i.e., in a balanced system. As a result, Germany, like South Korea, achieves particularly high scores in the indicators that measure the economic returns of innovation. In contrast, clear weaknesses are evident in the area of skilled labor. The ratio of university graduates to older employed graduates is unfavorable, and the proportion of vacant positions is very high. Despite improvements in recent years, Germany performs poorly in terms of venture capital investments. Some indicators of knowledge transfer between science and industry are also low, such as cooperation in basic research (measured by joint scientific publications). This reflects the fact that only few companies in Germany conduct basic research. The R&D activities of companies are strongly focused on implementation-oriented projects. On the one hand, this ensures a strong position in turning innovation into market successes. On the other hand, this makes it more difficult to quickly take up new topics of innovation that develop out of basic research.

German innovation policy in recent years has pursued two main approaches to keep the balanced system competitive in the face of global dynamics. On the one hand, Germany aims to increase R&D spending (3.5 percent target, i.e. increase R&D spending of GDP to this level by 2025). At the same time, the focus on excellence in science and collaboration between individual scientific institutions and between science and industry is to be strengthened. Examples here include both the Research Campus Program and the continuation and expansion of the ZIM (Central Innovation Program for small and medium-sized enterprises (SMEs)) program. At the European level, these efforts have been accompanied by flagship programs (for example, battery or quantum technologies) or programs of common interest (IPCEIs), for example, concerned with hydrogen or batteries.

The dynamics of innovation capabilities are different for the United Kingdom. Starting from a similarly high index value as Germany in the mid-2000s, the UK has lost innovation capability significantly, especially after the financial crisis of 2007/08. Since 2012, a slow but steady catching-up process has been taking place. The UK's strength clearly lies in science, which is characterized by a large publication output and a large output of highly qualified people. By contrast, performance in the area of translating knowledge into innovation and economic returns is weak. This shows that knowledge and technol-

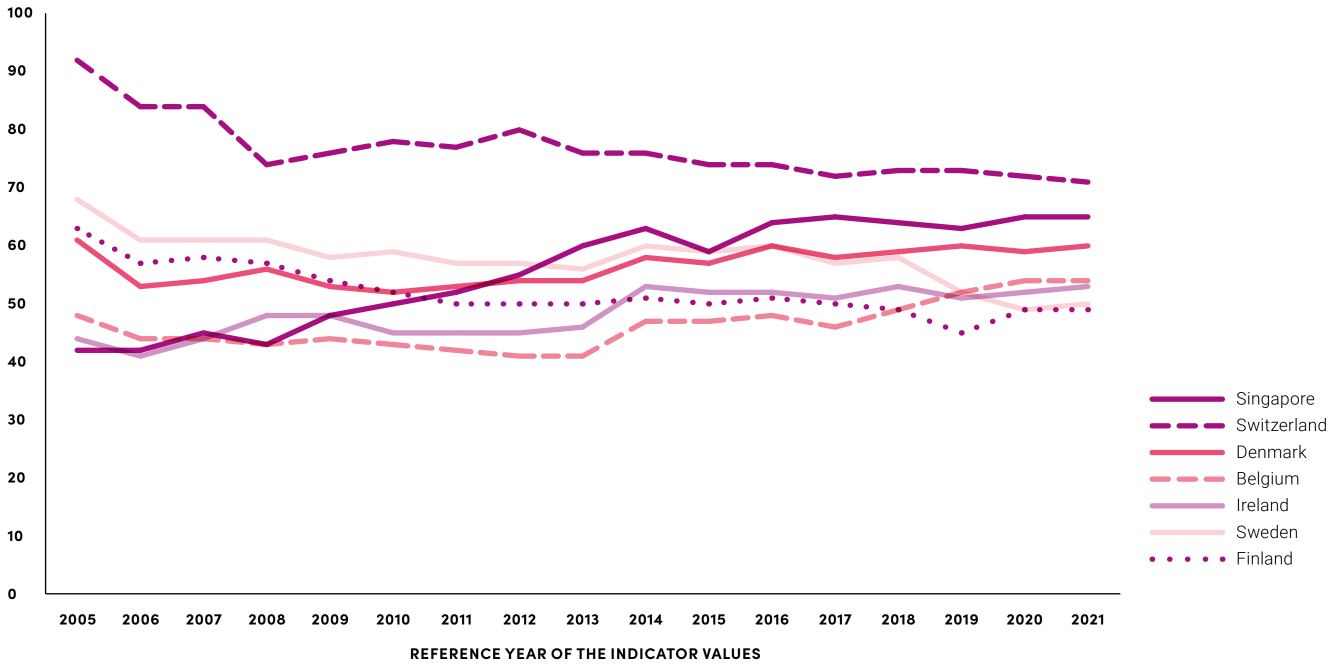
» GERMANY HAS A STABLE INNOVATION SYSTEM WITH LITTLE MOMENTUM. «

INNOVATION CAPABILITY: OVERALL RANKING OF ECONOMIES

RANK	2005	2010	2015	2020	2021
1	SWITZERLAND	SWITZERLAND	SWITZERLAND	SWITZERLAND	SWITZERLAND
2	SWEDEN	SWEDEN	SWEDEN	SINGAPORE	SINGAPORE
3	FINLAND	DENMARK	SINGAPORE	DENMARK	DENMARK
4	DENMARK	FINLAND	DENMARK	BELGIUM	BELGIUM
5	USA	SINGAPORE	IRELAND	IRELAND	IRELAND
6	NORWAY	USA	FINLAND	SWEDEN	SWEDEN
7	THE NETHERLANDS	AUSTRIA	BELGIUM	FINLAND	FINLAND
8	AUSTRIA	IRELAND	ISRAEL	THE NETHERLANDS	THE NETHERLANDS
9	CANADA	GERMANY	THE THE NETHERLANDS	SOUTH KOREA	SOUTH KOREA
10	BELGIUM	THE NETHERLANDS	AUSTRIA	GERMANY	GERMANY
11	GERMANY	BELGIUM	GERMANY	ISRAEL	ISRAEL
12	UNITED KINGDOM	NORWAY	USA	NORWAY	NORWAY
13	IRELAND	CANADA	SOUTH KOREA	AUSTRIA	AUSTRIA
14	ISRAEL	ISRAEL	NORWAY	USA	USA
15	SINGAPORE	FRANCE	UNITED KINGDOM	UNITED KINGDOM	UNITED KINGDOM
16	AUSTRALIA	SOUTH KOREA	CANADA	AUSTRALIA	CANADA
17	FRANCE	UNITED KINGDOM	AUSTRALIA	CANADA	AUSTRALIA
18	SOUTH KOREA	AUSTRALIA	FRANCE	FRANCE	FRANCE
19	JAPAN	JAPAN	SPAIN	TAIWAN	TAIWAN
20	SPAIN	SPAIN	HUNGARY	SPAIN	SPAIN
21	ITALY	TAIWAN	CZECHIA	HUNGARY	HUNGARY
22	TAIWAN	HUNGARY	TAIWAN	ITALY	GREECE
23	RUSSIA	RUSSIA	JAPAN	GREECE	CZECHIA
24	CZECHIA	ITALY	PORTUGAL	CHINA	PORTUGAL
25	HUNGARY	CZECHIA	RUSSIA	CZECHIA	ITALY
26	GREECE	PORTUGAL	GREECE	PORTUGAL	CHINA
27	SOUTH AFRICA	GREECE	ITALY	JAPAN	JAPAN
28	TURKEY	CHINA	POLAND	POLAND	POLAND
29	PORTUGAL	POLAND	CHINA	RUSSIA	RUSSIA
30	POLAND	SOUTH AFRICA	TURKEY	TURKEY	TURKEY
31	CHINA	INDONESIA	BRAZIL	MEXICO	MEXICO
32	INDONESIA	MEXICO	MEXICO	SOUTH AFRICA	INDIA
33	MEXICO	TURKEY	SOUTH AFRICA	INDIA	SOUTH AFRICA
34	BRAZIL	BRAZIL	INDIA	BRAZIL	BRAZIL
35	INDIA	INDIA	INDONESIA	INDONESIA	INDONESIA

Source: Innovation Indicator

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



Source: Fraunhofer ISI calculations

ogy transfer is inadequate. Political efforts in this area, such as the application-oriented Catapult program, have not had a broad impact due to the EU exit and the current economic crisis.

An upward trend can also be observed for France over the last five years. This is due, among other things, to the high level of investment by the state in supporting R&D in businesses (tax incentives) and the very good performance of the science system. However, France – like the UK – comes up short in the ability to translate this knowledge into market success.

In the USA, on the other hand, the index value is falling slowly but steadily. Until around 2010, the USA was clearly in first place among the large economies. With the financial crisis, the position deteriorated noticeably. Since then, there has been a steady decline. It should be noted that the innovation performance of the USA is concentrated to a greater extent than in most other economies in a relatively small number of highly innovative sub-regions. These include first and foremost Silicon Valley and other regions in California, the northeastern region around New York and Boston, the region surrounding Seattle, as well as individual locations in the Great Lakes area and the southern states. Conversely, the by far largest parts of the USA have hardly any innovation centers of global significance. In the overall view of this large country, this does not result in a prominent position in an international comparison, although the global importance of the USA as an innovation location is undisputed. At the same time, less innovation-oriented economic activities have grown more strongly in the past decade, while in many innovation fields there have been relocation processes to lower-cost locations abroad.

China's position in the innovation rankings has improved continuously. The large gap to the leading major economies has been more than halved since 2005. However, in 2021, for the first time since 2013, there was no increase in the index value. China's strengths are on the input side, i.e. high R&D spending by industry and an increasingly capable science sector. This is typical of countries that move from a relatively low level of development towards becoming a modern industrialized country. On the implementation side, the strongly positive trade balance in high-tech goods stands out.

Japan plays a special role. The country has been lagging 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 contradicts the strong innovative position of Japanese companies in many markets and technology fields. However, this position is based on structures and investments that were created or made a long time ago. In addition, the development of the competitive situation with China poses a particular challenge to Japan's "traditional" technology areas such as microelectronics and consumer electronics.

Japan is in a weak position as far as terms of future-oriented indicators are concerned, such as e.g., the performance of the science system, the supply of skilled workers, the international orientation of the innovation system, the exchange of knowledge between science and industry, and venture capital investment. Japan is well aware of the danger that results from persisting on established structures for too long. However, the country 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 of the past three decades, the increasing shortage of skilled labor, but also strongly hierarchical decision-making mechanisms and a certain tendency of Japanese society to close itself off have created and continue to create difficult conditions for a fundamental change in the Japanese innovation system. The Innovation Indicator shows that it still has not been possible to set this change in motion.

SOUTHERN AND EASTERN EUROPE ARE CATCHING UP

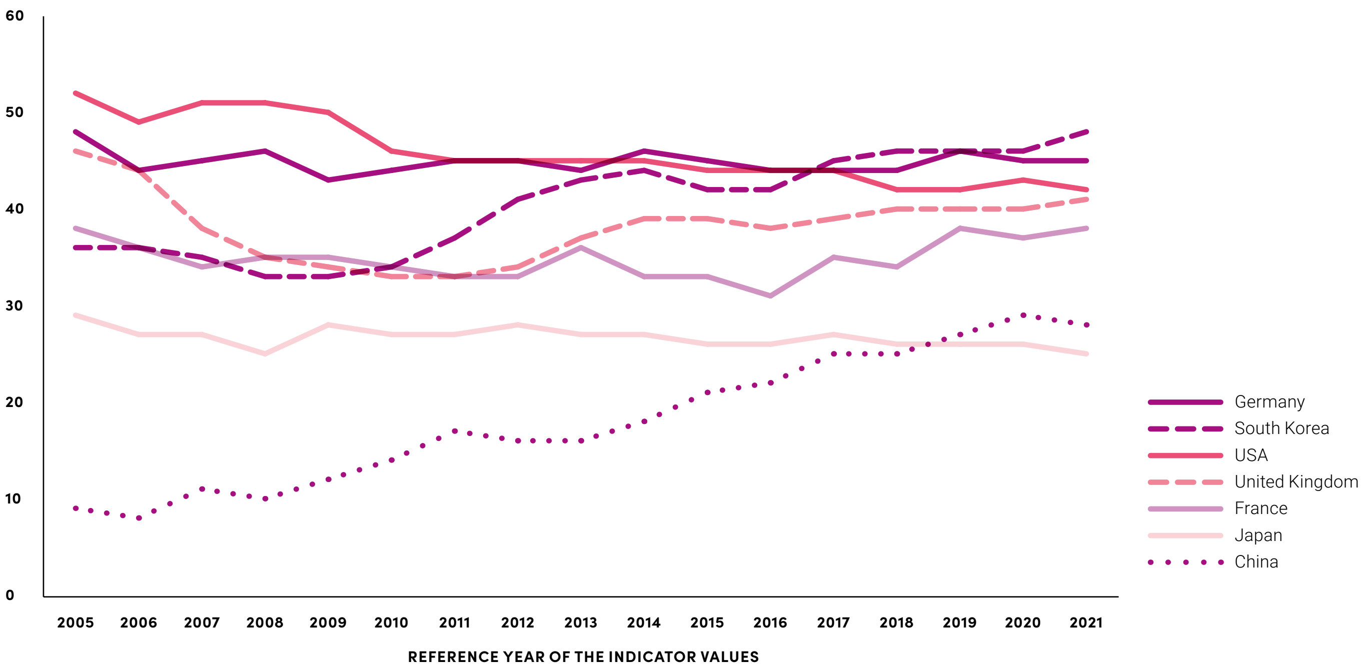
The Innovation Indicator also looks at Southern and Eastern European countries because, from a scientific and technological point of view and due to their economic developments, they are a notable factor not only in Europe but worldwide. All the countries examined place in the lower half of the ranking. In an overall narrow field, Spain scores best with 33 points and Poland worst with 25 points. In between lie Hungary (30), Greece (29), Czechia (29), Italy (28) and Portugal (28). Over the past 15 years, all countries in this group managed to improve. At the same time, the innovation performance of the countries converged significantly. This is particularly due to the fact that Greece, Portugal and Poland significantly increased their investments in an innovation-based competitive strategy.

Spain and Czechia recorded increases in the index value until the mid-2010s but have stagnated since then. Apparently, the resources in these countries are not sufficient to dynamically continue the catch-up process. Hungary also experienced setbacks in further increasing its innovation performance after 2015 but has been able to improve noticeably again since 2020. After an initial decline, Italy was able to successively increase its innovation performance from 2012 onwards. The Southern and Eastern European countries show quite similar strengths and weaknesses in innovation performance. In all six countries, the state makes substantial financial contributions to corporate R&D spending. The science system is relatively extensive, and the supply of well-trained skilled workers is large. Weaknesses relate to the low R&D and patent activities of industry, the low quality of scientific output and a low level of cooperation between science and industry. Innovation results are low overall, although Czechia and Hungary have been able to focus their economic activities strongly on high-tech industries, thanks in part to investment from abroad.

EMERGING ECONOMIES LAG BEHIND

The Innovation Indicator also examines the innovation capability of so-called emerging economies. These countries are attempting a structural shift towards higher-value production activities and greater integration into the global economy. An important lever for achieving this goal is the expansion of innovation activity. However, there has been no noticeable improvement in any of the countries in recent years. They form the bottom group in the innovation ranking. Russia and Turkey lead this group

INNOVATION CAPABILITY: DEVELOPMENT OF LARGE ECONOMIES



Source: Fraunhofer ISI calculations

INNOVATION CAPABILITY: DEVELOPMENT OF THE SOUTHERN AND EASTERN EUROPEAN ECONOMIES

Source: Fraunhofer ISI calculations

with index scores of 20 and 19 points respectively. They are followed by Mexico (14), India (9), South Africa (8) and Brazil (6). Indonesia brings up the rear with one point.

Within the group, only Turkey has shown a clear upward trend over the past twelve years. India and Mexico also report a tendency towards rising index values. South Africa and Indonesia, on the other hand, tend to show declining index values. Russia shows little overall momentum but has largely been able to maintain its starting level over time.

The emerging economies have very low scores for almost all indicators. They score mainly with large government support for corporate R&D spending and a high level of patent internationalization. This means that the few patent applications often result from collaborations with foreign partners. In most countries, the indicator for the number of young graduates is favorable, i.e., significantly more young people complete university level education than older people with university level education leave the labor market. Russia is characterized by a very high ratio of academically educated people in the labor force, which is a remaining legacy of the Soviet era. In addition, the trade balance in high-tech goods is strongly positive, but this is also the result of low imports due to trade restrictions on high-tech goods. India is the only emerging country with a developed venture capital market.

RECOMMEN- DATIONS

1

MAKING OPTIMUM USE OF AND EXPANDING THE POTENTIAL FOR SKILLED WORKERS

The potential for skilled workers available in Germany must be exploited more extensively. Working conditions for women must improve significantly, from the elimination of all discrimination in pay and advancement opportunities to the full reconciliation of work and family life. Continuing education for employees must become both more individualized – keyword: personalized learning – and needs-oriented. And in school education, as many young people as possible should leave the school system with an adequate basic qualification. In addition, the potential of people who want to continue working after retirement must be recognized and promoted through appropriate working arrangements.

However, mobilizing the potential of skilled labor is not enough to compensate for demographic change. Therefore, the immigration of skilled workers is indispensable. The legal prerequisites for this have been significantly improved with the recent reform of the Immigration Act for Skilled Workers. However, in order for the legal simplifications to reach the immigrants, the administrative processes must be completely reorganized. Instead of the immigration authorities and embassies, the process must be handed over to a new "new citizens" authority from the very first step. By using digitalization in all procedural steps, this authority can be kept lean.

Germany must ensure steady progress of its innovation ecosystem to maintain its innovation capability. This has been achieved well over the past 15 years. The 3.5 percent target is intended to continue this path of steady expansion of innovation resources. The challenge is to translate the high level of investment in R&D into innovation. This involves not only the introduction of new technologies, but also new business models and the development of new value creation networks.

Overall, efficiency has to increase. It is crucial to increase innovation capability in all sectors of the economy, accelerate the diffusion of knowledge and technologies, deepen the transfer between research and application, and remove obstacles to the exploitation of innovation. The government's new Future Research and Innovation Strategy has provided impetus in this regard. However, additional efforts are needed, particularly in the areas of skilled labor supply, innovative start-ups, and technology diffusion.

SUPPORTING INNOVATIVE START-UPS WITH SUITABLE TOOLS

Innovative start-ups are important drivers of technological change and can create new markets with innovative business models. Venture capital is needed so that such start-ups can quickly turn their ideas and economic potentials into growth. With its Start-up Strategy, the German government has recognized the importance of these companies and has implemented a number of effective measures to increase venture capital investment in Germany, such as the Future Fund, the DeepTech & Climate Fund and the increase in the High-Tech Start-up Fund.

However, in order for venture capital to reach growth-oriented start-ups, attractive exit channels are needed for investors. In addition to the classic initial public offering (IPO), alternative forms such as special purpose acquisition companies (SPACs for short) should also be made possible. In many business areas, going public is not always the best exit channel since the global roll-out of business models requires industrial partners with appropriate market knowledge as well as production and distribution capacities. In order to push the entry of established companies into start-ups, it is above all necessary that companies are willing to invest. This can be supported via tax regulations, for example by facilitating capital increases.

STRENGTHEN KNOWLEDGE TRANSFER AND DIFFUSION OF TECHNOLOGIES

Spin-offs from science are a promising way to turn new research results into commercial applications. A longer parallel or transition phase can lead to a higher spin-off quality. Founders can thus work on the validation and further development of the research results on the one hand and on the other hand advance the development of their company. Flexible employment opportunities at science institutions should be offered for this purpose.

For successful cooperation between science and industry, managing the intellectual property (IP) created in the cooperation plays an important part. Professional and efficient administration on the part of the scientific institutions as well as fair and suitable agreements are essential for this. At universities in particular, care must be taken to ensure that such agreements are implemented quickly and based on the costs actually incurred at the university as well as on a realistic assessment of the value of the IP.

In the public debate, it is discussed whether the introduction of a grace period for novelties could reconcile academic and exploitation interests, in order to increase the patent activity which has been stagnating recently.

FINLAND: A NARROW LEAD

Developing future fields through key technologies

The term key (enabling) technologies is used to describe those technologies that form the basis for new products in a large number of economic sectors, enable technological change and address the major challenges of our time. In addition to the term "key enabling technologies" (KETs), which emphasizes the enabling character of these technologies, the term "general purpose technologies" (GPTs), which emphasizes their cross-industry character, is also used in English. In the Innovation Indicator, we look at seven key technologies with very different focuses. 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 or cloud computing);
- advanced production technologies (modern machines, facilities respectively 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 or microorganisms and processes based on them as well as processing and measuring methods);
- circular economy (technologies for returning materials into the materials cycle).

The technologies were selected on the basis of four criteria. First, each key technology should cover a technology field that is distinct from other key technologies and in which sufficient activities already take place (critical mass) and various methods and technological solutions are used. This critical mass of activities should be present at all stages of the innovation process and be able to be represented in the Innovation Indicator via performance indicators in order to be able to ensure a sufficient degree of maturity of the technology field.

In addition to intensive scientific activities, there should also be technological applications (patents) and new products or processes. The latter need not necessarily be the case for all sub-areas of a technology field. For example, quantum technologies have so far been more important in science and basic applications, while markets for these technologies have yet to develop. However, they are part of an overarching technology field (digitalization or digital hardware and digital networks) for which markets can be identified. Furthermore, the key technologies should be relevant in several economic sectors or for a variety of applications. Finally, the key (enabling) technologies are expected to play a major part in the competitiveness and innovation activity of national economies in the future and therefore also be part of the innovation policy agenda in numerous countries.

The choice of selection of the seven key technologies examined here will be reviewed at regular intervals in the future to ensure that they are up to date and relevant.

The indicators aim to cover the entire innovation spectrum from basic research to technological applications and market activities (diffusion of innovation).

INDICATORS FOR MEASURING KEY TECHNOLOGIES

For all seven key technologies, the following indicators are collected and combined into both an index per key technology and an overall index for all seven key technologies.

- Share of scientific publications in the area of the individual key technologies among all national publications
- Share of scientific publications in the area 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 population of a country
- Balance of trade in the area of the individual key technologies in relation to global exports in the area of 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, including Series C and D) in the individual key technologies in relation to GDP (only used for the integrated indicator, not for calculating the key figures in the individual key technologies)
- Share of computer-implemented inventions (software patents) in all inventions in the area of the respective key technology

» GERMANY IS MERELY FOLLOWING THE GENERAL TREND AND INVESTING TOO LITTLE. «

KEY TECHNOLOGIES: OVERALL RANKING OF ECONOMIES

RANK	2007	2010	2015	2020	2021
1	SWITZERLAND	SWITZERLAND	SWITZERLAND	FINLAND	FINLAND
2	JAPAN	JAPAN	FINLAND	JAPAN	SWITZERLAND
3	USA	FINLAND	JAPAN	SWITZERLAND	JAPAN
4	GERMANY	GERMANY	GERMANY	SINGAPORE	DENMARK
5	SINGAPORE	USA	USA	DENMARK	CHINA
6	SWEDEN	SINGAPORE	SINGAPORE	CHINA	SINGAPORE
7	DENMARK	SWEDEN	SWEDEN	GERMANY	GERMANY
8	FINLAND	DENMARK	DENMARK	SWEDEN	SWEDEN
9	THE NETHERLANDS	THE NETHERLANDS	SOUTH KOREA	SOUTH KOREA	SOUTH KOREA
10	IRELAND	IRELAND	IRELAND	USA	USA
11	AUSTRIA	AUSTRIA	THE NETHERLANDS	IRELAND	IRELAND
12	UNITED KINGDOM	UNITED KINGDOM	CHINA	THE NETHERLANDS	THE NETHERLANDS
13	ISRAEL	BELGIUM	AUSTRIA	UNITED KINGDOM	UNITED KINGDOM
14	BELGIUM	CHINA	UNITED KINGDOM	AUSTRIA	AUSTRIA
15	FRANCE	SOUTH KOREA	BELGIUM	ITALY	ITALY
16	CANADA	FRANCE	SPAIN	BELGIUM	SPAIN
17	CHINA	NORWAY	FRANCE	ISRAEL	AUSTRALIA
18	NORWAY	ISRAEL	PORTUGAL	SPAIN	BELGIUM
19	ITALY	PORTUGAL	ISRAEL	NORWAY	INDIA
20	SPAIN	CANADA	CANADA	FRANCE	FRANCE
21	SOUTH KOREA	SPAIN	NORWAY	AUSTRALIA	ISRAEL
22	AUSTRALIA	AUSTRALIA	ITALY	INDIA	NORWAY
23	INDIA	CZECHIA	HUNGARY	CZECHIA	PORTUGAL
24	GREECE	ITALY	AUSTRALIA	CANADA	CANADA
25	BRAZIL	GREECE	INDIA	PORTUGAL	CZECHIA
26	CZECHIA	BRAZIL	CZECHIA	POLAND	POLAND
27	POLAND	INDIA	MEXICO	HUNGARY	HUNGARY
28	RUSSIA	RUSSIA	POLAND	GREECE	RUSSIA
29	PORTUGAL	POLAND	BRAZIL	SOUTH AFRICA	GREECE
30	SOUTH AFRICA	SOUTH AFRICA	RUSSIA	RUSSIA	SOUTH AFRICA
31	HUNGARY	MEXICO	SOUTH AFRICA	INDONESIA	INDONESIA
32	TURKEY	HUNGARY	TURKEY	BRAZIL	BRAZIL
33	MEXICO	TURKEY	GREECE	MEXICO	TURKEY
34	INDONESIA	INDONESIA	INDONESIA	TURKEY	MEXICO

Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2023

At the same time, they should be able to capture the competitiveness of countries in the different dimensions of innovation capability. In the case of the innovation capability of economies, the Innovation Indicator adopts a relative perspective that is independent of a country's size (measured by GDP or population). This perspective is also adopted for key technologies.

In addition, for "ensuring future competitiveness," indicators that take into account size effects in the various economies are also included. This is because, firstly, scale and learning effects play a major part in the development of technologies and their commercialization. Secondly, economies of scale have a beneficial effect in the creation and development of markets, which should be taken into account when assessing innovation capability and competitiveness, for example via market shares or first-mover advantages. Finally, thirdly, to maintain momentum key technologies, it is crucial to test as many potential development paths as possible and not just focus on a specific sub-area or a specific technological solution.

Therefore, the breadth and diversity of technology developments play a major part, which is strongly related to the absolute size of technological activities.[5] Accordingly, indicators are used that are independent of a country's size as well as those that take size effects into account (for example, the indicator "number of patents in a key technology out of all patents in a country" is independent of the size of an economy, while the indicator "share of a country in all patents in a key technology worldwide" also reflects the country's size).

CENTRAL RESULTS

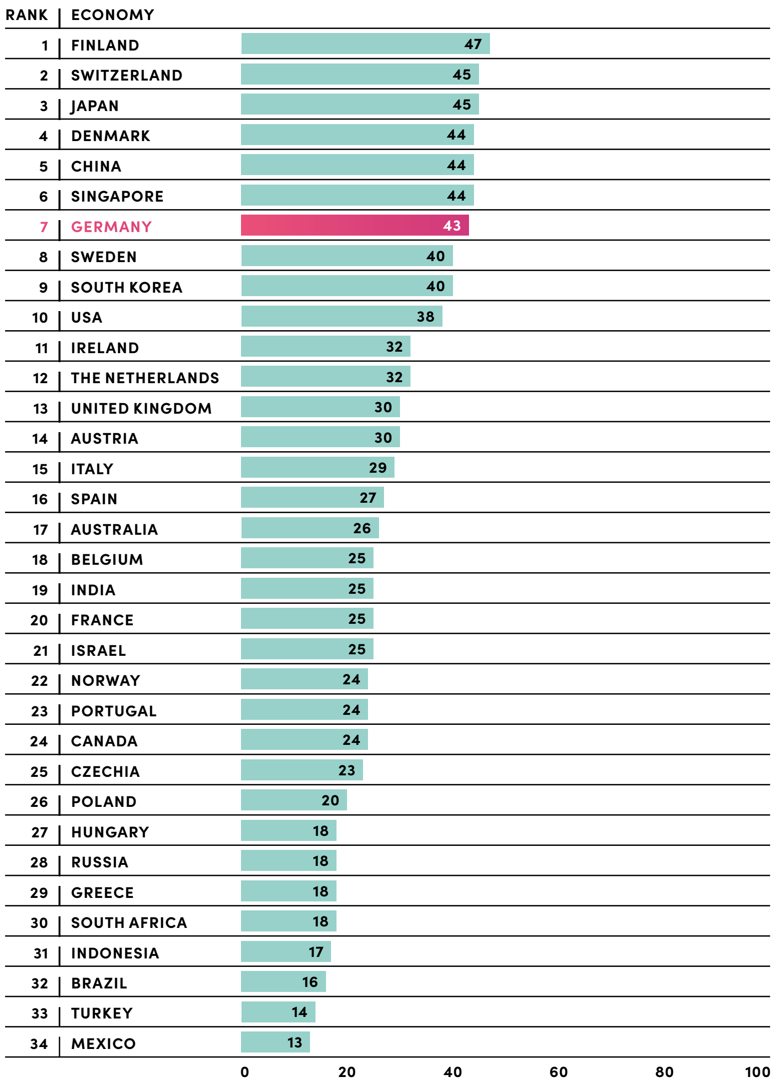
In the following passage, the overall indicator in this area is considered first, before the results of the individual seven key technologies are presented in the following sections.

Finland leads the field in key technologies with 48 points, just ahead of Switzerland, which scores 46. The leading field is very close, with Japan (45), Denmark (45) and China (44) in third to fifth place. Singapore and Germany are sixth and seventh with 43 points each. South Korea (41), Sweden (40) and the USA (38) are also connected to the top group.

The midfield is slightly separated from this top group and is led by the Netherlands (32) and Ireland (32). The United Kingdom (30), Austria (30) and Italy (29) line up in the other places. Spain, Australia, Belgium, France, India, Israel, Norway, Canada, Portugal, and the Czech Republic follow at a slightly greater distance from the top group with index values between 27 and 21 points. Countries behind the midfield in this ranking include Russia, Hungary, South Africa, Brazil, Indonesia, and Greece (between 18 and 16 points). At the lower end are Turkey and Mexico with 14 and 12 points respectively.

In addition to China, which has caught up in all technology areas and has therefore also steadily moved up from a mid-table position towards the top group in the overall ranking of key technologies since 2007, Finland was also able to achieve a top position. The country owes this to its good positions in all seven key technologies, with a particularly strong position in the fields of digital networks, advanced materials, and circular economy. By contrast, the USA has lost considerable ground over the entire period, falling from third place in 2007 to tenth place in 2020 and 2021. Apart from slight fluctuations, the USA has been able to maintain its index values, but has been overtaken by other countries due to their increased performances.

KEY TECHNOLOGIES OVERALL: RANKING AND INDEX VALUES OF ECONOMIES



Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2023

» VENTURE CAPITAL INVESTMENTS ARE AN IMPORTANT LEVER FOR TRANSLATING NEW RESEARCH RESULTS INTO INNOVATION. «

Switzerland placed first in the overall assessment of all key technologies for a long time and was only replaced at the top in the recent past. Switzerland achieves good to very good positions in all key technology areas and therefore continues to be one of the most innovative economies in these technology areas. Switzerland performs particularly well in digital technologies, production technologies and biotechnology. However, the main reason for losing its top spot was a less strong position in energy technologies and, in particular, loss of position in advanced materials and circular economy technologies.

THE LARGER ECONOMIES LIVE OFF THEIR ASSETS

Germany also dropped a few places in the rankings over time, but has been able to maintain its average index score across all key technologies. This means that, similar to the USA, other countries were able to expand their innovation capability in the area of key technologies more strongly and have thus overtaken Germany. These countries include Singapore, Denmark and, most recently, China. Looking at all seven key technologies as a whole, Germany's current position can be described as good. However, Germany is in danger of falling behind in some of these technologies due to other countries investing more and being more involved, while Germany is merely following the general trend. Above all, Germany does not seem to be succeeding in bringing about an improvement regarding the weaknesses in the key technology portfolio. This applies in particular to biotechnology. Against the backdrop of further intensifying innovation competition and the increased need to maintain and expand technological sovereignty, Germany's momentum in the overall view of all areas must be rated as unsatisfactory. As in the case of other large industrialized nations – especially the USA and Japan – the picture that emerges for Germany is one of living more off one's assets and not being able to keep up with the momentum of other countries.

Venture capital (VC) investments are an important lever for translating new research findings into innovation and economic growth. In the Innovation Indicator, the volume of VC investments for individual key technologies was set in relation to a country's GDP in order to reflect the importance of venture capital. However, correspondingly detailed data on VC investments are only available for the European countries. The technology field circular economy cannot be examined due to a lack of data, and only one joint value is available for the two digitalization technology fields.

Finland performs best in terms of VC investments in key technologies. In three of the five technology fields – digital technologies, production technologies and energy technologies – it achieves top scores almost every year. In materials technologies and biotechnology, VC investments are also above average. Other countries with relatively high VC investments in all key technologies are Belgium and the United Kingdom. In other countries, however, VC investors focus strongly on individual technology fields. In Switzerland, this is biotechnology, where the country has the highest value almost every year. In Denmark, biotechnology is also the focus, supplemented by quite high VC investments in digital technologies and production technologies. In Ireland, the VC market is particularly strong in investments in digital technologies as well as biotechnology. In the period of 2018 to 2020, Ireland also led in VC investment intensity in energy technologies. In all other years, Norway took the top position in this technology field.

In terms of VC investment in key technologies, Germany performs below average in a European comparison. While it achieves a roughly average VC investment intensity in digital, production and energy technologies, it falls sharply behind in biotechnologies and even more so in materials technologies.

The relatively small gaps between the individual countries, both at the top and in the middle of the overall cross-technology index, result in part from very different performances in the individual key technologies. While some of the countries specialize strongly in individual technologies and therefore perform well overall, other countries are well positioned in many or all technologies without achieving a top position in any single one. A differentiated view of the individual technology fields therefore allows a more detailed assessment of both the trends and the competitiveness and innovation capability of the individual economies.

DIGITAL HARDWARE

Digital hardware comprises microelectronic and nanoelectronic components, first and foremost computer chips, but also other integrated circuits. They form the basis for numerous applications ranging from consumer electronics, vehicles, and machines to medical technology.

Over the entire observation period from 2007 to 2021, Japan (59 points) placed top of the 35 countries. The country achieved the highest score for patents and the balance of trade in each case, while it lost index points over time for scientific publications and was unable to achieve high values for computer-implemented inventions (software patents) at any time. Overall, these results for Japan mean that classic microelectronics continues to play a major part and that the technological competitiveness also appears to be secured via a large number of patents. However, the position could erode further in the future, since on the one hand the pressure from other economies is increasing and on the other hand the technological reorientation – measured by scientific publications, but also software patents – is taking place faster and more purposefully in other countries.

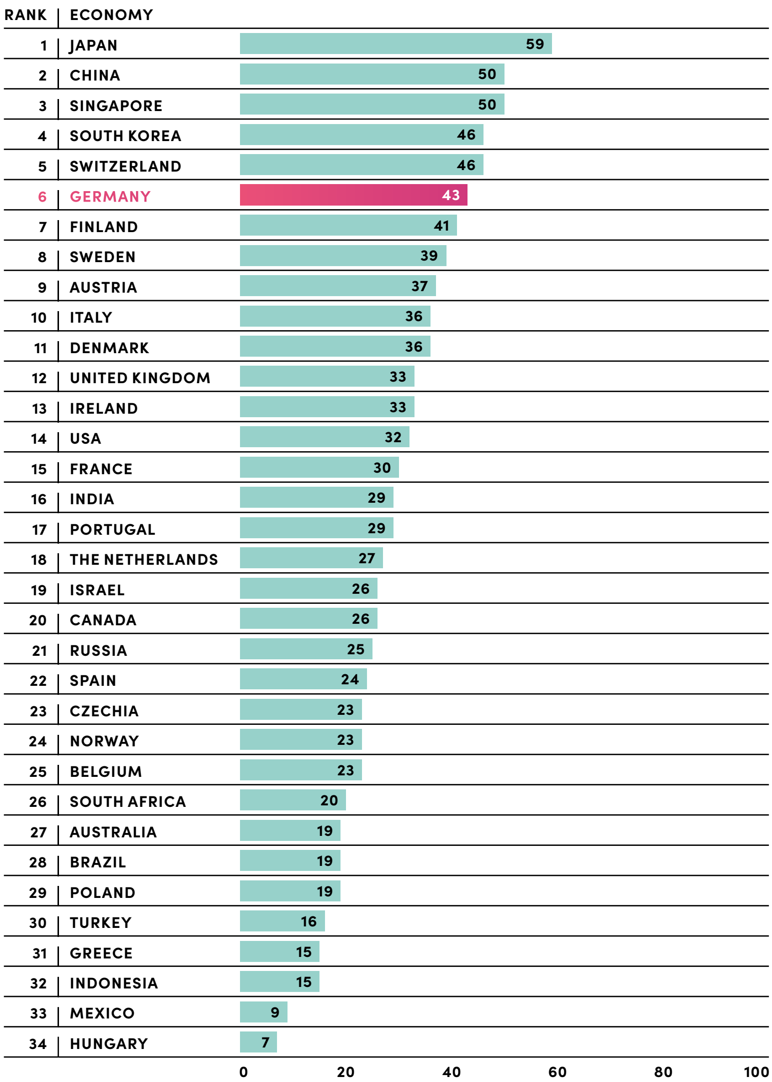
China, currently in second place (50), has caught up significantly in the past ten years and – after an interim period of weakness – has been able to significantly narrow the gap between itself and Japan, the leader. Overall, the catching-up processes in China and South Korea (46) in the microelectronics sector places Japan under considerable pressure .

The trend in China is likely to continue despite slower economic growth in the future, due to electronics for years holding a prominent position among the key technologies in China's science and innovation policy. Many international companies not only have electronic components manufactured in China because of cost advantages, but can also draw on new technological developments from Chinese research institutions and companies. Their technological competencies have been significantly expanded thanks to government support. China thus wants to reduce its dependence on foreign technology imports not only in microelectronics, but also in areas of application such as production technology (Made in China 2025) or data and communication technologies (Internet Plus Strategy).

GERMANY LOSES GROUND

Singapore (50) is also among the frontrunners in the field of digital hardware and is in third place in 2021, level on points with China. Germany (43) had been able to improve its position in the upper midfield considerably in the meantime and had moved up into the top group, but has lost this position again in the recent past. Germany is currently still in a respectable sixth place, however with a gap of three points behind South Korea and Switzerland. As perhaps the most important remaining production

DIGITAL HARDWARE: RANKING AND INDEX VALUES OF ECONOMIES



Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2023

location in Europe (Silicon Saxony, for example), Germany can once again score points with a positive balance of trade, including for digital hardware, and with noteworthy index values in the area of scientific publications and trademark applications. However, patent intensity and also the absolute number of patents lag behind many other countries in this area, even if individual companies such as Osram, Siemens, Bosch or Infineon produce noteworthy numbers of patents. It is therefore to be feared that Germany's position will continue to erode, as patents are the central basis for competitiveness in this field of technology.

The Scandinavian countries Finland, Sweden and also Denmark follow in the upper midfield together with Austria and Italy (with 41 to 36 points). The UK, Ireland and the USA are still in the top half, ranking fourteenth to twelfth. The USA has lost its top position since around the middle of the last decade and has been overtaken by a number of other economies. A large number of scientific publications in the field of digital hardware continue to come from the USA, but numerous other countries publish more relatively speaking, meaning they specialize and focus more on the field of digital hardware. The number of patents from the U.S. also remains high, indicating a continuedly strong knowledge base. However, the U.S. trade balance is strongly negative, as hardware components are produced only to a relatively small extent within the USA. As revenue from licenses for digital hardware is not accounted for, the position of the USA in international trade, as far as digital hardware is concerned, is undervalued.

In the middle of the distribution, with 30 to 29 points, are France, India, and Portugal. The Netherlands, Israel, Canada, and Russia follow on the next places. Spain, the Czech Republic, Norway, and Belgium are still in contact with the midfield, while South Africa, Australia, Brazil, and Poland already lie three respectively four points behind this group. Turkey, Greece, and Indonesia have index values of 15 and 16 respectively in the digital hardware sector, which is primarily due to notable exports. However, these are largely based on imported intermediate inputs, meaning that the balance of trade in digital hardware remains negative. Mexico and Hungary are at the bottom end of the distribution of the 35 economies surveyed.

Due to an insufficient database Taiwan cannot be shown in the index data and the ranking on key technologies. We only have information on scientific publications and patents, while all other indicators in the key technology area are unfortunately missing. On the basis of the available data, Taiwan's innovation capability can be assessed in part. According to this, Taiwan's strengths lie particularly in the area of digital hardware, while the other fields of key technology are less pronounced. Taiwan's technological strength is more visible in patents than in scientific publications.

» PATENTS ARE THE CENTRAL BASIS FOR COMPETITIVENESS IN THE FIELD OF DIGITAL HARDWARE. «

DIGITAL NETWORKS

The area of digital networks encompasses 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 up to quantum computers. In addition, there are software-based application areas such as artificial intelligence or cloud computing.

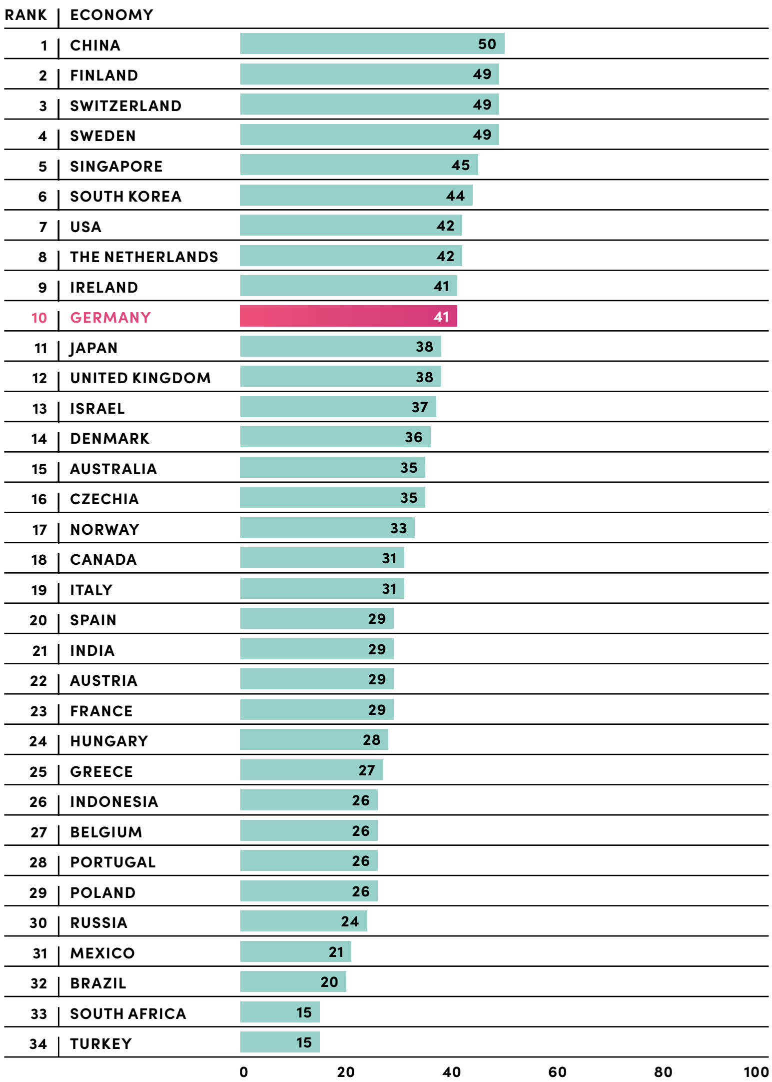
In 2021, China (50) leads the comparison countries in terms of digital networks, but only just ahead of Finland, Switzerland, and Sweden, which are only one point behind China with 49 points each. Accounting for the size of the country (in relation to gross domestic product or population), China would not be at the top, because the relative resources the country has available in the area of digital networks remain comparatively small. But China's enormous size, and thus both its resulting market power and economies of scale, must be considered when analyzing technologies. The reverse is true for the three other countries that rank behind China at the top. They are at the top of the ranking because they provide a relatively high amount of resources in the area of digital networks. However, in absolute terms, they play a very subordinate part compared to China and ultimately also the USA.

GERMANY LAGS BEHIND

Singapore (45) and South Korea (44) place slightly behind the top group, followed by the USA (42) and the Netherlands (42). Germany, in tenth place inhabits a position at the top end of the midfield with 41 points, the same number of points Ireland has. With the exception of absolute export figures in the field of digital networks, Germany cannot achieve a top score for any of the indicators. However, comparatively high values are found in the area of patent applications and trademark applications, which contribute to Germany's good position. Overall, given its factor endowment and economic size, Germany would have to invest significantly more in the area of digital networks if it wanted to be among the global leaders in this technology field. Modern German industry in particular, with its increasingly automated logistics and value creation chains, offers a wide range of application and development opportunities that are far from being fully exploited.

Japan and the UK follow with a gap of three points, followed by Israel, Denmark, Australia, and the Czech Republic. Norway ranks seventeenth with 33 points and constitutes the middle of the distribution together with Canada and Italy. Spain, India, Austria, and France are tied for twenty-fourth to twentieth place with an index score of 29, followed by Hungary and Greece and, slightly behind, Indonesia, Belgium, Portugal, and Poland. With the exception of India and Indonesia, these are therefore EU countries that score below the middle of the comparison countries in the area of digital networks. For the EU as a whole, this means massive knowledge and technology imports in these areas, even if individual countries such as Sweden, Finland or even Germany place in the top area. Russia, Mexico, Brazil, South Africa, and Turkey are at the lower end of the country distribution in the area of digital networks.

DIGITAL NETWORKS: RANKING AND INDEX VALUES OF ECONOMIES



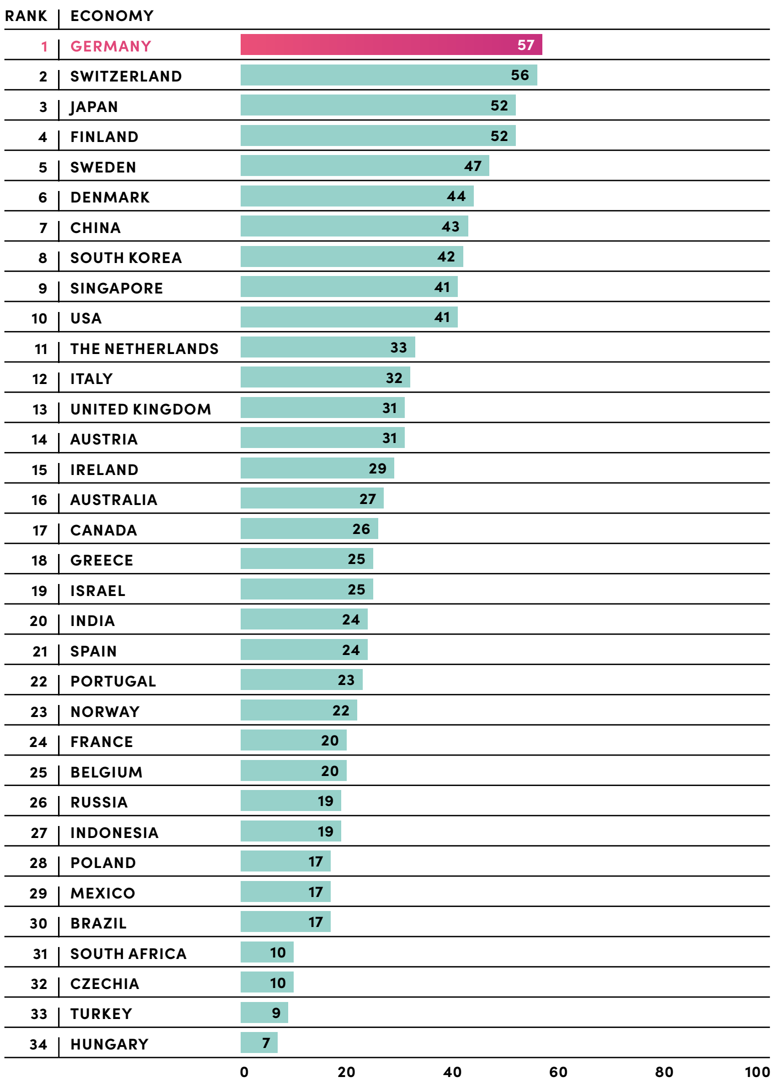
Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2023

ADVANCED PRODUCTION TECHNOLOGIES

The term advanced production technologies (advanced manufacturing 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. In the context of the Innovation Indicator, a broader definition of advanced production technologies is used. These include modern machines, but also entire facilities or their components, ranging from sensors and measuring devices to control systems and automated logistics. However, the production processes themselves are also included, such as joining (soldering, welding, gluing, etc.) or the pretreatment of production resources.

In the area of production technologies, Germany tops the ranking with 57 points, just ahead of Switzerland with 56 points. The two countries have repeatedly taken turns at the top of the ranking in the observation period since 2007, but have been in the top two positions over the entire period. Germany's position is essentially based on strengths in patents, foreign trade, and trademarks, both in absolute and relative terms. Switzerland also scores well in the relative indicators on patents and foreign trade, and additionally on scientific publications. Both countries have comparatively low shares of computer-implemented inventions (software patents) in total patents in this area. In Japan and the USA, these shares are significantly higher, which means that there is great potential here for Germany and Switzerland to further consolidate their positions at the top – or to lose them if they are overtaken by other countries.

ADVANCED PRODUCTION TECHNOLOGIES: RANKING AND INDEX VALUES OF ECONOMIES



Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2023

USA LOSES GROUND SIGNIFICANTLY

Over the entire period under review, Japan is in third place. In 2021, the country's index score of 52 was on a par with fourth-placed Finland. Sweden (47) and Denmark (44) follow at some distance in 5th and 6th place, followed only then by China (43), South Korea (42), Singapore (41) and the USA (41). As in the case of some other key technologies, the USA has lost considerable ground in production technologies since the mid-2000s. Whereas it was still in fifth place until 2010, by 2015 it was already sixth, in 2020 eighth and finally in 2021 tenth place out of 34 comparative countries. The index value has only fallen slightly compared with the first three years and has since mostly fluctuated around 40 points. This means that the drop in the rankings was primarily due to an improvement in other countries.

The USA slightly deteriorated its relative position in scientific publications and patents, while in absolute terms it continues to lead in both these indicators. The decline was offset by an improvement in computer-implemented inventions in the area of production technology, i.e. software controls and software-controlled processes are among the strengths in the USA. However, the balance of trade in these technologies remains clearly negative; this does not include revenues from software or hardware licensing.

At a clear distance behind the USA, there is a broad midfield, led by the Netherlands and followed by Italy, the UK and Austria. Ireland, Australia, Canada, Greece, Israel, India, Spain, Portugal, and Norway follow in the next places. The lower midfield is led by France, which scores 20 index points because it does not achieve high values in any of the indicators used here in the area of advanced production technologies. It is followed by Belgium, Russia, and Indonesia. Slightly apart from these in the lower midfield are Poland, Mexico, and Brazil, each with 17 points, while South Africa, the Czech Republic, Turkey, and Hungary form the lower end of the country distribution for production technologies.

ENERGY TECHNOLOGIES

New energy technologies are the basic prerequisite for climate-friendly energy supply and use and thus for the energy transformation of the economy and society. In addition, new energy technologies offer the opportunity to increase independence from energy imports and thus the competitiveness of one's own location. The existing market for energy technologies is changing both structurally and technologically, while at the same time facing strong international demand.

The structural changes relate to the actors, as suppliers of fossil energies will become less important, while production facilities for renewable energies may emerge in southern Europe or Africa. The technological changes aim both at the level of energy production as well as energy efficiency. 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).

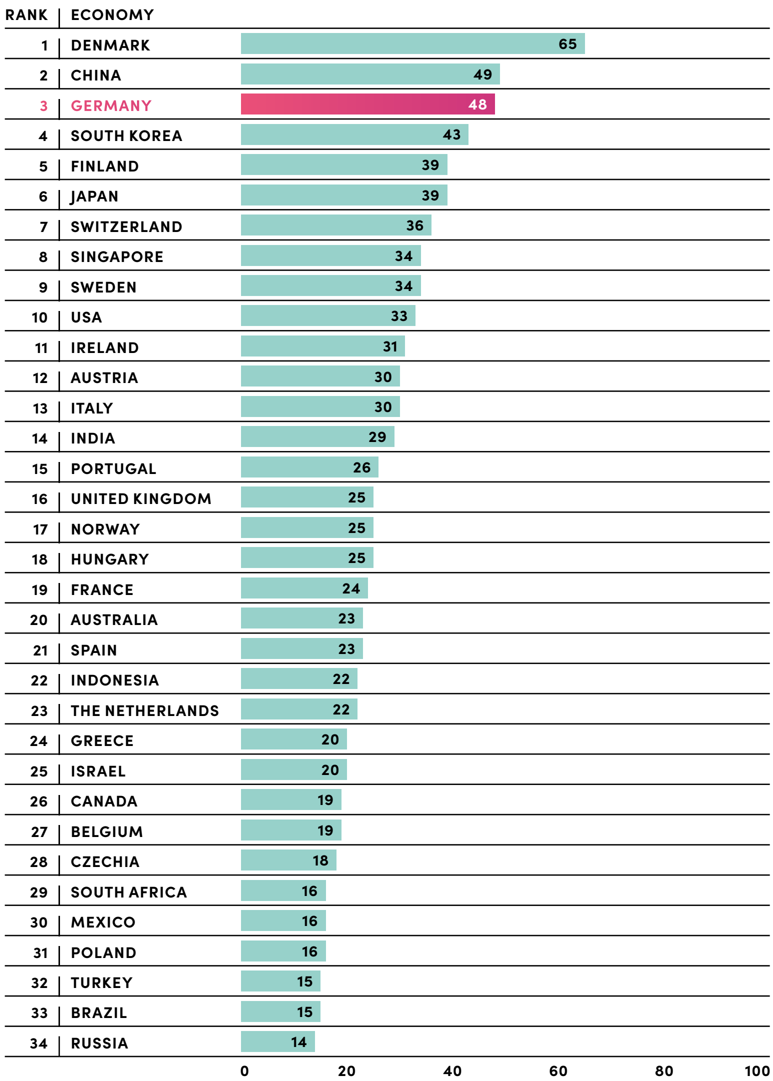
In terms of energy technologies, Denmark (65) is well ahead of China (49) in first place. Denmark not only has a strong competitive position in renewable energies, above all wind energy, but also in the sub-sectors of storage and energy efficiency. A high intensity can be observed at all stages of the innovation process. Denmark achieves maximum values for scientific publications and patents in relation to its population and also has a clearly positive balance of trade.

CHINA HAS ACHIEVED A STRONG POSITION

China has steadily worked its way up from a mid-table position over the past 15 years to reach second place in 2021 with 49 index points. Particularly in renewable energy technologies, China has now achieved a strong position on the international markets, which is reflected not least in a strongly positive trade balance. However, China itself is also one of the largest markets for new energy technologies in the world, and Chinese companies have a home advantage here. Coupled with the political will to become less dependent on international technology imports, the large Chinese sales market has led to the People's Republic also occupying a strong position in terms of the absolute numbers of scientific publications and patents. On the one hand, this means that the national knowledge base in the area of energy technologies was widened. On the other hand, economies of scale and knowledge spillovers have further consolidated the position in these markets.

With 48 points, Germany ranks third in terms of innovation capability in the field of energy technologies, only just behind China. Germany was able to maintain this third place for much of the observation period since 2007 and even moved up to second place in the years 2018 to 2020. The scientific base in the area of energy technologies – measured by the number of publications per inhabitant – is usually higher in other countries. Germany's intensity in patents is also comparatively low and has even declined over time. South Korea (43) had worked its way up to fourth place by the middle of the last decade and, in addition to competencies in energy storage, also shows a clear commitment to hydrogen technologies. The fifth and sixth places are occupied by Finland and Japan with 39 points each. Japan's position has already deteriorated significantly since the middle of the last decade, from second place in 2007 to sixth place. This loss of position is due to a relative decline in almost all the indicators considered here, regarding scientific publications as well as patents and foreign trade.

ENERGY TECHNOLOGIES: RANKING AND INDEX VALUES OF ECONOMIES



Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2023

They are followed in seventh to tenth place by Switzerland, Singapore, Sweden, and the USA. In energy technologies, as well as in some other key technologies, the USA has recently dropped down some ranks. The index value of the USA has also declined over time, i.e., the USA has not been able to increase its number of publications and patents to the same extent as many other countries. The trade balance of the USA is clearly negative in the area of energy technologies. It is interesting to note, that in this field of technology the shares of computer-implemented inventions (software patents) are also a clearly visible strength of the USA.

RUSSIA'S IMPORTANCE DECLINES

Ireland (31), Austria (30), Italy (30) and India (29) rank behind the USA. Portugal, the United Kingdom and Hungary follow in sixteenth, seventeenth and eighteenth place, each with 25 index points. France ranks nineteenth with 24 points. France does not achieve high values in any of the indicators used here. France's involvement in the field of energy technologies, be it as this concerns patents, publications, or foreign trade, is not particularly pronounced. This is true both in relation to the size of the country respectively the gross domestic product and in absolute terms. Australia (23), Spain (23), Indonesia (22) and the Netherlands (22) lie in the lower midfield in the comparison group considered, ranking twentieth to twenty-third. Greece, Israel, Canada, Belgium, and the Czech Republic follow, while the lower end is occupied by the emerging countries South Africa and Mexico. This group also includes Poland, Turkey, Brazil and finally Russia. This last place of Russia makes it very clear that the country's role for energy supply will decrease as soon as the transformation towards alternative energy sources and corresponding technologies significantly gains momentum.

ADVANCED MATERIALS

Advanced materials with special properties are the basis for numerous other developments and enable new possibilities, for example in lightweight construction. But they also play a significant role in the area of material efficiency by replacing existing raw materials. Material technologies such as coatings also enable improved properties of products. This category therefore includes composites, coatings, or plastics with special properties such as nanomaterials, but also processes for their production and processing.

In the area of advanced materials, Japan is the undisputed leader with 62 index points and by a wide margin over the entire period under review. This strong position can be seen in patents, foreign trade, and computer-implemented inventions. Only in scientific publications can a gap be detected compared to many other countries in the comparison group, both in relation to the worldwide figures and in relation to the Japanese scientific system.

A group formed by Finland, South Korea and China follows the Japanese lead at a large distance with 50 and 49 points respectively. These three countries also have a large gap between them and the countries behind them and can therefore be described as the chasing pack. Germany ranks fifth with 44 points, just ahead of Switzerland. The overall German score for advanced materials is achieved by positive values for all individual indicators. However, Germany does not manage to achieve a top score for any individual indicator. While both index values for patents have declined over time, they have risen slightly for trademarks since the mid-2010s. Germany can boast high scores for digital technologies in the area of advanced materials.

ADVANCED MATERIALS: RANKING AND INDEX VALUES OF ECONOMIES

RANK	ECONOMY	Index value (0–100)
1	JAPAN	62
2	FINLAND	50
3	SOUTH KOREA	49
4	CHINA	49
5	GERMANY	44
6	SWITZERLAND	43
7	SINGAPORE	40
8	SWEDEN	39
9	POLAND	36
10	CZECHIA	35
11	USA	33
12	IRELAND	31
13	ITALY	30
14	AUSTRIA	29
15	UNITED KINGDOM	29
16	DENMARK	28
17	BELGIUM	28
18	INDIA	28
19	THE NETHERLANDS	27
20	SPAIN	26
21	AUSTRALIA	25
22	ISRAEL	23
23	PORTUGAL	22
24	HUNGARY	22
25	FRANCE	22
26	CANADA	21
27	SOUTH AFRICA	21
28	RUSSIA	20
29	NORWAY	19
30	GREECE	17
31	TURKEY	16
32	BRAZIL	14
33	INDONESIA	13
34	MEXICO	12

Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2023

FRANCE FAR BEHIND

Further down the list are Singapore, Sweden and a little further back, Poland and the Czech Republic. The USA (33) reaches eleventh place in 2021. Since ranking fifth in 2007, the USA's ratings have fallen continuously. In absolute terms, the U.S. continues to be the country with the most scientific publications in the area of advanced materials. Measured in terms of the size of the scientific system, however, it is not one of the countries with a pronounced specialization. The absolute number of patents and also the balance of trade allow the USA to remain in the top half of the country distribution. The share of computer-implemented inventions, i.e., digital applications and materials relevant to digital technologies, also plays a comparatively significant role in the USA's patent portfolio.

A very broad midfield with index values between 25 and 31 points is led by Ireland, closely followed by Italy as well as Austria, the UK, Denmark, Belgium, India, the Netherlands, Spain, and Australia. Israel, Portugal, Hungary, France, Canada, South Africa, Russia, and Norway make up the lower midfield. It may be surprising to find France so far back in advanced materials. However, France does not have high index scores in either scientific publications, patent applications or foreign trade that would legitimize a better ranking.

At the bottom of the distribution in terms of innovation capability in the area of advanced materials in 2021 lie Greece, Turkey, Brazil, Indonesia and finally Mexico.

BIOTECHNOLOGY

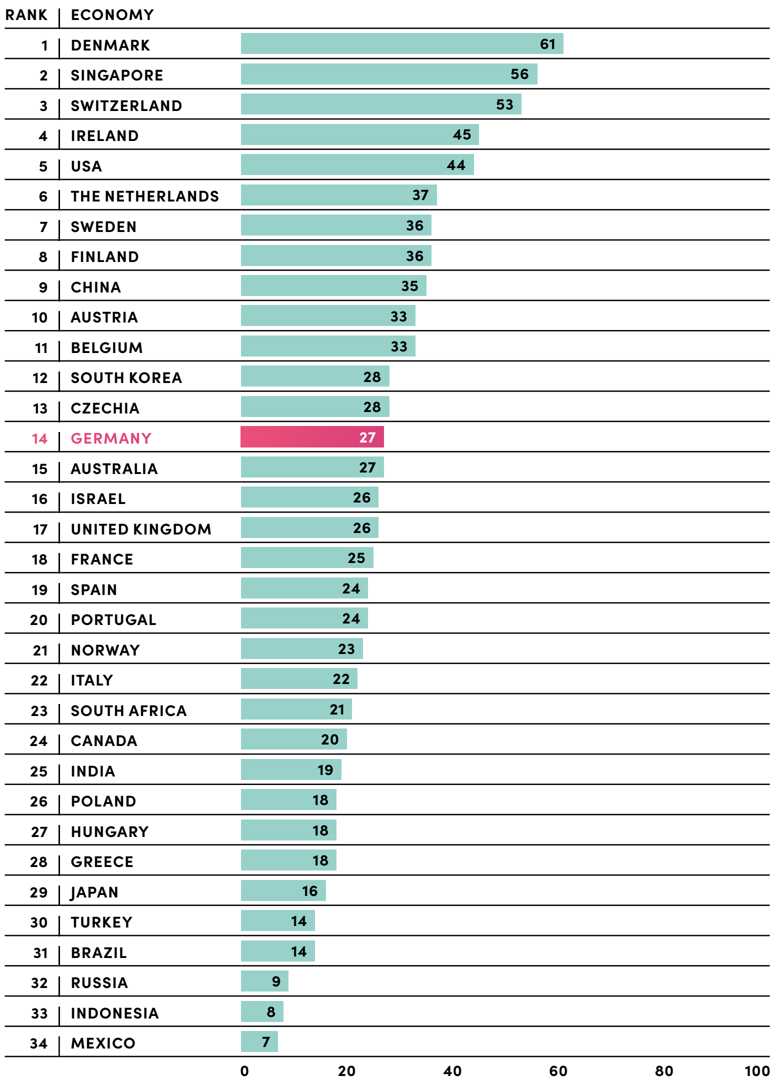
Biotechnology refers to the scientific and technological use of living organisms or biological processes. The definition used here covers all areas of biotechnology and its applications in health, industry, the environment, and food production. In addition to enzymes, peptides, proteins or microorganisms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

Denmark (61) has been the number one in biotechnology since the middle of the last decade. Denmark had previously already been in the top group but was able to improve its relative position in scientific publications and patents, as well as in trademark applications, and therefor take the lead. In terms of foreign trade in biotechnology products, Denmark has been among the best in the world since the beginning of the past decade.

Singapore (56) has managed to secure second place in the last two years of observation but has almost always been among the top 4 since 2007. Switzerland (53) in third place and is still connected to the top group, while Ireland with 45 and the USA with 44 index points already lag somewhat behind in fourth and fifth place respectively. In the field of biotechnology, Switzerland has strengths in science and patents and has been able to significantly expand its position in computer-implemented inventions over the past ten years or so. Switzerland is also comparatively well positioned in terms of trademark applications in the area of biotechnology. In terms of absolute indicators, the Alpine republic lags behind. In addition, there is a slightly negative balance of trade in biotechnology products.

They are followed by the Netherlands, Sweden, Finland, and China in sixth to nineth place, with index values between 37 and 35. Austria and Belgium are tied on points, still have a connection to the upper midfield and can set themselves apart from a broad field in the middle of the distribution. Countries in the middle group include South Korea, the Czech Republic, Australia, Israel, and the UK, as well as Germany, which ranks fourteenth with 27 index points.

BIOTECHNOLOGY: RANKING AND INDEX VALUES OF ECONOMIES



Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2023

GERMANY'S POSITION IS WOBBLY

In the past, in the 2000s, Germany's position in the international comparison has been better, then eroded significantly until around 2015 before recovering somewhat from 2018 on. Germany's index value of 27 would only suffice for a place in the lower midfield in many other fields. This shows that in the field of biotechnology, the leading economies stand out more clearly from the midfield than in other technology fields, and thus even a relatively good ranking position for Germany does not indicate an inherently satisfactory technological performance capability. None of the indicators considered have shown any appreciable positive development in Germany. Comparatively low values are recorded in the area of patents. Germany's position in the midfield can be explained by the fact that numerous other countries also show a rather low innovation capability and focus on biotechnology. Since the countries in the midfield differ only slightly from one another, the German position can also erode very quickly if other countries expand their efforts only somewhat.

Israel's (26) strengths are essentially to be found in white biotechnology (food). This is only one sub-area of biotechnology. It is difficult for Israel to score points against countries that have a broad range of biotechnological applications or focus on red biotechnology (health).

The bottom half starts with France, followed by a group of other European countries, namely Spain, Portugal, Norway, and Italy. South Africa, Canada, India, Poland, Hungary, and Greece all rank ahead of Japan, which is only twenty-nineth with 16 index points. Trailing Japan are exclusively emerging countries. These are Turkey, Brazil, Russia, Indonesia and, finally, Mexico at the end of the list.

CIRCULAR ECONOMY

The circular economy encompasses various approaches to the long-term use of materials and products. In the broad definition, this includes processes for the shared use of products (sharing economy), for the further use of products by third parties (re-use) or via improved repair options. This field of technology also includes recycling processes that start as early as the development and production of products and, for example, the selection of materials. In the Innovation Indicator, we focus on a narrower definition and essentially cover recycling technologies aimed at returning materials to the material cycle.

US IMPORTS ON THE RISE

In terms of the innovative capacity of economies in the area of circular economy technologies, Finland, in first place with 54 points, has replaced the previous leader Germany. Germany (53 points) had been in the top spot since 2014, after displacing Switzerland, which had been the leader for many years. Since then, Switzerland (43) has steadily dropped in rank, and in 2021 now ranks fifth behind Denmark (48) and Japan (47). Germany's position among the top is based on its strengths in patents and trademarks, but also in trade with circular economy technologies. As far as scientific publications in this field are concerned Germany does not score well, neither in absolute nor relative terms. Germany has also fallen behind other countries in the computer-implemented inventions among the patent applications.

The USA (43) ranks sixth. Singapore, Sweden, Italy, and Austria follow at some distance. The good position of the USA is based on the high absolute number of scientific

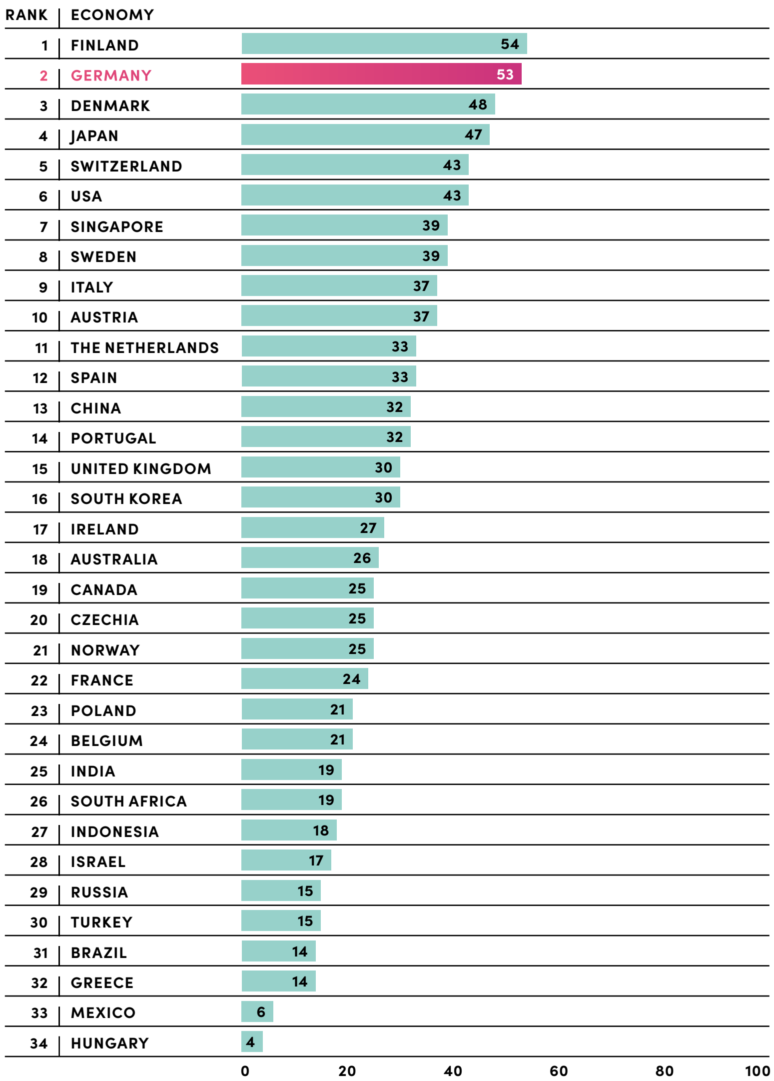
» IN BIOTECHNOLOGY, THE LEADING ECONOMIES CAN DISTINGUISH THEMSELVES MORE CLEARLY FROM THE MIDFIELD. «

publications and patents, while the relative importance of the circular economy in the USA's technology portfolio is comparatively low. As with numerous other technologies, computer-implemented inventions (software patents) also play a prominent part in the field of circular economy in the USA in an international comparison. In terms of the balance of trade, the position is dropping, i.e., over time compared to most countries in the comparison group imports in these technologies have increased relatively more than exports have.

In the middle of the country distribution is a group of countries consisting of the Netherlands, Spain, China, Portugal, the United Kingdom and South Korea. China is able to secure a place in the midfield thanks to a large absolute number of scientific publications and, more recently, patent applications. The other indicators, including the balance of trade, lag well behind the level of other countries in the circular economy.

The bottom half of the country ranking is led by Ireland, just ahead of Australia and followed by Canada, the Czech Republic and Norway, all of which have equal points. France can also be counted as part of this midfield group. The lower midfield consists of Poland, Belgium, India, South Africa, Indonesia, and Israel. Russia, Turkey, Brazil, and Greece also often achieve notable index values, while Mexico and Hungary at the bottom end of the country distribution only achieve few points.

CIRCULAR ECONOMY: RANKING AND INDEX VALUES OF ECONOMIES



Taiwan is not shown here due to lack of data.
Source: Innovation Indicator 2023

RECOMMEN-DATIONS

STRENGTHENING TECHNOLOGY SOVEREIGNTY TO ESTABLISH VALUE CREATION NETWORKS

Securing technology sovereignty is central in the area of key technologies. This means maintaining and expanding access to new technologies along supply chains and within value creation networks so that companies' scope for innovation is not restricted and economies of scale can be realized. This means that in-house competencies and capacities should be maintained or, if necessary, established and expanded in all key technological areas.

The state can create the conditions for this by means of thematic or technological support programs and appropriate frameworks, for example, in the curricula at universities. However, this should not be done from a purely national perspective; instead, European cooperations should be sought.

Key technologies are crucial for new technological solutions and innovation in many different industries. They are at the heart of securing technological sovereignty and determine companies' scope for action in the development of new products and processes.

Key technologies are often the basis for the emergence of new markets. They are central both for a country's future technological capability and for its economic success. Innovation policy can support the development and dissemination of key technologies in various ways. Research funding can be used to lay the scientific foundations.

Promoting knowledge and technology transfer can drive widespread use in industry. Regulatory frameworks and demand-driven policies can significantly accelerate diffusion and upscaling.

EXPAND KEY TECHNOLOGY FUNDING AND THINK EUROPEAN

For Germany as an industrial and innovation location , it is crucial to significantly expand investment in science, research, development, and innovation in all key technology areas, in order to significantly increase both the marketability of technologies and the speed of their introduction. In doing so, a balance must be struck between a fundamental openness to technology and a focus on those technology fields that are of great importance for economic development in Germany and Europe in the short and medium term.

Good European examples are the EU Chips Act and the IPCEIs (Important Projects of Common European Interest). These instruments must be expanded and better used to achieve the goals. Germany should more strongly embrace its role as a pioneer and thought leader in the European context and proactively initiate and drive the issues that are essential for Germany and Europe. An adjustment of laws governing state aids and subsidies in the area of key technologies must be tackled without triggering a subsidy competition. Diffusion- and demand-oriented measures should be prioritized.

ENSURE TARGETED TECHNOLOGY FOCUS THROUGH BOTTOM-UP PROCESSES

As well as increasing the funds made available for key technologies, these simultaneously must be used in a more targeted and efficient manner. Specialization or focusing on specific technology fields is unavoidable here, even though Germany is one of the world's largest economies and can therefore maintain a broad portfolio.

However, the analyses have shown that, in many areas, Germany can only keep pace with international momentum, but cannot catch up. Specialized countries usually have more momentum. Here, too, it makes sense for innovation policy to coordinate the activities of individual actors. This initially involves criteria-based, forward-looking, strategic capacity planning in the individual technology fields, in particular to promote the interaction of basic scientific research and industrial, application-oriented research. Bottom-up processes involving all relevant players, for example, via innovation platforms, ensure the flow of information and an application orientation. One example of such a coordination is the German strategy for battery cell production.

THE DANISH ECONOMY IS THE GREENEST

Acting sustainably

Sustainability is a challenge for society as a whole. It aims at satisfying the economic and social needs of the current generation without compromising the opportunities of future generations. Sustainability is also relevant to the national economy because only by respecting planetary boundaries can economic systems be successful in the long term and thus form the basis of societal prosperity. Ecological sustainability, which is the focus here, is the central prerequisite for the Sustainable Development Goals (SDGs) of the United Nations. To achieve sustainably oriented innovation systems, civil society, science, government, and business must all make contributions. Achieving sustainability is thus a task for society as a whole.

COMPANIES ARE IMPORTANT LEVERS

The business sector (energy industry, other industrial combustion) is not only the largest emitter of CO2 in Germany, accounting for more than two-thirds of the total, but is also the bearer of many innovations and innovation potentials in the field of sustainability. This makes it clear that companies are the decisive lever for reducing environmental impacts, decreasing dependence on fossil fuels, and conserving natural resources. Companies can make a significant contribution to sustainability by switching to more environmentally friendly production methods, business models and products. In this context, entering into a circular economy model and the development of environmentally friendly technologies are particularly important.

The circular economy plays a central role in sustainable development because it focuses on the principle of resource conservation. In contrast to a linear economy, in which raw materials are extracted, processed, and ultimately disposed of as waste, in a circular economy products are designed to be manufactured in a way that conserves resources, to be kept in circulation for as long and at as high a quality as possible, and to be recycled at the end of their life cycle. This helps reduce the use of resources and the impact on the environment. In addition, the implementation of a circular economy can create new business models and value creation chains that are both economically and ecologically sustainable .

The development of environmentally friendly technologies plays an equally important role in sustainability, as these can help reduce environmental impacts and conserve natural resources. Companies that invest in environmentally friendly technologies can not only make the economy more sustainable, but also contribute to the preservation of the environment. This includes, for example, supporting renewable energies, reducing resource consumption in production and manufacturing environmentally friendly products.

However, science also has a special part to play in the development of such technologies. By generating new technological knowledge, but also by improving the understanding of the interrelationships in society as a whole, science can contribute to the emergence of new environmentally compatible production methods and products. In this context, science and industry must cooperate from an early stage in the innovation process.

In addition to industry, which develops and implements environmentally friendly products and processes, and science, which provides the necessary knowledge, consumer behavior plays a central part. Environmentally conscious consumer behavior reduces environmental impacts and at the same time provides an incentive for companies to develop sustainable offerings and introduce them into the market. Consumer behavior also has a significant influence on the sustainability of the traffic system, which is one of the sectors with a particularly high environmental impact. For example, traffic/transportation is responsible for about 20 percent of CO2 emissions. In order to change consumption and mobility patterns, it is necessary to raise awareness of the issue of sustainability across the whole of society.

POLICYMAKERS ARE CALLED UPON

Policymakers also have a central part to play in initiating, accompanying, and safeguarding these changes. They can support the development of a sustainable economy and society through legislation and incentive programs. One example is the support of renewable energies and energy efficiency via subsidies and incentive programs. Policymakers can also help reduce environmentally harmful behavior through regulations and taxes. In addition, policymakers can promote education and awareness of sustainability.

The Innovation Indicator maps these various aspects in its sustainability indicator via eleven individual indicators. These take into account not only environmental technologies and their use, but also central areas of the environmental innovation system with a view to the industry, science, the state and civil society. The aim of the analyses presented here is to assess the orientation of national economies towards sustainability innovation. The same set of countries is considered as for the topics innovation and key technologies. All indicators are also standardized, so that pure size effects do not distort the compilation.

CENTRAL RESULTS

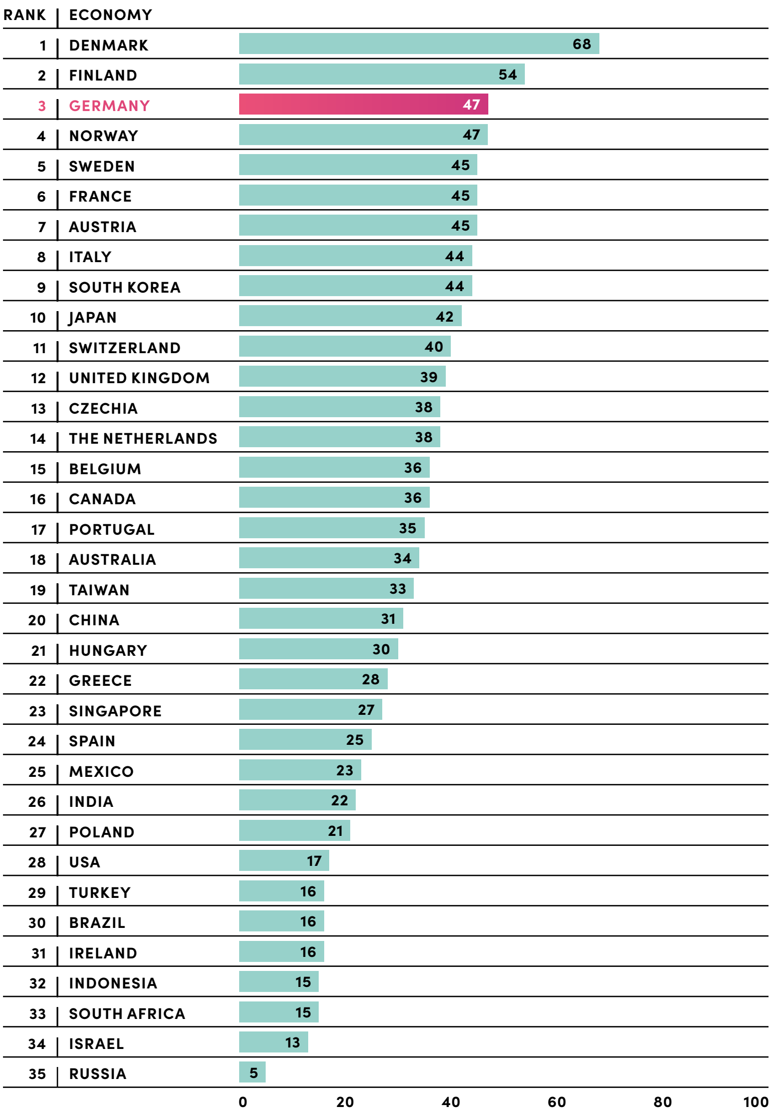
The ranking for the sustainability indicator is led by Denmark by a wide margin, which achieves 68 points. Finland, another Nordic country, follows with a gap of 14 points in second place. With 47 points, Germany takes third place in this indicator, even though the gap to the leader Denmark is very large. The two Scandinavian countries Norway (47 points and level on points with Ger-

INDIVIDUAL INDICATORS FOR MEASURING SUSTAINABILITY AND THEIR SOURCES

- R&D in renewable energies and energy efficiency as a share of GDP
- Green early-stage investments
- State R&D support environment and energy
- Attitude towards environmental issues, preference environment versus economy
- Environmentally relevant scientific publications per capita of the population
- Exports of sustainable goods as a share of GDP
- Environmental innovation in companies
- Environmental Policy Stringency Index
- Environmentally relevant patents per inhabitant
- ISO 14001 certifications
- Environmental taxes

many) and Sweden (45) follow in fourth and fifth place. France (45), Austria (45), Italy (44), South Korea (44) and Japan (42) follow in sixth to tenth place, followed by a broader midfield. Overall, it can be seen that the ranking is very clearly dominated by European economies, especially those from northern Europe. It is striking that the leading nations in the innovation capability indicator, Switzerland and Singapore, score only averagely and severely below average in the area of sustainability, with 40 points (Switzerland, eleventh place) and 27 points (Singapore, twenty-third place) respectively. Whether and to what extent nations focus on acting sustainably does not therefore necessarily go hand in hand with their current ability to generate innovation.

SUSTAINABILITY: RANKING AND INDEX VALUES OF THE ECONOMIES



Source: Innovation Indicator 2023

In addition to Switzerland, the broader midfield also includes some other European countries such as the UK (39), the Netherlands (38) and Belgium (36). Many of the eastern and southern European nations are also found here. Portugal (35), Greece (28) and Spain (25) are ranked seventeenth, twenty-second and twenty-fourth respectively, while the Czech Republic is still in a relatively good position with 38 points (13). Hungary (30) is much further back in twenty-first place. Poland is only twenty-seventh with 21 points, while China is also in the middle of the pack in 20th place with 31 points.

The performance of the USA, on the other hand, must be described as disappointing, with a score of just 17 points and twenty-eighth place, turning it into the leader of the group of stragglers. For a modern industrialized nation in the 21st century, this result is sobering, especially since the USA scores poorly in almost all sustainability indicators. Also in this group are a number of emerging economies: Brazil (16), Indonesia (15), South Africa (15) and Russia (5).

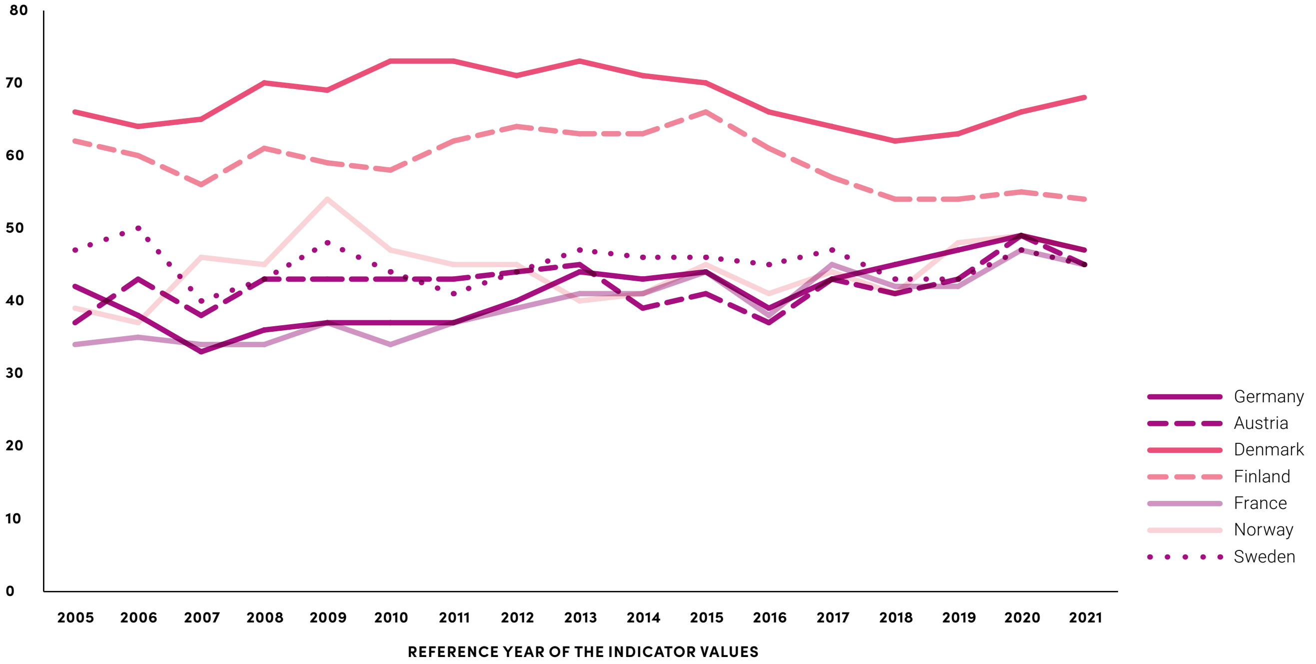
However, it is worth noting that Ireland and Israel are two other established industrialized countries with scores of only 16 and 13 points respectively. Ireland shows particular weaknesses as far as companies are concerned, for example regarding environmental innovation, R&D in the field of renewable energies and ISO 14001 certifications. Israel scores well in the area of environmental taxes, but is rather cautious with regard to environmental regulations, which is also reflected in the environmental innovation of the companies.

In order to take a more detailed look at the individual economies, the chronological developments and the positions of the countries concerning the individual indicators are examined in more detail. In analogy to the procedure in the innovation capability chapter, comparable groups (leading countries, large economies, eastern and southern Europe, emerging economies) are formed.

EUROPE DOMINATES

As the figure on the next page shows, the points scores for most of the leading economies in the sustainability indicator are quite stable over time. For example, Denmark already achieved a score of 66 in 2005. In 2021, the most recent year, this was two points higher at 68. A similarly stable development can be noted for Sweden, which achieved 45 points in 2021 (-2 compared with 2005). Germany improved moderately from 42 to 47 points during this period – as did Norway, which also managed 47 points in 2021, compared with only 39 in 2005. The biggest leap in the ranking was made by France, which now has 45 points, having had 34 in 2005. The only country in the top group to deteriorate significantly is Finland, which fell from 63 points in 2005 to 54 points in 2021. However, as the gap to the follow-on nations was sufficiently large, it was able to maintain second place.

SUSTAINABILITY: DEVELOPMENT OF ECONOMIES WITH A HIGH INDEX VALUE



Source: Fraunhofer ISI calculations

A look at the properties of the individual indicators reveals clear strengths/weaknesses profiles. The leader Denmark, scores particularly well with a high relative number of environment-related scientific publications, environmental innovation by companies and environment-related patents, in each of which it achieves the top results and thus 100 points. The only area in which it is poorly positioned is ISO certification. Denmark shares this weakness with most of the other countries in the leading group. The reasons for the different diffusion of environmental standards such as ISO 14001 are generally to be found in national, sometimes idiosyncratic, regulatory frameworks.[6]

Germany does not occupy absolute top positions for any of the indicators. However, good scores are achieved for government support for environmentally relevant R&D (84), purchasing behavior (78) and green early-stage investments (74). Germany's good overall performance can be explained by the fact that there are no downward outliers. Thus, almost all indicators place in the solid midfield. This underlines that the German system is oriented toward sustainability issues across the board. However, it should be noted critically that there is clear potential for improvement in key indicators of success in the economy, such as environmental innovation (45), R&D in renewable energies (34) and patents (35).

France, which improved significantly in the ranking, scores above all for progress attributable to the state. France achieved the highest score on the Environmental Stringency Index in the comparison group of 35 countries. This index is a measure of the strength of environmental regulations. By way of comparison, Germany scores only 41 points here. France also has a very high score for the support of environment-related R&D. In the economy and in consumer behavior, there remains a high potential for improvement. Austria stands out for its particular strengths in the area of green early-stage investments. For most other indicators, Austria rather scores in the midfield.

CHINA'S GREEN PLAN

Within the group of major economies, the UK, South Korea, and China in particular improved their places in the ranking. Whereas China scored only 14 points at the beginning of the reporting period and was thus part of the bottom group, it had already reached 31 points by 2021. The improvement took place primarily up to 2010. Since then, there has been only a slight upwards trend. The Chinese government had already been focusing on sustainable energy supply and environmental innovation since the mid-2000s during the phase of emerging economic development, a trend that has further intensified more recently.

Critics, however, saw this as merely a "greenwashing" of research, innovation and economic policy in many areas, especially since the classic energy supply was maintained, i.e., mainly coal-fired power generation. At the same time, the Chinese government not only focused on renewable energies, but also invested massively in nuclear energy. The main justification for the continued energy mix was that the rapidly increasing energy demand in China could not otherwise be met.

» ACROSS THE BOARD, GERMANY STRIVES FOR SUSTAINABILITY. «

SUSTAINABILITY: OVERALL RANKING OF ECONOMIES

RANK	2005	2010	2015	2020	2021
1	DENMARK	DENMARK	DENMARK	DENMARK	DENMARK
2	FINLAND	FINLAND	FINLAND	FINLAND	FINLAND
3	JAPAN	NORWAY	ITALY	NORWAY	GERMANY
4	HUNGARY	SWEDEN	SWEDEN	GERMANY	NORWAY
5	SWEDEN	AUSTRIA	NORWAY	AUSTRIA	SWEDEN
6	SWITZERLAND	THE NETHERLANDS	JAPAN	ITALY	FRANCE
7	GERMANY	HUNGARY	GERMANY	FRANCE	AUSTRIA
8	THE NETHERLANDS	CANADA	FRANCE	SWEDEN	ITALY
9	BELGIUM	CZECHIA	SWITZERLAND	SOUTH KOREA	SOUTH KOREA
10	NORWAY	SWITZERLAND	SOUTH KOREA	UNITED KINGDOM	JAPAN
11	AUSTRIA	SOUTH KOREA	AUSTRIA	JAPAN	SWITZERLAND
12	SOUTH KOREA	JAPAN	UNITED KINGDOM	SWITZERLAND	UNITED KINGDOM
13	CZECHIA	GERMANY	THE NETHERLANDS	CZECHIA	CZECHIA
14	AUSTRALIA	ITALY	TAIWAN	THE NETHERLANDS	THE NETHERLANDS
15	FRANCE	AUSTRALIA	AUSTRALIA	TAIWAN	BELGIUM
16	CANADA	UNITED KINGDOM	CANADA	CANADA	CANADA
17	ITALY	FRANCE	BELGIUM	BELGIUM	PORTUGAL
18	UNITED KINGDOM	SPAIN	PORTUGAL	PORTUGAL	AUSTRALIA
19	MEXICO	TAIWAN	CZECHIA	AUSTRALIA	TAIWAN
20	SPAIN	CHINA	POLAND	CHINA	CHINA
21	PORTUGAL	BELGIUM	CHINA	HUNGARY	HUNGARY
22	GREECE	MEXICO	HUNGARY	GREECE	GREECE
23	SINGAPORE	PORTUGAL	SPAIN	SPAIN	SINGAPORE
24	POLAND	POLAND	GREECE	SINGAPORE	SPAIN
25	SOUTH AFRICA	SINGAPORE	MEXICO	MEXICO	MEXICO
26	IRELAND	TURKEY	SINGAPORE	POLAND	INDIA
27	ISRAEL	GREECE	TURKEY	INDIA	POLAND
28	TURKEY	IRELAND	SOUTH AFRICA	USA	USA
29	USA	ISRAEL	BRAZIL	TURKEY	TURKEY
30	CHINA	USA	INDIA	BRAZIL	BRAZIL
31	TAIWAN	BRAZIL	IRELAND	INDONESIA	IRELAND
32	RUSSIA	SOUTH AFRICA	USA	SOUTH AFRICA	INDONESIA
33	INDIA	RUSSIA	ISRAEL	ISRAEL	SOUTH AFRICA
34	BRAZIL	INDIA	INDONESIA	IRELAND	ISRAEL
35	INDONESIA	INDONESIA	RUSSIA	RUSSIA	RUSSIA

Source: Innovation Indicator 2023

China's strengths in the sustainability indicator are ISO certifications (100) and the environmental attitudes of the population (84). China lags behind in most other individual indicators. This also applies to the state, which is not particularly active in either environmental taxes (0) or environment-related regulations (27). On the other hand, China is setting very ambitious targets for electromobility, for example. There are now clear restrictions on the registration of combustion vehicles in some cities. In the case of electromobility, regulation is centrally prescribed and regionally enforced, partly because it is part of China's innovation policy to catch up with the top economies in terms of vehicles with new drive technologies by essentially leapfrogging combustion technology. In the case of other central environmental regulations, however, regional economic interests sometimes stand in the way; they are therefore less consistently implemented.

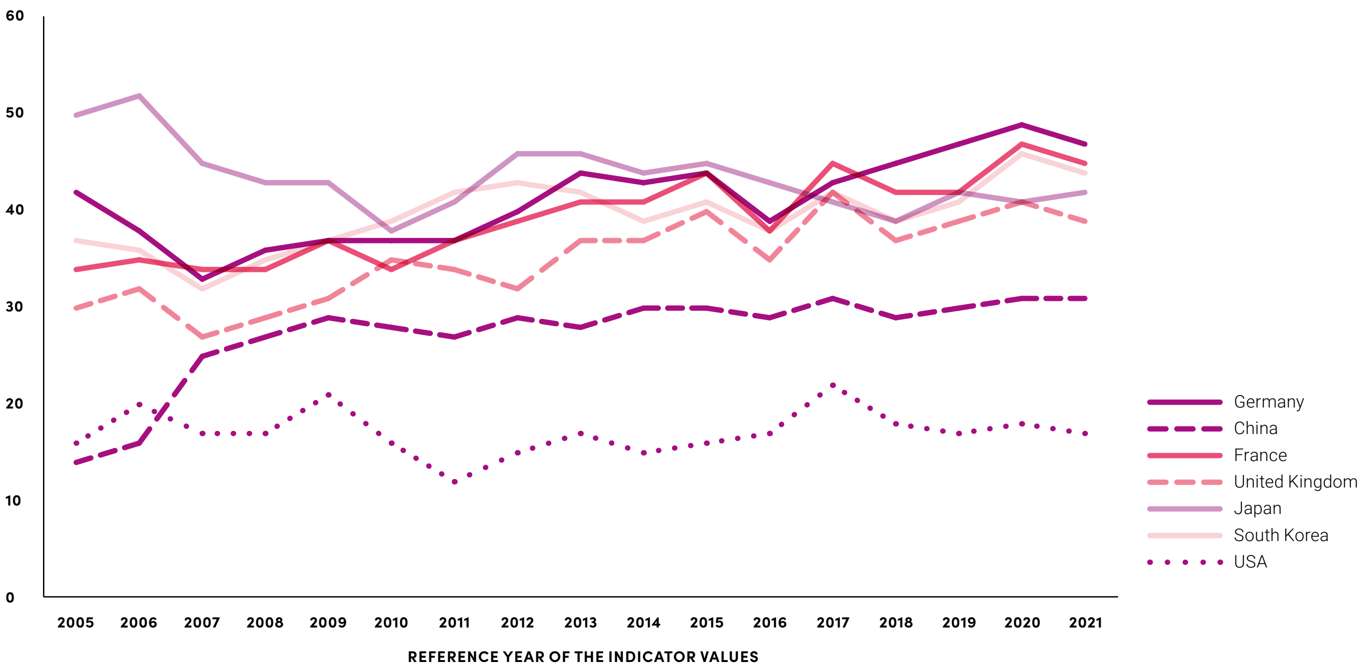
USA FAR BEHIND

The UK scored 30 points in 2005 and improved by nine points to an indicator value of 39 16 years later. South Korea scored 44 points lately, an increase of seven points compared with 2005. Japan, on the other hand, deteriorated from 50 to 42 points over the period under review. The USA has to be counted as the negative outlier among the major economies. The indicator value has changed little over the years. Most recently, the United States scored 17 points, which corresponds to an only marginal increase of one point. However, it should be noted that the sustainability indicator also looks at relative values along the benchmark group. As a result, the USA may have improved in absolute terms regarding individual indicators, but in relative terms there has been virtually no improvement.

It is particularly striking that the USA scores below average on almost all indicators. Only in the case of environmental attitudes, with 43 points, does the USA score in the midfield. The maximum score for all other indicators is 27 points (R&D in the field of renewable energies). The USA has zero points for the export of sustainable goods and for environmental taxes. These results, particularly in view of the low rate of success for exports, clearly show that a low focus on sustainability is also associated with economic costs. However, this result must be put into perspective by the fact that the USA also has a negative trade balance for research-intensive goods overall. In addition, domestic trade is an important factor in the USA, as national demand is partly met by national supply. Thirdly, the recently passed Inflation Reduction Act also aims to boost sustainable technologies.

Like Germany, the UK shows few pronounced strengths and weaknesses. Solid scores are achieved for many indicators, especially in the area of government regulations or support. However, the UK does not fare quite as well in terms of environmental patents (15) and exports of sustainable goods (7). Japan and South Korea share some of their strengths. For example, both nations are characterized by a pronounced support for R&D in the

SUSTAINABILITY: DEVELOPMENT OF MAJOR ECONOMIES



Source: Fraunhofer ISI calculations

fields of environment and energy. Accordingly, both countries score well in terms of R&D spending on renewable energies and energy efficiency. Both countries have weaknesses in the export of sustainable goods.

ITALY AND PORTUGAL MAKE GAINS

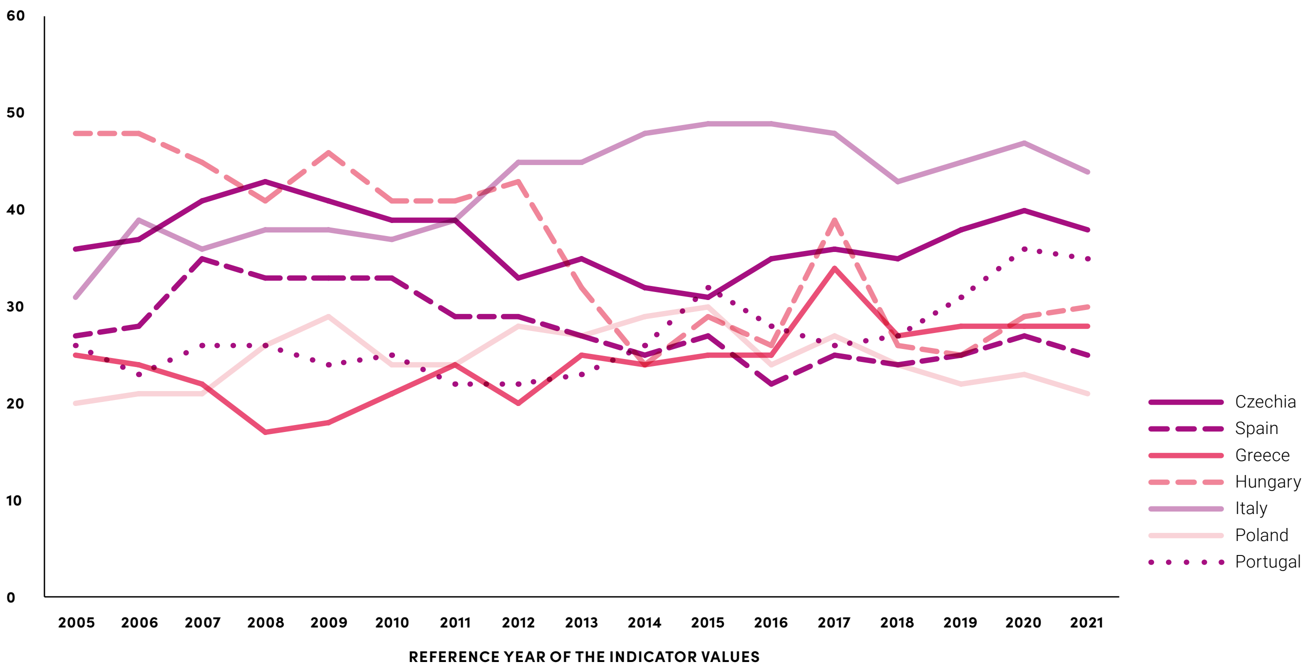
In the group of economies from Southern and Eastern Europe, Italy and Portugal in particular improved their ranking. While Italy scored 31 points in 2005, it was able to increase this figure to 44 points 16 years later. Portugal increased its score to 35 points (+9). Hungary, on the other hand, fell sharply behind, having originally scored 48 points and therefore placing very high. In 2021, it scored only 30 points. Most of the other countries in Southern and Eastern Europe changed their scores only slightly, including Spain, which most recently scored 25 points (-2 compared with 2005).

It is interesting to note that all economies in Southern and Eastern Europe share two strengths and two weaknesses. For example, all the countries considered are very far ahead in terms of environmental taxes in relation to total tax revenue. Greece even scores a tally of 100 here. With the exception of Spain, which scores 35 points, all the other countries are above the 50 points mark. In the case of environmental patents, on the other hand, no country scores more than six points, which can be explained in part by the generally below-average patenting activities in this group of countries.

Apart from that, some interesting aspects emerge: Italy, which is otherwise considered rather unfriendly to start-ups, still scores 53 points for green early-stage investments. Portugal even manages 56 points in this regard. Almost all countries in this comparison group are characterized by quite high government support for R&D in the field of environment and energy. Here Hungary leads the group with 81 points. Poland, which traditionally relies heavily on fossil fuels (coal), is the negative outlier (0). In Portugal, government support is also having an effect, as the country scores 66 points for R&D activities in the field of renewable energies. The Czech Republic is in second place here with 40 points. Spain (12) and Greece (0) achieve poor results.

The Czech Republic (100) and Hungary (86) in particular can exhibit economic successes in the sense of a positive trade balance concerning sustainable goods, i.e. they export significantly more of these goods than they import. Portugal has strengths in the area of knowledge generation. It scores 73 points for environmental publications. Overall, the picture that emerges for Portugal is one of a specialization in the area of sustainability, which comes about primarily through government support for sustainable economic activities. However, as in most other countries in the sample, there is still potential for growth in this area among companies.

SUSTAINABILITY: DEVELOPMENT OF ECONOMIES IN SOUTHERN AND EASTERN EUROPE



Source: Fraunhofer ISI calculations

» IT IS ENCOURAGING THAT WITH SOUTH AFRICA AND BRAZIL, AT LEAST TWO EMERGING COUNTRIES ACHIEVE SOLID RESULTS IN TERMS OF ENVIRONMENTAL INNOVATION. «

ENVIRONMENTAL REGULATION A DRAWBACK

In the group of emerging countries, India, Brazil and Indonesia in particular were able to improve their position in the ranking. Whereas India scored only seven points in 2005, it did manage 21 points by 2021 after all. Indonesia increased its score in the sustainability indicator from three to 15 points, Brazil from seven to 16 points. Russia (5 points in 2021 compared with 10 points in 2005), Mexico (23 points in 2021 compared with 28 points in 2005) and South Africa (15 points in 2021 compared with 19 points in 2005) especially have fallen back in the rankings. Turkey remained virtually unchanged with 16 points most recently (-1 compared with 2005).

All emerging economies are characterized by very low scores in the area of environmentally relevant publications and patents. This also reflects the fact that these nations are generally far behind in patenting and scientific publishing. In addition, all countries show weaknesses in the area of environmental regulation. Turkey scores the highest here with 16 points. Brazil, Indonesia, Mexico, Russia and South Africa score only zero in this area. Similarly, exports of sustainable goods are low in most countries. Here, Mexico is at a comparatively high level with 28 points. Turkey and South Africa manage a tally of 17 and 16 respectively. All other countries score zero points.

The strengths in terms of environmental attitudes, on the other hand, are interesting. Indonesia with 97 points almost achieves the best score. Behind it place India (87) as well as Brazil (73). Mexico and Turkey are also well positioned here with 54 and 50 points respectively. Russia achieves a below-average score of 34, while South Africa fails to score here. Data regarding R&D funding as well as R&D activities in environmentally relevant areas are patchy in this comparison group. It is interesting to note, however, that Mexico actually achieves the best score for government R&D funding in the environment and energy sector.

Equally encouraging is the fact that two of the emerging countries, South Africa and Brazil, achieved scores of 27 and 28 respectively in the area of environmental innovation in companies. While not top marks, these are solid results. These two countries are thus even well ahead of many of the Southern and Eastern European countries in this indicator.

RECOMMEN-DATIONS

1

PROMOTING SUSTAINABILITY WITH NEW TECHNOLOGIES

Technology development is essential for achieving sustainability goals. It is true that new sustainability-oriented technologies will not be sufficient in the short term to ensure a sufficiently strong decoupling of production from the consumption of natural resources. Nevertheless, new technologies are of particular importance for significantly increasing resource efficiency and replacing unsustainable forms of production with sustainable ones.

The further development of these technologies should be increasingly supported with appropriate incentives within the framework of government innovation funding. At the same time, however, care must be taken to provide sufficient space for new approaches. The incremental improvement of existing technologies should be complemented by appropriate support for novel technological solutions.

Start-ups also play a major role here, as it is often more difficult for them to access the relevant innovation funding programs. Existing access restrictions, which not only favor the emergence of funding careers for established companies but also keep new companies away from funding, must be dismantled consistently.

Sustainability is a challenge for society as a whole. It aims to meet the economic and social needs of the population of the current generation without compromising the opportunities of future generations.

Sustainability is also relevant to the national economy because only by respecting planetary boundaries can economic systems be successful in the long term and thus form the basis of societal prosperity. Companies are the decisive lever for reducing environmental pollution, decreasing dependence on fossil fuels and conserving natural resources.

In addition, national and international markets with competitive advantages for German companies can emerge via sustainable business models and value creation chains.

BUILD CIRCULAR BUSINESS MODELS

Innovation funding in the EU has traditionally had a strong technology focus. In the area of sustainability, the development of new technologies is seen as a central anchor point of an innovation-oriented transformation policy. There is no doubt that new, disruptive technologies play a major part. However, this focus obscures the fact that a socioeconomic transformation of the economy very often depends on the development of new circular business models. These can be based on new technologies, but equally require the transformation of entire value creation chains. This requires a significant degree of coordination, trust and financial investment from all companies involved in the production steps.

Research has shown that this is not easy to achieve even when the necessary technologies are available, because existing business models make transformative changes seem unattractive in the short term. In addition, silo mentality on the part of the players often does not lead to those solutions that would ultimately need to be implemented across the entire network. Existing R&D-oriented support programs such as the Central Innovation Programme for small and medium-sized enterprises (ZIM) only partially address this point. It is therefore important to develop programs that aim not only at technology development but also at reducing systemic barriers to the new development of circular business models in value creation chains.

CREATING SUSTAINABILITY-ORIENTED MARKETS

In Germany, public procurement accounts for around 15 percent of gross domestic product. This large volume represents a considerable economic lever for the creation of new markets, because government demand reliably geared to green aspects can significantly reduce economic uncertainty on the part of companies. In terms of transforming the economy toward circular business models, sustainability-oriented government procurement can even be particularly effective.

Firstly, the inclusion of sustainability-oriented objectives in the catalog of requirements for procurement is fundamentally unproblematic from the perspective of laws governing state aids and subsidies, as individual companies are generally not specifically favored if this is done appropriately. Secondly, a frequent objection to innovation-oriented government procurement is that a considerable proportion of government demand inevitably relates to rather simple products. This objection is less relevant for sustainability-oriented procurement, as products with a low degree of complexity can also be provided more sustainably by switching to circular or energy efficiency-oriented approaches – a reorientation pursued, for example, by the Inflation Reduction Act (IRA) in the USA. Particularly with a view to promoting new circular business models, sustainability aspects should therefore be consistently taken into account in public procurement.

THE CONCEPT UNDERLYING THE STUDY

Methodology of the Innovation Indicator

The Innovation Indicator represents a so-called composite indicator. The index value is obtained by combining individual indicators, which must be adapted to a uniform scale for aggregation. In the past, the Innovation Indicator had adopted an "actor perspective" and captured the main actor groups in innovation systems via various indicators. The new Innovation Indicator, on the other hand, adopts a more functional perspective in order to be able to better capture the change in innovation processes and the dynamics in the systems. This way factors and technologies that are relevant for future innovation capacity are better accounted for. The functional perspective focuses more on the functions to be performed and the interaction of groups of actors within a national innovation system. On the one hand, this change takes into account more recent scientific findings in the field of innovation systems theory. On the other hand, the functional perspective enables a closer interlocking with current topics of innovation policy. A comparison of the performance capabilities of the countries with regard to these functions is thus the subject of the analyses carried out.

The new Innovation Indicator distinguishes three key objectives of innovation systems:

- **generating innovation;**
- **developing future fields through key technologies;**
- **acting sustainably.**

For each key objective, a separate composite indicator is calculated.

There are three main stages that have to be performed in the calculation of composite indicators, namely the selection of the indicators (selection), the normalization of the values, and the aggregation of the individual values into an index.[7]

SELECTION OF INDICATORS

The list of individual indicators used to calculate the index values of the three functions can be found in the respective chapters. The individual indicators were determined through a three-step selection process. First, a list of indicators that are frequently used in the conceptual scientific literature on innovation research as well as in empirical innovation indicator sets was compiled. Then, the indicators were assigned to stages in the innovation process, from inputs to throughputs to outputs, and care was taken to ensure an even representation of the stages. Finally, a statistical analysis of the individual indicators was performed to identify individual indicators with a high significance and low redundancy in regard to other indicators. Correlation and factor analyses were used for this purpose. Indicators with very low coverage as well as large overlap in explained variance were removed from the selection set to achieve the most parsimonious model possible in a statistical sense.

NORMALIZATION

Normalization is necessary to make the individual indicators independent of their original units of measurement and to be able to subsequently offset them against each other. For this purpose, an indicator value of a country is set in relation to the indicator value of a comparison group. The following countries serve as a comparison group: Belgium, Denmark, Germany, Finland, France, Greece, the United Kingdom, Ireland, Italy, Japan, the Netherlands, Austria, Poland, Portugal, Sweden, Switzerland, Spain, the Czech Republic, the United States. The countries selected were those for which measured values are available for almost all individual indicators for as many years under review as possible. The countries in the benchmark group should have stable values or stable trends in order to ensure the stability of the benchmark over time. If the benchmark were to change massively in each year, the values of the individual economies would also change, possibly even without a de facto change in the original values of the economy under consideration.

Therefore, economies catching-up or even newly industrializing economies are therefore not represented in the benchmark group.

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

AGGREGATION

The aggregation of the individual indicators is of decisive importance for the respective results of the indices. In the Innovation Indicator, all selected individual indicators are given the same weight, i.e., there is no additional weighting of the individual indicators in the offsetting. Within the three target functions, therefore, the respective overall indicators are calculated as equally weighted mean values of the respective individual indicators. The reason for the equal weighting is, on the one hand, the simpler communicability or transparency respectively. On the other hand, both the theoretical-conceptual framework as well as the empirically guided selection of the individual indicators ensure that only indicators relevant to the respective function are taken into account and that, at the same time, there are no redundant indicators in the set, so that there is also no indirect weighting through the multiple mapping of a dimension by means of several indicators that measure the same thing.

SELECTION OF ANALYZED ECONOMIES

Within the framework of the Innovation Indicator, a selection of 35 economies is analyzed comparatively. The countries contained in the analysis include, on the one hand, the established industrialized nations, which are highly innovation-oriented and generally also engage in an intensive exchange of knowledge- and technology-intensive goods and services on the world markets. On the other hand, emerging economies and "newly industrializing countries" are also included in the group of economies under review. These include in particular the so-called BRICS group (Brazil, Russia, India, China, South Africa), which are interesting for international comparison in the Innovation Indicator not only because of their current or expected dynamics, but also because of their economic size.

For further details on the methodology, please refer to the English-language methodology document on the Innovation Indicator website.
innovationsindikator.de

ENDNOTES

1 Cf. 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 Cf. Edler, J.; Blind, K.; Kroll, H. & Schubert, T. (2021). Technology sovereignty as an emerging frame for innovation policy: Defining rationales, ends and means (no. 70). Fraunhofer ISI Discussion Papers-Innovation Systems and Policy Analysis.

3 Cf. Kroll, H.; Berghäuser, H.; Blind, K.; Neuhäusler, P.; Scheifele, F.; Thielmann, A. & Wydra, S. (2022). Schlüsseltechnologien (Nr. 7–2022). Studien zum deutschen Innovationssystem.

4 Cf. Rammer, C.; Trunschke, M. (2018). Forschung und Innovation: Die Schweiz im Vergleich zu anderen Innovationsregionen, Studie im Auftrag des Staatssekretariats für Bildung, Forschung und Innovation SBFI, Bern.

5 Expertenkommission Forschung und Innovation (EFI) (Ed.) (2022). Gutachten zu Forschung, Innovation und technologischer Leistungsfähigkeit Deutschlands 2022, EFI, Berlin; Kroll, H.; Berghäuser, H.; Blind, K.; Neuhäusler, P.; Scheifele, F.; Thielmann, A. & Wydra, S. (2022). Schlüsseltechnologien, Studien zum deutschen Innovationssystem Nr. 7–2022, Expertenkommission Forschung und Innovation, Berlin: EFI Geschäftsstelle; Frietsch, R.; Neuhäusler, P.; Rothengatter, O. (2022): Key Enabling Technologies in Europe: insights from patents and trademarks, RISIS Policy Brief Series, issue #12, Paris: RISIS; https://www.risis2.eu/policy-briefs/.

6 Cf. Braun, B. (2004). Umweltmanagement in der Wirtschaft. Rahmenbedingungen, Diffusionsprozesse und Erfolgsfaktoren auf globaler und regionaler Ebene. Petermanns Geographische Mitteilungen, 148(4), 56–65.

7 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 is drives towards a modern, sustainable, and successful industry in Germany, Europe, and the world.
bdi.eu

Roland Berger

Roland Berger is the only management consultancy of European heritage with a strong international footprint. As an independent firm, solely owned by our Partners, we operate 51 offices in all major markets. Our 3000 employees offer a unique combination of an analytical approach and an empathic attitude. Driven by our values of entrepreneurship, excellence and empathy, we at Roland Berger are convinced that the world needs a new sustainable paradigm that takes the entire value cycle into account. Working in cross-competence teams across all relevant industries and business functions, we provide the best expertise to meet the profound challenges of today and tomorrow.
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 pioneers 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 economic research institute. It is a member of the Leibniz Association. It was founded in 1990 on the initiative of the Baden-Württemberg state government, the state's business community and the University of Mannheim and began operations in April 1991. Since then, ZEW has established itself as one of the leading German economic research institutes with a high European reputation.
zew.de/en

EDITORIAL INFORMATON

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

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

AUTHORS
Rainer Frietsch, Christian Rammer, Torben Schubert,
Cecilia Garcia Chavez, Sonia Gruber, Valeria Maruseva,
Katrin Ostertag, 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. Sophia Helmrich (BDI),
Dr. Carsten Wehmeyer (BDI), Laura Biehn (Roland Berger),
Dr. David Born (Roland Berger)

GRAPHICS AND LAYOUT
SeitenPlan GmbH, Dortmund

TRANSLATION
Mahler Übersetzungen GbR, Walzbachtal

STATUS
April 2023

» INNOVATION ARE THE KEY TO SOLVING ESSENTIAL CHALLENGES OF THE FUTURE. «