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EFI - Commission of Experts for Research and Innovation (Ed.)

**Research Report**

# Report on research, innovation and technological performance in Germany 2021

Report, No. 2021e

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REPORT ON RESEARCH,
INNOVATION AND TECHNOLOGICAL
PERFORMANCE IN GERMANY

COMMISSION OF EXPERTS
FOR RESEARCH
AND INNOVATION

EFI

# REPORT 2021

2022 2023
2024 2025 2026
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REPORT ON RESEARCH,
INNOVATION AND TECHNOLOGICAL
PERFORMANCE IN GERMANY

COMMISSION OF EXPERTS
FOR RESEARCH
AND INNOVATION

EFI

# REPORT 2021

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The Commission of Experts wishes to emphasize that the positions expressed in the report do not necessarily represent the opinions of the aforementioned persons.

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# Foreword

It is not only from the perspective of R&I policy that the year 2020 presents itself as a very special one. The COVID-19 pandemic and the severe economic crisis that followed have shown how existential science and innovation are for tackling grand societal challenges. To better understand the health and socio-economic problems and to quickly arrive at fundamental solutions, scientific competence is required in all its breadth. In the medical-pharmaceutical sector, the development of new vaccines and drugs has been given top priority. Weaknesses in economic and social structures, as revealed by the COVID-19 crisis, call for explanations and solutions based on science. To be better prepared for future crises, approaches that increase the resilience of the economy and society are increasingly coming into focus.

In its 2021 report, the Commission of Experts first addresses the short-term developments attributable to COVID-19 and relates these to the priorities of R&I policy. Reconciling the need for stabilization in the crisis with long-term R&I policy is a particular political challenge. The short-term, debt-financed stabilization measures run the risk of weakening the R&I system in the long term because fewer funds will be available for future investments in subsequent years. Only if a stabilization-oriented policy explicitly includes and strengthens the R&I system will it continue to be able to produce innovative solutions to problems in the future. Society and policymakers need to recognize this as a prerequisite for continuing to address grand challenges such as climate change, health, social inequality, and resilience from an economically strong and socially broadly supported R&I system.

The Commission of Experts' 2021 report should be seen against the background of these considerations.

Chapter A 1 is dedicated to the impact of the COVID-19 crisis on the innovation activities of companies. For the majority of German companies, the current crisis situation negatively affects ongoing or planned innovation projects. In the Commission of Experts' opinion, the crisis can also act as a catalyst for the transition to new technologies and thus improve Germany's long-term competitiveness. This assumes that economic stimulus programmes and growth policy measures are designed with R&I in mind.

In chapter A 2, the Commission of Experts comments on the Federal Government's research and innovation policy measures of the past year. It appreciates that the establishment of the Future Fund improves the financial framework conditions for the provision of venture and growth capital. It also welcomes the promotion of future

technologies such as hydrogen and quantum technology within the framework of the Future Package. At the same time, it suggests accompanying measures to increase the effectiveness of key R&I policy initiatives launched in 2020.

Although overcoming the COVID-19 crisis will be a key task for the new Federal Government in the coming legislative period, R&I policy must continue to be prioritized. In chapter A 3, the Commission of Experts names five priorities that should guide R&I policy in the next legislative period. These are: 'Addressing Grand Societal Challenges', 'Catching Up and Avoiding Technological Gaps', 'Securing the Skilled Labour Base', 'Increasing Innovation Participation', and 'Increasing the Agility of R&I Policy'.

R&I policy has the responsibility to contribute to addressing the grand societal challenges and to initiate transformative change. As the policy approach of New Mission Orientation supports this, the Commission of Experts advocates in chapter B 1 that the Federal Government should give greater attention to this policy approach in a market-oriented version. The successful implementation of New Mission Orientation requires agile policy making. The Commission of Experts welcomes that R&I policy has already become more agile in recent years but calls on the Federal Government to incorporate agility in political action even more systematically.

In chapter B 2, the Commission of Experts analyses how the system of vocational and continuing education and training (VET/CET) must change to keep pace with changing competence requirements due to digital transformation. To secure employment and realize innovation potentials, it is necessary to adapt VET to the requirements of the digitalized world of work and to strengthen job-related CET. The Commission of Experts recommends strengthening occupational adaptability by expanding flexible additional qualifications, providing sufficient resources for higher-quality CET programmes, and additionally promoting preventive adaptation qualifications. It moreover welcomes initiatives for the comprehensive monitoring of occupational skills in support of more tailored VET/CET.

In chapter B 3, the Commission of Experts looks at the gene scissors CRISPR/Cas, a new tool for gene editing, and its use for medical purposes. Measured by the number of publications, Germany occupies a good position in CRISPR/Cas research in an international comparison. However, Germany falls behind when key performance indicators in the application and commercialization of this technology are considered. To be able to exploit untapped potential in the translation of research results into application, the framework conditions for approval procedures and the provision of private venture and growth capital must be improved and interdisciplinary cooperation and working groups must be promoted.

Berlin, 24 February 2021

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# EXECUTIVE SUMMARY

# Executive Summary

# A CURRENT DEVELOPMENTS AND CHALLENGES

## A 1 Impact of COVID-19 Crisis on R&I

The COVID-19 crisis has hit the global economy abruptly and hard. The lockdowns imposed in Germany to control SARS-CoV-2 entail massive economic imbalances as well as impairments in the science sector. For the majority of German companies, the current crisis situation negatively affects ongoing or planned innovation projects. In particular SMEs expect significant decreases in their innovation spending under the conditions of the pandemic.

The Federal Government has provided important political impulses such as immediate short-term measures for maintaining solvency and the prevention of wide-ranging bankruptcy as well as economic stimulus packages for combating the recession that also benefit the R&I system. However, the Commission of Experts calls for swift disbursement of the announced funds based on reliable eligibility criteria.

In the Commission of Experts' opinion, the crisis can also act as a catalyst for the transition to new technologies and thus improve Germany's long-term competitiveness. To this end, further economic stimulus programmes and growth policy measures should be designed with as much focus on R&I as possible. Against this background, the Commission of Experts explicitly welcomes the Federal Government's intention of using €60 billion from the economic stimulus package for investment and innovation.

## A 2 Commentary on Current R&I Policy

In the past year, despite yet also partly because of the COVID-19 crisis, key future issues were advanced in R&I policy that are of great importance for maintaining Germany's competitiveness in the long-term.

The establishment of the Future Fund will strengthen the venture capital market in Germany and aims to improve the financing situation for start-ups. The Commission of Experts calls on the Federal Government to swiftly implement the Future Fund and suggests early and regular evaluations so that the instrument can be adapted where necessary.

The Commission of Experts welcomes the inclusion of the National Hydrogen Strategy and its additional funding of €7 billion as part of the Future Package. It points out, however, that national market ramp-up should not take place without the parallel, added provision of renewable energy.

It likewise welcomes the Federal Government's provision of funding for quantum technologies totalling €2.65 billion. The joint initiative of the Federal Government, the Fraunhofer-Gesellschaft and IBM to operate Europe's first universal quantum computer at a German site serves to improve Germany's position in this field.

The Commission supports the intention of making the public sector a pioneer of data provision and utilization. It also suggests establishing coordination structures between the responsible agencies to ensure the transparent and standardized provision of data for research as well as more data- and evidence-based policies, and to enable the linking of data across public authorities.

## A 3 Priorities for R&I Policy in the Coming Legislative Period

Although overcoming the COVID-19 crisis will be one of the key tasks of the new Federal Government in the coming legislative period, R&I policy must continue to be prioritized. A coherent policy approach for the entire innovation process to which all ministries are committed will be needed.

The Commission of Experts recommends that in the coming legislative period the new Federal Government should adjust its R&I policy to five key priorities. High priority must be given to the grand societal challenges and, in particular, to the sustainability goals. It is equally important for the development of prosperity that Germany catches up with existing technological gaps and avoids these in potential key technologies from the outset. To achieve these objectives, Germany, as a country poor in natural resources, must have a strong skilled labour base. With regards to R&I investments in private enterprises, it is moreover important to increase innovation participation. Finally, the agility of R&I policy is an important prerequisite for successfully implementing the transformative change desired by society.

# B CORE TOPICS 2021

## B 1 New Mission-Orientation and Agility in R&I Policy

R&I policy has the responsibility to help meet the grand societal challenges. The Commission of Experts advocates that to this end the Federal Government should focus more on the policy approach of New Mission Orientation. This means that the state guides innovation activities towards socially agreed directions, which private sector stakeholders would not pursue on their own accord. However, the Commission of Experts is of the opinion that the market as a process of discovery must not be removed. It therefore proposes

a market-oriented version of New Mission Orientation, characterized by an openness to problem-solving and catalytic market interventions.

The successful implementation of this policy approach requires agile policy making. The Commission of Experts welcomes that R&I policy has already become more agile in recent years but calls on the Federal Government to incorporate agility in political activity even more systematically. To this end, the Commission of Experts recommends the following measures:

- The Federal Government should ensure close cooperation between the various ministries as well as active involvement of stakeholder groups, panels of experts, citizens as well as the Länder and municipalities in the drafting of missions.

- Concrete objectives must be derived from the missions. These must have a time frame and their fulfilment must be measurable. The time frame should be based on the objective of the missions and not on the duration of legislative periods.

- When implementing missions, it is necessary to strengthen horizontal coordination within and between ministries. This can be done by way of inter-ministerial task forces as well as, within ministries, inter-departmental project teams or mission-related units within the organizational structure. These are each to be equipped with their own discretionary competences and budgets.

- Innovation-oriented public procurement should be further expanded and increasingly aligned with the socially agreed missions.

- In terms of a positive error culture, policy learning should be implemented more strongly to ensure that goal adjustments, readjustments of the organization and measures and even a complete discontinuation are possible and accepted when implementing missions.

- For the purpose of policy learning, it makes sense to create more scope for reflection and freedom and to free up staff capacities in ministries and project executing agencies to this end.

## B 2 Adapting Vocational and Continuing Education and Training to Digital Transformation

As a result of the digital structural change, many employees in Germany will have to change jobs in the coming years and reorient themselves professionally. In addition, job profiles in many existing workplaces will continue to change. To maintain professional action competence, it is therefore not only necessary to develop better core digital skills, but increasingly also essential core skills such as problem-solving skills, creativity, initiative, and adaptability. It is therefore necessary to adapt vocational education and training (VET) to the requirements of the digitalized world of work and to strengthen job-related continuing education and training (CET). With this in mind, the Commission of Experts recommends:

- The Federal Government should work towards ensuring that all training regulations are adapted to the changes brought about by digitalization and kept sufficiently up to date. Advice and assistance for implementing a VET design adapted to digitalization should be expanded – especially for SMEs.

- The training and continuing education of teachers must be geared even more closely to the new content-related and methodological requirements resulting from digitalization. In addition, it is urgently necessary to equip vocational schools with a high-performance digital infrastructure.

- The supply of additional qualifications during VET should be further expanded and be opened to job-related CET.

- Great weight should be attached to output-oriented criteria in the accreditation and approval of CET providers in the field of publicly funded job-related CET.

- To support SMEs in job-related CET, the establishment of local and regional networks that organize efficient inter-company solutions should be promoted.

- Instruments supporting preventive adjustment qualifications should be tested, which in sufficient time facilitate the transition of employees to a new employer and appropriately involve both the previous and the new employer.

- To improve the information base for career and educational decisions, initiatives for a comprehensive monitoring of occupational skills that supports more tailored education and training should be advanced.

## B 3 Gene Editing and CRISPR/Cas

The CRISPR/Cas gene scissors are a tool for gene editing that gives new impetus to basic medical research and enables new therapeutic approaches for many diseases. The targeted alteration of genetic information enables the direct elimination of the causes of hereditary diseases. The field of somatic-cell gene therapy in particular offers significant potential. To leverage the potential associated with CRISPR/Cas, further major advances are needed both in research and in the translation of research results into application. The Commission of Experts therefore recommends the following measures:

- Approval procedures must be designed – always under the maxim of maintaining safety and ethical justifiability – in such a way that the administrative burden for researchers is reduced.

- To ensure that licensing procedures can continue to be completed as quickly as possible, staffing levels within the approval authorities must be adjusted at an early stage to reflect the expected increase in licensing procedures.

- The bundling of related applications and approval procedures should be made possible. In addition, efforts should be made to harmonize licensing procedures across the Länder.

- In particular, interdisciplinary collaborations and working groups should be initiated and promoted that support translation and generate innovations through early interaction between research and clinical practice.

- For advising researchers and networking with various stakeholder groups, the establishment of a German Gene Therapy Centre should be discussed, which can assume the role of a competence centre for translation from basic research and preclinical research into clinical application.

- The feasibility of clinical trials should be improved by means of more favourable framework conditions, such as faster, more efficient, and less detailed approval procedures.

- The framework conditions for the provision of private venture and growth capital should be improved.

- It is important to regularly inform society about the potentials and risks associated with CRISPR/Cas and to continue the associated social discourse.

# CURRENT DEVELOPMENTS AND CHALLENGES

A

# A 1 Impact of COVID-19 Crisis on R&I

The COVID-19 crisis has hit the global economy abruptly and hard. The lockdowns imposed in Germany to contain SARS-CoV-2 entail massive economic imbalances. Disruptions in international supply chains, the collapse of international trade and limited domestic economic activity have resulted in a decline in the supply of and demand for products and services. For a large part of the companies, this is associated with sometimes significant losses in turnover. This affects larger companies with 100 or more employees to the same extent as companies with five to 19 and 20 to 99 employees.[1] As a result of such loss of turnover, companies have fewer financial resources available for R&I projects. For stakeholders in the science system, too, the lockdowns impose restrictions, the effects of which will be reflected in research performance. As the duration of the pandemic increases, these developments in the corporate and scientific sectors may lead to a longer-term weakening of the German R&I system.

## Majority of Companies Affected by COVID-19 Crisis

An evaluation of data from the ZEW Business Survey in the Information Economy shows that for most German companies the COVID-19 crisis has negative effects on current or planned innovation projects (cf. figure A 1-1). This most often results in delays of existing innovation projects. Around 32 percent of companies in the information sector and 45 percent of companies in the manufacturing sector are affected. The second and third most frequent reports are that companies have not started previously planned projects or have not planned any new innovation projects. Companies are much less likely to say that they have completely abandoned innovation projects that are already under way.

Yet apart from the primarily negative effects of the COVID-19 crisis, positive impulses on innovation activity, too, can be observed. For instance, about 26 percent of companies in the information sector and 28 percent of companies in manufacturing report that the impact of the COVID-19 crisis has led to new innovation projects. For 18 percent of companies in the information sector and 10 percent in manufacturing, the crisis has even led to an acceleration of innovation projects (cf. figure A 1-1).

Both positive and negative effects on innovation projects are perceived by 14 percent of companies in the information sector and 22 percent of companies in manufacturing. About 20 percent of companies in the information sector and 13 percent of companies in the manufacturing sector describe themselves as not affected by the COVID-19 crisis (cf. figure A 1-1).

## Lack of Financial Resources for Innovation Activities

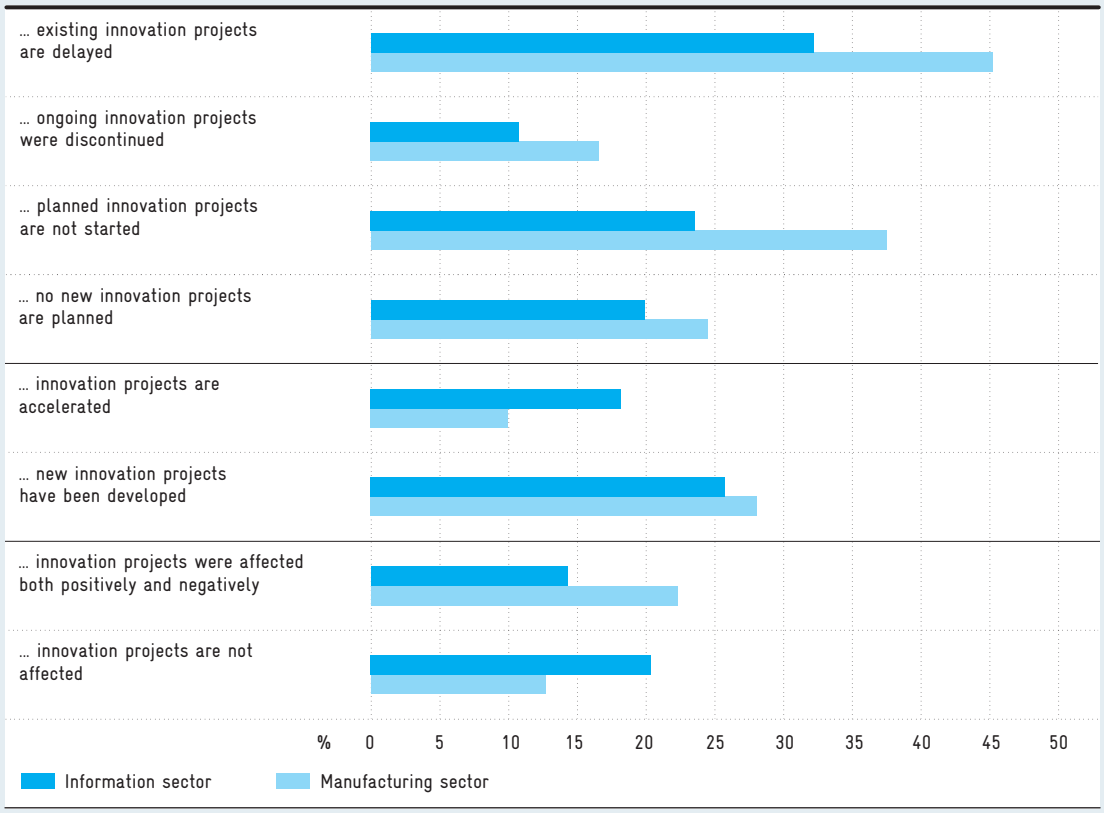
For companies, whose innovation activity is affected by the COVID-19 crisis, the reduced availability of financial resources is the most common reason for impairment of innovation activity. About 79 percent of the negatively affected companies in the manufacturing sector point to this. In the information sector, this percentage is significantly lower at around 64 percent (cf. figure A 1-2).

In addition to a lack of funds for the financing of innovation activities, many companies are confronted with the problem of declining demand for innovative products and services; this, too, affects the manufacturing sector more, with 50 percent of companies compared to 35 percent in the information sector. A slightly smaller number of companies

Fig. A 1-1

Download data

## Impact of COVID-19 crisis on innovation activity




Sector-specific extrapolation of the results to the question:
'What impact does the COVID-19 pandemic have on your company's innovation activities? Due to the COVID-19 pandemic ...'
Legend: At 24 percent of companies in the information sector, planned innovation projects are not started.
Source: ZEW Business Survey in the Information Economy 2020.
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state that supply difficulties regarding materials and intermediate inputs important for innovation negatively affect their innovation activities. Some companies see their innovation projects hampered by the fact that R&D personnel and R&D cooperation partners are only available to a limited extent because of the crisis, or that premises cannot be used for R&D. Here, there are only minor differences between the information sector and manufacturing. Another problem is the lack of access to data relevant to innovation. In many companies, this access is only possible on site and not from the home office. About 15 percent of companies in the information sector and 19 percent of companies in manufacturing explain the negative influence of the COVID-19 crisis on innovation activity by the fact that their own digital infrastructure and equipment do not meet the new requirements (cf. figure A 1-2).

### Future Package (Zukunftspaket) Sets Important Impulses for R&I System

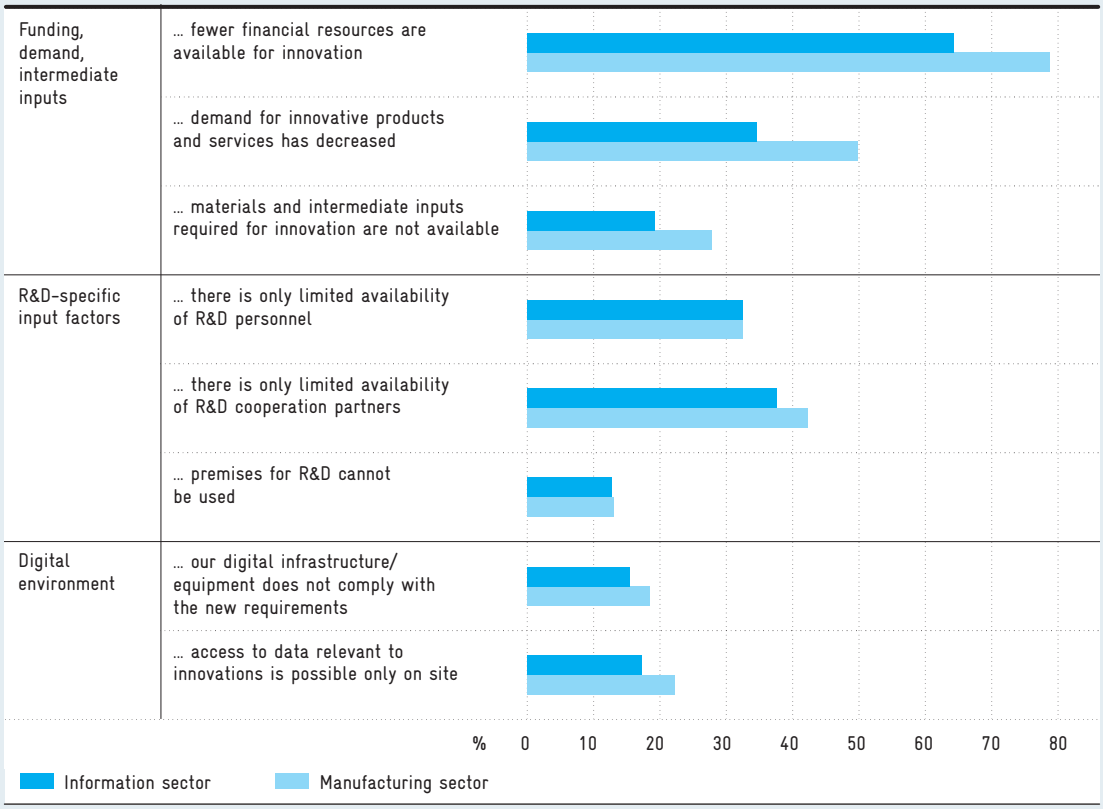
In June 2020, the Federal Government adopted a comprehensive economic stimulus package totalling €130 billion. In addition to short-term stabilization measures, this economic stimulus package also includes a Future Package (Zukunftspaket) with a volume of more than €60 billion to overcome the medium- and long-term consequences of the COVID-19 crisis.[2]

A

Fig. A 1-2

Download data

## Reasons for impairments due to the COVID-19 crisis




Sector-specific extrapolation of the results from companies that reported at least one negative impact when asked about the impact of the COVID-19 pandemic on their innovation activity, to the question: 'Does the COVID-19 pandemic impact on your company's innovation activity because ...?'
Legend: For 64 percent of companies in the information sector whose innovation activity has been negatively affected by the COVID-19 pandemic, innovation activity is impaired because fewer financial resources are available for innovation.
Source: ZEW Business Survey in the Information Economy 2020.
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The Federal Government has provided important political impulses such as immediate short-term measures for supporting solvency and the prevention of wide-ranging bankruptcy as well as economic stimulus packages for combating the recession and weathering out the COVID-19 crisis. These impulses also benefit the R&I system.

Liquidity support enables companies to retain R&D employees and their skills within the company. The aid bundled in the Federal Government's 'Package of measures to combat the impact of coronavirus on companies' represents an important support.[3] The Commission of Experts welcomes the fact that this aid has increasingly been adapted to the specific needs of small and medium-sized enterprises (SMEs). For example, liquidity support measures[4] were expanded. The Federal Government, together with the Länder, has also expanded its participation offers for start-ups and SMEs. They are intended to help companies, through a reinforced equity base, to temporarily remain able to act and to invest in innovation and modernization despite the crisis.[5] However, the Commission of Experts calls for the rapid disbursal of the announced funds based on reliable eligibility criteria.

The Future Package contains extensive investments in education, research and innovation as well as future technologies, which are intended to ensure

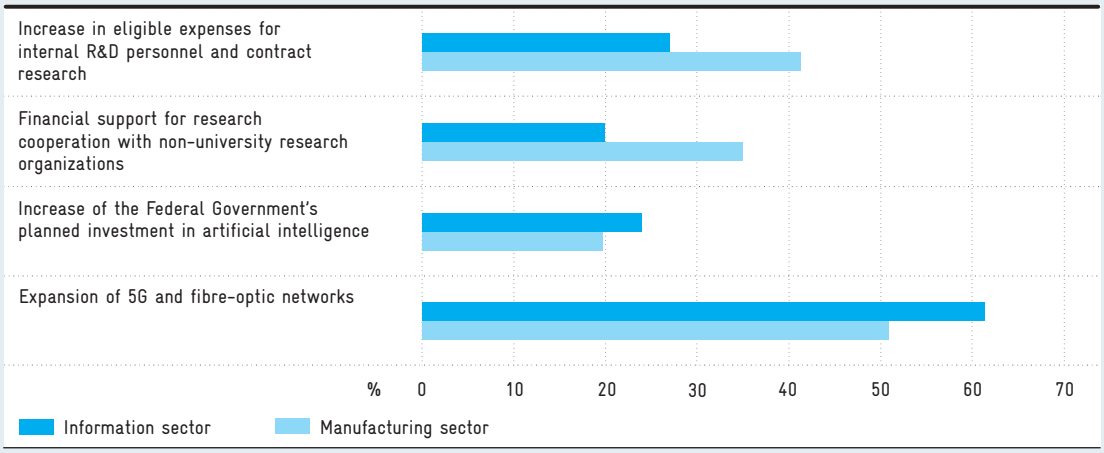
that 'Germany emerges stronger from the crisis and is successful in the long term'.[6] In this context, the Research Allowance Act (Forschungszulagengesetz (FZulG), cf. chapter A 3) was also amended.[7] By increasing the subsidy cap for a limited period until 2026, companies are to be given an incentive to invest in R&D despite the crisis. The Commission of Experts criticizes the fact that SMEs hardly benefit from this increase in the funding cap and therefore sees a need for further adjustment.[8] This is particularly relevant in light of the fact that SMEs expect significant declines in innovation expenditure in 2020 and 2021 given the conditions of the pandemic. The survey of the Mannheim Innovation Panel (MIP) from spring 2020 shows that SMEs expect their innovation expenditure to fall by almost 9 percent in 2020 and by another 5 percent in 2021. By contrast, large companies expect innovation budgets to remain largely stable in 2020 and to expand slightly by 2 percent in 2021.[9]

The ZEW Business Survey mentioned above also asked companies which measures from the Future Package would benefit their innovation activities (cf. figure A 1-3). The 'increase in eligible expenditures for internal R&D personnel and contract research' is regarded as conducive to their own innovation activities by 42 percent of companies in manufacturing and by 27 percent in the information sector. Measures to 'financially support research cooperation with non-university research organizations' meet with approval particularly in the manufacturing sector, at 35 percent. The approval of companies in the information sector is significantly lower here at 20 percent. The increase in the Federal Government's planned investment in artificial intelligence, as provided for in the Future Package, is perceived as a positive impulse for their own innovation activities by about 20 percent of companies in the manufacturing sector and 25 percent in the information sector. Finally, about 62 percent of companies in the information sector and 51 percent of companies in the manufacturing sector are of the opinion that innovation activities would benefit from the expansion of the digital infrastructure, especially the planned expansion of 5G and fibre-optic networks (cf. figure A 1-3).

Fig. A 1-3

Download data

**Positive assessment of the measures from the Federal Government's Future Package for innovation activity**




Sector-specific extrapolation of the results for the question: 'Which of the following measures from the Federal Government's Future Package would benefit your company's innovation activities?'
Legend: For 62 percent of companies in the information sector, innovation activity would benefit from the expansion of 5G and fibre-optic networks.
Source: ZEW Business Survey in the Information Economy 2020.
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### Use Crisis as Catalyst for Transition to New Technologies

The measures to bridge the COVID-19 crisis are primarily financed through debt. The Commission of Experts sees a risk that in the future limited budgetary leeway will have a negative impact on R&I policy. The Commission of Experts cautions that the short-term stabilization of the economy must not be at the expense of the medium- and long-term competitiveness of the German R&I system. It also points out that the short-term preservation of certain companies that will not be able to prove themselves on the market in the long term can hinder or at least delay the market introduction of new technologies and business models.

In the Commission of Experts' opinion, the crisis can also act as a catalyst for the transition to new technologies and thus improve Germany's long-term competitiveness.[10] To this end, further economic stimulus programmes and growth policy measures should be designed with as much focus on R&I as possible.[11] This allows for the setting of growth impulses that exceed the costs of the support measures in the medium term. A development such as the reduction of the announced budget of the Horizon Europe research and innovation framework programme by about 8 percent must be urgently avoided.

With that said, the Commission of Experts expressly welcomes the Federal Government's intention of using €60 billion from the economic stimulus package to target investments and innovation. For instance, the provision of more financial resources for the expansion of the digital infrastructure can help to sustainably consolidate the innovation activities of companies. The Commission of Experts also appreciates the increased promotion of future technologies such as artificial intelligence, hydrogen technology and quantum technology as an important step in advancing the innovation-driven transformation of the economy.

Crises such as the COVID-19 pandemic are not predictable. However, the current experiences should be used to be better prepared for future crises. The Commission of Experts recommends documenting and evaluating the experiences in dealing with the COVID-19 crisis, as well as taking resilience research approaches into account in the further development of the R&I system and promoting corresponding research projects in this regard.

### Substantial Funding Provided for Coronavirus Research

To overcome impairments in the science sector caused by the lockdowns, the Federal Government has initiated a series of measures ranging from relaxations in the Law on Fixed-Term Employment Contracts in Science (Wissenschaftszeitvertragsgesetz (WissZeitVG)) to simplifications in project applications and processing. The Commission of Experts welcomes the fact that some of its proposals in this regard have been adopted and implemented.[12]

An important item in the Federal Government's bundle of measures is the promotion of coronavirus research itself. Research activities in this field can be seen worldwide, not only in medical and pharmacological research, but also in the social and engineering sciences (cf. box A 1-4).

The Federal Government has given substantial funding for coronavirus-related research, especially for drugs and vaccines, with direct and indirect boosts to the economy. For example, the Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF) is supporting the CEPI (Coalition for Epidemic Preparedness Innovations) vaccine initiative with additional funding of €230 million and is supplying up to €750 million for the special programme to accelerate research into and development of urgently needed vaccines against SARS-CoV-2. With the development of a vaccine by BioNTech, a company directly funded by the BMBF, these measures have substantially contributed to a success that has received worldwide attention.[13] In addition, €150 million have been provided for the establishment of a national university medicine network to bundle and consolidate coronavirus-related research activities, and €45 million for the development of drugs.[14] To support the clinical testing of therapeutic agents, the BMBF has set up a programme with a volume of €50 million.[15] In addition to research in medicine and medicine-related disciplines, the BMBF has increased funding for social science research in the short term and has advanced the networking of empirical social science research into the COVID-19 crisis.[16] The Commission of Experts positively emphasizes that the funding of

Box A 1-4

A

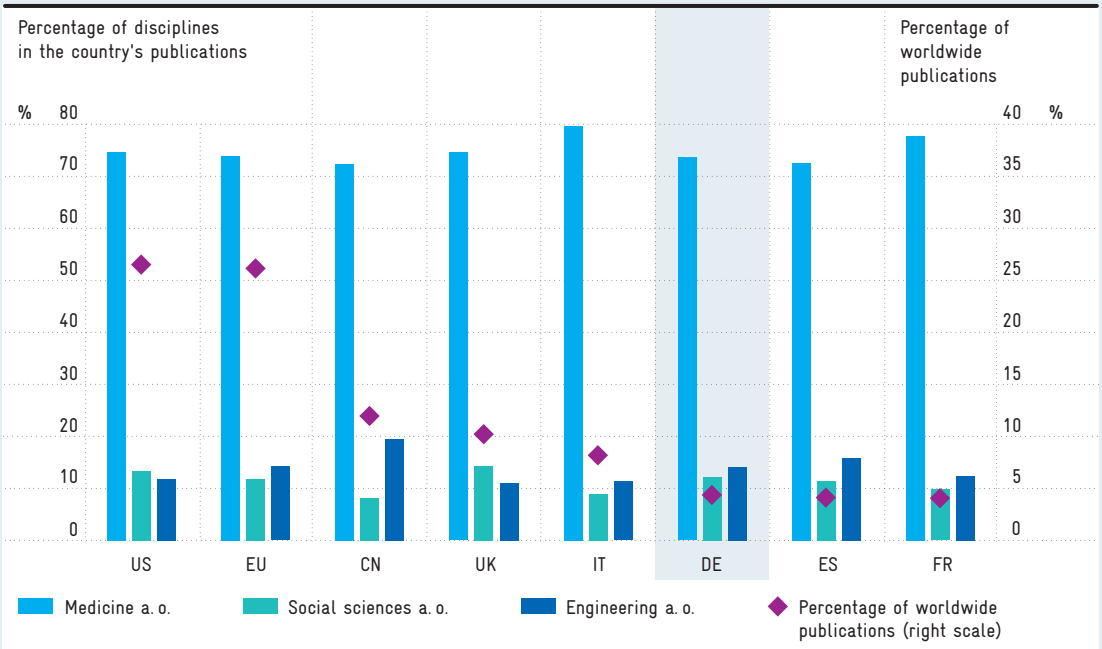
## Research on SARS-CoV-2 and COVID-19

An assessment of the activity of scientific research on the topic of SARS-CoV-2 and COVID-19 yields the following picture, which is based on publication data of scientific articles from the scientific database Scopus.[17] The largest share of all recorded publications is accounted for by researchers with affiliation in the USA (27 percent). They are followed by researchers in the EU (26 percent), China (12 percent), and the UK (10 percent).[18] Researchers with an affiliation in Germany achieve a share of about 4 percent. The thematic focus of research on SARS-CoV-2 and COVID-19 in Germany is concentrated on the disciplines of medicine, health, biochemistry, microbiology, and pharmaceutics. These disciplines make up 74 percent of all publications on the topic of SARS-CoV-2 and COVID-19. Social sciences account for 12 percent and engineering for 14 percent. A similar picture as in Germany emerges in the other six countries under investigation as well as for the EU.

Fig. A 1-5

Download data

### Publications related to SARS-CoV-2 and COVID-19 by country and discipline in percent




Diamonds indicate the percentage of SARS-CoV-2 and COVID-19-related publications of the respective country in the total number of worldwide publications on this (right scale). Columns represent the percentages of SARS-CoV-2 and COVID-19-related publications from medicine, social sciences, and engineering of all related publications within the respective country (left scale).

Legend: The share of publications related to SARS-CoV-2 and COVID-19 that are attributed to researchers with affiliation in the USA is 27 percent of all publications on this topic worldwide. The share of publications related to SARS-CoV-2 and COVID-19 from the social sciences by researchers with affiliation in Germany out of all publications on this topic from Germany is 12 percent.

In the allocation of publications to the respective countries, multiple counts occur in the case of international co-authorships. The publication media considered include journal articles, conference papers, reviews, book chapters, books, and data reports.
Source: Scopus (accessed on 30 November 2020; comprises publications published in 2020 and forthcoming publications).
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coronavirus-related research by the BMBF and the project executing organizations was initiated very quickly.[19]

Despite the impressive successes achieved in Germany in the fight against SARS-CoV-2, the Commission of Experts sees potential for improving structures that enable faster and more efficient intervention in the event of pandemics and ensure a rapid ramp-up of drug research and development in the event of a crisis. In the USA, the Biomedical Advanced Research and Development Authority (BARDA), among others, takes on this task. Its job is to coordinate and promote the procurement and development of medicines and vaccines against known and unknown diseases.[20] The Commission of Experts suggests examining whether it would make sense to set up a similar institution in Germany or at EU level.

# Commentary on Current R&I Policy A 2



The COVID-19 crisis has left its mark on 2020 also in terms of economic policy. Since March 2020, the public debate has focused mainly on short-term support measures to stabilize the economy. Despite yet also partly because of the COVID-19 crisis, key future issues were advanced in R&I policy that are of great importance for maintaining Germany's competitiveness in the long term. In addition to improving the financial framework conditions for R&I activities by the creation of a Future Fund (Zukunftsfonds), among other things, this also includes promoting future technologies such as hydrogen and quantum technology within the framework of the Future Package (Zukunftspaket). Furthermore, the European cloud infrastructure GAIA-X and the National Research Data Infrastructure (Nationale Forschungsdateninfrastruktur, NFDI) were advanced.

## Future Fund Launched

To strengthen the venture capital market in Germany and improve the financing situation of start-ups, the Federal Government has with the adoption of the Budget Act (Haushaltsgesetz) 2021 created the conditions for an equity fund for future technologies, the so-called Future Fund.[21] This fund will have various elements that include both the expansion of existing financing instruments and the development of new instruments for growth financing such as a deep tech fund and a growth fund. €10 billion have been earmarked for this over a ten-year period as of January 2021. The Commission of Experts expressly welcomes the fact that this will improve the possibilities for financing growth by a large amount. It calls on the Federal Government to swiftly implement the Future Fund and suggests early and regular evaluations so that the instrument can be adapted where necessary.

## Regulations on Foreign Direct Investment Tightened

Last year, the Federal Government further tightened the regulations for corporate takeovers and investments for non-European investors.[22] In future, a 'probable impairment' of public order or security, not merely an 'actual threat', will suffice as reason for a review of foreign investments.[23] In addition, this review may take into account whether the investor is directly or indirectly controlled by the government of a third country, including other public sector agencies or armed forces.[24] In its last report, the Commission of Experts addressed the issue of investment control in the context of German-Chinese knowledge and technology exchange.[25] Against this background, it welcomes this expansion of investment review options.

Regarding the planned expansion of the range of technologies defined as safety-relevant,[26] the Commission of Experts cautions that potentially negative consequences for innovation must be considered. For instance, the extension of direct investment controls can inhibit the dissemination of innovative technologies and business models. Also, an overly restrictive application of the control options could make it more difficult to reap the benefits of the international division of labour.

## Further Incentives for Mobility Turnaround Required

Regarding sustainable mobility, the carbon pricing for fuels that has been in effect since this year, with an initial price of €25 per tonne of $CO_2$,[27] creates moderate incentives to reduce the consumption of fossil fuels such as petrol, diesel, and LPG in private transport.

However, one of the main reservations of road users against the use of new propulsion technologies, apart from the high price, is the insufficient refuelling and charging infrastructure.[28] The intensification of the expansion of the refuelling and charging infrastructure for electric vehicles[29] that has been initiated is therefore a necessary step towards increasing the attractiveness of new propulsion technologies.[30] The Commission of Experts expects this to provide a higher and more persistent stimulus for the demand for electric vehicles than the innovation premium included in the Future Package. It also considers the Federal Ministry for Economic Affairs and Energy's (Bundesministeriums für Wirtschaft und Energie, BMWi) initiative for a uniform Europe-wide payment system at charging stations and hydrogen filling stations[31] to be another important step towards increasing the acceptance of new propulsion technologies.

### Increase Availability of Renewable Energy for Green Hydrogen

The Commission of Experts welcomes the inclusion of the National Hydrogen Strategy as a framework for the future production, transport, use and re-use of hydrogen, and its additional funding of €7 billion as part of the Future Package.[32] It is moreover of the opinion that the development of foreign trade partnerships, funded by a further €2 billion, represents an important approach in the production of green hydrogen.[33]

However, a national market ramp-up should not take place too quickly and not without the parallel, added provision of renewable energy. Otherwise, there is a danger that the relatively energy-intensive production of hydrogen will lead to added use of fossil fuels. The exemption of hydrogen production from the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG) levy advocated by the National Hydrogen Council (Nationaler Wasserstoffrat),[34] which acts as a subsidy for electricity as a production factor in hydrogen production, can exacerbate this and should therefore be a short-term instrument at best.

The sustainable target effect of the hydrogen strategy and of electromobility is linked to the expansion of the availability of green electricity. Given this, the Commission of Experts considers the intensification of project-based research such as the programme 'Smart Energy Showcases' (SINTEG)[35] and the regulatory test beds of the energy transition (Energiewende) in the Future Package to be important and necessary steps.[36]

### Advance Quantum Technology Research

According to experts, Germany's position in the field of quantum technology varies depending on the subfield.[37] While Germany's position in quantum sensing and imaging is generally considered good in an international comparison, it is only mid-table in quantum communication and simulators. Regarding quantum computing, Germany even occupies a bad position.[38]

The Commission of Experts welcomes the fact that the Federal Government is providing a total of €650 million for R&D in the field of quantum technologies by 2022[39] and is moreover increasing funding for quantum technology by €2 billion as part of the Future Package.[40] The joint initiative of the Federal Government, the Fraunhofer-Gesellschaft and IBM[41] to operate Europe's first universal quantum computer at a German site can significantly improve Germany's position in this field. In the long term, the goal should be to develop clusters or ecosystems in the field of quantum technology where basic and applied research as well as the industry work closely together to identify commercialization opportunities at an early stage.

### Further Accelerate Implementation of AI Strategy

On 2 December 2020, the Federal Cabinet adopted the updated AI Strategy: by 2025, the Federal Government's investment in artificial intelligence (AI) will be increased from three to five billion euros with funds from the Future Package.[42] The Commission of Experts expressly welcomes the increase in funding and the expansion of the areas of application as well as the European and international networking. It recommends that basic research on AI should focus on both symbolic and neuronal AI.[43] In addition, the Commission of Experts is of the opinion that the close cooperation already taking place within the European AI research networks ELLIS[44] and CLAIRE[45] should be continued.

The Commission of Experts still sees considerable need for action in filling the 100 new AI professorships listed in the 2018 AI Strategy. Only a fraction of the planned 100 AI professorships have been created.[46] The Commission of Experts has previously pointed out that one way to counteract the expected protracted filling of the positions is to make the positions more attractive and to increase the recruitment and promotion of young scientists.[47]

### Establish the Public Sector as Data and Services Provider on GAIA-X

The GAIA-X project,[48] launched in late 2019, aims to create a reliable, sovereign data infrastructure for Europe. In September 2020, the GAIA-X AISBL organization[49] was founded under Belgian law, comprising 22 companies and organizations – eleven each from Germany and France. It takes on the task of representing and coordinating the GAIA-X project. Other companies and organizations from various countries – more than 300 so far – dock on to this core team. The Federal Government is planning to include around €200 million in its 2021 budget[50] to support the definition of technical standards and a suitable certification process as well as the development of concrete examples of application. The Commission of Experts recommends that the public sector contributes to the acceptance and success of this project by supplying its own data and services on the GAIA-X infrastructure.

### Exploit Innovation Potential with Data Strategy

With its Data Strategy, the Federal Government aims to promote the innovative and responsible use of data in business, science, society and administration in Germany and Europe and thus contribute to growth and prosperity.[51] The Data Strategy's key fields of action include improved data provision and secure data access. GAIA-X as the European data infrastructure and the NFDI, among others, should also contribute to this. The Commission of Experts welcomes the fact that the public sector is to be made a pioneer in the provision and use of data and that it is planned to establish corresponding responsibilities and competences in the federal ministries. The second Open Data Act (Open-Data-Gesetz) and the new Data Use Act (Datennutzungsgesetz), the drafts of which are available for comment, will also contribute to this.[52] In order to ensure the transparent and standardized provision of data for research as well as for more data- and evidence-based political action and to enable the linking of data across public authorities, the Commission of Experts suggests establishing coordination structures between the responsible agencies. Otherwise, innovation potentials that can arise through the linking of data from different sources, cannot be exploited.

### Development of National Research Data Infrastructure Has Started

In 2018, the establishment of the NFDI was decided based on an agreement between the Federal Government and the Länder.[53] The NFDI aims to develop, sustainably secure, and make accessible data from research and science and to network this data on a national and international level.[54] By 2028, networking consortia are to create this infrastructure from within the scientific community. The NFDI will have its full impact on the German R&I system if all scientific fields are covered, parallel projects and silo formation can be avoided, and extensive synergy effects can be exploited as a result.

Since, based on an evaluation by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG), funding for individual consortia may expire, the Commission of Experts opines that sufficient financial resources must be made available to also support the formation of new consortia. A national research data infrastructure can only be established if it is compatible and adaptable. To this end, interoperability as well as consolidation with other infrastructures on a transnational and global level must be ensured in the future.[55] The Commission of Experts supports these developments and calls for long-term funding to guarantee further development of the infrastructure after it has been built.

### Social Innovations Increasingly Considered in R&I Policy

The Commission of Experts welcomes the fact that the term 'social innovations' was defined more precisely in the High-Tech Strategy 2025 and that increased opening of research funding for social

innovations is provided.[56] The social innovations addressed therein include new social practices and organizational models that aim to find viable and sustainable solutions to social challenges.[57] The competition 'Society of Ideas – Competition for Social Innovations' (Gesellschaft der Ideen – Wettbewerb für Soziale Innovationen), launched in spring 2020, is the first specific BMBF support measure that focuses exclusively on the development of social innovations.[58] The Commission of Experts advocates the use of new formats of participation and the testing of new funding instruments within the framework of the ideas competition.[59] It calls for the rapid implementation of the planned accompanying research and evaluation of the support measure in order to ensure learning effects for the future funding of social innovations.

# Priorities for R&I Policy in the Coming Legislative Period

A 3



The COVID-19 crisis hits the German R&I system at a time when it is addressing grand societal challenges and questions about the future. The crisis exposes and makes visible the strengths of the system as well as its weaknesses, for example, regarding digitalization of the economy and society.

In the past two decades, Germany has through smart financial and economic policies mastered challenges such as the reform of the labour market[60] and the management of the financial market crisis in 2008/09. It was also possible to create scope of action both for future investments and for coping with crises. On the one hand, Germany has in recent years been able to advance and further develop the R&I system and, on the other hand, it has recently been able to mitigate the most serious distortions caused by the COVID-19 crisis through extensive borrowing.

The Excellence Initiative and the Excellence Strategy[61] as well as the various pacts[62] have been able to give the science system a boost. The High-Tech Strategy[63] (HTS) was further developed as a cross-departmental, innovation-oriented policy approach with the aim of laying the foundations for future key technologies and supplying innovative solutions to key societal challenges. The innovation activity of East German companies has in recent years largely converged with the innovation activity of West German companies.[64] After reaching the three-percent target in 2017, Germany's R&D intensity has now reached the international top group with a value of 3.17 in 2019 (cf. chapter C 2) – a joint success of private-sector R&D activities and wide-ranging public sector funding policy. Germany has thus definitely achieved its goal of playing a leading international role as a location for innovation, or at least has come remarkably close to it.

Yet such a strengthened R&I system is no reason to relax. Although overcoming the COVID-19 crisis will be one of the key tasks of the new Federal Government in the coming legislative period, R&I policy must continue to be prioritized. The Commission of Experts expects the next Federal Government to make no, or at most only minor, cuts in R&I policy despite the greatly reduced budgetary leeway resulting from the COVID-19 crisis.

The new Federal Government still needs a coherent policy approach that focuses on the entire innovation process from basic research to application and to which all ministries are committed. For the next legislative period, existing R&I policy priorities must be further developed, and new priorities set, as the short- and long-term challenges to the German R&I system have also increased, parallel to the positive developments mentioned above and beyond the symptoms of the COVID-19 crisis. This is accompanied by the need for continuous adaptation of the R&I system itself, R&I policy, and its objectives.

In view of the tasks and problems awaiting solution, R&I policy in the coming legislative period should align its strategies and measures with five key priorities. The grand societal challenges and in particular the sustainability goals must be given a high priority. It is equally important for the development of prosperity that Germany catches up with existing technological gaps and avoids these in potential key technologies from the outset. To achieve these objectives, Germany, as a country poor in natural resources, must have a strong skilled labour base. With regards to R&I investments in private enterprises, it is moreover important to increase innovation participation. Finally, the agility of R&I policy is an important prerequisite for successfully

implementing the transformative change desired by society (cf. chapter B 1). The impact of the COVID-19 crisis on the R&I system must of course be considered.

## Priority 'Addressing Grand Societal Challenges'

The grand societal challenges and the Sustainable Development Goals (SDGs) have played an increasingly important role in shaping R&I objectives and programmes over the past decade. The Federal Government has taken these into account in the HTS 2025 and has formulated corresponding missions such as: 'Large-scale greenhouse gas neutrality of industry', 'Preserving biodiversity' and 'Safe, connected and clean mobility'. Although moderate progress has been made in some of these fields in recent years, such as the reduction of greenhouse gas emissions,[65] the initiated transformation processes are essentially still in their infancy. Necessary directional changes in technology are often slowed down, if not prevented, by lock-in in old technologies. Escaping this lock-in situation requires a combination of technological innovations, incentives to adapt behaviour, and sometimes also impulses to change attitudes.

### Meet Societal Challenges with Technological and Social Innovations

The grand societal challenges can only be met if ongoing transformative change processes are continued, and new ones are initiated (cf. chapter B 1). Such change processes cannot be achieved without technological and social innovations, for example, for a socially acceptable and universally accepted transition to sustainable mobility. Conflicting goals between SDGs, such as poverty reduction on the one hand, and combating climate change on the other, cannot be resolved without significant and often radical technological innovations and complementary behavioural changes.

To initiate and support the necessary transformative change processes, the Commission of Experts recommends to further pursue and consistently develop the approach of a mission-oriented R&I policy as already laid out in the HTS 2025. The extent to which the HTS 2025 missions currently in implementation phase should be continued, adapted, or terminated must be examined based on an evaluation. For the implementation of missions, incentives should be provided for technological and social innovations. Here, the Federal Government should rely even more consistently on price instruments. At the same time, sufficient funds must be made available for basic research and transfer.

### Further Expedite Energy Transition Through Innovation

Further efforts are needed to successfully continue the energy transition. The Commission of Experts sees high potential both in the expansion of $CO_2$-free electricity generation capacities and in the implementation of innovations for the intertemporal balancing of supply and demand. The latter refers especially to smart metering, smart grids, and new electricity storage technologies. In addition, innovative solutions are needed in the market design for electricity transmission.

The Hydrogen Strategy is an important pillar in the energy transition. The Commission of Experts welcomes this initiative and recommends the setting of further impulses for its development and diffusion and the development of corresponding competences. It emphasizes, however, that long-term subsidization of hydrogen production should be avoided. The production of hydrogen must not result in a displacement of green electricity in the regular electricity supply and thus to an increase in the use of fossil energy sources.

### Accompany Mobility Transition with Open Approach to Technology

The mobility transition puts pressure on the automotive industry, one of Germany's core industries. The Commission of Experts sees the need for R&I policy support to achieve a sustainable and socially acceptable mobility transition. Yet it also calls for openness towards alternative sustainable propulsion concepts instead of one-sided prioritization of a specific technology. Even though battery-powered electric vehicles currently have a technological and infrastructural lead over fuel cell vehicles, synergy potentials can be expected between hydrogen-powered long-distance, freight and passenger car transport. Since Asian countries, primarily Japan and South Korea, are investing

considerable resources in the further development of fuel cell technology for passenger cars and in their market penetration, Germany should not disconnect itself from this know-how.

## Priority 'Catching Up and Avoiding Technological Gaps'

In its previous reports, the Commission of Experts identified Germany's technological gap in an international comparison, especially regarding radically new technologies and their application. This applies, for example, to technologies and applications such as service robotics, artificial intelligence (AI), autonomous systems, cybersecurity applications, e-government, digital business models and the digitalization of universities.[66] Due to these developments, Germany is not in the top bracket of countries regarding the process of digital transformation. In the life sciences, too, such as red biotechnology with the development of CRISPR/Cas, Germany needs to catch up (cf. chapter B 3).

These gaps indicate problems in the development, adoption, and application of radically new technologies, which adversely affects the performance of the German R&I system. A first step towards avoiding backlogs was the establishment of the Federal Agency for Disruptive Innovations (Bundesagentur für Sprunginnovationen, SPRIN-D). Yet additional efforts are needed beyond that.

### Early Identification of New Technological Developments

The Commission of Experts recommends identifying technologies with high future potential at an early stage through foresight processes. The necessary promotion of these technologies must be underpinned by an adequate strategy and budget and implemented by means of suitable measures.

### Define and Promote Key Technologies

Key technologies are characterized by a wide range of applications and a high innovative potential. The Commission of Experts advocates promoting their development and diffusion based on the systemic relevance, innovative potential, and the high knowledge spillover (cf. box B 1-2) of these technologies. To this end, the Federal Government should define transparent and comprehensible criteria for the identification of key technologies. However, the Commission of Experts warns against the declaration and promotion of technologies as key enabling technologies for the sole purpose of giving domestic companies unfair advantages in international competition.

### Consider Technological Sovereignty in R&I Funding

More recently, a politico-economic debate has developed around the issue of technological and digital sovereignty, including cybersecurity issues and ethical and legal standards in the field of AI or cloud services. The Commission of Experts welcomes this debate but warns against tendencies to favour autarkic structures as a solution to the problem. The concept of technological sovereignty must not be misused to impede structural change and protect industries that are no longer competitive internationally.

### Increase Digitalization Momentum and Explore New Governance Options

The successful implementation of the digital transformation is an essential factor for maintaining Germany's international competitiveness. On the one hand, digital technologies themselves are the object of further developments, innovations, and business models. On the other hand, they fulfil direct and indirect support functions in many R&I processes. The Commission of Experts strongly urges increased support for digitalization activities on a broad scale and the setting of appropriate incentives for this. It once again recommends that the expansion of an efficient, digital infrastructure finally be vigorously pursued.

In view of these complex tasks and their great importance for the German economy and the German R&I system, the Commission of Experts considers it urgently necessary to think about new governance structures in the Federal Government, for example, in the form of a Ministry of Digitalization.

### Advance E-government and Consolidate Open Government Data

Compared with other European countries, Germany is lagging considerably and increasingly behind in e-government.[67] The Commission of Experts advises vigorous pursuit of the goals set in the Online Access Act (Onlinezugangsgesetz) of making all public administrative services digitally available by 2022 and also developing new, user-friendly offerings. Open administrative data available in real time also holds considerable innovation potential for the public sector, the economy and science.

## Priority 'Securing the Skilled Labour Base'

As a country poor in raw materials, Germany is dependent on highly educated people to ensure competitiveness and prosperity through the development and use of technological potential. That is why an efficient, socially permeable education system, technological and scientific competence through exceptionally good STEM education at all levels, and the recruitment of foreign skilled workers are of key importance for the economy and society. The performance of the German R&I system is also largely based on these elements. The Commission of Experts regularly points this out.[68]

In the coming years, the pressure to secure the skilled labour base in Germany will increase. The native working-age population will decline significantly in the years ahead, which means that skilled labour bottlenecks that hinder growth and innovation may intensify and become more entrenched. At the same time, new knowledge and skills need to be developed across the population to successfully advance R&I and technological change and to strengthen social participation.

### Strengthen Occupational Adaptability

Innovation-driven transformative developments entail increasing demands on occupational adaptability (cf. chapter B 2). To ensure that job-related continuing education and training (CET) for adaptability in face of these developments starts early, before employment is lost, the Commission of Experts recommends supplementing the existing funding instruments with measures to support preventive adaptation qualifications. Comprehensive monitoring of occupational skills should be set up to support needs-based vocational and continuing education and training (VET/CET). To ensure employability in times of digital transformation, VET and CET must be even more strongly geared towards teaching both digital and non-digital core skills.

### Improve Exploitation of Domestic Skilled Labour Base

The Federal Government should improve the framework conditions for the improved exploitation of the existing potential for securing the skilled labour base in Germany.[69] To this end, the Commission of Experts recommends the consolidation of measures for the in-service higher qualification and catch-up vocational qualification of groups that are poorly integrated into the labour market – specifically semi-skilled and unskilled workers and people with a migration background. It also recommends creating even stronger incentives for full-time employment of women and introducing measures to further increase the labour force participation of older people, such as creating more attractive conditions for employment beyond the standard retirement age.

### Attract More Foreign Skilled Workers

With the Skilled Workers Immigration Act, the Federal Government has made it easier for skilled workers from third countries to immigrate and work in areas of shortage. To position Germany even better in the international competition for skilled workers, the strategy developed by the Federal Government under the leadership of the BMWi for the targeted recruitment of skilled workers from third countries should be swiftly expedited.[70] The Commission of Experts emphasizes that, above all, job-related qualification measures and language support at home and abroad should be further consolidated. In addition, SMEs should be supported even more through help with recruitment abroad.

## Priority 'Increasing Innovation Participation'

In recent decades, a decline in productivity growth rates can be observed in Germany.[71] At the same time, the share of innovative firms in both industry and services is declining, and so is innovation participation.[72] In addition, a decline in start-up activities can be observed, especially in research-intensive industries and knowledge-intensive services.[73] The

conditions for profitable innovation activities on a broad scale, especially for SMEs, and for participation in R&I activities therefore appear to be deteriorating. These developments can be seen as early warning indicators of weaknesses in the R&I system. R&I policy must appropriately respond to this.[74]

### Reinforce Knowledge and Technology Transfer

The transfer of insights and knowledge from science to business and society can initiate and inspire innovation activities. Yet new ideas and findings from tertiary education institutions and non-university research institutions often remain unused. Researchers lack incentives and the necessary skills to communicate their findings beyond the academic context.[75] The framework conditions for transfer, for example, regarding the financing, investment, and licensing conditions for academic spin-offs, are also frequently rather inhibiting and not internationally competitive. The Commission of Experts urgently suggests that suitable funding formats be expanded[76] and further developed, and that appropriate framework conditions for transfer activities from the science sector be promoted.

### Evaluate Research Allowance and Adjust Where Necessary

Wide-ranging R&I participation and high R&I intensity are essential for the performance capability of an R&I system. One instrument for achieving this objective is tax incentives for R&D. The Commission of Experts has long called for it and therefore strongly welcomes the introduction of the Research Allowance on 1 January 2020.[77] It should be evaluated as soon as possible and then adjusted accordingly where necessary.

### Align Public Procurement and Investment to Focus on Innovation

Public procurement can provide important impulses for innovation activities and participation. In view of the considerable public procurement volume, the Commission of Experts advocates using part of these funds more intensively and in a more coordinated way than before to promote innovation.[78] For this part of the funds, public procurement law and practice would need to be adapted to allow 'priority for the innovative offer'.[79] Such an innovation criterion should, however, include a careful weighing of the positive effects of an expected market breakthrough against the potential additional costs of procurement.

The Commission of Experts sees potential in the proposal for a future quota, which supports a fixed share in the budget for investments in the areas of education, research, new technologies, environmental and climate protection as well as modern infrastructure for digitalization, among other things, and calls on the Federal Government to examine this proposal accordingly.

## Priority 'Increasing the Agility of R&I Policy'

Given the great importance of the R&I system for Germany's competitiveness and the background of the upcoming transformative change with major structural changes in the economy and society, the public sector has a special role in going with and initiating these processes.

The complexity and breadth of transformation processes, the associated uncertainty of funding outcomes and the need to coordinate policy measures require proactive, flexible, and reflexive, and often rapid, political action on the part of R&I policy. In addition, participatory formats and a high degree of structural adaptability constitute important elements of an agile R&I policy.

With this in mind, the German R&I policymakers do not yet act with sufficient agility. Instead, bureaucratic structures with long decision-making processes, inadequate superordinate coordination structures, a lack of space for reflection, a poorly developed error culture and a certain reluctance to evaluate and make the necessary adjustments prevail. Although participatory elements are practised, they do not yet influence political action in all respects.

### Market-oriented Alignment of New Mission Orientation

Against the background of the grand societal challenges, the Commission of Experts recommends pursuing R&I policy missions (cf. chapter B 1) that are aimed at enabling or accelerating transformative change. It advocates a market-oriented version of New Mission Orientation. The key feature of this R&I policy approach is not to prescribe specific technological or organizational solutions for the

missions, but to indicate a corridor in which the market can be used as a discovery process. R&I policy intervention in the market should be catalytic, if at all, to resolve lock-in situations or to promote infant industries.

### Further Improve Policy Coordination

In pursuing the policy approach of New Mission Orientation, R&I policy is particularly challenged to steer support measures and regulatory adjustments on a broad scale (cf. chapter B 1). To prevent contradictory policy impulses and to realize synergies, horizontal coordination in R&I policy in particular should be further improved. Measures and initiatives from different policy fields must be coordinated in terms of content and timing.

### Greater Integration of Policy Learning into Processes

The Commission of Experts recommends the development, testing and implementation of appropriate new formats to support and improve policy learning at the strategic, structural, and operational levels of government R&I policy. Policy learning must be integrated more intensively into the processes from the outset. A policy of experimentation, for example, by way of experimental spaces, as well as evaluations are important cornerstones here. In this context, the evaluation practice, too, must be critically questioned and scientifically assessed.

# CORE TOPICS 2021

B

# B 1 New Mission Orientation and Agility in R&I Policy

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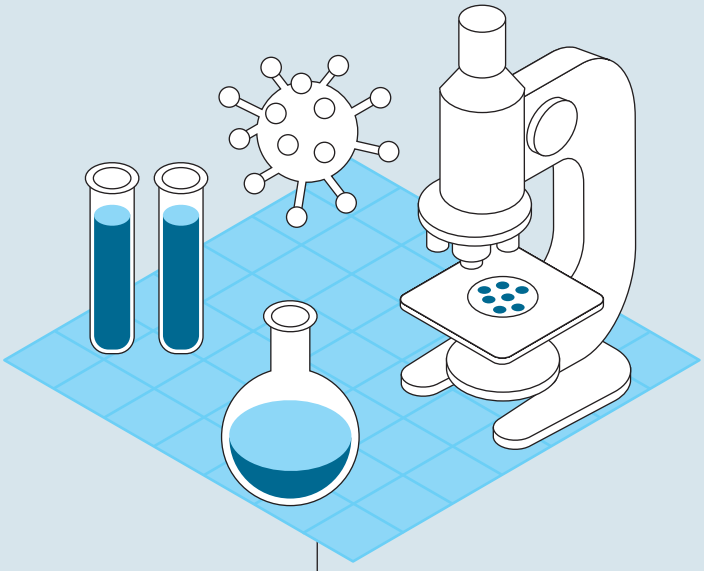
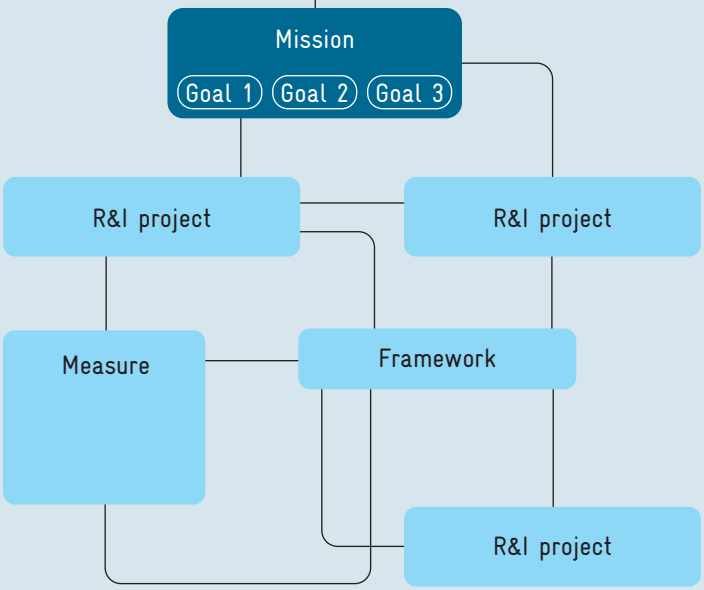
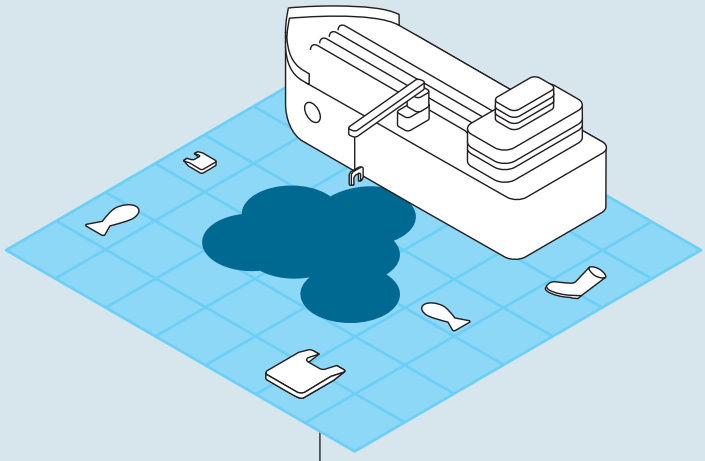
New Mission Orientation is an approach to R&I policy that focuses on addressing grand societal challenges and aims at transformative change in the economy and society. To this end, so-called missions are formulated that specify concrete transformation goals and are to be implemented through R&I projects as well as political measures and frameworks. Agile policy action is required to successfully realise New Mission Orientation.



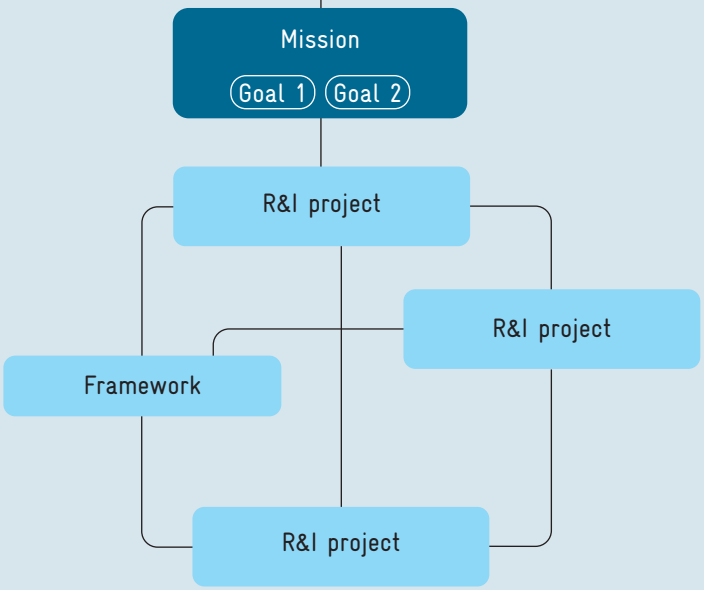


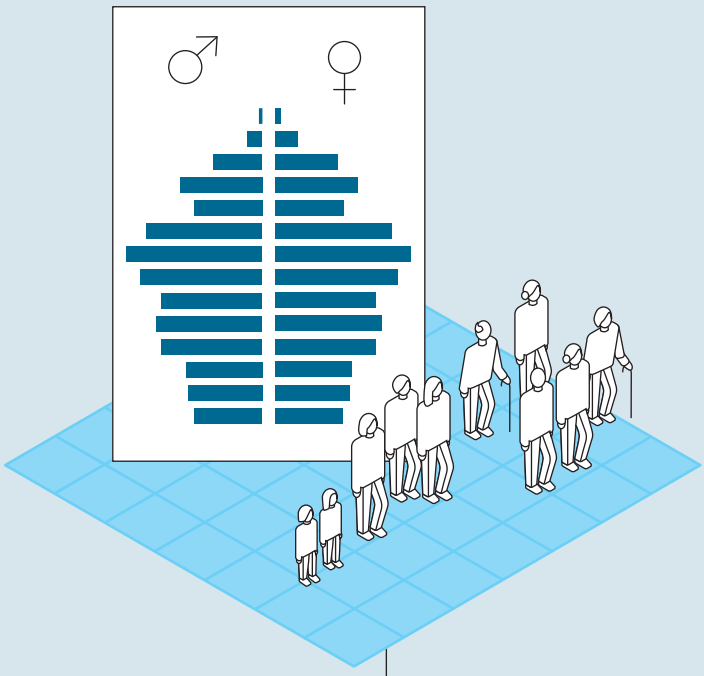
Societal challenge:
Health and well-being



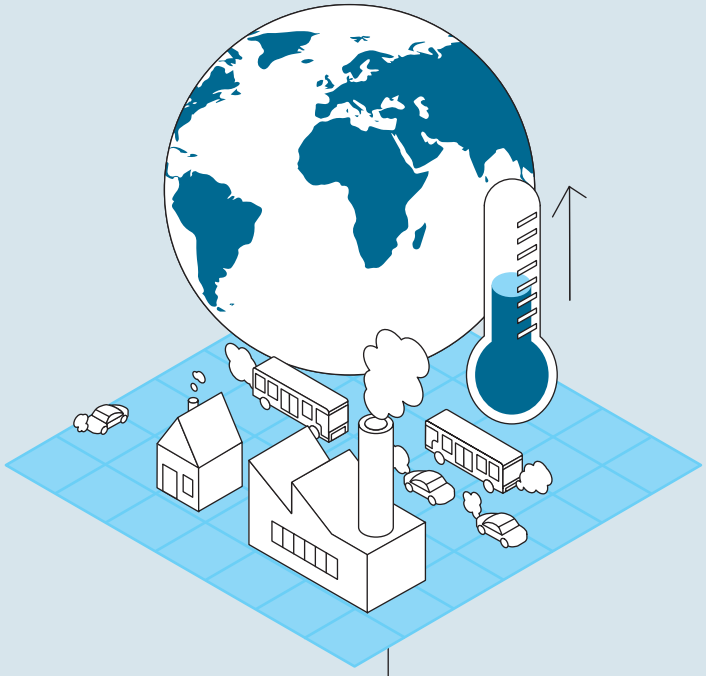



Societal challenge:
Protect life
under water

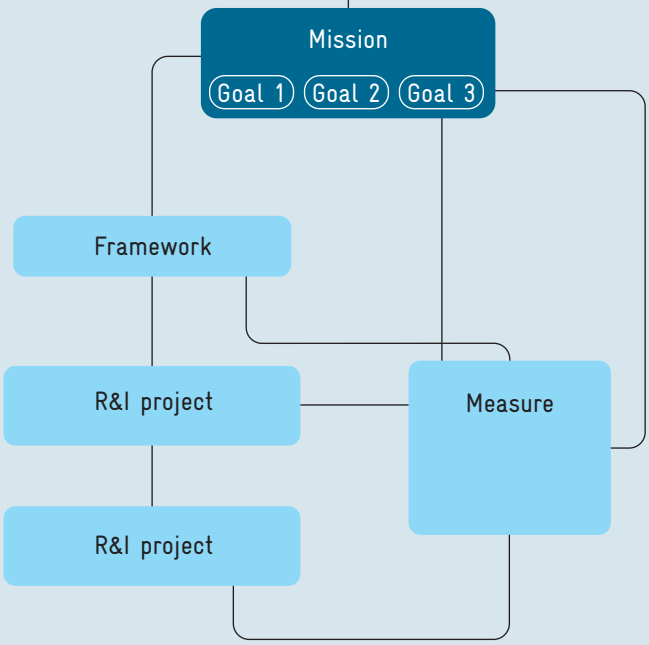


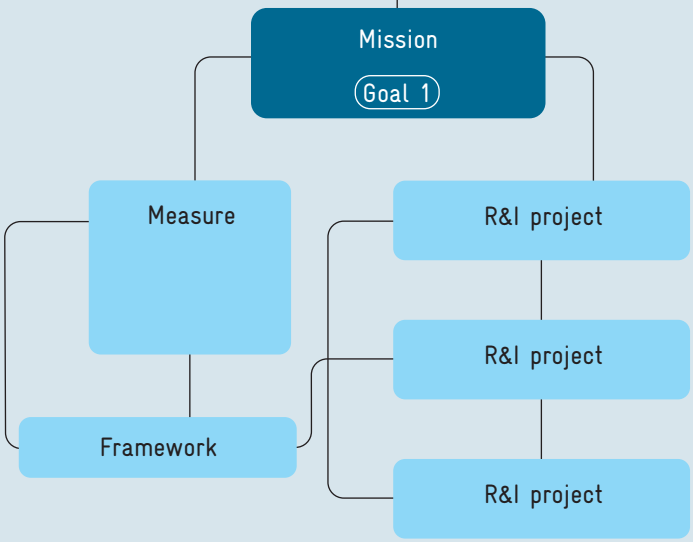


Societal challenge:
Demographic change



Societal challenge:
Implement climate protection



# B 1 New Mission Orientation and Agility in R&I Policy



With so-called New Mission Orientation, an approach to R&I policy is developing which, against the background of the Millennium Development Goals (MDGs) adopted by the United Nations in 2000 and the Sustainable Development Goals (SDGs) adopted in 2015, is directed at addressing the grand societal challenges and aims at transformative change in the economy and society. To this end, so-called missions are formulated that contain specific transformation goals to be implemented by way of R&I policy and complementary policy measures. The New Mission Orientation approach was first discussed intensively in the academic environment and in the political sphere. It now has found its way into political practice and is increasingly being implemented.

The grand societal challenges are complex and managing them is a long-term and complex task. This results in high demands on an R&I policy that formulates and implements missions. Its governance requires agility. Agile policy is not only characterized by a quick and flexible response to change, but it is also proactive, involves relevant stakeholders, continuously reviews the measures it has introduced and adjusts these where necessary.

## B 1-1 From Classical to New Mission Orientation

Over the past 75 years, different policy approaches have evolved in R&I policy in Germany and other industrialized countries with the aim of removing barriers to innovation and thus promoting growth and prosperity. The individual policy approaches and their justifications have not superseded each other, but rather build on each other additively (cf. figure B 1-1 and box B 1-2).[80]

- The policy approach of classical mission orientation was first established after World War II, focusing on the provision of public goods (cf. box B 1-2). In classical mission orientation, R&I policy is aimed at promoting the development of large-scale technologies for government needs, for example, in the fields of nuclear power and space travel, in addition to basic research. This approach saw, for instance, the creation of thematically specialized large-scale public research facilities in the 1950s, such as the Munich Research Reactor and CERN near Geneva.[81]
- Since the 1960s, the classical mission orientation has been supplemented by a diffusion-oriented approach that focuses on civilian key technologies with great commercial application potential. This promotion of civilian key technologies aims at the utilization of knowledge spillover (cf. box B 1-2). The funding is intended to address a broad target group from the fields of science and industry and to intensify R&I activities there. The policy approach is also reflected in national technology programmes. For instance, the Federal Government launched the first specialist programme to promote data processing in the late 1960s.[82] Current examples are the AI Strategy and the Blockchain Strategy.
- Since the 1990s, systemic R&I policy has adopted relevant concepts from innovation research, such as the innovation system approach and the cluster approach, emphasizing functional aspects of the innovation system such as cooperation between science and business, innovation activities in SMEs and start-ups, regional networks, and innovation-friendly framework conditions. This policy approach aims to overcome system failures (cf. box B 1-2) and thereby increase

Fig. B 1-1

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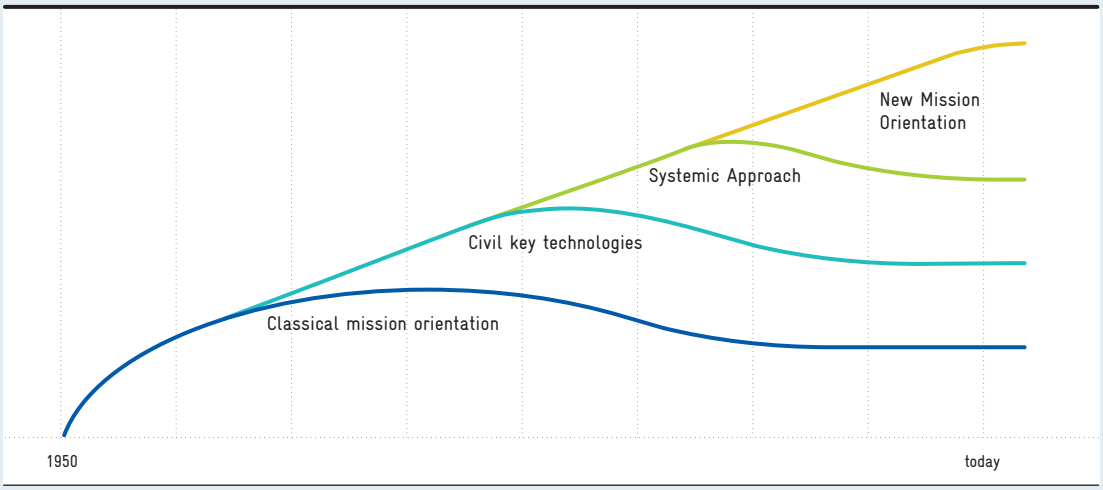
**Approaches to R&I policy over time**




Source: Own representation based on Gassler et al. (2006).
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the level of innovation activity. A wide range of instruments are used. Examples include the BMBF's Leading-Edge Cluster Competition, now expired, the BMBF's Innovation and Structural Change programme family and the BMWi's go-Inno programme.

– The policy approach of New Mission Orientation has been increasingly discussed in the academic environment and in the political arena for about 20 years.[83] However, the implementation of the approach is only just beginning and is more recently being explicitly reflected in strategies and programmes. New Mission Orientation addresses the difficulties of the R&I system to pursue completely new paths of innovation and develop technologies that are necessary for a socially desired transformative change. R&I policy measures should help overcome existing transformation failures (cf. box B 1-2) and accelerate the achievement of the SDGs. Although New Mission Orientation, like the other policy approaches, focuses on intensifying innovation activities, it primarily targets fundamental societal objectives, such as climate protection, preserving biodiversity, combating widespread diseases, and strengthening social cohesion.

## New Mission Orientation: R&I Policy Requirements B 1–2

The starting point of an R&I policy geared towards overcoming societal challenges are missions[84] that specify concrete transformation goals and are to be implemented through R&I policy and complementary policy measures. Missions constitute the policy approach of New Mission Orientation and are to be regarded as a link between the grand societal challenges and specific R&I projects (cf. infographic chapter B 1).[85]

Mission implementation is about solving urgent problems within an appropriate time frame and budget.[86] Missions have a catalytic function[87] – they serve to redirect towards a new development path and are fulfilled when this is achieved. However, missions cannot usually be fulfilled through the contributions

Box B 1-2

## Rationale for R&I Policy Measures

### Market Failures

Market forces do not always ensure that R&I is conducted to the economically optimal extent. There are important forms of market failures that have a negative impact on the incentives of private sector players to undertake R&I activities:[88]

**Public goods:** Public goods are characterized by non-rivalry in consumption and non-excludability. The use of the good by one player does not reduce the possibilities of use by other players. Moreover, these players cannot be excluded from use. A public good is, for example, the results of basic research that are not generated to a sufficient extent by private-sector players. In such a case, funding and provision by the state can make sense.

**Knowledge spillovers:** In R&I activities, externalities occur in the form of knowledge outflows that the knowledge producer cannot prevent. For example, competitors can obtain knowledge by inspecting an innovative product without having to bear the full costs of knowledge production themselves. In this case, the private returns of the innovation diverge from the social returns and the innovator will, from a social perspective, invest too little in knowledge production.

**Asymmetric information:** Asymmetric information is when one side of the market is better informed than the other. This occurs, for example, in the financing of R&I activities by third parties. External investors can assess the chances of success of R&I projects less reliably than the companies engaging in R&I. This information asymmetry leads to a smaller number of R&I projects being financed than would make sense in macroeconomic terms.

**Uncertainty:** While the probabilities of occurrence of certain conditions are known for risky situations, no probabilities of occurrence are available for situations of uncertainty. Uncertainty can lead to innovation players refraining from R&I activities because they cannot assess the consequences of their actions.

### System Failures

The term system failure summarizes functional deficiencies of the innovation system. These deficiencies lead to innovation activities being carried out to a lesser extent than would be desirable from an economic perspective:[89]

**Network failure:** Lack of interaction with other players inhibits the use of complementary knowledge sources and interactive learning processes. The close cooperation in established innovation networks can in turn lead to a lack of exchange with partners outside the network; thus, too few new stimuli and ideas are injected, and path dependencies are solidified.

**Institutional failure:** Institutional deficiencies exist when laws and regulations, e.g., intellectual property rights or liability rules for autonomous systems, inhibit innovation activities. Societal values and norms, such as the establishment of a start-up culture or attitudes towards new technologies, can also have an impact on innovation.

**Infrastructural failure:** Innovation-relevant infrastructure is provided by private investors to an insufficient extent due to the associated expense and long-term operation.

**Capabilities failure:** A lack of skills among innovation players means they do not absorb new knowledge, take up new technologies and adapt to new situations.

## Transformation Failures

Innovations can fundamentally help to overcome societal challenges and thus enable and accelerate transformative change to achieve socially desired goals. Yet there are various forms of transformation failure that lead to corresponding innovations not being made or not being applied to a sufficient extent.[90]

**Demand articulation failure:** Transformative change can be slowed down or impeded by the fact that there is no demand for innovative products and services that support it and are desirable from the perspective of society as a whole. As there is no market yet, users do not have the opportunity to articulate their needs. Potential providers can therefore not develop offers that meet the needs. Another reason for a lack of demand-supply coordination may be the absence of complementary technological and social innovations.

**Directionality failure:** Due to network or lock-in effects, the players involved in the transformation process are unable to coordinate themselves towards the socially desired transformation objectives and to act collectively. In addition, regulation and standardization, traditional R&I funding and infrastructures may be insufficiently geared towards facilitating the coordination of private players towards transformative change.

**Policy coordination failure:** There are deficits in horizontal, vertical, and temporal policy coordination, which are essential for transformative change, as well as in the coordination of the public and private sectors.

**Reflexivity failure:** The required readjustment of measures and objectives for transformative change is insufficiently developed. This means that the achievement of transformation objectives is not continuously monitored, and appropriate adaptation strategies are not developed.

of R&I alone but require complementary impulses from other policy fields. These impulses are of fundamental importance, especially for adopting new solutions on a broad scale and the accompanying adaptation to societal demands.

### Formulation of Missions as a Strategic Task

At the strategic level, there is the requirement to establish a suitable process for formulating the missions.[91] This process should be broadly conceived because transformative change affects many social groups. This means that acceptance, which is crucial for the success of the missions, can be built up from the very start.

Since transformative change requires both technological and social innovation, it is conducive to align missions in such a way that they trigger R&I activities among different groups of stakeholders. Measures in this regard must consider user needs and possible impairments of those affected.

### Policy Coordination as a Crucial Task in Mission Implementation

The implementation of missions requires not only coordinated R&I policy measures, but also a coherent policy mix across policy fields.[92] Consequently, the policy approach of New Mission Orientation results in a variety of requirements for policy coordination at the operational level.[93]

- To make missions a success, horizontal policy coordination is required, i.e., R&I policy and other policy fields are coordinated in terms of content and timing. For instance, missions that include climate targets may interface with environmental, fiscal, and social policies.
- Missions can affect several policy levels – from the municipal level to the Länder and Federal Government levels and to the EU level. Consequently, vertical policy coordination is of relevance here.
- Within the ministries involved in missions, different departments may be involved, which means that intra-ministerial coordination is required. Furthermore, there is a need for close coordination with the implementing agencies.

A policy geared towards transformative change requires continuous monitoring at the operational level, as well as evaluation of the measures taken and adjustments where necessary.[94]

- Due to the complexity of the policy approach, it is not only necessary to look at the impact of individual R&I policy instruments, but also to evaluate the interaction of the measures and initiatives in the policy mix. However, such an evaluation is very demanding and may stretch traditional methods to their limits.[95]
- Experimental R&I policies, such as those in the form of experimental spaces and demonstration projects, can provide insights into the possible adaptation of measures.

### Missions as an Element of the High-Tech Strategy 2025

Missions were introduced as a new element of German R&I policy (cf. box B 1-3) in the context of the High-Tech Strategy (HTS) 2025. In its Annual Report 2019, the Commission of Experts acknowledged that with the formulation of missions a new approach was ventured.[96] However, this approach does not correspond to the New Mission Orientation concept in all the missions formulated there.

The Fraunhofer Institute for Systems and Innovation Research (ISI) will conduct accompanying research for the HTS 2025 missions, the results of which are expected to be published in spring 2021. The



Box B 1-3

### Missions of the High-Tech Strategy 2025

According to the Federal Government, missions are intended to reinforce interdepartmental cooperation in R&I policy and bring research results into implementation in a targeted manner.[97] The HTS 2025 contains twelve missions that were formulated under the leadership of the BMBF in a top-down approach. These are: 'Combating cancer', 'Digitally networking research and healthcare – for intelligent medicine', 'Building up battery cell production in Germany', 'Putting artificial intelligence into practical application', 'Achieving substantial greenhouse gas neutrality in industry', 'Creating sustainable circular economies', 'Finding new sources for new knowledge', 'Substantially reducing plastic discharged into the environment', 'Preserving biological diversity', 'Developing safe, networked and clean mobility', 'Ensuring good living and working conditions throughout the country' and 'Shaping technology for the people'.

These twelve missions are very heterogeneous. They differ, among other things, in the breadth and measurability of objectives as well as in the anticipated time horizons. While, for example, the mission 'Ensuring good living and working conditions throughout the country' offers a lot of room for interpretation and action, the mission 'Building up battery cell production in Germany' is formulated much more narrowly.

The implementation of the HTS 2025 is accompanied by an advisory body, the High-Tech Forum (HTF). One of the purposes of the HTF is to provide the Federal Government with recommendations for action and implementation proposals regarding the twelve missions and thereby initiate policy learning. The HTF's thematically specific impulse papers pursue two objectives: on the one hand, they are made available to the public to advance the discourse from the various points of view; on the other hand, the recommendations are discussed across ministries in regular round table meetings of state secretaries.

In 2020, the HTF implemented a participatory approach with representatives from science and society through its monitoring of the participation process for the further development of the HTS 2025. Stakeholders were able to actively contribute to various thematic focal points in the context of online discussions and conferences. The insights gained from this were further discussed in results dialogues and finally presented in the round table meetings of state secretaries. According to the BMBF, the results will be incorporated into the follow-up strategy of the HTS 2025.

Commission of Experts welcomes the fact that accompanying research is being established and expects a final evaluation of the missions to be carried out within the framework of HTS 2025.

## B 1-3 New Mission Orientation: The Role of the State

### Scope of State Intervention in the Market Controversially Discussed

There are different views on what role the state should take in its transformative change-oriented policy. At the centre of the controversial discussion is the question of the limits of public sector action in the context of market versus state. Some[98] deem it sufficient that the state identifies market or system failures in the R&I system and remedies the resulting underinvestment in R&I by funding basic research and individual, incentive-compatible measures. This aims at intensifying innovation activities and developing these out of the market in the direction of the set objectives and mission.

Others[99] see the fact that the desired changes in direction cannot be achieved through market forces precisely as the central problem. Unarticulated demand and lock-in effects are reasons why it is not worthwhile for innovative actors to pursue new socially desired directions of innovation. That is why mere intensification of innovation activities in known fields of technology falls short, as this fails to steer these activities in the direction of set missions, or not sufficiently so. For this reason, policy interventions aimed at changing direction are considered necessary. In this context, individual voices propose an entrepreneurial state[100] that would directly take over all activities along the innovation process – or closely guide these – and consequently also generate the corresponding profits. Critics of this notion fear that the public sector acts in an industrial policy manner and uses measures in the implementation of missions that interfere with the creativity of the market and thus with an open problem-solving process.[101]

The redirection of innovation activities by the public sector in directions that the private sector players themselves do not take is associated with interventions in market economy dynamics. The Commission of Experts emphasizes that these interventions can be reduced by the way mission-oriented policies are designed. It proposes a market-oriented version of New Mission Orientation that relies not only but heavily on market forces to solve problems. This approach is guided by the following considerations:

- Compared to an a priori specification of a particular problem solution, such as 'battery-powered vehicles', an open description of missions, such as 'non-fossil propulsion technologies', relies more on the creative forces of market players, as they can take different paths to achieve the goal.
- Promoting problem-solving alternatives in the pre-market phase, i.e., up to the point of knowledge and technology transfer, does not represent a massive intervention in market dynamics. Private sector players decide for themselves whether and to what extent they want to use certain innovation opportunities.
- If direct market interventions are unavoidable, they should have a catalytic character, i.e., they should only provide an impulse and then be withdrawn again. This applies, for example, to the promotion of young technologies, to overcoming lock-in in old technologies and to the development of new infrastructures[102] such as refuelling systems for innovative forms of mobility.

### Implementation of New Mission Orientation Requires Agility

New Mission Orientation is a policy approach that places special demands on politics and administration. These include a particularly high coordination effort as well as the need to constantly review, evaluate and adjust measures for the implementation of missions regarding their functioning. To successfully implement New Mission Orientation for R&I policy, policymakers and administrators must have capabilities that can be described by the term agility.

Agility is usually understood to be a form of 'ability, nimbleness and mobility of organizations and people or in structures and processes'[103].[104] It is primarily regarded as a reaction to change and emerging uncertainties. Like the OECD in its

concept of strategic agility,[105] the Commission of Experts emphasizes that it is not enough to react flexibly and quickly to changes. Rather, politics and administration must also proactively prepare long-term decisions, design them in a participatory manner and implement them reflexively. In doing so, a balance must be struck between long-term planning and short-term adaptation. This expands the concept of agility to include proactivity, participation, reflexivity, and ambidexterity in addition to speed and flexibility (cf. box B 1-4).

In the context of New Mission Orientation, superordinate strategic as well as implementation-related operational aspects must be considered in R&I policy. The strategic aspects are the processes for formulating new and reformulating existing missions, while the operational aspects are the processes and procedures for implementing missions.[106] The anticipatory planning of these processes requires a high degree of proactivity.

Participation of stakeholders and social groups is an essential element of the strategic level. Participation creates a broad information base and shared perception of problems that players in politics and administration need for strategic foresight and for an appropriate definition of objectives and priorities. These objectives and priorities subsequently also serve as shared orientation for collective action. Furthermore, broad participation can improve the acceptance of decisions taken.

The implementation of missions requires continuous adaptation processes. This requires reflexive action based on systematic feedback processes and expressed in accompanying experiments, subsequent evaluations and, where necessary, reformulation of the overarching objectives and measures. The acceptance of uncertainty and mistakes as well as the rejection of the idea of deterministic controllability of processes are important characteristics of the reflexive implementation of a mission-oriented R&I policy.[107] At the level of political-administrative decision-makers, reflexive action takes place by way of continuous adaptation of institutional and organizational structures to the changing tasks. This adjustment requires space for reflection and freedom where existing processes can be questioned and reorganized across hierarchies and with the help of external knowledge. In this way, policy learning is supported.

The main challenge of an agile R&I policy is to balance the stability and reliability of its objectives and measures on the one hand and a flexible response to changing requirements on the other. Facing this challenge and maintaining balance is called ambidexterity.

### Sporadic Use of Elements of Agile Politics

The federal ministries are already using agile policy elements in isolated cases. At the strategic level, the BMBF's current foresight process VORAUS:schau! aims to proactively identify and discuss trends and future topics.[108] By means of various laboratories, for example, the BMWi's regulatory test beds[109] and the digital laboratories of the Federal Ministry of the Interior (Bundesministerium des Innern, für Bau und Heimat, BMI),[110] reflexive adjustments to the legal and regulatory framework for new technologies and business models are being tested and digitalization processes in the administration are being advanced. In addition, the BMBF has established various dialogue formats to promote participatory exchange and discussion regarding future topics and technologies.[111]

At the operational level, some ministries are experimenting with the use of modern collaboration methods and human resources tools, which also promotes agile working.[112] Under the aegis of the Federal Chancellery, the Work4Germany initiative supports federal ministry employees[113] in their acquisition of modern working methods and relevant future competences and their integration into everyday work.[114]

## R&I Policies for Overcoming Transformation Failures B 1–4

A mission-oriented R&I policy must be aware of the facts that lead to transformation failures to counter these with targeted measures. Since the manifestations of transformation failures can differ greatly, the range of possible public sector action is

Box B 1-4

### Characteristics of Agility

**Speed, flexibility**
Speed and flexibility are given when changes are reacted to at short notice and in a way that is appropriate to the problem.

**Proactivity**
Proactivity is characterized by forward-looking action that anticipates or predicts potential obstacles to the implementation of measures. Evaluation ensures that catalogues of measures and impact periods of possible instruments are in line with the timeliness of the requirements.

**Participation**
Participation means that all relevant players are involved to both ensure a broad information base and improve the acceptance of collective decisions and solutions.

**Reflexivity**
Reflexivity is given when there are effective feedback loops based on qualitative or quantitative evidence that are used by operational staff for readjustment and feed into the information situation of staff at the strategic level.

**Ambidexterity**
Ambidexterity refers to the balancing of stability on the one hand and change on the other.[115]

There are some tensions between the agility criteria. For instance, participatory processes come at the expense of speed and flexibility. It is therefore hardly possible in practice to establish a political-administrative process that equally satisfies all agility criteria.

also very wide (cf. box B 1-2). The measures outlined below show how public sector action to overcome transformation failures can be designed in practice.

#### Stimulating Demand for Innovation

The problem of demand articulation failure has as yet hardly been considered by R&I policy. Transformative change can be slowed down or impeded by the fact that there is no demand for innovative products and services that support it and are desirable from the perspective of society as a whole. On the one hand, demand articulation does not take place if potential customers are unable to assess the benefits of innovative products and services. On the other hand, the dissemination of innovative products and services on the market often requires the development of new infrastructures, rapid standardization processes and complementary technological or social innovations (cf. box B 1-2).[116]

One instrument to overcome the problem of a lack of demand articulation is innovation-oriented public procurement. Its potential derives from the considerable scale of public demand.[117] If it is aligned with socially agreed missions, it offers a multitude of opportunities to initiate transformation processes and influence the direction of their development.

- Public innovation-oriented procurement can contribute on the demand side to directing private R&D and innovation spending in the desired direction. Public demand for certain new goods and services can lead to an R&D-promoting effect for technologies that would otherwise tend not to be approached by private players. An example of this funding format is the Dutch Small Business Innovation Research programme (SBIR programme) (cf. box B 1-5).[118]
- Innovation-oriented procurement enables the gathering of information about new technologies and their use and making this available to other players. The application experiences of government agencies can thus make it easier for private users to evaluate and use the innovations. In this way, new consumption patterns and new consumer groups, e.g., for non-fossil fuel vehicles, can be opened.

– Innovation-oriented procurement is an instrument that can at least partially remedy undesirable developments resulting from lock-in effects and network externalities. Public procurement of new technical products can achieve a demand volume for a new technology that is sufficient to overcome a lock-in and thus initiate the replacement of an obsolete technology by a new technology. This is particularly important when a specific infrastructure, such as charging stations for electric vehicles, is needed to enable the spread of a new technology.

Box B 1-5

### Stimulating Demand for Innovation Using the Practical Example of the Small Business Innovation Research Programme in the Netherlands

In 2005, the Dutch government launched the Small Business Innovation Research programme (SBIR programme), which was inspired by a programme of the same name in the USA. The SBIR programme aims to use public procurement to mobilize the innovative capacity of Dutch companies to solve grand societal challenges. At the same time, innovation activities are to be promoted, especially in small and medium-sized enterprises, and competitiveness reinforced.[119] At the beginning of a funding line within the SBIR programme, ministries and other public authorities identify a societal problem for which innovative solutions are required and provide a budget. In a first step, companies are invited in an open competition to submit a feasibility study for the solution of the problem described.[120] After selection of the best feasibility studies, R&D activities are further promoted in a second step up to the creation of prototypes and initial test series. In a third step, the companies prepare the market launch of the new product or service. This last step does not involve direct funding; however, the public sector can provide indirect support by acting as the first buyer of the new products. In this way, it acts as a lead user, generates demand for innovative products and itself benefits from the possibilities offered by the innovative solutions developed under the SBIR programme.[121]

B

#### Strengthen Directionality

One form of transformation failure is the lack of directionality of innovation activities towards missions (cf. box B 1-2). To strengthen directionality, an agile policy is helpful in the sense that social forces are proactively involved in the formulation of missions. One instrument for this are participatory foresight processes.[122] Within the framework of foresight processes, decision-makers can develop a common orientation regarding complex issues and clarify normative questions of principle in the context of potentially highly controversial issues in cooperation with stakeholders and experts across sectors or ministries. This can facilitate consensus building in subsequent policy decisions and enable directionality.[123] Government Foresight in Finland is such an example (cf. box B 1-6).

#### Improve Coordination

A mission-oriented R&I policy is associated with high coordination requirements. Coordination should be proactive and include both the strategic and operational levels. The instrument of Mission Boards, as used by the EU to prepare Horizon Europe, is an example of this format (cf. box B 1-7). At the strategic level, mission objectives need to be coordinated between several ministries and subordinate authorities. At the operational level, there is also a need, beyond inter-ministerial coordination, for coordination between the various specialist departments within the ministries involved.[124]

The organizational structure of the institutions in charge of implementing missions, usually ministries, stands in the way of the coordination requirements mentioned above. Ministries are characterized by

their own functional structures and logics, which usually exist in isolation from each other. The development of an aligned understanding of mission objectives and the measures needed to achieve them requires coordination structures and mechanisms between ministries. In Germany, a State Secretaries' Round Table was established for this purpose as a standing body for the strategic orientation and implementation of the HTS 2025.

Box B 1-6

### Strengthening Directionality Using the Practical Example of Government Foresight in Finland

Strategies for the future of the country have been developed in Finland at the beginning of each legislative period since 1993, serving as a strategic framework for the current legislative period, but also beyond it. Strategy development is led by a cross-party working group based at the Prime Minister's Office,[125] a so-called Government Foresight Task Force. The reports it submits are discussed within the government and presented to the Finnish Parliament, in particular its Committee on Future Affairs. One aim of the working group is to bundle a wide range of foresight activities and related information and to support decision-making processes. The preparation of the foresight reports does not follow a strictly defined methodological approach. Depending on the topic, different organizational and procedural paths are taken, and national and international institutions are involved. The institutionalized nature of foresight reporting, the link to the highest levels of government and parliament, and the involvement of stakeholder groups from science, business and civil society help to strengthen the influence of foresight reports on the political agenda. In addition, the results are also heard outside of government, for example, by national science institutions. Foresight reporting thus facilitates an active approach to future societal challenges.[126]

Box B 1-7

### Improving Coordination Using the European Union Mission Boards as a Practical Example

Missions are an integral part of the Horizon Europe research framework programme. For the concretization of the missions, corresponding Mission Boards were set up for the five themes defined in consultation with the Member States, the so-called Mission Areas, which submit their proposals directly to the commissioners responsible for the respective themes. These Mission Boards are characterized by a high degree of autonomy in defining missions and developing an associated R&I agenda. In addition, the missions are each staffed with around 15 leaders from different areas of politics, business, research, and societal stakeholder groups and are accompanied not only by the Directorate General for Research and Innovation, but also by up to ten Directorate Generals that pursue both R&I-related and sectoral policy agendas. The Mission Boards chairs report directly to the commissioners, who also take the final decision on the missions and agendas.[127] A new Mission Board is appointed for the implementation phase of each mission.[128]

### Increase Reflexivity

A mission-oriented R&I policy faces the challenge of actively managing transformative change and constantly adjusting measures as it progresses. This adjustment requires a high degree of reflexivity (cf. box B 1-4). Instruments for this can be, for example, stage-gate models (cf. box B 1-8). They are based on continuous monitoring and accompanying evaluation processes that provide those responsible with the necessary information to adapt ongoing measures to current developments, to develop them further or to discontinue them. An example of how reflexive elements can be systematically built into mission implementation is the Swedish programme Challenge Driven Innovation by VINNOVA (cf. box B 1-8).[132]

Box B 1-8

#### Increasing Reflexivity Using the Practical Example of Challenge Driven Innovation in Sweden

Challenge Driven Innovation (CDI) is a programme of the Swedish innovation agency VINNOVA, which was implemented in 2011. CDI aligns with four overarching, broadly defined challenges (future healthcare, sustainable and attractive cities, information society 3.0 and competitive manufacturing) and relies on cross-sectoral collaboration between a range of public and private players.[129]

CDI uses a stage-gate model to align projects against the four challenges and other overarching objectives (e.g., transdisciplinarity, end-user involvement, diversity, etc.). This allows regular adjustments to be made to the project portfolio. To move from one stage to the next, projects are evaluated and assessed on this basis (gate). Project partners have the option of dropping out after one phase or joining in at a later phase. This means that the project and the consortium must adapt continuously. In addition, the involvement of private sector partners increases with each phase, as commercialization and implementation issues come to the fore in later phases.[130] During evaluations, content-related project adjustments are made on an ongoing basis; projects can also be terminated if they do not develop in the desired direction.[131]

## Recommendations for Action B 1–5

### Use New Mission Orientation to Address Grand Societal Challenges

R&I policy has the responsibility to contribute to addressing the grand societal challenges and to initiate transformative change. As the policy approach of New Mission Orientation supports this, the Commission of Experts advocates that the Federal Government should give greater attention to this policy approach in a market-oriented version. It recommends pursuing missions that initiate transformative change also in the new legislative period and beyond.

With the New Mission Orientation policy approach, the public sector has a changed role in R&I policy. It must steer innovation activities in socially agreed directions that the private sector players themselves, due to transformation failures, do not take. However, the Commission of Experts is of the opinion that, despite all state guidance, the market as a discovery process must not be undermined but should be explicitly used as a source of new technologies and creative solutions. A correspondingly market-oriented version of New Mission Orientation must take the following principles into account:

- No specific solutions are defined in advance in favour of an open approach that allows for different solutions. This allows for utilization of the creative forces of market players.
- The promotion of alternative problem solutions focuses primarily on the pre-competitive area from basic research to knowledge and technology transfer.
- If direct interventions in the market are necessary, these will be temporary in the sense of a catalytic R&I policy.

The successful implementation of the New Mission Orientation requires agile political action. The Commission of Experts welcomes the fact that R&I policy has already become more agile in recent years. Yet it calls on the Federal Government to enshrine agility even more systematically in political action.

### Establish Participatory Processes for Formulating Missions

The implementation of missions requires complementary innovations from different stakeholder groups and, where appropriate, changes in societal behaviour. Missions can only be successfully implemented if they are supported by those with political responsibility and broad sections of the population.

- The Commission of Experts advocates ensuring close cooperation between the various ministries as well as the active involvement of stakeholder groups, expert panels, citizens as well as the Länder and municipalities in the formulation of the missions.
- Concrete objectives must be derived from the missions. These must have a time frame and their fulfilment must be measurable. The time frame should be based on the objective of the missions and not on the duration of legislative periods. However, the Commission of Experts considers it sensible to formulate legislature-specific milestones to make use of the existing political incentive structures. When the objective of a mission is achieved or a mission falls significantly and persistently short of the objectives set, the funding associated with the mission should be terminated.

### Expand Policy Coordination for Implementation of Missions

Superordinate coordination structures are needed for the efficient implementation of missions. In addition to coordination with other policy fields in terms of content and timing, the funded R&I projects usually must be accompanied by appropriate adjustments in the legal framework and by triggering standardization processes.

- The Commission of Experts considers it necessary to strengthen the horizontal coordination of ministries in the implementation of missions. This can be done through inter-ministerial task forces led by the state secretary level and involving the working level. The Commission of Experts recommends setting up a separate inter-ministerial task force for each mission and providing it with decision-making powers and its own budget.
- In the case of particularly complex missions, it should also be examined whether it makes sense to adjust the structure of the ministries involved or even to set up a separate ministry for this purpose.
- The Commission of Experts recommends reinforcing horizontal coordination not only between the ministries, but also within the ministries. Depending on the nature of the mission, it is advisable to set up cross-departmental project teams or to create separate mission-related units within the organizational structure. These project teams or units are each to be equipped with their own discretionary competences and budgets.

### Intensify Innovation-oriented Public Procurement

- The Commission of Experts repeats its recommendation to further expand innovation-oriented public procurement.[133] In order to support transformative change, procurement should also increasingly align itself with socially agreed missions.

### Create Conditions for More Policy Learning

When implementing the policy approach of New Mission Orientation, policy learning must be integrated into the processes more strongly than before. The Commission of Experts advocates taking the following aspects into account:

- Against the background of existing uncertainty, mission-oriented R&I policy is also a policy of experimentation. Experiments include the possibility of learning from

failure. In terms of a positive error culture, policy learning should be implemented more strongly to ensure that goal adjustments, readjustments of the organization and measures and even complete discontinuation are possible and accepted when implementing missions.

- Missions must be continuously subjected to a monitoring process as well as to accompanying and final evaluations. Due to the complexity of missions, further research on evaluation methodology is needed and should be encouraged.
- For policy learning, it makes sense to create more scope for reflection and freedom[134] and to free up staff capacities in ministries and project management organizations to this end. In this context, it is important to increasingly involve external experts from business and science, e.g., through temporary fellowships, in addition to employees from different hierarchical levels.

# B 2 Adapting Vocational and Continuing Education and Training to Digital Transformation

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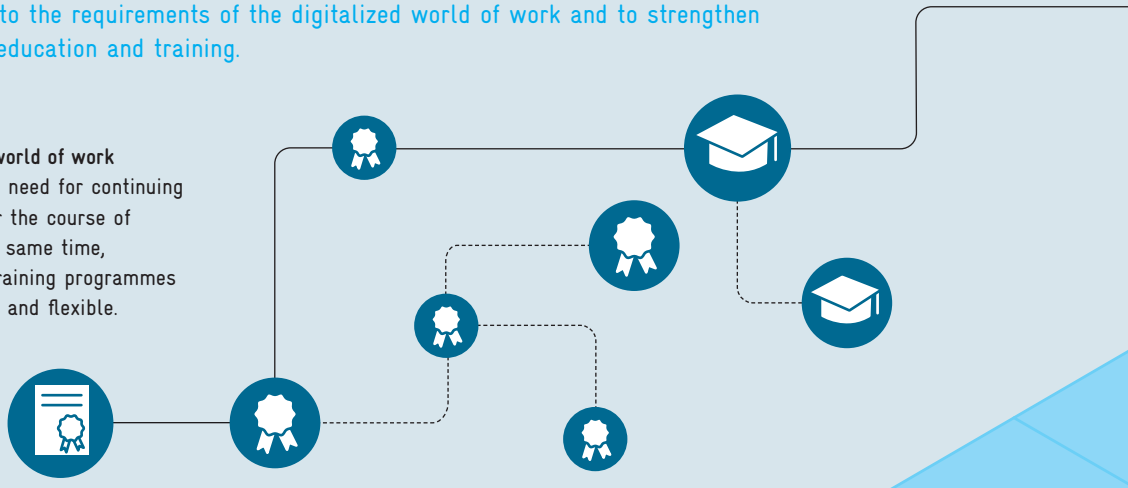
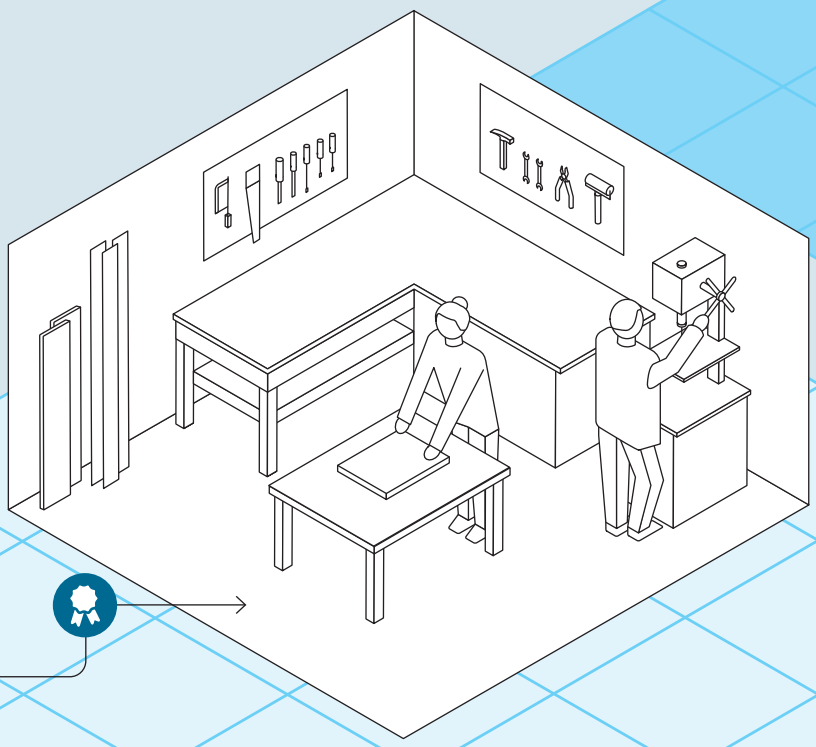
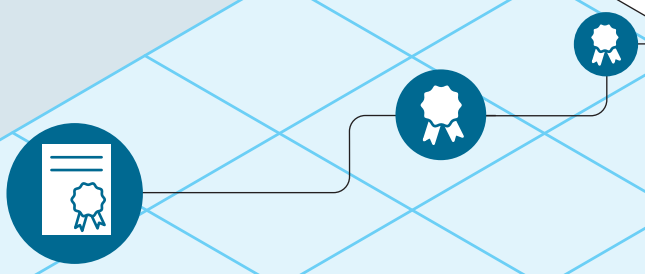
As a result of the digital structural change, many employees in Germany will have to change jobs in the coming years and reorient themselves professionally. In addition, job profiles in many existing workplaces will continue to change. It is therefore necessary to adapt vocational education and training to the requirements of the digitalized world of work and to strengthen job-related continuing education and training.

**Career paths in the digital world of work**
Digitalization increases the need for continuing education and training over the course of employment history. At the same time, continuing education and training programmes are becoming more diverse and flexible.

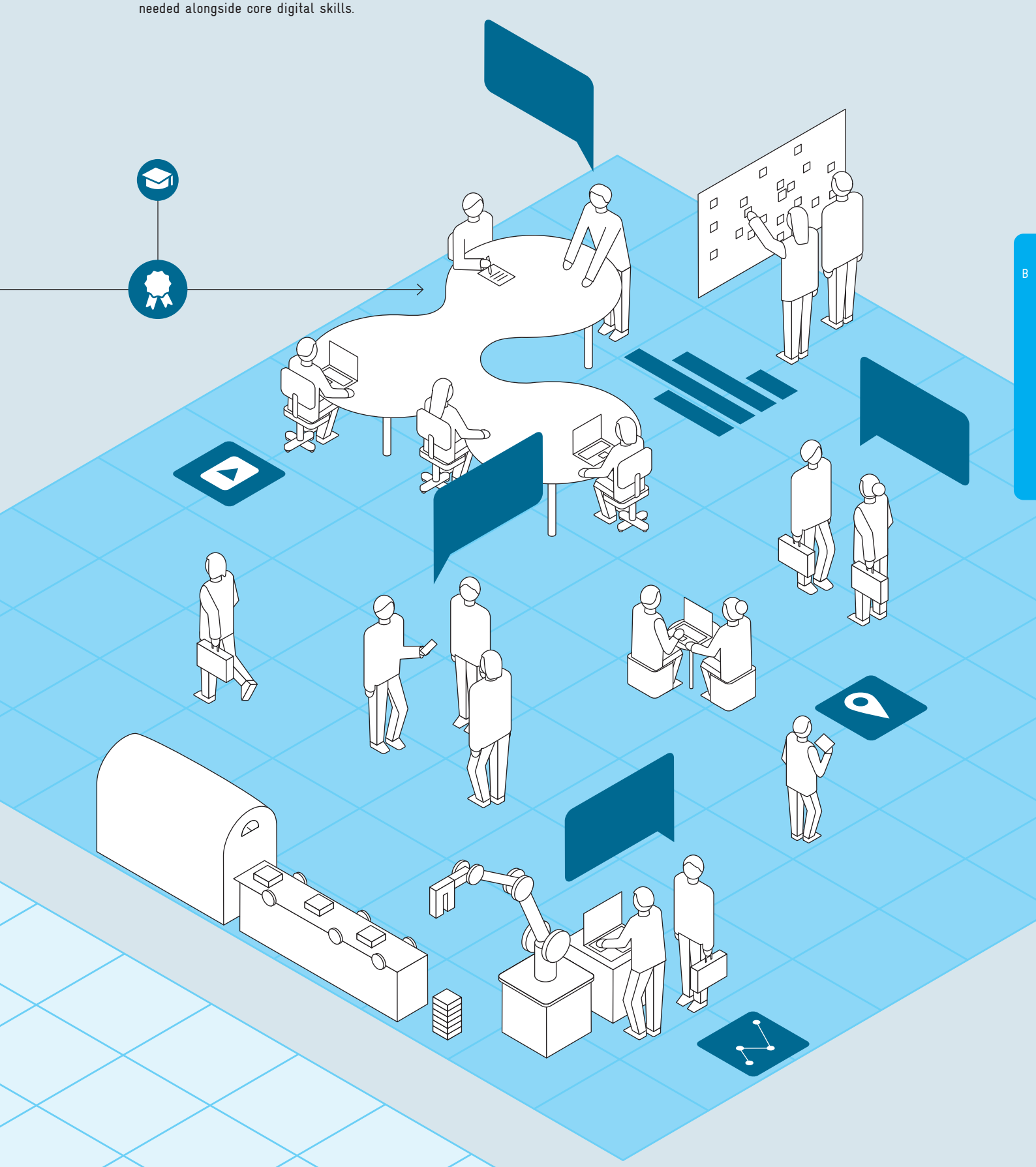




**Career paths in the past**
Previously, career paths in Germany mostly followed narrow occupational pathways. Continuing education and training took place rather rarely and mainly served the advancement in the occupation learnt.



**New world of work**
The digitalized world of work requires performance of fewer and fewer routine tasks. Increasingly, core personal and social-communicative skills are needed alongside core digital skills.



# B 2 Adapting Vocational and Continuing Education and Training to Digital Transformation



The increasingly digital value chains in the economy are changing the world of work.[135] There tends to be less routine work to be done at the individual workplace.[136] As a result, the demands on individual occupational action competence are growing. The automation of processes through the increased use of intelligent machines, algorithms and artificial intelligence is replacing human labour. At the same time, digitalization creates new attractive fields of activity and previously disadvantaged groups can achieve better access to occupations.[137] Thus, the structure and quality of jobs in Germany will change significantly in the coming years.

In the course of digitalization, many people in the current labour force will therefore have to gain further professional qualifications. There is an increasing demand not only for technological skills, which are necessary for the design of transformative technologies, and core digital skills.[138] The new digital business and work processes also increasingly require so-called essential core skills. These include problem-solving skills, creativity, initiative, adaptability, and perseverance.[139] Young people coming out of the education system, too, must have these core digital and non-digital skills to be well prepared for a successful career in the digitalized world of work.

Only if the diverse core skills are sufficiently available in the labour force can the economic and social potentials of new technologies fully unfold, and digitalization rapidly penetrate all parts of the economy.[140] It is not only the employed who benefit from this. Germany's innovation capacity and competitiveness will also be strengthened in the long term.[141]

That is why it is important that the system of vocational and continuing education and training (VET/CET) in Germany keeps pace with the changes in the economy and the world of work brought about by digitalization. To this end, VET opportunities must be further developed, and structures must be designed in such a way that the core skills for the digitalized world of work are imparted to the workforce in line with demand. The private stakeholders involved, especially companies and people in the labour force, continue to play a key role in the necessary adjustments in VET/CET. However, there is also a need for impulses from public authorities to reinforce the readiness for necessary changes and the framework conditions for them.

## Digitalization and the World of Work B 2–1

### Labour Market Effects of Digital Transformation

In debates about new technological unemployment, the automation risks for workers are often overestimated. In many cases, they are based on estimates which occupations, considered as a whole, could in principle be rationalized away by new technological possibilities.[142] In an overall view of the effects of digital transformation on the labour market, however, it must be taken into account that there is also considerable employment potential in the use of new technological possibilities. These result directly from the growing demand for workers involved in the development and implementation of innovative technologies. In addition, completely new business models are emerging because of digitalization.[143] Furthermore, the productivity gains achieved with technological progress can translate into falling product prices on the one hand and rising incomes on the other. This feeds consumer demand and thus labour demand.[144]

In the past, more precisely between 1999 and 2010, the induced productivity effects of computerization

were so strong that the number of jobs in the European Union increased on balance by a good twelve million, although six million jobs were lost due to the direct displacement effects of technological change.[145] Another study shows that although the increased use of robots in German industry led to a loss of manufacturing jobs between 1994 and 2014, this was fully offset by the employment effects of the induced stronger demand for consumer-related services.[146] However, the resulting changes in the structure of employment may contribute to a polarization of employment and earnings, i.e. relatively weak growth or even decline in employment and earnings for people with middle-level qualifications.[147]

The Federal Ministry of Labour and Social Affairs (Bundesministerium für Arbeit und Soziales, BMAS) has been conducting forward-looking skilled labour monitoring for several years with the aim of highlighting potential future labour market developments at the level of occupations and sectors as well as identifying medium- and long-term problems in matching labour supply and demand in Germany in good time. For this purpose, scenario calculations are prepared that map in particular the effects of changes in the global economic framework conditions, demographic change and expected technological change.[148] The scenario of the transition to an Economy 4.0 presented in 2019 as part of the Skilled Labour Monitoring concludes that as a result of the associated economic and occupational structural change, around 3.8 million jobs that still existed in Germany in 2018 will no longer exist in 2035.[149] At the same time, however, about 3.2 million jobs will have been created by 2035 that did not exist in 2018. The predicted decline in employment opportunities in the increasingly digitalized world of work remains moderate on balance at 571,000. Behind this, however, lies a gross turnover of about seven million jobs. In the future, many workers will therefore have to find employment in other occupations than before.[150]

The calculations in the context of the BMAS's Skilled Labour Monitoring show that this upheaval is accompanied by a considerable need for further and higher qualification. According to this estimate, the major occupational groups of transport and logistics (except vehicle driving), drivers of vehicle and transport equipment, cleaning occupations and sales occupations will lose the most employees in Economy 4.0 by 2035, compared to 2018. On the other hand, the major occupational groups of information technology and other ICT occupations, occupations in business management and organization, occupations in advertising, marketing and media as well as occupations in technical development, construction and production control in particular are gaining employees.[151] Obviously, the new jobs cannot simply be filled with employees whose jobs no longer exist after a transition to Economy 4.0.

The structural shifts at the occupational level are associated with an increase in the average level of skill specialization,[152] which creates a need for higher qualification. Assuming even greater digitalization in the coming years, the number of employed experts, whose range of tasks predominantly requires a tertiary education institution degree of at least four years, will be higher by around 110,000 in 2035. The number of employed specialists, whose range of tasks predominantly requires training as a master craftsman or technician or an equivalent technical college or tertiary education institution degree, is higher by 76,000 (cf. figure B 2-1). On the other hand, the number of employed elementary workers whose range of tasks predominantly requires no VET or a maximum of one year of regulated VET is reduced by around 113,000 persons and the number of employed skilled workers whose range of tasks predominantly requires at least two years of VET is even reduced by about 210,000 persons (cf. figure B 2-1).[153] In order to meet the demand for employees who can fulfil high levels of skill specialization and to avoid a growing inequality of employment opportunities in Economy 4.0, those with simpler professional qualifications would therefore have to be increasingly enabled to fulfil higher levels of skill specialization in their occupation.

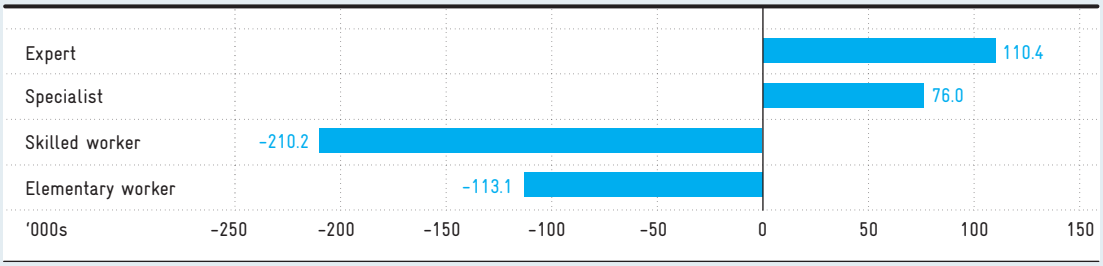
### Change in Occupational Profiles and Competence Requirements

In the digital structural change, the occupational profiles of employees in workplaces are changing. A decline in routine tasks and an increase in non-routine tasks were already observed in connection with the increasing spread of computers in the workplace in the 1980s and 1990s. This change took place almost exclusively within occupations.[154] An empirical study commissioned by the Commission of Experts and carried out by the Kiel Institute for the World Economy and the RWI – Leibniz Institute

Fig. B 2-1

Download data

**Projected change in the number of people in employment by level of skill specialization in the transition to Economy 4.0 compared to a status quo baseline projection 2035 in thousands**




Source: Results of the BMAS's Skilled Labour Monitoring. Own representation based on Wolter et al. (2019: 30).
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for Economic Research finds that this continued until the mid-2000s.[155] After that, both the decline in routine and the increase in non-routine tasks slowed down significantly and the changes in task shares are increasingly due to shifts in employment shares between occupations.[156] The slowdown in the change in occupational profiles is in line with the end of a first phase of accelerated digitalization.[157]

Occupational non-routine tasks are divided into analytical, interactive, and manual non-routine tasks (cf. box B 2-2). Manual non-routine tasks lost importance again in the 2000s and 2010s after their intensity had increased in the 1980s and 1990s.[158] The decline is mainly fed by changes in task profiles within occupations rather than by occupational structural change. The intensity of interactive and analytical non-routine tasks has continued to grow in the German labour market since the mid-2000s, albeit less strongly than before. Moreover, both types of tasks still show clear complementarities with digital technologies. The increase in interactive non-routine tasks can most recently be attributed to the change in the structure of employment towards occupations in which these tasks play a greater role. The growth of analytical non-routine tasks, on the other hand, is driven more by the change in task profiles within occupations.

The change in job profiles at the workplace that goes hand in hand with the use of digital technologies also changes the need for skills, capabilities, and competences (for definitions cf. box B 2-2) that are needed to maintain occupational action competence. According to the results of a representative survey of HR managers, changes in the workplace due to investments in self-controlling machines and systems or IT-integrated office and communication tools lead to an increasing importance of non-technical skills, which are necessary, for example, for more interdisciplinary and creative ways of working as well as more intensive customer relationship management.[159]

To form the basis of the Future Skills initiative, launched in 2018 by the Stifterverband as a major joint action programme of business and civil society, 18 core skills were identified, the importance of which in professional life will soon increase significantly across all sectors as digitalization and the associated new ways of working progress. In addition to various technological skills that are necessary for the design of transformative technologies, these also include core digital skills such as digital literacy, digital interaction, and digital learning, as well as so-called essential core skills such as problem-solving ability, creativity, initiative, adaptability, and perseverance.[160]

A comparative analysis of studies focusing on 14 VET occupations in Germany documents that the change in tasks accelerated by digitalization can be better managed by strengthening comprehensive action competence than by constantly acquiring new occupation-specific competences. A central

component of this comprehensive action competence is learning competence.[161] The competence to learn new things independently and in a self-determined manner enables employees to adapt in a self-regulating manner to the tasks that are changing rapidly and continuously with the digital transformation of the world of work. Promoting or developing this learning competence in a job-related manner is therefore an important requirement for the VET/CET system.

## B 2-2 VET/CET System and Digital Transformation

### Adaptation of Content and Teaching/Learning Formats in VET

The VET system in Germany is undergoing change. Among newly concluded VET contracts, the percentage of occupational groups characterized by a high or very high degree of digitalization has increased from 50 percent in 2010 to 55 percent in 2018.[162] In addition, the rate of first-year students has risen sharply.[163] The growing and increasingly differentiated range of tertiary education institutions and degree course options apparently offers attractive alternatives for many young people.[164] The German VET system faces the challenge of reconciling standardized training regulations and framework curricula on the one hand and rapid adaptation to changing skill requirements due to digital structural change on the other.

On behalf of the Commission of Experts, the Institute for Applied Economic Research (Institut für Angewandte Wirtschaftsforschung, IAW) has conducted and systematically evaluated expert interviews on the effects of digitalization on the area of VET, among others. The interviewed experts stated that in the long term, digitalization will not completely eliminate any VET occupations and that

Box B 2-2

### Key Terms

**Professional tasks:** Occupations are made up of different tasks and activities. These are often divided into five categories: manual routine tasks such as monitoring machines, cognitive routine tasks such as correcting texts, manual non-routine tasks such as carrying out repairs, analytical non-routine tasks such as researching, and interactive non-routine tasks such as negotiating.[165] Managing these different tasks and related activities requires different skills and competences.

**Competences, capabilities, and skills:** The terms skills and competences are both blurred in their range of meaning and are often used synonymously.[166] In a broad sense, competence can be understood as the capability and skill of an individual to cope with a specific problem or problem area as well as the associated motivational, volitional, and social readiness and capabilities to be able to variably use the problem solutions. Competence is always related to a specific field of application. Therefore, a reference designation is often prefixed (e.g., social competence, digital competence). The terms capability and skill are also often used synonymously. However, a distinction can be made between capability as a talent for something (such as musicality) and skill as the realization of a capability acquired through practice (such as playing a musical instrument). Capabilities belong to the personality traits. They are thus relatively stable but can in principle be consciously changed – albeit with greater effort or over a longer period.[167]

**Qualifications:** Qualifications denote the outcome of a formal assessment and validation process. In this process, an appropriately responsible institution (e.g., in a final examination) determines that the individual competences, skills and capabilities meet predefined standards.[168]

VET occupations are rarely newly created. Rather, they are constantly evolving.[169] The pressure to adapt due to digitalization is reflected in the fact that the number of restructured VET occupations has been unusually high in recent years.[170] Framework curricula have also been rapidly adapted to changes related to digitalization.[171] New standard occupational profile elements, expanded to include the topic of digitalization, apply to all training regulations that come into force from August this year.[172] The Agile Procedure initiated by a social partner agreement between Gesamtmetall, the Metalworkers' Union (Industriegewerkschaft Metall), the German Engineering Federation (Verband Deutscher Maschinen- und Anlagenbau) and the German Electrical and Electronic Manufacturers' Association (Zentralverband Elektrotechnik- und Elektronikindustrie) pursues the goal of systematically observing and evaluating the changing occupational requirements for Industry 4.0-relevant VET occupations in the metalworking and electrical sectors in order to change curricular specifications promptly and to identify any need for adaptation in the design of training.[173]

Experts see the practical implementation of the adapted regulatory means[174] in the design of VET at the company level as more of a problem.[175] Many companies have recognized the growing importance of digital competences and already teach a large number of the skills and capabilities that are needed by skilled workers in the digital economy in their in-house training.[176] However, the less digitalization has penetrated the company and its environment, the less often training design is adapted to match the development of professional action capability in digitalized work and business processes.[177] This particularly affects small and medium-sized enterprises (SMEs), which generally operate on a less digitalized level than large companies.[178] More digitalized companies use digital media more intensively in training and teach more digital skills.[179]

As a reaction to the varying degrees of digitalization and the resulting increased diversification of work and training environments, formal additional qualifications have developed in some VET occupations that enable specialization.[180] Many companies would like to see these flexible supplements to standard training, especially in highly specialized sectors.[181] These formats are already used quite frequently in the areas in which they exist, but are rarely examined by a chamber, so that qualification certificates are lacking.[182] The expert interviews conducted by the IAW resulted in the recommendation to increasingly expand the training regulations to include additional qualifications, because these make it possible to adapt to current content-related needs at shorter intervals.[183] In addition, this format allows training to be better aligned to specific in-house demand situations and the degree of digitalization in the specific training environment, and anchor points are set for occupational specializations and specialist careers.[184]

The experts interviewed by the IAW attest that overall the training companies and the vocational schools have available good technical equipment.[185] However, the vocational schools have major deficits in terms of equipment involving digital media, hardware and software.[186] There is a need for action with regard to the qualification and further training of the trainers in the companies and the teachers at the vocational schools.[187] So far, these have mainly concentrated on the vocational dimension.

Digitalization leads to a greater mix of methods in VET. The importance of digital teaching/learning formats as well as self-organized and independent learning is growing. This also changes the demands on the methodological knowledge and didactic skills of the staff involved in training. According to the experts interviewed by the IAW, the specific didactic competences required for the effective use of digital teaching/learning formats and the teaching of personal and social-communicative skills for the digitalized world of work are often not sufficiently available.

### Systematic Differences in Participation in CET

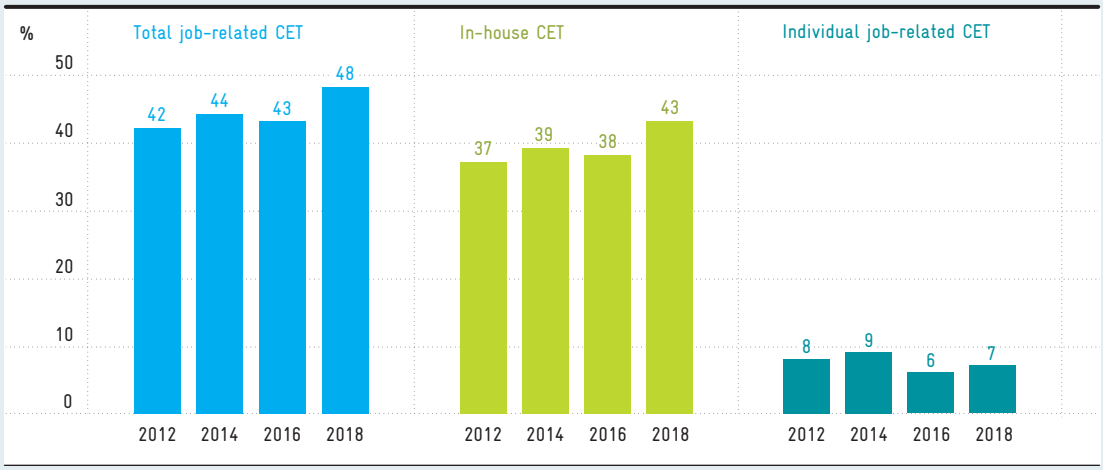
Digitalization increases the need for job-related continuing education and training (CET). In the continuing education survey conducted by the German Economic Institute (Institut der deutschen Wirtschaft, IW) in 2017, around 26 percent of the companies surveyed stated that their need for continuing education had increased significantly due to the introduction of new digital technologies. Another 40 percent said it had increased slightly.[188]

The proportion of 25 to 64-year-olds who participated in at least one job-related CET activity during the last

Fig. B 2-3

Download data

## Participation rates in job-related CET in Germany 2012–2018 in percent




Weighted values. The definition of CET segments differs slightly in 2018 from that in the previous years under review. For detailed information cf. endnote 191.
Source: Adult Education Survey. Own representation based on calculations of the German Institute for Adult Education (Deutsches Institut für Erwachsenenbildung) in BIBB (2020: 303).
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twelve months was 48 percent in 2018 (cf. figure B 2-3).[189] The rate was thus 6 percentage points higher than in 2012.[190] This increase can only be attributed to higher participation in in-house CET, which therefore continues to characterize the picture of job-related CET in Germany. In 2018, 43 percent of 25 to 64-year-olds participated in in-house training, compared to 7 percent participating in individual job-related training.[191]

Participation in job-related CET among people with low professional qualifications is clearly below average.[192] However, it has grown significantly since 2012. Employees whose jobs are potentially more easily replaceable by technology because they perform a high proportion of routine tasks are less likely to undergo continuing training, and this applies to all qualification groups.[193] This is partly due to the fact that their employers are generally less likely to provide continuing training and less likely to offer individual training to employees with a high proportion of routine tasks.[194]

The percentage of companies active in continuing education increased from 36 percent to 53 percent between 2001 and 2011 and was fairly stable thereafter. It has recently increased again slightly and has risen to well over 54 percent in 2018 (cf. chapter C 1).[195] The rates of CET activity vary greatly depending on the sector, the structure of the workforce and the size of the company. Small companies are significantly less active in CET. While almost all companies with 50 to 249 employees, with 250 to 499 employees and with 500 or more employees engage in CET activities (92, 97 and 98 percent respectively), only 52 percent of companies with fewer than 50 employees are active in CET (cf. chapter C 1).[196] Companies with a higher degree of digitalization, i.e., with a higher number of digital technologies in use, are systematically more active in CET.[197]

On average, the less digitalized SMEs have less structured human resources management and thus more often have difficulties in identifying training needs in advance. They are also more dependent on external training providers.[198] Intercorporate training structures are rather weak. SMEs could benefit from more advice and assistance to obtain more information on development trends in qualification requirements resulting from digitalization and better orientation in the selection of suitable and high-quality training offers.

### Provider Diversity in the Field of Job-related CET

Job-related CET in Germany is provided by a wide range of institutions, in particular by companies themselves, commercial providers (such as language schools), public sector providers (such as adult education centres) and community providers (such as medical associations). In-house CET activities, i.e., CET activities that take place entirely or predominantly during paid working hours or paid time off for educational purposes, or where direct CET costs are covered at least proportionally by the employer, were carried out by companies themselves to 65 percent in 2018. In just over one in three cases, however, an external provider was involved.[199] Individual job-related CET was distributed as follows: 30 percent by commercial providers, 28 percent by public sector providers, 20 percent by community providers and 18 percent by in-house providers.[200] Tertiary education institutions play a very minor role as providers of job-related CET.[201] There are calls for them to become more prominent in this area because the need for tertiary VET is increasing in view of technological changes.[202]

A reliable assessment of the quality of the diverse CET providers and individual CET programmes is difficult. In the field of publicly funded CET, the Accreditation and Approval Ordinance for Employment Promotion (Akkreditierungs- und Zulassungsverordnung Arbeitsförderung, AZAV)[203] links the approval of providers and employment promotion measures to criteria such as the suitability of the employed teaching staff and quality assurance procedures. In contrast, there are no binding requirements in freely financed CET programmes. Voluntary quality assurance procedures have been established in some cases.[204] However, these input- and process-oriented procedures are only of limited value for evaluating the effectiveness of the offered training with regard to the qualification objectives. This also applies to customer reviews on rating portals.[205]

### Increasing Importance of Digital CET Formats

One challenge for providers of job-related CET is that the content demanded is changing rapidly with digitalization. CET programmes must be continually adapted or redesigned to meet changing requirements. Against this background, it is advantageous if CET programmes are divided into modules that can be quickly adjusted and flexibly combined.[206] At the same time, digitalization is changing the formats and methods of CET. Digital teaching/learning formats in particular are gaining in importance. These developments create a considerable need for further training among the teaching staff employed. Yet as these are often freelance trainers, providers find it difficult to organize them accordingly.[207]

In the segment of individual job-related CET, the demand for digital teaching/learning formats is currently still relatively weak. One of the main reasons for this is that in this area personal encounters with other participants and lecturers are valued.[208] However, in the segment of in-house CET, face-to-face formats are increasingly being supplemented by digital formats.[209] The advantages of online formats are, on the one hand, cost savings for companies, on the other hand, gains in flexibility in terms of time and content as well as greater personalization of CET content. However, the usefulness and applicability of digital programmes are strongly dependent on the CET learning objective and on the learners' abilities for self-organization and self-determined learning. Especially programmes purely focusing on information and knowledge can be presented well online. In the foreseeable future, hybrid formats in particular are likely to be attractive for in-house CET.[210]

## Federal Initiatives for VET/CET in the Digital World of Work B 2-3

The organization of VET/CET primarily involves employers and trade unions, the Federal Government and the Länder, and to some extent also the Federal Employment Agency (Bundesagentur für Arbeit, BA).[211] In the following paragraphs, the focus is on the measures and programmes implemented by the Federal Government to strengthen the performance of VET/CET to cope with the changed requirements in the digital world of work. These are running against the background and partly within the framework of the VET umbrella initiative Berufsbildung 4.0 and the National Skills Strategy (cf. box B 2-4).[212]

In general, no reliable statements can be made about the effects of the numerous support measures in VET/CET. A systematic evaluation of the measures has for the most part not yet been carried out.

### Measurement of Competence and Qualification Requirements

Within the VET umbrella initiative Berufsbildung 4.0, the Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF) funded from 2016 to 2018, among other things, the research initiative Skilled Worker Qualification and Competences for the Digitalized Work of Tomorrow (Fachkräftequalifikation und Kompetenzen für die digitalisierte Arbeit von morgen). In this context, competence and qualification requirements for selected occupations were identified and conclusions were derived for the further development of the regulatory means for VET.[213] With the feasibility study Competence Compass (Kompetenz-Kompass), funded from 2019 to 2020 and conducted by the Institute for Employment Research (Institut für Arbeitsmarkt- und Berufsforschung, IAB), the BMAS is also aiming to gain knowledge on how current and future technical and interdisciplinary competence requirements can be systematically identified.[219]

The counterpart to ongoing measurement of competence requirements is monitoring of existing skills and competences in the labour force. This entails major conceptual challenges. In the context of VET in Germany, several concepts for measuring skills and competences are available, but they focus on commercial, industrial-technical, and health occupations and deal significantly more often with technical than with general and social-communicative skills and competences. In addition, there is often a lack of wide-ranging transfer of these concepts into practice.[220] In order to further develop the instruments of competence measurement in VET based on technology and to make these more applicable in



Box B 2-4

### Umbrella Initiative Berufsbildung 4.0 and National Skills Strategy

The BMBF launched the VET umbrella initiative Berufsbildung 4.0 in 2016 as part of the strategy Education Offensive for the Digital Knowledge Society (Strategie Bildungsoffensive für die digitale Wissensgesellschaft).[214] It pursues the goal of supporting digital transformation in VET.[215] To this end, various programmes and initiatives with different focus areas and target groups are combined and interlinked.[216]

Berufsbildung 4.0 also contributes to the National Skills Strategy.[217] The latter was adopted in June 2019 by the BMAS and BMBF together with the Länder, industry, trade unions and the BA and is intended to lay the foundation for a new CET culture.[218] The partners want to align CET in Germany in such a way that the structural change driven especially by digitalization can be successfully organized. The National Skills Strategy focuses on job-related CET and aims to safeguard professional action capability, among other things, within the context of adaptation qualifications or to expand it within the context of advanced qualifications. Ten operational objectives are defined for this purpose:

1. Support the transparency of CET opportunities and programmes.
2. Close funding gaps, set new incentives, adapt existing funding systems.
3. Network lifelong CET guidance throughout the country and improve qualification guidance, especially for SMEs.
4. Strengthen the responsibility of the social partners.
5. Review and reinforce the quality and quality assessment of CET provision.
6. Make visible and recognize acquired competences of workers in VET/CET.
7. Develop CET degrees and training opportunities.
8. Strategically develop educational institutions as competence centres for CET.
9. Support CET staff and qualify them for the digital transformation.
10. Strengthen strategic foresight and optimize CET statistics.

The first implementation report on the National Skills Strategy is to be presented later this year.

practice, the BMBF has been funding the transfer initiative ASCOT+ since 2017. It aims at developing digital measurement tools for vocational and cross-occupational skills and competences of apprentices in three occupational fields and to test these in training and examination practice.[221]

### Modernization of Training Design and Methods

Other measures are aimed at promoting digital teaching in VET. These include the BMBF's Digital Media in Vocational Education and Training programme (Digitale Medien in der beruflichen Bildung), which aims to enhance the quality and attractiveness of VET/CET through the use of digital media for teaching and learning.[222] In addition, the BMBF's qualification initiative Digital Change – Q 4.0 (Digitaler Wandel – Q 4.0), launched in 2019, supports the development and testing of CET concepts for VET staff.[223] Here, the focus is on the one hand on the training staff's media education skills, and on the other hand on their qualifications to adapt training content and processes to digitalization.

The modernization of training in SMEs is also being supported with measures such as the VET/CET in the Economy 4.0 (Aus- und Weiterbildung in der Wirtschaft 4.0) funding line in the context of the JOBSTARTER plus programme. This funding line supports SMEs in the methodological-didactic further development of training design to take account of the changed framework conditions and requirements resulting from digitalization, particularly regarding personal competences.[224]

### Expansion of Job-related CET

The support of job-related CET is mainly the responsibility of the BMAS. The traditional target group of publicly funded CET measures is the unemployed. More recently, however, support services for employees have been greatly expanded. For example, the Act to Strengthen Opportunities for Qualification and for More Protection in Unemployment Insurance, short: Skills Development Opportunities Act (Gesetz zur Stärkung der Chancen für Qualifizierung und für mehr Schutz in der Arbeitslosenversicherung, Qualifizierungschancengesetz) came into force in early 2019.[225] The Skills Development Opportunities Act promotes job-related CET outside the workplace for employees who perform tasks that are being replaced by new technologies, are otherwise affected by structural change, or are seeking job-related CET in a bottleneck vacancy.[226] A right to CET and qualification advice for employees and companies was introduced. In addition to the absorption of CET costs, the possibility of partial wage compensation is granted in the event of CET.[227]

The Act on the Promotion of CET in Structural Change and the Further Development of Training Assistance, short: Work of Tomorrow Act (Gesetz zur Förderung der beruflichen Weiterbildung im Strukturwandel und zur Weiterentwicklung der Ausbildungsförderung, Arbeit-von-morgen-Gesetz), which came into force in May 2020, extends the benefits for employees particularly affected by structural change beyond the Skills Development Opportunities Act. It supports post-qualification training for workers without vocational qualifications, improves funding opportunities for CET during short-time work, and has raised cost rates for CET providers to ensure quality.[228]

To provide even greater protection for employees in the event of fundamental upheavals in the economy, the trade unions are proposing the introduction of a so-called transformation short-time allowance (Transformations-Kurzarbeitergeld). This is to be granted as a wage replacement benefit during attendance of a CET course if the parties in the workplace jointly determine that, due to changes in products, processes and workflows, the activities of a significant number of employees will change fundamentally and their professional knowledge and skills will not be sufficient to fulfil expected future tasks in the company. In addition, the BA is to assume the full costs of CET.[229] The Commission of Experts considers this approach to be unsuitable, since it would transfer entrepreneurial risks to the social insurance community and considerable bandwagon effects are to be expected. Above all, however, necessary structural change could be impeded. Employee transfer to more competitive companies would be slowed down. Start-ups entering the market with innovative products, processes or business models would be systematically disadvantaged.

Regional networks can play an important role in establishing a new CET culture. For this reason, the BMAS has been promoting the establishment of

CET networks since June 2020 to establish binding cooperation and networking structures between companies, stakeholders in the CET landscape and other labour market stakeholders with the help of regional coordination offices. The CET networks are intended to support SMEs in particular in planning, organizing, and designing job-related CET for their employees.[230]

## B 2-4 Recommendations for Action

As a result of the digital structural change, many employees in Germany will have to change jobs in the coming years and reorient themselves professionally. In addition, job profiles in many existing workplaces will continue to change. Those in working life must therefore develop not only better core digital skills, but increasingly also core personal and social-communicative skills and competences to maintain professional action competence. It is therefore necessary to adapt VET to the requirements of the digitalized world of work and to strengthen job-related CET. With this in mind, the Commission of Experts recommends:

### Adapt Training Design to Digitalization

- The Federal Government should work towards ensuring that all training regulations are adapted to the changes brought about by digitalization and kept sufficiently up to date. Between updates, changing occupational requirements should be systematically monitored on a wider scope and assessed to update curricular specifications in a timely manner and to identify adaptation requirements in training design.
- Advice and assistance for implementing a VET design adapted to digitalization should be expanded. The focus here should be on weakly digitalized businesses, especially among SMEs. The formation of training alliances with companies whose business and work processes are already more digitalized should be supported more strongly and the networking of digital training locations and training offerings should be promoted.

### Making Vocational Training Staff and Schools Fit for Digitalization

- At vocational schools and in companies, the training and continuing education of teachers and trainers must be geared even more closely to the new content-related and methodological requirements resulting from digitalization. The results of the BMBF's qualification initiative Digitaler Wandel – Q 4.0 should therefore be scientifically evaluated and the implementation of the most successful concepts in practice should be supported.
- Incentives for appropriate CET of vocational training personnel should be consolidated.
- In addition, the Commission of Experts believes it is urgently necessary to equip vocational schools with a high-performance digital infrastructure, modern media, and access to high-quality learning software. The funds provided for the digitalization of schools in general and VET schools as part of the DigitalPakt Schule are not considered sufficient.[231]

### Strengthen Occupational Adaptability Through Flexible Additional Qualifications

- To strengthen both occupational adaptability and the basis for more differentiated specialist careers, the supply of elective modules and additional qualifications during VET should be further expanded and, if possible, made available everywhere. The inclusion of optional, codified additional qualifications in training regulations should be increased. To increase the willingness of companies to offer additional qualifications, SMEs in particular should be better informed about how they can use these to cover company-specific competence requirements.
- The supply of additional qualifications should be opened to job-related CET.

### Advance Implementation of the National Skills Strategy

- The Commission of Experts welcomes the fact that the Federal Government is taking account of the increasing importance of lifelong learning with its National Skills Strategy, in which it is designing specific activities and projects together with the social partners. However, it urges swift and coordinated implementation of the planned measures. In addition, the National Skills Strategy should provide more concrete criteria against which the quality of implementation and the success of the proposed measures will be evaluated.

### Provide Sufficient Resources for Higher-quality CET

- The Commission of Experts advocates that quality aspects be given greater weight in the ongoing update of the Accreditation and Approval Ordinance for Employment Promotion (AZAV). In this context, not only should the previous input-oriented specifications be made more demanding, but output-oriented criteria, such as the qualifications achieved and labour market results of the persons who have received CET, should also be given strong weight. In the area of publicly funded job-related CET, funding levels must be set so that high-quality programmes are profitable.
- Application-oriented tertiary education institutions could, on a voluntary basis, position themselves more strongly in the market for job-related CET with special offerings. If tertiary education institutions take on additional tasks as providers of CET, they must be provided with the necessary resources to do so.
- To support SMEs in job-related CET, the establishment of local and regional networks that organize efficient inter-company solutions should be promoted. For this reason, the Commission of Experts welcomes the support launched by the BMAS for the establishment of CET networks.

### Preventive Support for Occupational Mobility

- The Federal Employment Agency's support instruments for job-related CET to adapt to technological change are primarily geared towards the goal of continued employment with the previous employer and often only kick in when the job is severely threatened or even already lost. The Commission of Experts recommends additionally developing and testing instruments to support preventive adjustment qualifications that facilitate the transition of individual employees to a new employer. Viable bridging solutions must involve both the previous and the new employer and ensure an appropriate balance of their interests.

### Expand Monitoring of Occupational Skills

- The fit of job-related VET/CET can benefit from a monitoring system that comprehensively and continuously records the skills used in the profession and those available in people in employment. The Commission of Experts therefore welcomes initiatives to tap into and evaluate data from the Federal Employment Agency, from companies and from social networks for this purpose. This, together with the establishment of a central database on existing job-related VET/CET opportunities, could significantly improve the information base for career and educational decisions.

### Improve Structures for Guidance on Job-related CET

- As with career guidance, the employment agencies as local contact points could take on another task in the future with guidance on job-related CET for employees. To prevent conflicts of objectives, the Commission of Experts recommends that guidance on individual job-related CET be strictly separated from related support measures in organizational terms.

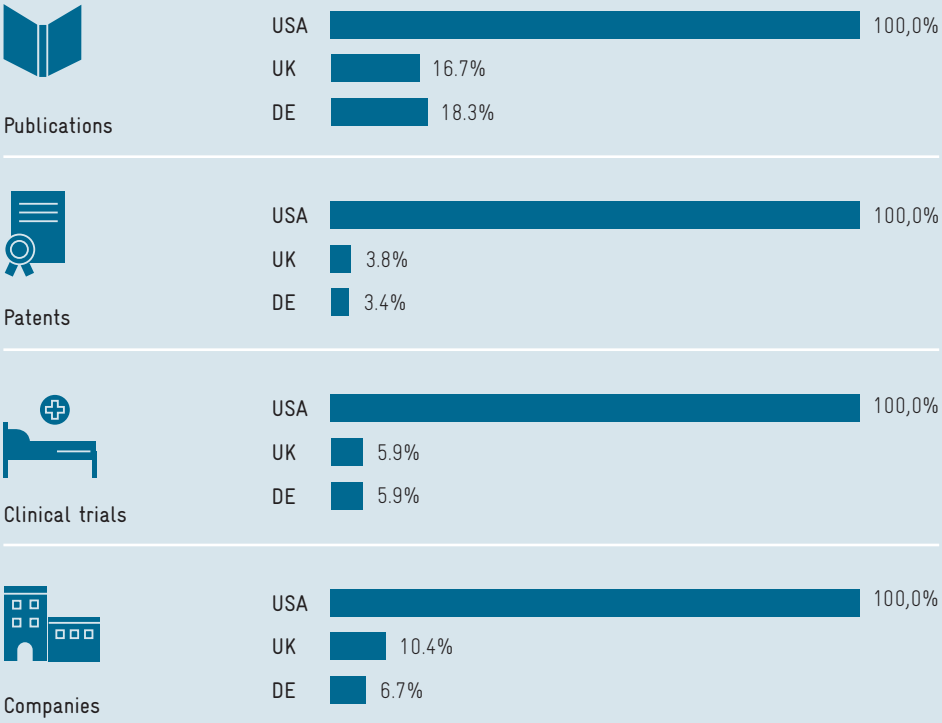
# B 3 Gene Editing and CRISPR/Cas

Download data

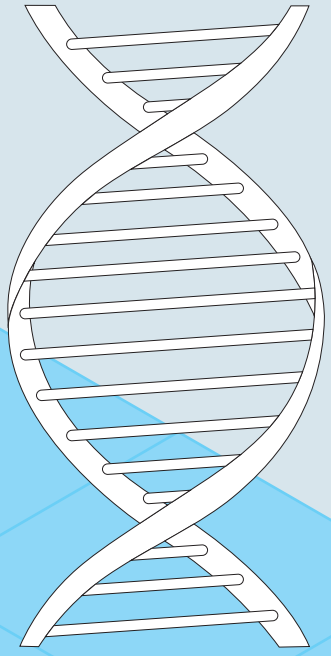
CRISPR/Cas is a gene editing tool that can be used, among other things, to find new therapeutic approaches and to decipher the causes of diseases. Experts attribute great potential to CRISPR/Cas because it simplifies gene editing and thus enormously expands the circle of researchers as well as the fields of application.

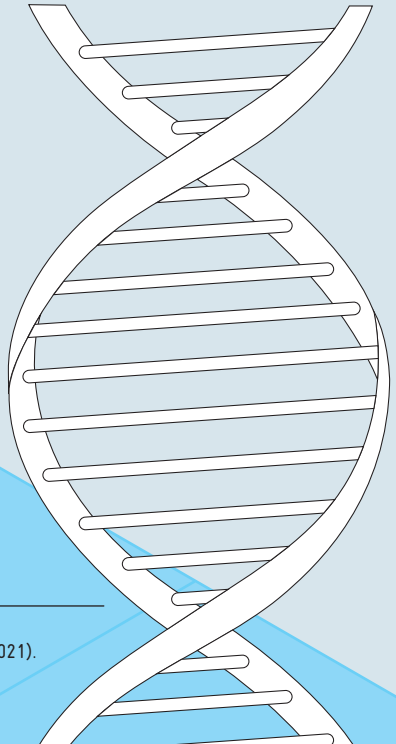
1. The guide RNA and a protein for cutting the DNA, such as Cas9, form a CRISPR system. 2. The CRISPR/Cas system binds a specific target DNA sequence. 3. This is where the double-stranded DNA is cut. 4. DNA can be inserted into or removed from the cleavage point.

**CRISPR/Cas-related research and innovation activities in the fields of health and medicine as well as technical improvements in Germany and the United Kingdom relative to those in the USA 2012–2019**




Germany is comparatively well positioned in CRISPR/Cas research in the fields of health and medicine as well as technical improvements. However, there is still untapped potential in Germany regarding CRISPR/Cas inventions, their use for patients and commercialization by companies.





Source: Illustration of how CRISPR/Cas works: Fröndhoff et al. (2019).
CRISPR/Cas research and development activities: Zyontz and Pomeroy-Carter (2021).

# B 3 Gene Editing and CRISPR/Cas



The CRISPR/Cas gene scissors are a tool for gene editing that can be used, among other things, to find new therapeutic approaches,[232] to decipher the causes of diseases,[233] to develop genetic testing[234] and to conduct basic medical research[235] (cf. boxes B 3-1 and B 3-2).

In addition to the use of CRISPR/Cas for medical purposes (red biotechnology), CRISPR/Cas is also used in agriculture (green biotechnology) and in industrial applications (white biotechnology), for example, to produce genetically modified enzymes, cells, or microorganisms.[236] In some cases, there is enormous potential for value creation in these fields.[237] This chapter focuses on the use of CRISPR/Cas for medical purposes.

CRISPR/Cas can be used to alter, switch off and switch on genes.[238] This opens new possibilities for treating hereditary diseases. At least 3 percent of the world's population is affected by a hereditary disease caused by the error of a single gene. Correcting this faulty gene could cure the disease.[239]

Researchers attribute great potential to CRISPR/Cas because it simplifies gene editing and thus enormously expands the circle of researchers as well as the fields of application. This has in recent years

Box B 3-1

### CRISPR/Cas

CRISPR/Cas was discovered as part of the adaptive bacterial immune system.[240] When this immune system detects an infection by viruses, it cuts the deoxyribonucleic acid (DNA) of the viruses to render them harmless. The excised parts of the viral DNA are then inserted into the DNA of the bacterium. Within the DNA of the bacterium, the parts of the viral DNA are located between flanking constant regions of the bacterial DNA. The alternation of repetitive flanking DNA sequences and variable DNA sequences in the DNA of bacteria was given the name CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats[241]). These CRISPR sequences in turn help the bacterium's immune system to recognize, cut and render the viral DNA harmless the next time it invades. The ability to cut DNA is used for gene editing.

To cut DNA, a CRISPR system needs two components: a guide ribonucleic acid (guide RNA) and a protein that cuts the DNA.[242] The most commonly used protein is the Cas9 protein from the scarlet fever pathogen (Streptococcus pyogenes) – spCas9. However, it can happen that the DNA is not only cut at the intended position. In this case, one speaks of so-called off-target effects. In the worst case, these can result in degeneration of the affected cell and thus the formation of a tumour.[243] Reducing off-target effects is a key subject of current research.

led to a strong increase in R&D activities related to CRISPR/Cas. Most current development work on medical applications of CRISPR/Cas is considered ethically unobjectionable.[244]

Researchers in Germany are actively involved in the further development of CRISPR/Cas. Although Germany plays a significant role in CRISPR/Cas research measured in terms of the number of publications in scientific journals, ranking third in a country comparison, it lags far behind the USA and China. In addition, weaknesses in the translation of research results into application are becoming apparent in Germany.

## B 3-1 The CRISPR/Cas Gene Scissors as a New Tool for Medicine

Genetic material has a significant influence on the structure and functioning of organisms. An alteration in the genetic material can therefore result in an alteration in the structure or functioning of organisms. In humans, such alterations occur naturally through reproduction and mutation. These alterations can have positive or negative effects or can remain inconsequential. The negative effects include a variety of hereditary diseases.

One field of application for CRISPR/Cas is the cure of such hereditary diseases through the targeted modification of the genetic material. In the case of applications on humans, a distinction is made between applications in which the resulting genetic alteration is passed on (germ-line therapy,[245] cf. box B 3-13) and applications in which the change is passed on, i.e., which only affect the individual being treated (somatic-cell gene therapy).[246] CRISPR/Cas is not the first tool to be used for gene editing (cf. box B 3-2). However, it has key advantages over other gene editing tools. CRISPR/Cas is much easier to use than previous gene editing tools, while still offering high precision and effectiveness. High precision means that components of the genetic material can be cut precisely and unwanted alterations in the genetic material at other locations, so-called off-target effects, can be better addressed. In addition, it is easier to achieve high efficiency with CRISPR/Cas than with other gene editing tools. This means that it is easier to develop a suitable CRISPR/Cas tool that can successfully make the intended alteration to the genome in a large proportion of target cells. In addition, CRISPR/Cas is easier to adapt to new applications than was the case with previous gene editing tools.[247]

These advantages over earlier methods have led to CRISPR/Cas already being widely used in basic research. The principles of Open Science, too, have favoured the further dissemination of CRISPR/Cas (cf. box B 3-3). Due to its advantages over previous gene editing methods, CRISPR/Cas has the potential to contribute to new therapeutic approaches (cf. box B 3-2).

However, to make these individual and targeted new therapeutic approaches available to patients in Germany, the necessary expertise for the development and application of these treatments must be available in Germany. This requires the capacity and mechanisms to transfer research results into applications, thereby also opening new potential for value creation for companies.[248]

## B 3-2 Germany's Performance Level in an International Comparison

Germany's performance in the further development and application of CRISPR/Cas can be measured by looking at various indicators. These include indicators regarding scientific publications, patent applications, number of companies and clinical trials. The following paragraphs focus on data relating to the application of CRISPR/Cas in the field of medicine and health[249] as well as data on technical improvements of CRISPR/Cas[250] that aim at the further development of CRISPR/Cas in general and are therefore not assigned to a specific field of application.

Box B 3-2

## Discovery of CRISPR/Cas and Applications in Medical Research

The first targeted alterations to the existing genetic material of organisms with a cell nucleus, which includes humans, occurred in 1979 in yeasts. Later, better tools for gene editing were developed with zinc finger nucleases and so-called transcription activator-like effector nucleases (TALENs).

The fact that CRISPR/Cas9 can be used as an easily programmable tool to cut any DNA sequence was demonstrated in 2012 by a research group led by Jennifer Doudna and Emmanuelle Charpentier,[251] who received the 2020 Nobel Prize in Chemistry for their discovery. Shortly after the discovery, research groups led by Feng Zhang and George Church showed that CRISPR/Cas9 works not only in bacteria but also on animal cells, where it can cut genomic DNA.[252]

The development of CRISPR/Cas as a tool that can alter, switch off or switch on genes has made editing of genetic information present in cells accessible to a larger group of scientists. CRISPR/Cas now makes it possible for virtually any molecular biology laboratory to specifically alter genes in almost any cell. Thus, work steps that were previously impossible for most researchers became routine tasks. In addition to basic medical research, CRISPR/Cas is also used to develop new treatments for curing diseases.

Genetic diseases are often caused by the mutation of a single gene. Approximately 250 million people worldwide are affected by such a monogenic disease.[253] Examples of diseases triggered by a single faulty gene are beta-thalassaemia and sickle cell anaemia,[254] which are associated with anaemia, Leber congenital amaurosis,[255] which leads to blindness, and Huntington's disease,[256] which is associated with symptoms such as muscle atrophy and dementia and leads to premature death.[257] CRISPR/Cas-based treatments are already being tested in clinical trials for some of these diseases.

In addition to treating hereditary diseases, CRISPR/Cas can also be used to treat infectious diseases such as chronic diseases caused by the human immunodeficiency virus (HIV). The aim of the treatment is to make the cells of the immune system resistant to the pathogen by specifically inactivating certain genes.[258]

In addition, immune cell treatments against cancer are to be made more effective in the future with CRISPR/Cas by editing the immune system's cancer-fighting cells in such a way that they become resistant to the immune-inhibiting effect of the tumour cells.[259]

### Good Position Regarding Number of Publications

Publications can be used as an indicator for research in the field of CRISPR/Cas. The analysis below considers scientific publications as from July 2012, the time of the landmark CRISPR/Cas publication by Doudna and Charpentier.[260] The period under consideration ends at the end of December 2019. Publications on CRISPR/Cas can be assigned to the fields of health and medicine, technical improvements, agriculture, and industrial applications.[261] Of the total of 11,552 publications recorded, 5,585 belong to the field of health and medicine, 4,719 to the field of technical improvements, 962 to the field of agriculture and 286 to the field of industrial applications.[262] The following evaluation relates to the fields of health and medicine as well as technical improvements.

The number of publications per year has risen sharply since 2012 (cf. figure B 3-4).[263] In a comparison between countries, the USA has the highest number of publications in the fields of health and medicine as well as technical improvements with 5,151 publications, followed by China (2,402), Germany (944), Japan (877) and the UK (860) (cf. figure B 3-5). With 3,003 publications in these fields, the European Union (EU) has more publications than China, but fewer than the USA. In recent years, however, China has been able to narrow the gap to

Box B 3-3

## Significance of Open Science for CRISPR/Cas Research

Since the discovery of CRISPR/Cas as a gene-editing tool in 2012, over 11,000 scientific papers have been published on the subject (by December 2019) and over 4,000 patent families have been filed (by December 2018).[264]

An important factor in the dissemination of CRISPR/Cas among researchers are services such as those provided by the non-profit company Addgene.[265] As a repository, Addgene collects, shares and stores plasmids (small DNA molecules) that can be used by scientists for, inter alia, CRISPR research. This allows researchers to build directly on the work of other research groups without having to duplicate their efforts. Researchers use repositories such as Addgene to deposit plasmids so that they can access their efficient, global delivery process when they request plasmids. This saves time and money. In addition, the deposit of plasmids increases the visibility of scientists, which can result in increased citations of their publications.[266]

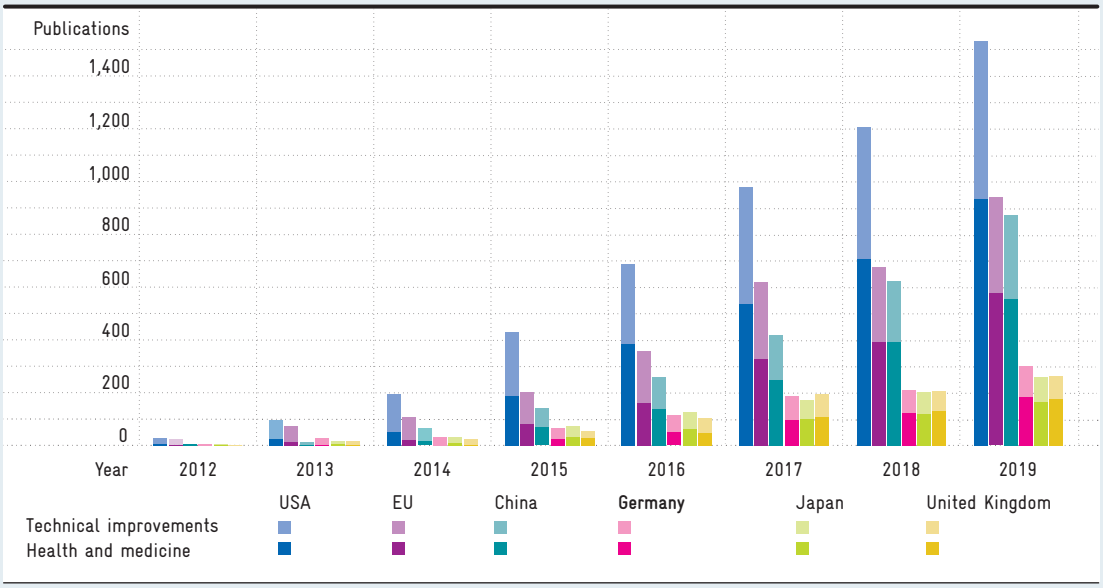
In addition, the rapid development of research on CRISPR/Cas is also due to the fact that the Broad Institute,[267] which holds the rights to Feng Zhang's basic CRISPR patent, licenses the technology free of charge for scientific research. However, commercial use is paralyzed by an ongoing patent dispute and the uncertainties that accompany it.[268]

B

Fig. B 3-4

Download data

## Number of CRISPR/Cas publications of selected countries and regions in the fields of health and medicine as well as technical improvements Q3 2012–2019




Source: Own representation based on Zyontz and Pomeroy-Carter (2021).
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the EU. The share of publications by researchers in Germany in the fields of health and medicine and technical improvements in all publications in these fields is 9.2 percent.

Researchers in the countries and regions considered are active both in the field of health and medicine and in the field of technical improvements. In the first years of research after the discovery of CRISPR/Cas as a tool for gene editing, a large proportion of publications were about technical improvements. Over time, the share of publications in the field of health and medicine has increased in all countries and regions considered (cf. figure B 3-4).

The total number of publications in highly cited scientific journals can be used as an indicator of the quality of the research work. Here, the USA ranks first with 2,283 of these top-class publications, followed by China (587), the UK (377), Germany (369)[269] and Japan (219). The EU accounts for 1,146 top-class publications.

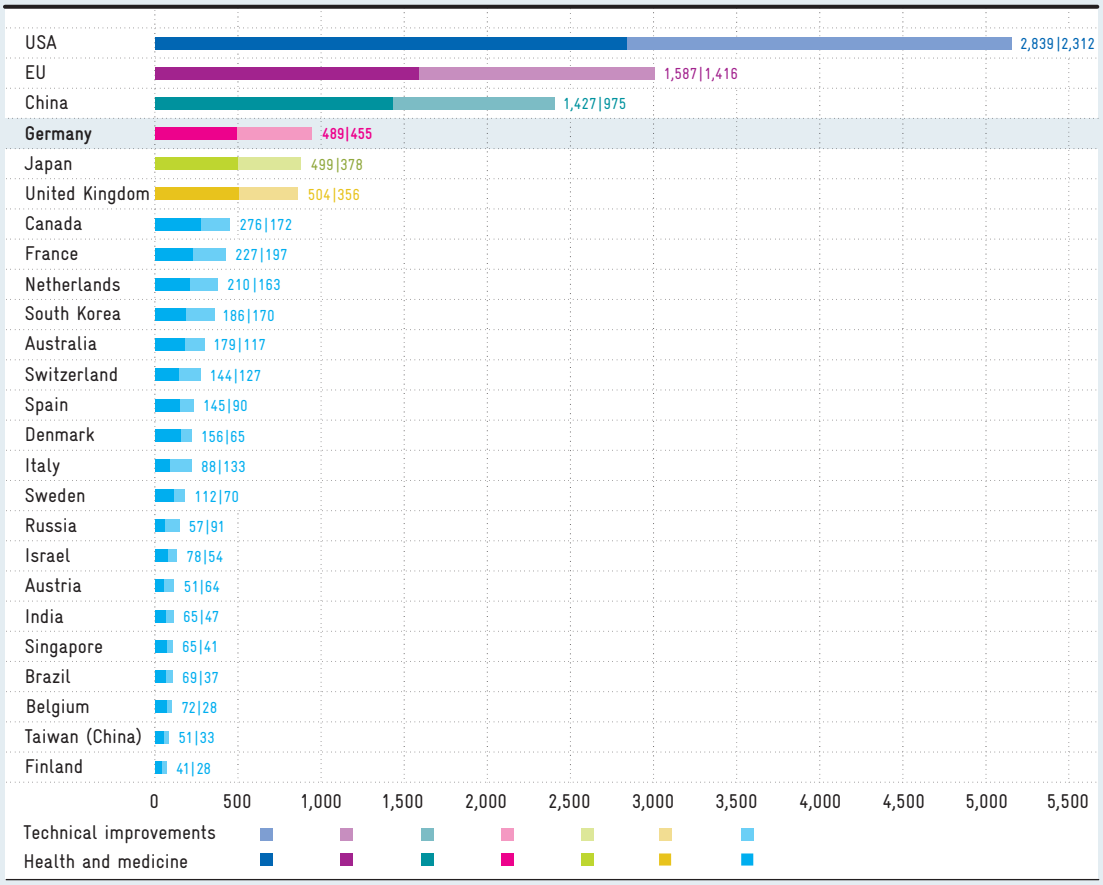
Looking at the percentage of publications by researchers at German institutions published in highly cited journals (cf. figure B 3-6),[270] Germany, with 39.1 percent of publications, is only in the crowded midfield and just above the EU average of 38.2 percent. Switzerland, Austria, and the Netherlands have the largest percentages of publications in highly cited journals. It moreover becomes apparent that despite the large number of Chinese publications, only a relatively small proportion (24.4 percent) appear in high-ranking journals. Researchers in Japan, too, publish comparatively little in highly cited journals, at 25.0 percent of publications.



Fig. B 3-5

Download data

**Number of CRISPR/Cas publications by top 25 countries and regions in the fields of health and medicine as well as technical improvements Q3 2012–2019**




Source: Own representation based on Zyontz and Pomeroy-Carter (2021).
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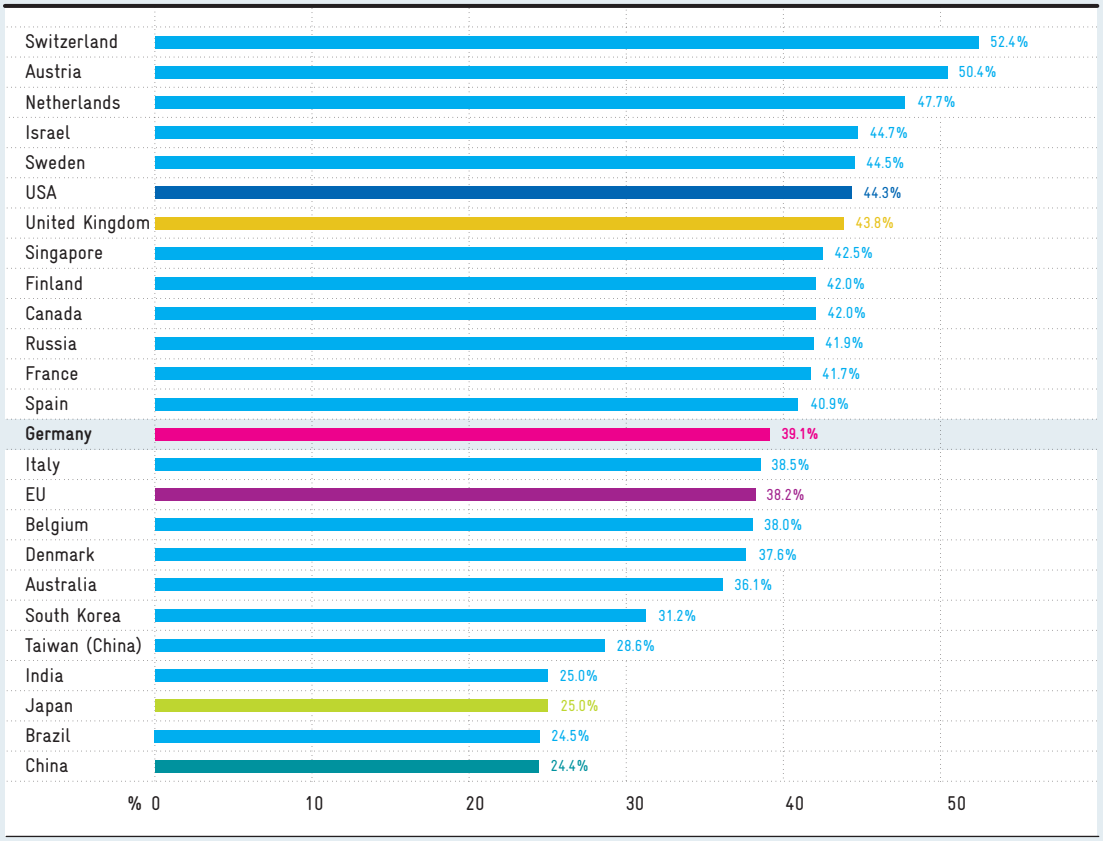
Fig. B 3-6

Download data

## Share of CRISPR/Cas publications by top 25 countries and regions in the fields of health and medicine as well as technical improvements in highly cited scientific journals Q3 2012–2019




The publications from the fields of health and medicine as well as technical improvements are summarized in this representation.
Source: Own representation based on Zyontz and Pomeroy-Carter (2021).
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### Patent Backlog

By the end of 2018, patents had been filed in a total of 3,652 CRISPR/Cas patent families.[271] Of these, 1,192 patent families were in the field of health and medicine, 1,800 in the field of technical improvements, 536 in the field of agriculture, and 124 in the field of industrial applications. Some of these patent families are assigned to a year prior to 2012, the year of the first publication on CRISPR/Cas as a gene editing tool. These are patents that have been applied for before the first scientific publication to obtain patent protection. In addition, patent families are assigned to the earliest year of the patents they contain. This may result in CRISPR/Cas patent families being assigned to a year prior to 2012, as important preliminary work was patented at that time.

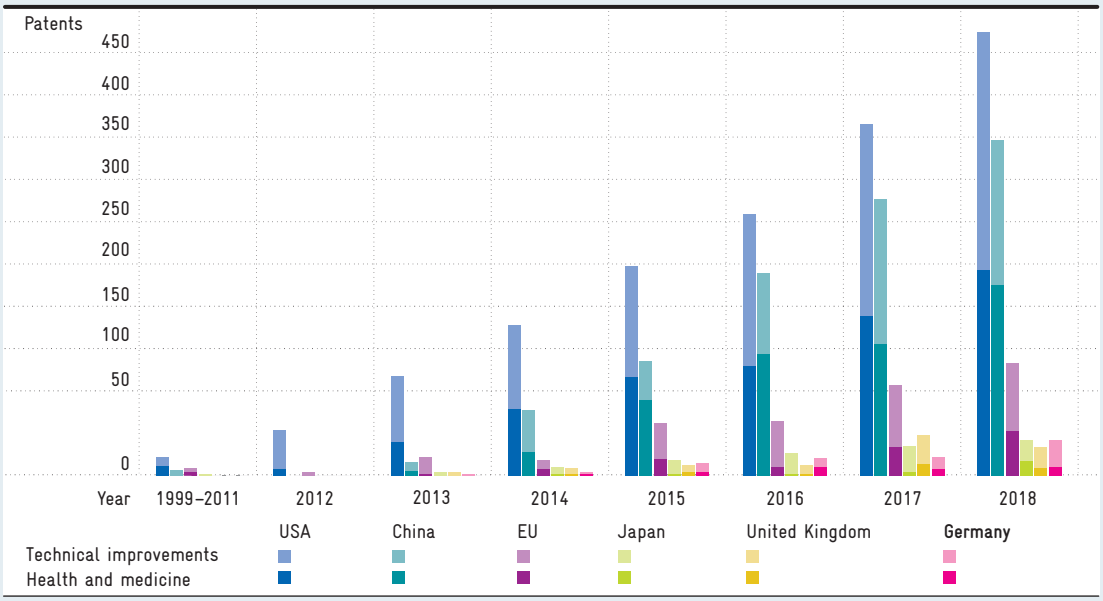
The number of CRISPR/Cas patent families in the fields of health and medicine as well as technical improvements has increased sharply after 2012 in the countries and regions considered (cf. figure B 3-7).[272] The percentage relating to technical improvements is significantly higher than that relating to the field of health and medicine. In comparison to CRISPR/Cas publications, however, the EU falls far behind the USA and China when it comes to CRISPR/Cas patent families.

Germany occupies a significantly weaker position regarding CRISPR/Cas patent families than regarding CRISPR/Cas publications. While researchers in Germany account for 9.2 percent of all publications in the fields of health and medicine as well as technical improvements, the share of patent families by inventors in Germany in the

Fig. B 3-7

Download data

## Number of CRISPR/Cas patent families of selected countries and regions in the fields of health and medicine as well as technical improvements 1999–2018




Source: Own representation based on Zyontz and Pomeroy-Carter (2021).
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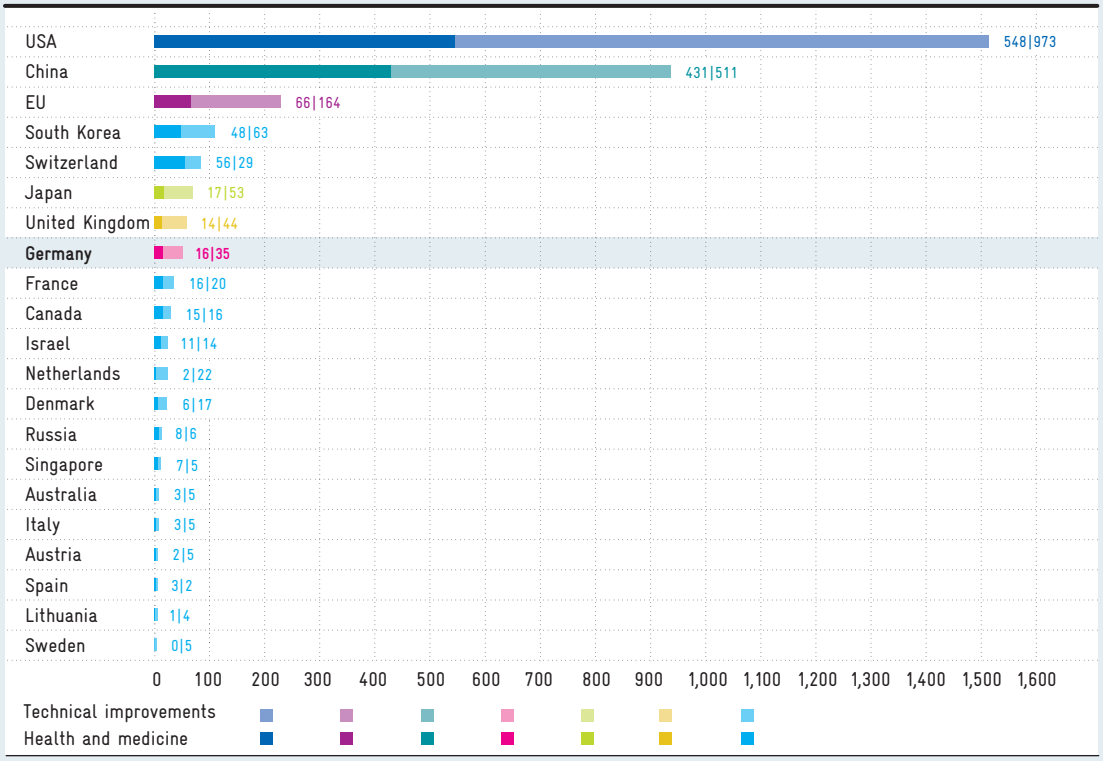
Fig. B 3-8

Download data

## Number of CRISPR/Cas patent families by top 20 countries and EU in the fields of health and medicine as well as technical improvements 1999–2018




The representation considers countries with a total of at least five patent families in the fields of health and medicine as well as technical improvements.
Source: Own representation based on Zyontz and Pomeroy-Carter (2021).
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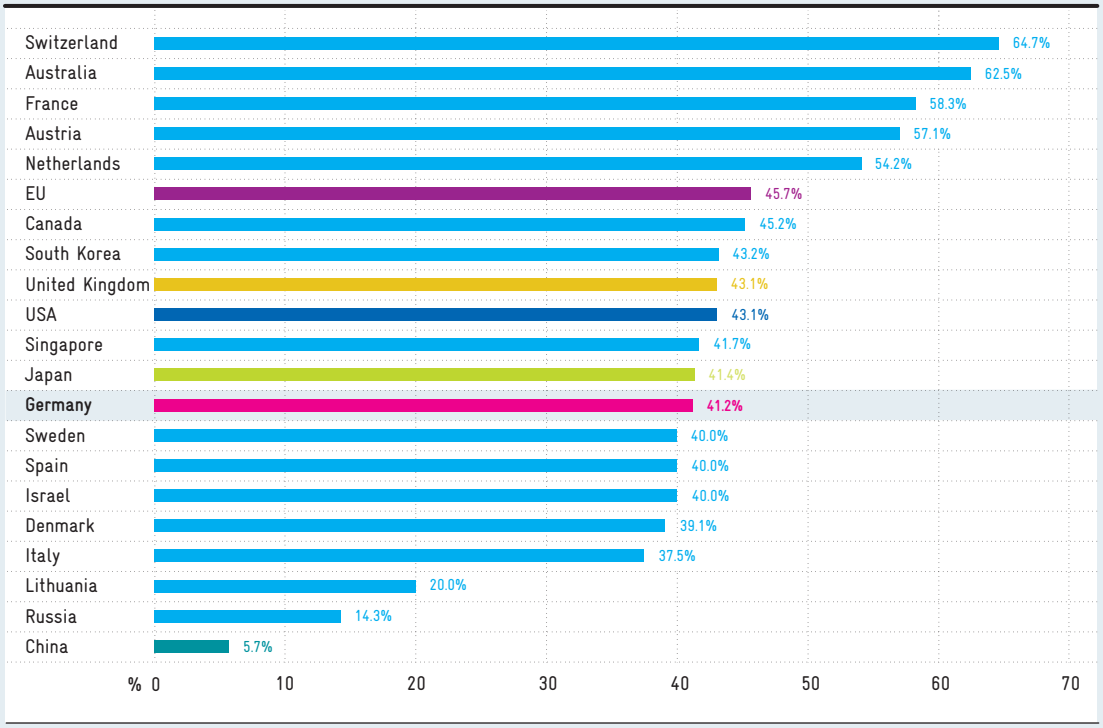
Fig. B 3-9

Download data

**Share of CRISPR/Cas patent families filed in at least three jurisdictions in the fields of health and medicine as well as technical improvements for selected countries and regions 1999–2018**




The representation considers countries with a total of at least five patent families in the fields of health and medicine as well as technical improvements. The patent families from the fields of health and medicine as well as technical improvements are summarized in this representation. Large CRISPR/Cas patent families are those that are filed in at least three jurisdictions.
Source: Own representation based on Zyontz and Pomeroy-Carter (2021).
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period under review (1999 to 2018) is only 1.7 percent of the corresponding worldwide CRISPR/Cas patent families.[273] Furthermore, although the UK, Japan, Switzerland and South Korea have fewer publications than Germany,[274] inventors in these countries file more patents than those in Germany (see figure B 3-8).

The number of jurisdictions in which a patent is filed can be used as a measure of the quality of patents. Inventors in Switzerland filed 64.7 percent of patent families in at least three jurisdictions (cf. figure B 3-9). This puts Switzerland well above the EU average of 45.7 percent, the UK and the USA with 43.1 percent each, Japan with 41.4 percent and Germany with 41.2 percent. Inventors from China filed only 5.7 percent of patent families in three or more jurisdictions.

### Small Number of German CRISPR/Cas Companies

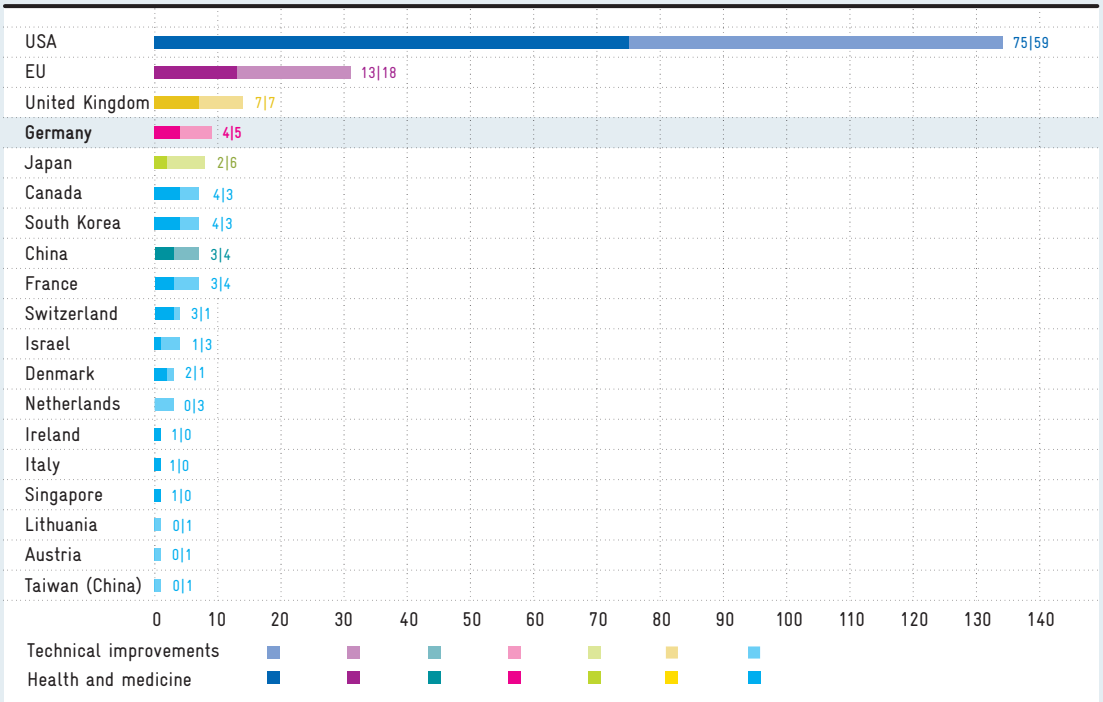
Companies commercializing CRISPR/Cas were identified by way of patent applications and company websites.[275] The basis for analysis are those companies for which further information is available in addition to their CRISPR/Cas patents.[276] For the second quarter of 2020, 278 CRISPR/Cas companies can thus be identified, some of which are active in several fields.[277] Most of these companies are active in the field of health and medicine (111 companies), followed by the fields of technical improvements (102 companies), research services (101 companies), agriculture (42 companies) and industrial applications (22 companies).[278]

By far the most CRISPR/Cas companies that can be assigned to the fields of health and medicine as well as

Fig. B 3-10

Download data

## Number of CRISPR/Cas companies in the fields of health and medicine as well as technical improvements for selected countries and regions Q2 2020




Source: Own representation based on Zyontz and Pomeroy-Carter (2021).
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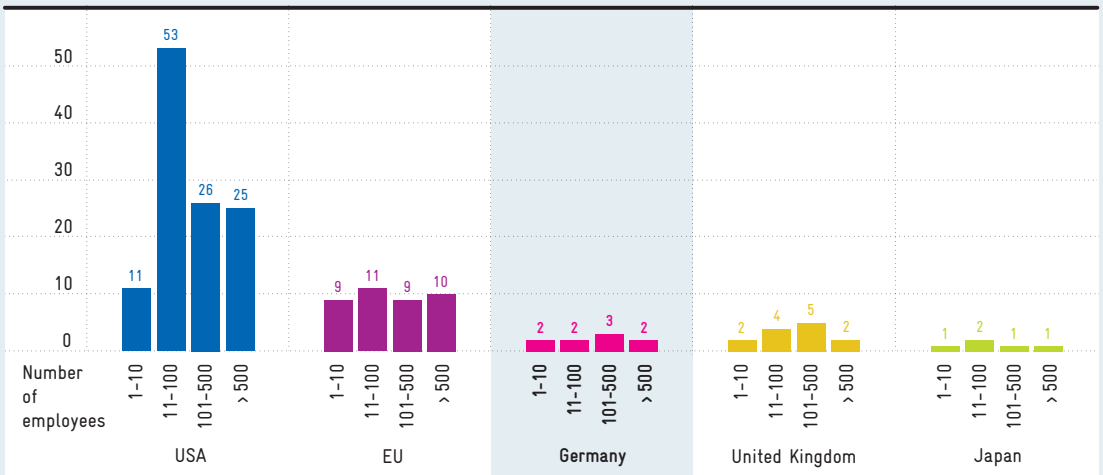
Fig. B 3-11

Download data

## Number of CRISPR/Cas companies in the fields of health and medicine as well as technical improvements by number of employees for selected countries and regions Q2 2020




Companies from the fields of health and medicine as well as technical improvements are summarized in this representation.
Source: Own representation based on Zyontz and Pomeroy-Carter (2021).
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technical improvements can be found in the USA with 134 companies. 14 such companies are in the UK and nine in Germany (cf. figure B 3-10).

In the comparison by countries, the characteristics of the companies working with CRISPR/Cas differ as well. The percentage of companies with over 100 employees is higher in Germany, at five out of nine, than in the USA, where this applies to 51 out of 115 companies (cf. figure B 3-11).[279] At the same time, the percentage of CRISPR/Cas start-ups founded from 2010 onwards is significantly higher in the USA, with 77 out of 124 companies, than in Germany, with one out of eight companies.[280] Despite the low number of observations for German companies, there are indications that CRISPR/Cas technology is being commercialized more by young companies in the USA than is the case in Germany.[281]

### Need to Catch Up with Clinical Trials

In the field of health and medicine, clinical trials play a key role in the translation of research results into application. They are used, among other things, to ensure that treatments and drugs are safe and effective.

Clinical trials using CRISPR/Cas have been conducted since 2015. In most registered[282] clinical trials (32 out of 48 trials worldwide), cells modified with CRISPR/Cas have therapeutic purposes. In eight studies, CRISPR/Cas is used to create cell lines, in six studies it is used for genome sequencing and two studies are review papers.

Most registered clinical trials are conducted in China (27) and the USA (17) (cf. figure B 3-12). In Germany, only one clinical trial using CRISPR/Cas is registered.[283] In Switzerland, five clinical trials are registered, all of which go back to CRISPR Therapeutics, a company founded by Emmanuelle Charpentier.

### Mixed Picture Regarding Germany's Performance

Germany ranks third behind the USA and China in CRISPR/Cas research in the fields of health and medicine and technical improvements, measured by the number of publications. However, Germany falls behind in an international comparison when key performance indicators in the application and commercialization of this technology are considered. In terms of inventions, measured by the number of patents, Germany ranks behind South Korea, Switzerland, Japan and the UK, whose researchers, however, have fewer publications than researchers in Germany.

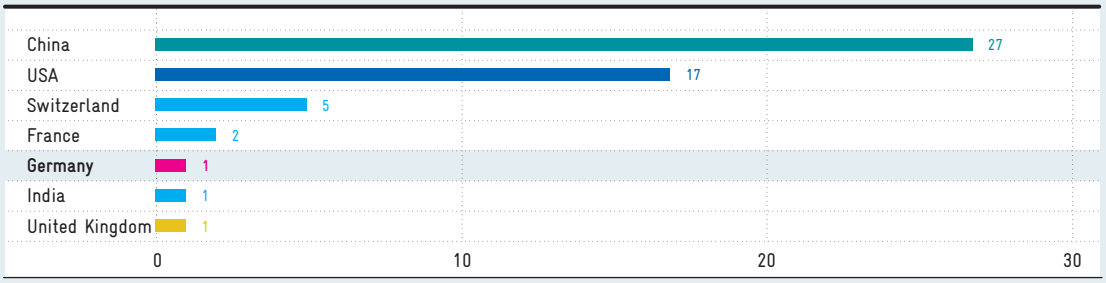
There are fewer CRISPR/Cas companies in Germany than in the UK and significantly fewer than in the USA. It also shows that commercialization in Germany tends to be driven by larger and older companies, while in the USA it is driven more by young companies. Clinical trials are necessary to make CRISPR/Cas available to patients in the form of treatments. Yet, the number of clinical trials in Germany lags significantly behind its comparatively good research position.

The analysis suggests that there is still untapped potential in Germany regarding CRISPR/Cas inventions and their use for patients and commercialization by companies.

Fig. B 3-12

Download data

**Number of registered clinical trials using CRISPR/Cas by countries**




Source: Own representation based on Zyontz and Pomeroy-Carter (2021).
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## B 3-3 Legal and Financial Framework Conditions

An international comparative study conducted on behalf of the Commission of Experts analyses the regulation of gene editing in selected countries in the fields of somatic-cell gene therapy and germ-line gene therapy with a view to its impact on R&I. The comparison looks at countries that play a leading role worldwide in the fields of genetic engineering and gene editing.[284] These countries are in intense competition with each other, particularly in basic and preclinical research and in the production of advanced therapy medicinal products,[285] which also include gene therapy medicinal products.[286] Regulatory framework conditions are of fundamental importance for R&I activities and can therefore influence competitiveness either positively or negatively.[287]

The section below first describes the legal framework governing basic medical research and preclinical research in Germany. This is followed by investigation of the regulatory framework and its interpretation regarding the clinical testing of therapeutics for somatic-cell gene therapies.[288] Subsequently, the non-legal framework conditions, in particular the financial and institutional conditions for clinical trials in the field of medical biotechnology are discussed.

### Complex Research Application Processes

Basic medical research and preclinical research are prerequisites for understanding the effects of medical processes and developing new drugs.

In Germany, basic medical research and preclinical research on somatic-cell gene therapy are mainly regulated by the Genetic Engineering Act (Gentechnikgesetz, GenTG).[289] Laboratories and genetic engineering facilities in which medical research with genetically modified organisms (GMOs) is carried out must be reported by researchers and registered and approved by the competent authorities in the respective Länder.[290]

To ensure safety in basic medical research and preclinical research with GMOs, the reporting, registration, and approval procedures are associated with high content requirements. However, some researchers in Germany complain that, despite decades of experience and the means of digitalization, these procedures result in a bureaucratic burden that is disproportionate to the risk.[291] Furthermore, the enforcement of genetic engineering law in Germany seems to have recently become rather more restrictive again, probably depending on the respective Land. In addition, there is not always a uniform practice of law enforcement regarding genetic engineering law throughout Germany.[292]

The bureaucratic and regulatory hurdles mentioned here affect not only somatic-cell gene therapy, but all basic medical research and preclinical research. From the scientific point of view, animal welfare regulation has the greatest negative impact on research and development. Many scientists complain about excessive regulation and see their research significantly impaired as a result. This ultimately leads to Germany losing its appeal as a location for basic medical research and preclinical research.

To reduce the administrative burden on researchers, genetic engineering work with certain types of GMOs could by ordinance be fully or partially exempted from GenTG regulations and application procedures could be bundled. To improve the framework conditions in basic research and preclinical research, efforts could also be made to harmonize the requirements of the authorities at Länder level across the country.[293]

### High Administrative Hurdles for Clinical Studies

Clinical trials are needed to ensure the safety and efficacy of therapeutics and to translate research results into application. In Germany, these are subject to approval for all types of therapeutics, i.e., also for therapeutics for somatic-cell gene therapy, and are regulated by pharmaceutical and (bio)medical law. Both pharmaceutical law and (bio)medical law are determined to a considerable extent by laws at the level of the European Union.[294]

The regulation of clinical trials in Germany, as in France, the UK, and Switzerland, is based on double preventive control.[295] Thus, on the one hand, the performance of clinical trials in Germany requires prior official approval by the Paul-Ehrlich-Institute (PEI), which certifies the safety of the clinical trial. On the other hand, the approving assessment of the institute's responsible internal ethics committee is required, which confirms the ethical justifiability of the risks of the clinical trial. The paragraphs

below first look at the requirements of the approval procedures at the PEI and the ethics committees. This is followed by a discussion of the procedural deadlines.

To obtain approval for a clinical trial, researchers must submit a corresponding application to the PEI. The documents to be submitted include, among other things, information on the subject and objectives of the clinical trials, the trial protocol, and results of preclinical studies. In addition, an official manufacturing authorization is required for the investigational medicinal products used in the clinical trials. This must be proven by compliance with good manufacturing practice (GMP) and is granted by the responsible authority at Länder level.[296]

The concrete application of compliance with the European GMP standard for the granting of manufacturing authorization for investigational medicinal products is in some cases interpreted differently within EU Member States.[297] According to researchers, the implementation and interpretation of the regulations is stricter in Germany than in other EU Member States. In the UK, for example, which at the time of the study was no longer a member of the EU but for which EU law continued to apply for the time being, compliance with a pre-GMP standard is sufficient for the granting of a manufacturing authorization.[298] In contrast, investigational medicinal products in Germany must fully comply with the GMP standard from the start.[299]

A prerequisite for approval by the responsible ethics committee to conduct clinical trials is the positive assessment of the submitted documents. These include an assessment of the foreseeable risks and disadvantages of the clinical trials as well as weighing them against the expected benefit for the patient.[300] However, the assessment is as yet not carried out based on uniform federal criteria but is left to the discretion of the respective ethics committee responsible. The same applies to multi-centre clinical trials,[301] where the ethics committee at the location of the project leader assesses the ethical acceptability of the clinical trial. This ultimately leads to different assessments of the ethical acceptability of clinical trials by the ethics committees.

In addition, approval procedures differ in their design in the countries considered here. While clinical trials in Germany require regulatory approval, in Japan they only need to be registered with the Pharmaceuticals and Medical Devices Agency.[306] In contrast to Germany, where the procedural deadlines for the approval and release of clinical trials are 90 days, in Japan and the USA approval is deemed granted after a 30-day period.[307]

In recent years, a large increase in R&D activities has been observed in the field of medicinal products for innovative treatments.[308] In view of this development, it can be assumed that, in addition to an increase

Box B 3-13

### Regulation of Embryo Research and Germ-line Gene Therapy

Embryo research, i.e., research on embryos for the purpose of gaining scientific knowledge, is permitted, except for Germany, in all countries considered in the international comparative study under certain, usually extremely strict, conditions. In the countries under consideration, surplus so-called in vitro fertilization embryos produced by artificial insemination may be used for high-level research purposes and cultivated up to a maximum of the 14th day of their development. In the UK, embryos created specifically for research purposes may also be used for research.[302]

Germ-line gene therapy, i.e., the genetic modification of embryos for therapeutic purposes, on the other hand, is prohibited in practically all countries. In its statement on interventions in the human germ line published in 2019, the German Ethics Council (Deutscher Ethikrat) takes the position that no categorical inviolability of the human germ line results from the ethical analysis.[303] At the same time, however, it currently judges germ line interventions to be ethically irresponsible due to their incalculable risks and calls for a worldwide moratorium on use, in line with the WHO, among others.[304] In order to create a better information basis and to raise awareness on the subject of germ line gene therapy in particular and gene editing in general, the German Ethics Council also recommends a wide-ranging social discourse.[305]

in informal requests for advice, there soon will also be a considerable increase in formal approval procedures.[309]

Aside from huge administrative requirements, researchers in Germany are confronted with strict interpretation of the legal regulations in the approval of clinical trials, for instance, regarding manufacturing authorization. In addition, applicants must contact several authorities at federal and Länder level. Particularly in the case of multi-centre studies, Länder-specific contract models with differing content might apply, which may lead to considerable delays in the approval procedures. In addition, the localized presence of the ethics committees at universities and research institutions means that there is no evaluation based on uniform standards.

Simplification of the approval procedure,[310] the nationwide harmonization of contracts for multi-centre studies and a less restrictive interpretation of regulations could help to improve Germany's clinical trials position in international competition. To be able to process all approval procedures on time also in the future, consideration should moreover be given to expanding staff capacities at the competent approval authorities.

### Lack of Translation Funding

Making the findings from medical research available to patients quickly and effectively is of great social and economic interest. Clinical trials are of key importance in translating findings from basic medical research into application and are also evidence of the innovative power of clinical research.[311]

Medical research goes hand in hand with long development and innovation cycles (cf. figure B 3-14), which is why long-term and continuous funding is needed. In particular, clinical trials are very costly. Clinical trials can be differentiated between industry-funded commercial trials and publicly funded non-commercial trials (investigator-initiated trials). While industry-funded trials are primarily associated with a commercial interest and aim to develop drugs, publicly funded trials are science-driven and often deal with open complex questions of medical care.[312] A subcategory of publicly funded trials are the so-called treatment optimization trials, which examine whether an already approved drug can possibly be used to treat other diseases.[313] In this context, the findings obtained from science-driven studies and treatment optimization studies can make an important contribution to increasing the effectiveness and quality of patient care and are thus of great importance for patient welfare.[314]

The financing of science-driven clinical trials and treatment optimization trials without a direct commercialization interest, where the expenditure often amounts to tens of millions, is a considerable problem.[315] Consequently, many fundamental questions of medical care, especially in highly innovative fields such as somatic-cell gene therapy, cannot be transferred to clinical trials.[316] Higher financial and personnel capacities of university hospitals and an improved infrastructure could remedy this situation.

Regarding industry-funded studies, experts complain that the supply of venture capital and other sources of funding for clinical trials in the field of medical biotechnology is extremely low in Germany. This is due in particular to the long investment phases in drug development, which are associated with a high level of risk.[317] For example, due to a lack of financial resources, potential drug candidates from research can often not be developed to proof of concept in phase II, in which the safety and efficacy of the drug are evaluated in clinical trials. Experts also point to considerable financing problems in the transition from phase II to phase III, in which the new drugs are tested on several hundred patients (cf. figure B 3-14).

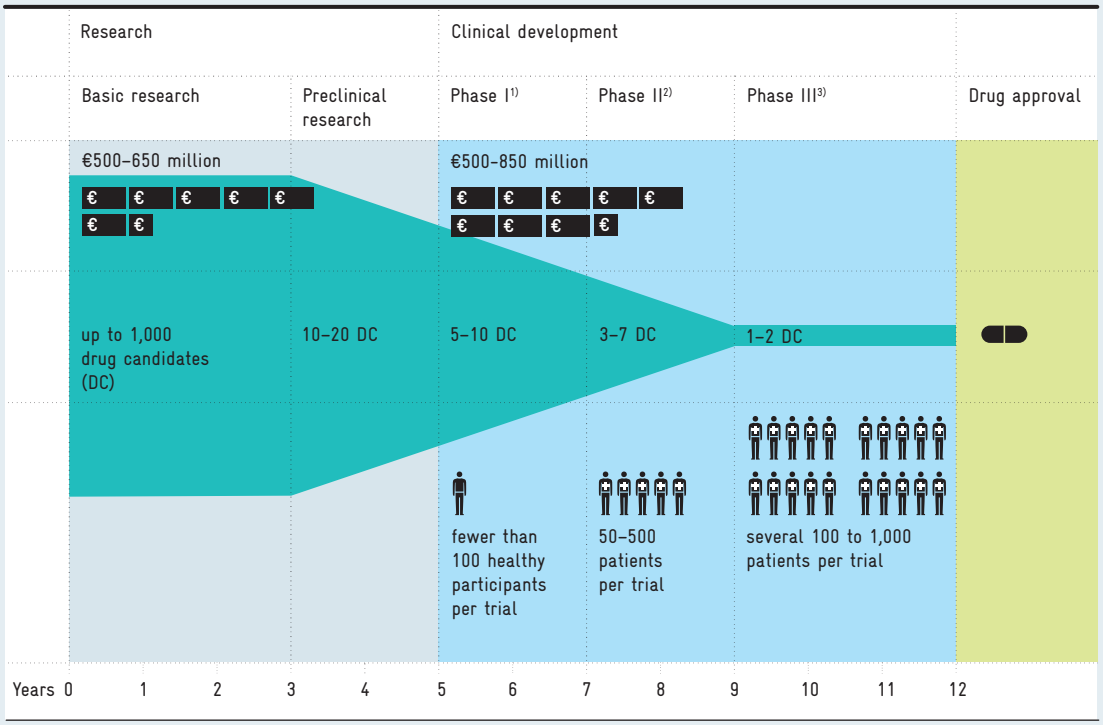
The lack of an end-to-end funding chain from public research funding to seed funding to growth funding makes it difficult to translate research results into commercial implementation and application. Against this background, the Commission of Experts welcomes initiatives such as the recently announced support programme for the development of drugs and other therapeutics against COVID-19, initially endowed with €50 million, which aims to support clinical development in phases I and II.

To improve the financing of commercial clinical trials, especially in the final phases of drug development, and to promote translation, private capital needs to be mobilized. Adequate (tax) incentives for investors could be created for this purpose. In addition, the

Fig. B 3-14

Download data

## From basic research to drug




[1)] Phase I: Safety and tolerability tests of potential active substances.
[2)] Phase II: Proof of efficacy and tests for side effects.
[3)] Phase III: Confirm efficacy and test for interaction with other drugs.
Source: Representation based on Schüler (2016).
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Future Fund (Zukunftsfonds) set up by the Federal Government can contribute to improving the financial framework conditions.[318]

In addition to financial framework conditions, there are other catalysts that are conducive to translation. For example, the 'GO-Bio initial' support measure of the Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF), which was introduced in 2019, aims to support the identification and development of early research approaches in the life sciences with recognizable innovation potential.[319] To better prepare researchers for knowledge transfer, the programme also integrates complementary support measures such as start-up talks. The aim of the programme is to further develop the research approaches to the extent that a continuation in other support programmes, such as EXIST Research Transfer, is made possible and the translation of research results into application succeeds.[320] Equally promising are approaches such as Stanford ChEM-H,[321] where researchers from different disciplines cooperate with clinicians to quickly produce innovations in medicine.

A prerequisite for the success of such programmes is to make the performance of clinical trials attractive for physicians.[322] This can be achieved, among other things, by firmly incorporating research hours as well as through suitable organizational structures. These should allow for an appropriate ratio between research and care, thereby allowing for exchange between researchers.[323]

Some experts also advocate the creation of a centre that would network research stakeholders from different locations.[324] An institution like the Catapult programme in the UK would be conceivable. This programme

pools know-how on application and approval issues, provides start-ups and small genetic engineering companies with expertise on setting up businesses, and is a central platform for financing needs and investment opportunities.[325]

## B 3–4 Recommendations for Action

The CRISPR/Cas gene scissors are a tool for gene editing that gives new impetus to basic medical research and enables new therapeutic approaches for many diseases. The targeted alteration of genetic information enables the direct elimination of the causes of hereditary diseases. The field of somatic-cell gene therapy in particular offers significant potential and is associated with high patient benefit and economic value creation potential. To leverage the potential associated with CRISPR/Cas, further major advances are needed both in research and in the translation of research results into application. The Commission of Experts therefore recommends the following measures:

### Accelerate Approval Procedures

- For projects ranging from basic and applied research to human application in clinical trials, approval procedures – always under the maxim of maintaining safety and ethical justifiability – must be designed in such a way that the administrative burden for researchers is reduced.
- To ensure that approval procedures can continue to be completed as quickly as possible, staffing levels within the approval authorities must be adjusted at an early stage to reflect the expected increase in approval procedures.
- Moreover, the bundling of related applications and approval procedures should be made possible. In addition, efforts should be made to harmonize approval procedures across the Länder.

### Consolidate Cutting-edge CRISPR/Cas Research

- To consolidate cutting-edge research in the field of CRISPR/Cas, several lighthouse projects at internationally competitive German locations should be expanded or newly created. In these lighthouse projects, the translation of scientific results into medical application should be given high priority.

### Support Translation of Scientific Findings

- In particular, interdisciplinary collaborations and working groups should be initiated and promoted that support translation and generate innovations through early interaction between research and clinical practice.
- For advising researchers and networking with various stakeholder groups, the establishment of a German Gene Therapy Centre should be discussed, which can assume the role of a competence centre for translation of basic research and preclinical research into clinical application.
- Clinical trials are a prerequisite for the translation of research results into application. The feasibility of clinical trials should therefore be improved by means of more favourable framework conditions, such as faster, more efficient, and less detailed approval procedures. In addition, the attractiveness of participating in clinical trials should be increased for physicians.
- Programmes such as ‘GO-Bio initial’, which start at an early stage of the R&D process and aim at the seamless and professionalized translation of ideas into application, should be continued and provided with sufficient financial resources.

### Improve Framework Conditions for Venture Capital Provision

- The long research and development cycles in medical biotechnology go hand in hand with enormous financing requirements and high risk. The Commission of Experts once again urges that the framework conditions for the provision of private venture and growth capital be improved. In this context, it welcomes the establishment of the Future Fund, which is intended to support both pioneering technologies, especially in the field of biotechnology, and large funding rounds for start-ups and their scaling, and calls for its rapid implementation.

### Promote Social Discourse

- The Commission of Experts considers it important to regularly inform society about the potentials and risks associated with CRISPR/Cas and to continue the associated social discourse.

## Expand Open Science

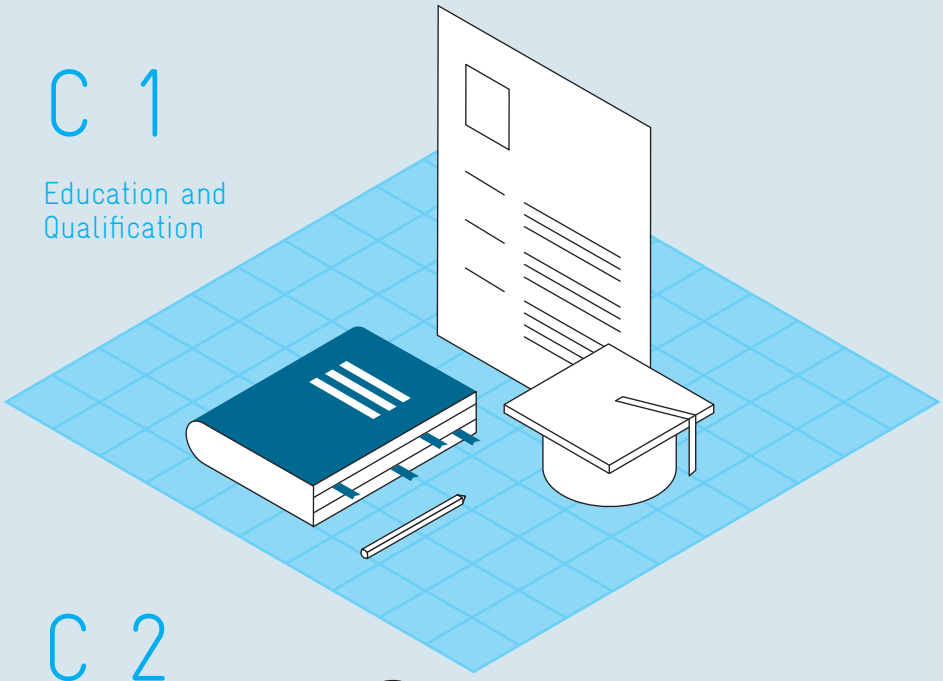
– The principle of Open Science made knowledge in the field of CRISPR/Cas transparent and accessible at an early stage, thus accelerating both the dissemination of scientific knowledge and its further development, as well as supporting excellence in scientific work. The possibilities and instruments of Open Science throughout the research process should therefore be further developed and supported.

# STRUCTURE AND TRENDS

C

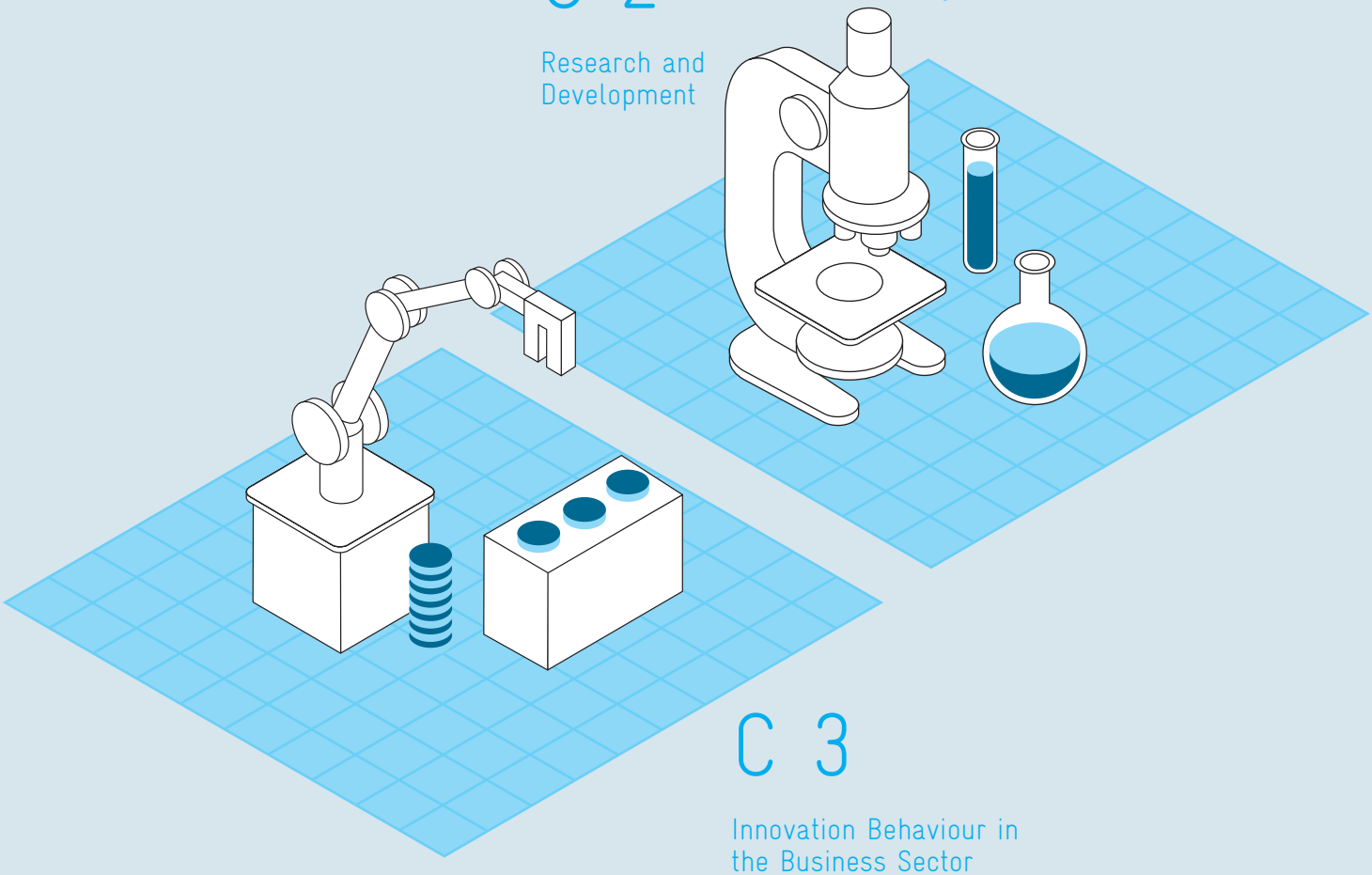
# C Structure and Trends

Measuring and reporting Germany's performance as a location for research and innovation is an integral part of the Commission of Experts' annual reporting. The data is collected based on various indicators, which are divided into eight indicator sets organized by topics.



## C 1

Education and Qualification



## C 2

Research and Development

## C 3

Innovation Behaviour in the Business Sector

# C 4

Financing Research and Innovation

# C 5

New Businesses

# C 6

Patents

# C 7

Scientific Publications

# C 8

Production, Value Added and Employment

# Overview

Measuring and reporting Germany's performance as a location for research and innovation is an integral part of the Commission of Experts' annual reporting. The reporting is based on the presentation of various indicators that allow the drawing of conclusions about the dynamics and performance of the research and innovation system. For reasons of clarity, the indicators are divided into eight thematically ordered indicator sets. Using these sets of indicators, the performance of the German research and innovation system is presented in an intertemporal comparison as well as in comparison with the most important international competitors. Individual indicators are also reported at the level of the Länder to show differences in performance within Germany. Most indicators derive from the studies on the German innovation system commissioned by the Commission of Experts. In addition to the indicators listed here, these studies include further extensive indicator and analysis material. They can be viewed and downloaded on the Commission of Experts' website. The same applies to all figures and tables in the Report as well as to the associated data sets.

## C 1 Education and Qualification

Investments in education and a high level of qualification strengthen a country's medium- and long-term innovative capacity and economic growth. The indicators listed in chapter C 1 provide information on the qualification status and provide an overview of the strengths and weaknesses of Germany as a location for innovation. The international comparison allows an assessment of how these findings compare to other industrialized nations.

## C 2 Research and Development

Research and development processes are an essential prerequisite for the creation of new products and services. In principle, a high R&D intensity has positive effects on competitiveness, growth, and employment. R&D investments and activities by companies, tertiary education institutions and the public sector therefore provide essential clues for assessing a country's technological performance. Chapter C 2 outlines how Germany compares internationally in terms of its R&D activities, the extent to which the individual Länder invest, and which sectors of the economy are particularly research-intensive.

## C 3 Innovation Behaviour in the Business Sector

Innovation activities of companies aim to create competitive advantages through innovation. A product innovation is when a new or improved good is launched on the market whose characteristics differ from the goods previously offered on the market. The introduction of a new or improved manufacturing process is called a process innovation. The presentation of the innovation behaviour of the German economy in an international comparison in chapter C 3 is based on the innovation intensity in industry and knowledge-intensive services as well as on the percentage of turnover generated by new products.

## C 4 Financing Research and Innovation

Financing business and especially R&D activities is a key challenge, especially for young, innovative companies. As these companies initially generate little or no turnover, financing out of their own resources is hardly possible. Debt financing is difficult because it is hard for investors such as banks to assess the prospects of success for innovative start-ups. Alternative ways of company funding include raising equity capital or venture capital as well as financing through government funding. Chapter C 4 describes the availability of venture capital and public sector R&D funding in Germany and in an international comparison.

## C 5 New Businesses

Start-ups, especially in research- and knowledge-intensive sectors, challenge established companies with innovative products, processes, and business models. The establishment of new companies and the exit of unsuccessful (or no longer successful) companies from the market is an expression of innovation competition for the best solutions. The business dynamics described in chapter C 5 are therefore an important aspect of structural change. Especially in new fields of technology, in the emergence of new demand trends and in the early phase of transferring scientific findings to the development of new products and processes, young companies can open new markets and help innovative ideas achieve a breakthrough.

## C 6 Patents

Patents are industrial property rights for new technical inventions. Consequently, they often form the basis for the valorization of innovations on the market and at the same time support coordination as well as the knowledge and technology transfer between stakeholders in the innovation system. Chapter C 6 illustrates the patent activities of selected countries. It also examines the extent to which these countries have specialized in the areas of high-value technology and cutting-edge technology.

## C 7 Scientific Publications

The continuous generation of new knowledge is particularly dependent on the performance of the respective research and science system. With the help of bibliometrics, this performance is presented in chapter C 7 in an international comparison. The performance of a country is determined based on the publications of its scientists in scientific journals. The perception and importance of these publications is captured by the number of citations.

## C 8 Production, Value Added and Employment

The share of labour input and value added in research-intensive and knowledge-intensive sectors in a country reflects their economic importance and allows conclusions to be drawn about a country's technological performance. Chapter C 8 presents the development of value added and productivity in research-intensive industries and knowledge-intensive services in an international comparison. In addition, Germany's world trade position in research-intensive goods and knowledge-intensive services is shown.

# C 1 Education and Qualification[326]

The percentage of the working population with tertiary qualifications (ISCED 5+6 and ISCED 7+8) was 32.6 percent in Germany in 2019, significantly lower than in most comparative countries (C 1-1). In terms of higher academic qualifications (ISCED 7+8), Germany's share of 14.7 percent was also around 2 percentage points below the average for the countries under consideration. By contrast, with 56.7 percent in a European comparison, Germany has the highest proportion of intermediate degrees (ISCED 3** and ISCED 4) that formally allow entry to the tertiary level.

The share of new tertiary students in the age-matched population of under-25s (C 1-2) was 52 percent in Germany in 2018, 2 percentage points below the OECD average. The adjusted rate for under-25s and excluding international new tertiary students in Germany was 45 percent, the same level as the year before.

Due to demographic factors, the number of qualified school-leavers in 2019 has decreased by almost 10,000 to 422,784 compared to the previous year. In contrast, the rate of qualified school leavers, i.e., the number of school-leavers qualified for higher education as a percentage of the relevant age group, was 50.6 percent in 2019, the same level as in 2018 (C 1-3). According to the new projections of the Standing Conference of the Ministers of Education and Cultural Affairs of the Länder in the Federal Republic of Germany (Kultusministerkonferenz, KMK), the rate of qualified school-leavers will remain at about this level and reach 50 percent in 2030.

The number of students without German citizenship who gained their university entrance qualification in Germany (Bildungsinländer) fell slightly in 2019 compared to the previous year from 92,508 to 91,699 (C 1-4). On the other hand, the total number of foreign students in Germany increased once again. The number of foreign students, i.e., students without German citizenship who gained their university entrance qualification abroad (Bildungsausländer) enrolled at German tertiary education institutions, was 319,902 in 2019, around 6 percent higher than in 2018.

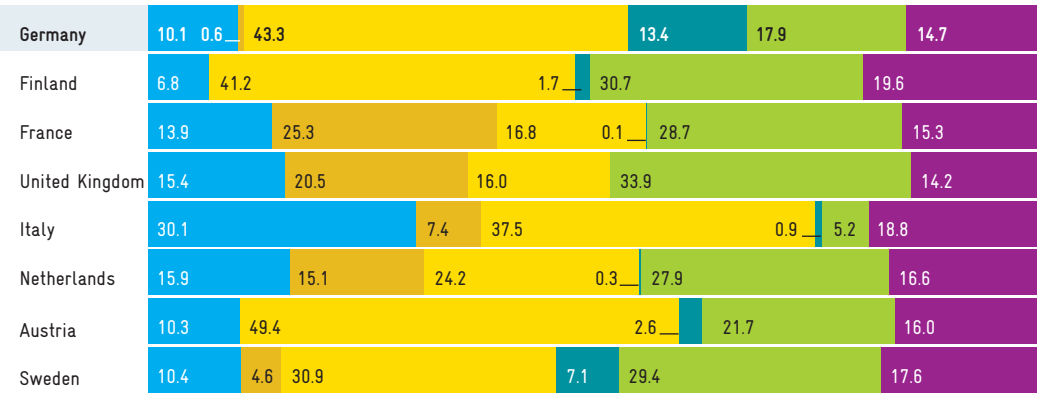
The number of first-time graduates (C 1-5) has increased from 303,155 in 2018 to 310,747 in 2019. Women accounted for 53.6 percent of first-time graduates in 2019, 0.6 percentage points higher than in 2018. Once again, the proportion of first-time graduates who completed their degree at a university fell slightly, from 53.0 percent to 52.8 percent.

The rate of people aged 25-64 who participated in continuing education and training (CET) in the last four weeks (C 1-6) increased slightly compared to 2018 and was 5.0 percent in 2019. The rates of low-skilled and medium-skilled workers with a CET participation increased by 0.2 percentage points each. The participation of businesses in CET reached 54.5 percent in 2018, 1.5 percentage points higher than the year before.

Fig. C 1-1

Download data

## Qualification levels of gainfully employed persons in selected countries in 2019 in percent




**Classification of ISCED qualification levels**

- ISCED 0–2: (Pre)primary and lower secondary education
- ISCED 3*: Upper secondary or completion of VET without access to tertiary education
- ISCED 3**: General and vocational upper secondary education with access to tertiary education
- ISCED 4: Post-secondary non-tertiary education (Abitur school-leaving examination and apprenticeship)
- ISCED 5+6: Short, career-related tertiary education (2 to less than 3 years), Bachelor's degree, training as a master craftsman or technician or equivalent vocational school qualification
- ISCED 7+8: Master's, doctoral or equivalent level

The ISCED education levels are recognized UNESCO standards for international comparisons of country-specific education systems.
Source: Eurostat, European Union Labour Force Survey. Calculations by CWS in Gehrke et al. (2021).
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Tab. C 1-2

Download data

## Number of new tertiary students in the age-matched population of under-25s in selected countries 2013–2018 in percent

| Countries | 2013[1)] | 2014[1)] | 2015[1)] | 2016[1)] | 2017[1)] | 2018[1)] | 2013[2)] | 2014[2)] | 2015[2)] | 2016[2)] | 2017[2)] | 2018[2)] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Belgium | 64 | 64 | 66 | 69 | 73 | 68 | 54 | 57 | 59 | 62 | 67 | 62 |
| **Germany** | **51** | **54** | **53** | **51** | **52** | **52** | **46** | **48** | **46** | **45** | **45** | **45** |
| Finland | 45 | 44 | 46 | 46 | 47 | 47 | 41 | 40 | 42 | 42 | 43 | 43 |
| United Kingdom | 48 | 54 | 56 | 60 | 61 | 63 | 42 | 47 | 49 | 52 | 53 | 54 |
| Italy | 40 | 40 | 42 | 43 | 46 | 48 | – | – | 41 | 41 | 43 | 46 |
| Japan | – | – | – | – | 71 | 73 | – | – | – | – | – | – |
| Sweden | 42 | 45 | 45 | 44 | 45 | 46 | 40 | 42 | 41 | 40 | 41 | 41 |
| Switzerland[3)] | 48 | 55 | 55 | 55 | 56 | 48 | – | 47 | 47 | 47 | 47 | 40 |
| USA | 48 | 48 | 48 | 47 | 46 | 46 | 47 | 47 | 46 | 46 | 44 | 44 |
| **OECD average** | **–** | **–** | **–** | **–** | **–** | **54** | **50** | **51** | **48** | **49** | **50** | **49** |

University entry rate: number of new tertiary students under 25 years of age entering tertiary education for the first time, as a percentage of the population of the corresponding age.
1) The university entry rates for under-25s are given according to the ISCED 2011 classification for levels 5, 6, 7 and 8.
2) Adjusted rate for under-25s, excluding new international tertiary students.
3) Since 2018, changed calculation: Only new entrants to the tertiary level (levels 5 to 7) are taken into account; before, there were some double counts.
Source: OECD (Ed.): Education at a Glance 2020 as well as OECD.Stat database in Gehrke et al. (2021).
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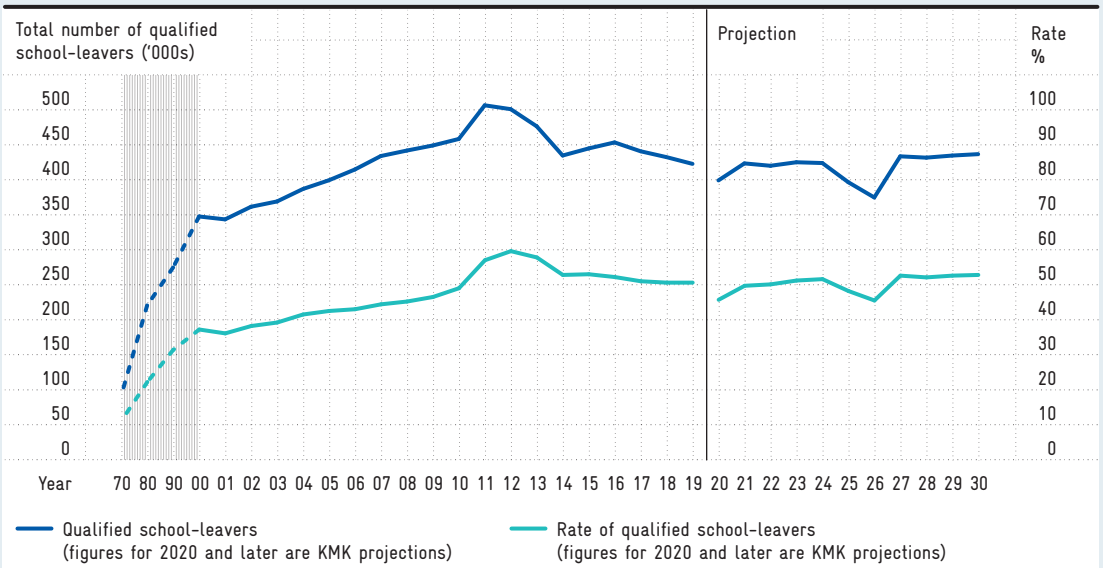
Fig. C 1-3

Download data

## School-leavers qualified for higher education in Germany 1970–2030




School-leavers qualified for higher education: either with a 'general' or a 'technical' school-leaving certificate (in Germany: Abitur).
Rate of qualified school-leavers: number of school-leavers qualified for higher education as a percentage of the relevant age group.
Source of actual figures: Federal Statistical Office in Gehrke et al. (2021).
Source of forecast figures: Statistical publications by the Standing Conference of the Ministers of Education and Cultural Affairs (Kultusministerkonferenz, KMK) in Gehrke et al. (2021).
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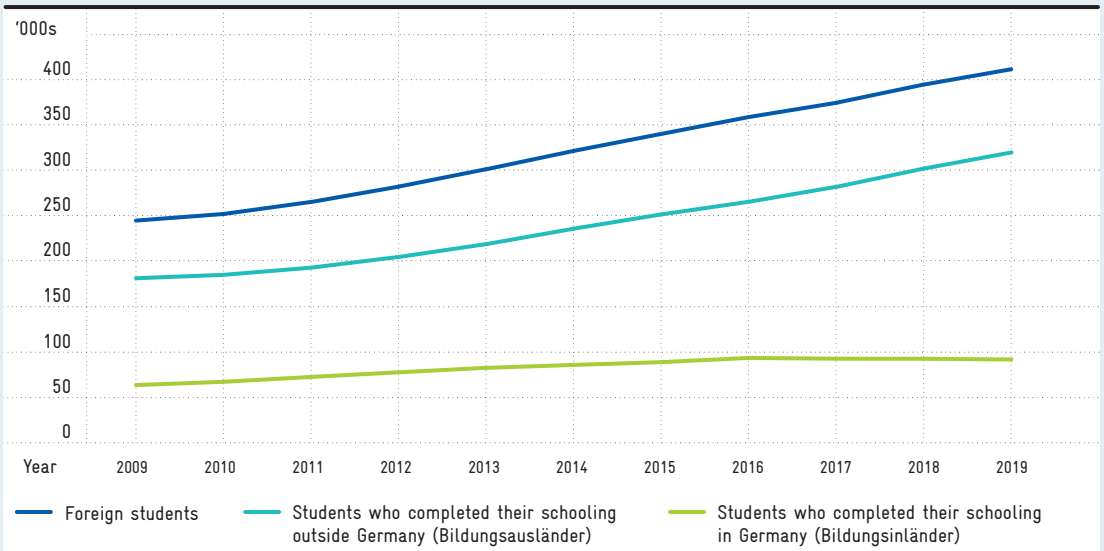
C

Fig. C 1-4

Download data

## Foreign students at German tertiary education institutions 2009–2019[1)]




Foreign students are defined as persons without German citizenship. They can be divided into students who attained their higher-education entrance qualification in Germany (Bildungsinländer), and those who attained this qualification abroad (Bildungsausländer).
[1)] The data are submitted annually by the higher education institutions to the statistical offices in the winter semester after the end of the enrolment period.
Source: Federal Statistical Office, research by DZHW-ICE in Gehrke et al. (2021).
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Tab. C 1-5

Download data

## First-time graduates and subject-structure rate 2015–2019

| | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|
| **Total number of graduates** | **317,102** | **315,168** | **311,441** | **303,155** | **310,747** |
| Percentage of women | 51.1 | 52.0 | 52.6 | 53.0 | 53.6 |
| Percentage of graduates from universities | 56.8 | 54.7 | 53.9 | 53.0 | 52.8 |
| **Humanities** | **37,135** | **34,886** | **32,205** | **30,491** | **30,660** |
| Percentage of subject group | 11.7 | 11.1 | 10.3 | 10.1 | 9.9 |
| **Legal, economics and social sciences** | **128,273** | **132,737** | **134,605** | **131,832** | **135,165** |
| Share subject group in percent | 40.5 | 42.1 | 43.2 | 43.5 | 43.5 |
| **Human medicine, health sciences** | **17,935** | **19,521** | **20,308** | **20,101** | **21,957** |
| Percentage of subject group | 5.7 | 6.2 | 6.5 | 6.6 | 7.1 |
| **Agriculture, forestry and nutritional sciences, veterinary medicine** | **7,442** | **6,978** | **7,148** | **7,252** | **7,226** |
| Percentage of subject group | 2.3 | 2.2 | 2.3 | 2.4 | 2.3 |
| **Art, art history** | **11,514** | **11,268** | **11,119** | **10,892** | **10,905** |
| Percentage of subject group | 3.6 | 3.6 | 3.6 | 3.6 | 3.5 |
| **Mathematics, natural sciences** | **30,001** | **28,081** | **26,261** | **25,677** | **26,765** |
| Share subject group in percent | 9.5 | 8.9 | 8.4 | 8.5 | 8.6 |
| **Engineering** | **81,300** | **78,552** | **76,133** | **73,849** | **74,868** |
| Share subject group in percent | 25.6 | 24.9 | 24.4 | 24.4 | 24.1 |

First-degree graduates and subject-structure rate: The subject-structure rate indicates the percentage of first-time graduates who have completed their degree course in a particular subject or group of subjects. First-degree graduates are persons who have successfully completed a first degree.
Source: Federal Statistical Office as well as research by DZHW-ICE in Gehrke et al. (2021).
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C

Tab. C 1-6

Download data

## Participation of individuals and companies engaging in continuing education and training (CET) 2009–2019 in percent

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **a) Individual CET rate** | **5.0** | **4.9** | **4.9** | **5.1** | **4.9** | **4.8** | **4.9** | **5.2** | **5.0** | **4.9** | **5.0** |
| **Gainfully employed persons by qualification level** | **5.8** | **5.6** | **5.6** | **5.9** | **5.6** | **5.5** | **5.5** | **5.8** | **5.4** | **5.3** | **5.4** |
| low (ISCED 0-2) | 1.4 | 1.3 | 1.0 | 1.4 | 1.4 | 1.3 | 1.2 | 1.5 | 1.5 | 1.3 | 1.5 |
| medium (ISCED 3-4) | 4.2 | 3.9 | 3.9 | 4.1 | 3.9 | 4.2 | 4.3 | 4.5 | 4.2 | 4.0 | 4.2 |
| high (ISCED 5-8) | 10.6 | 10.5 | 10.3 | 10.6 | 10.1 | 9.4 | 9.3 | 9.7 | 8.9 | 8.9 | 8.9 |
| **Unemployed persons by qualification level** | **4.3** | **3.9** | **4.6** | **3.8** | **3.6** | **3.7** | **3.7** | **4.2** | **5.3** | **5.1** | **4.5** |
| low (ISCED 0-2) | 2.7 | 3.5 | 3.6 | 3.1 | 2.9 | 2.8 | 2.6 | 3.3 | 5.1 | 4.9 | 3.3 |
| medium (ISCED 3-4) | 4.0 | 3.2 | 4.0 | 3.6 | 3.4 | 3.3 | 3.4 | 3.6 | 4.3 | 4.2 | 3.0 |
| high (ISCED 5-8) | 8.4 | 8.3 | 10.0 | 6.6 | 5.4 | 6.4 | 6.3 | 7.2 | 8.6 | 7.7 | 9.8 |
| **Inactive persons by qualification level** | **1.9** | **2.0** | **1.9** | **1.6** | **1.8** | **1.8** | **2.0** | **2.4** | **3.2** | **2.9** | **2.7** |
| low (ISCED 0-2) | 1.8 | 1.6 | 1.5 | 1.4 | 1.4 | 1.3 | 1.7 | 2.5 | 4.0 | 3.8 | 3.4 |
| medium (ISCED 3-4) | 1.5 | 1.8 | 1.9 | 1.4 | 1.5 | 1.6 | 1.6 | 1.8 | 2.2 | 2.0 | 2.0 |
| high (ISCED 5-8) | 3.4 | 3.6 | 2.7 | 2.8 | 3.5 | 3.4 | 3.7 | 4.4 | 4.9 | 4.2 | 3.9 |
| **b) Corporate participation in CET*** | **44.6** | **44.1** | **52.6** | **53.1** | **52.1** | **53.6** | **52.8** | **53.2** | **53.0** | **54.5** | **-** |
| **By sector** | | | | | | | | | | | |
| Knowledge-intensive manufacturing | 52.6 | 55.9 | 62.9 | 65.5 | 66.7 | 69.9 | 70.6 | 64.0 | 65.0 | 63.0 | - |
| Non-knowledge-intensive manufacturing | 32.5 | 33.3 | 41.2 | 43.2 | 41.8 | 43.0 | 44.5 | 46.3 | 45.5 | 46.0 | - |
| Knowledge-intensive services | 58.7 | 57.1 | 68.7 | 67.2 | 67.4 | 67.0 | 67.5 | 69.2 | 66.1 | 69.1 | - |
| Non-knowledge-intensive services | 38.0 | 37.5 | 44.9 | 45.3 | 44.3 | 46.0 | 43.8 | 43.7 | 45.2 | 46.8 | - |
| Non-commercial industry | 51.9 | 51.2 | 59.0 | 60.3 | 58.4 | 61.9 | 60.1 | 59.3 | 59.3 | 60.0 | - |
| **By company size** | | | | | | | | | | | |
| < 50 employees | 42.5 | 41.8 | 50.5 | 50.9 | 49.8 | 51.4 | 50.5 | 50.8 | 50.6 | 51.9 | - |
| 50–249 employees | 81.3 | 83.3 | 90.8 | 89.7 | 90.1 | 90.8 | 89.3 | 89.5 | 89.0 | 92.0 | - |
| 250–499 employees | 92.0 | 93.3 | 95.9 | 96.5 | 97.0 | 96.9 | 96.8 | 96.4 | 96.0 | 97.2 | - |
| ≥ 500 employees | 96.0 | 97.9 | 98.4 | 97.8 | 99.1 | 99.1 | 97.1 | 97.9 | 97.2 | 97.9 | - |

Individual CET rate: Percentage of people who participated in CET in the last four weeks prior to the time of the survey. Corporate participation in CET: percentage of companies where employees were released for CET or whose CET costs were paid. On ISCED cf. C 1-1.
Population a): All persons aged between 25 and 64.
Population b): All establishments with at least one employed person subject to social security.
* The data for corporate CET participation in 2019 were not yet available by the editorial deadline.
Source a): European Union Labour Force Survey (special evaluation). Calculations by CWS in Gehrke et al. (2021). Data as from 2016 relating to unemployed and inactive persons are comparable to previous years only to a limited extent due to methodological changes and stricter confidentiality rules.
Source b): IAB Establishment Panel (special evaluation). Calculations by CWS in Gehrke et al. (2021).
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C

# Research and Development[327] C 2

Statistics on R&D expenditure indicate the extent to which activities are developed to generate new ideas. R&D intensity, as a share of R&D expenditure in the gross domestic product (for countries) or in turnover (for companies), provides information on the willingness to invest in R&D; the distribution of R&D expenditure across sectors and industries indicates focal points of R&D activity.

R&D intensity (C 2-1) in Germany, i.e., the share of R&D expenditure in the gross domestic product, reached 3.17 percent in 2019, higher than the previous year's figure of 3.13 percent. Germany is thus continuing the trend of increasing R&D intensity. South Korea achieved by far the highest R&D intensity of all the comparative countries with 4.53 percent (2018). Of the EU countries, Sweden had the highest R&D intensity (2019) at 3.39 percent. The USA's increased slightly by 0.02 percentage points to 2.83 percent (2018). China's R&D intensity also grew by 0.02 percentage points, with 2.14 percent of its GDP invested in R&D in 2018.

Germany's budget estimate for civil R&D (C 2-2), i.e., the budget allocated in the national budget for financing R&D, increased again compared to 2018, reaching an index value of 172 percent in 2019. This means that the budget allocated in the German national budget for financing R&D has increased by 72 percent between 2009 and 2019. The budget for civil R&D in Switzerland has increased significantly more; here the increase was 123 percent. Switzerland thus recorded by far the strongest growth of all comparative countries. The weakest development was in the USA, where the budget estimate for civil R&D fell slightly by 1 percent between 2009 and 2019.

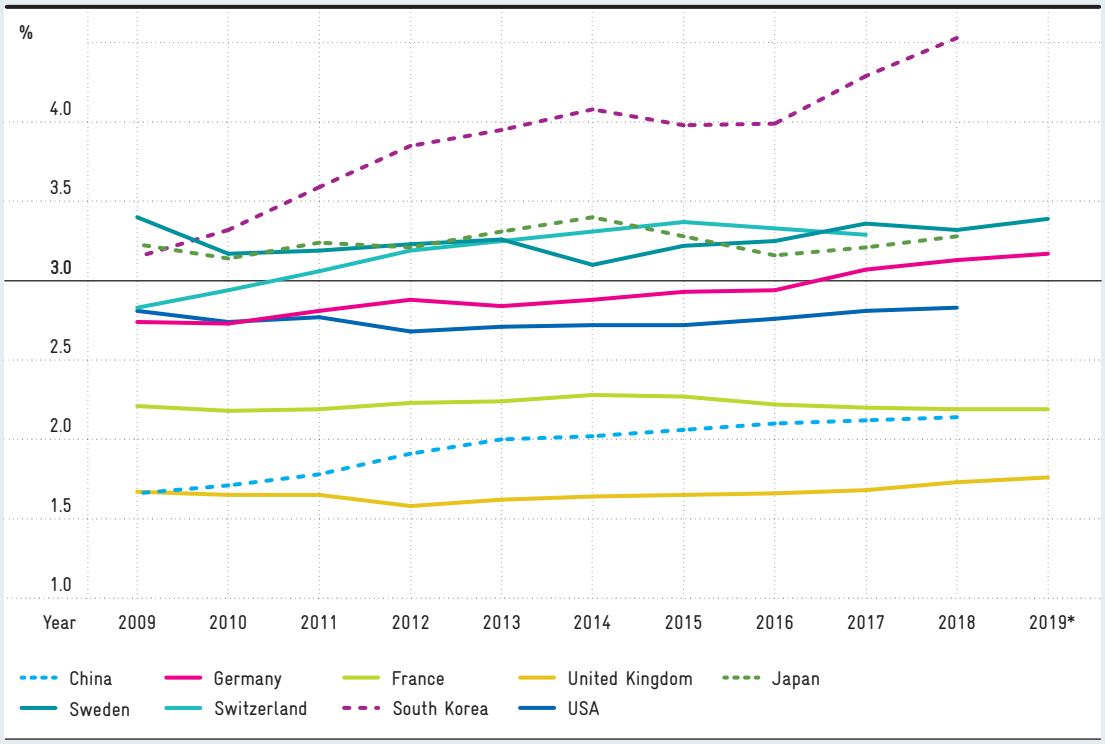
The distribution of gross domestic expenditure on R&D by performing sector (C 2-3) shows that the share of expenditure on R&D performed in the public sector declined between 2008 and 2018 in all countries shown, apart from Switzerland.[328] Expenditure shares for R&D carried out by the business sector declined in Germany, Sweden, and Switzerland during this period, while they increased in the other countries. The shares relating to the higher education sector increased from 2008 to 2018 in Germany, France, Sweden, and Switzerland. In the other countries, these shares decreased. For Germany, however, the changes in these three shares were small in each case.

For the indicators R&D intensity of the Länder (C 2-4), internal R&D expenditure of companies (C 2-5) and internal R&D expenditure as a percentage of turnover from own products (C 2-6), no updated data was available at the editorial deadline. Therefore, the tables and the illustration from the previous year were carried over to be included here.

Fig. C 2-1

Download data

## R&D intensity in selected countries 2009–2019 in percent




R&D intensity: percentage of an economy's gross domestic product (GDP) spent on research and development.
* Preliminary figures for 2019.
Source: OECD, Eurostat. Calculations and estimates by CWS in Schasse (2021).
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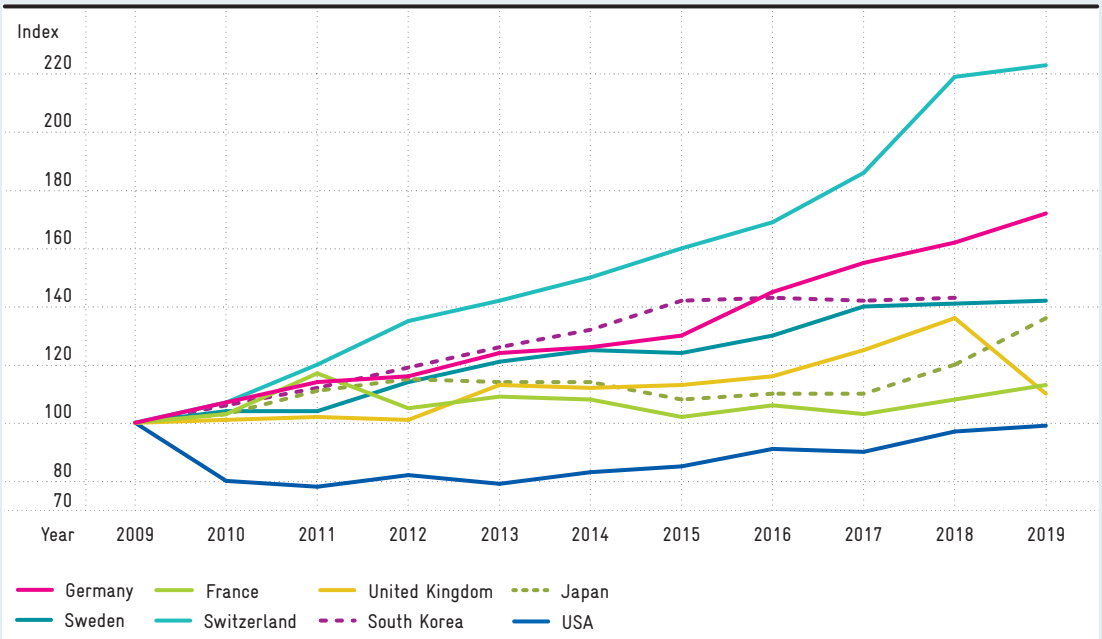
C

## State budget estimates for civil R&D in selected countries 2009–2019 (index values)

Fig. C 2-2

Download data




R&D budget estimates: the chart shows the amounts set aside in the budget to finance R&D.
Index: 2009 = 100, data partly based on estimates.
Source: OECD, Eurostat. Calculations and estimates by CWS in Schasse (2021).
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## Distribution of gross domestic expenditure on R&D (GERD) by performing sector in selected countries in 2008 and 2018

Tab. C 2-3

Download data

| | 2008 | | | | | 2018 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | of which (%) carried out by ... | | | | | of which (%) carried out by ... | | | |
| Countries | GERD in US$m | Business sector | Tertiary education institutions | Public sector | Private non-profit | GERD in US$m | Business sector | Tertiary education institutions | Public sector | Private non-profit |
| China | 145,071 | 73.3 | 8.5 | 18.3 | - | 468,062 | 77.4 | 7.4 | 15.2 | - |
| Germany | 81,173 | 69.2 | 16.8 | 14.0 | - | 141,300 | 68.9 | 17.6 | 13.5 | - |
| France | 46,567 | 62.7 | 20.0 | 16.0 | 1.2 | 68,441 | 65.4 | 20.5 | 12.5 | 1.6 |
| United Kingdom | 36,542 | 62.0 | 26.5 | 9.2 | 2.4 | 53,953 | 67.6 | 23.6 | 6.6 | 2.2 |
| Japan | 148,719 | 78.5 | 11.6 | 8.3 | 1.6 | 171,294 | 79.4 | 11.6 | 7.8 | 1.3 |
| Sweden | 13,487 | 74.1 | 21.3 | 4.4 | 0.2 | 18,162 | 71.0 | 25.3 | 3.6 | 0.1 |
| Switzerland* | 10,917 | 73.5 | 24.2 | 0.7 | 1.6 | 18,688 | 71.0 | 28.2 | 0.8 | 2.3 |
| South Korea | 43,906 | 75.4 | 11.1 | 12.1 | 1.4 | 98,451 | 80.3 | 8.2 | 10.1 | 1.4 |
| USA | 407,238 | 71.4 | 13.2 | 11.3 | 4.0 | 581,553 | 72.6 | 12.8 | 10.4 | 4.2 |

Data from 09/2020. * 2017 instead of 2018
Germany and China: private non-profit organizations included under 'Public sector'.
Source: OECD, Eurostat. Calculations by CWS in Schasse (2021).
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Tab. C 2-4

Download data

## R&D intensity of the Länder and Germany in 2007 and 2017 in percent

| | 2007 | | | | 2017 | | | |
|---|---|---|---|---|---|---|---|---|
| Länder | Total | Business sector | Public sector | Tertiary education institutions | Total | Business sector | Public sector | Tertiary education institutions |
| Baden-Württemberg | 4.16 | 3.38 | 0.37 | 0.40 | 5.63 | 4.71 | 0.41 | 0.51 |
| Bavaria | 2.81 | 2.21 | 0.25 | 0.35 | 3.09 | 2.34 | 0.31 | 0.43 |
| Berlin | 3.02 | 1.25 | 1.00 | 0.77 | 3.40 | 1.37 | 1.19 | 0.84 |
| Brandenburg | 1.22 | 0.32 | 0.64 | 0.26 | 1.68 | 0.57 | 0.74 | 0.37 |
| Bremen | 2.14 | 0.85 | 0.71 | 0.58 | 2.75 | 0.88 | 1.10 | 0.76 |
| Hamburg | 1.80 | 1.07 | 0.40 | 0.33 | 2.14 | 1.24 | 0.38 | 0.53 |
| Hesse | 2.49 | 2.03 | 0.15 | 0.31 | 2.91 | 2.20 | 0.28 | 0.43 |
| Lower Saxony | 2.41 | 1.67 | 0.33 | 0.41 | 3.10 | 2.20 | 0.37 | 0.53 |
| Mecklenburg-Western Pomerania | 1.38 | 0.40 | 0.56 | 0.42 | 1.79 | 0.58 | 0.64 | 0.58 |
| North Rhine-Westphalia | 1.70 | 1.07 | 0.25 | 0.38 | 2.09 | 1.23 | 0.30 | 0.55 |
| Rhineland-Palatinate | 1.78 | 1.32 | 0.14 | 0.32 | 2.43 | 1.78 | 0.18 | 0.47 |
| Saarland | 1.03 | 0.42 | 0.28 | 0.33 | 1.74 | 0.86 | 0.36 | 0.53 |
| Saxony | 2.58 | 1.34 | 0.66 | 0.58 | 2.78 | 1.21 | 0.79 | 0.78 |
| Saxony-Anhalt | 1.17 | 0.35 | 0.42 | 0.40 | 1.49 | 0.41 | 0.51 | 0.57 |
| Schleswig-Holstein | 1.18 | 0.53 | 0.31 | 0.34 | 1.55 | 0.83 | 0.34 | 0.38 |
| Thuringia | 1.87 | 0.96 | 0.43 | 0.48 | 2.19 | 1.10 | 0.48 | 0.61 |
| **Germany** | **2.44** | **1.71** | **0.34** | **0.39** | **3.03** | **2.10** | **0.41** | **0.52** |

R&D intensity: Länder expenditure on research and development as a percentage of their gross domestic product, broken down by performing sector.
Source: SV Wissenschaftsstatistik and statistical offices of the Federal Government and the Länder in Gehrke et al. (2020).
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C

Tab. C 2-5

Download data

## Internal corporate R&D expenditure by origin of funds, business sector, company size and technology category in 2017

| | Internal R&D expenditure | | | | |
|---|---|---|---|---|---|
| | Total | of which funded by | | | |
| | | Business sector | Public sector | Other domestic entities (e.g. universities) | Foreign entities |
| | in 1,000 euro | in percent | | | |
| **All researching companies** | **68,787,323** | **90.4** | **3.2** | **0.1** | **6.3** |
| Manufacturing | 58,493,502 | 91.6 | 1.8 | 0.1 | 6.5 |
| Chemical industry | 4,065,084 | 91.1 | 1.4 | 0.0 | 7.5 |
| Pharmaceutical industry | 4,630,940 | 80.2 | | | 18.9 |
| Plastics, glass, and ceramics | 1,468,445 | 94.9 | 2.7 | 0.2 | 2.2 |
| Metal production and processing | 1,499,201 | 80.2 | 8.3 | 0.3 | 11.2 |
| Electrical engineering/electronics | 10,431,420 | 89.7 | 2.7 | 0.0 | 7.6 |
| Mechanical engineering | 7,116,706 | 95.6 | 2.3 | 0.1 | 2.0 |
| Vehicle construction | 27,431,531 | 93.7 | 1.0 | 0.2 | 5.2 |
| Other manufacturing industries | 1,850,175 | 93.0 | 4.3 | 0.1 | 2.6 |
| Remaining sectors | 10,293,822 | 86.1 | 9.5 | 0.1 | 4.2 |
| | | | | | |
| < 100 employees | 3,153,908 | 70.8 | 21.6 | 0.5 | 7.1 |
| 100–499 employees | 5,731,228 | 84.5 | 8.0 | 0.2 | 7.3 |
| 500–999 employees | 4,098,690 | 88.5 | 6.2 | 0.1 | 5.2 |
| ≥ 1,000 employees | 55,803,497 | 92.3 | 1.4 | 0.1 | 6.2 |
| **Technology categories in industry** | | | | | |
| Cutting-edge technology (> 9 percent of costs/turnover spent on R&D) | 14,263,536 | 84.5 | 3.4 | 0.0 | 12.0 |
| High-value technology (3–9 percent of costs/turnover spent on R&D) | 38,768,519 | 94.3 | 0.9 | 0.1 | 4.6 |

Internal R&D: R&D that is conducted within the company, either for the company's own purposes or commissioned by a third party.
Source: SV Wissenschaftsstatistik in Gehrke et al. (2020).
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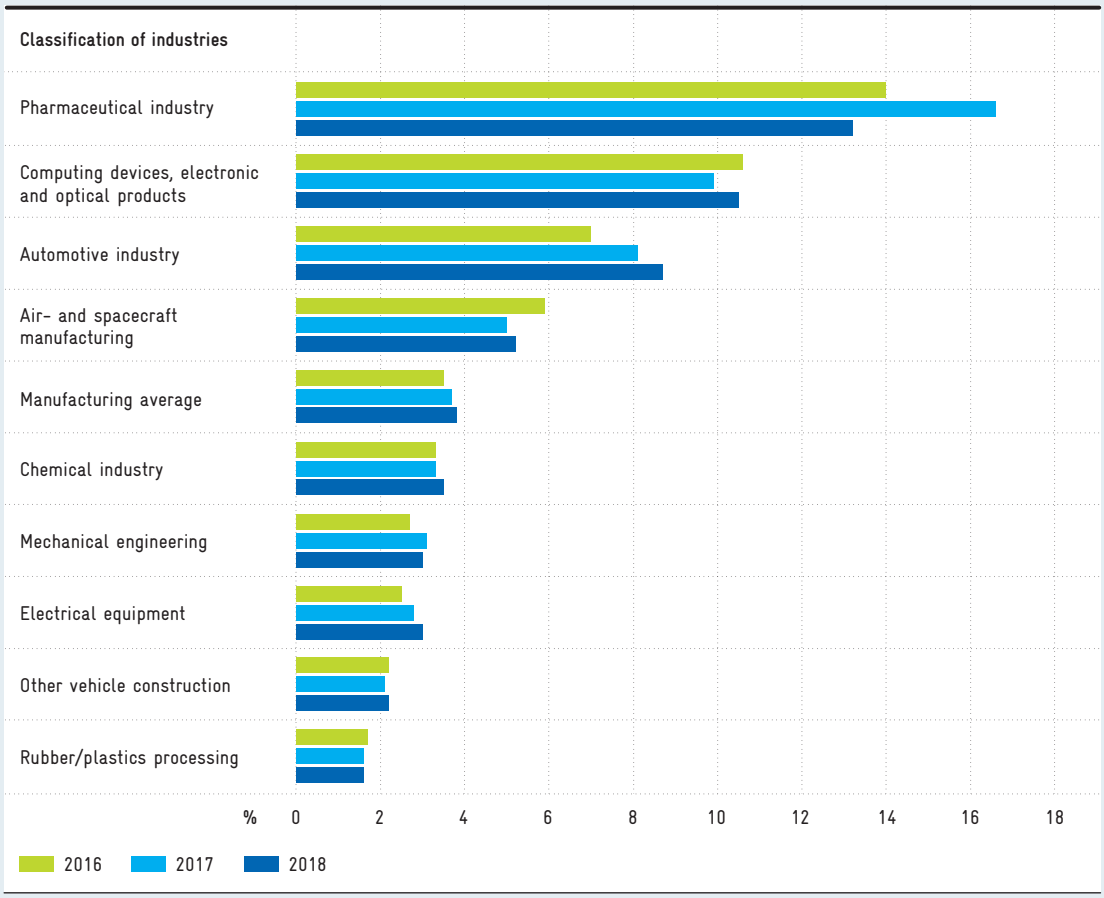
C

Fig. C 2-6

Download data

## Internal corporate R&D expenditure as a percentage of turnover from company's own products 2016–2018




Internal R&D: R&D that is conducted within the company, either for the company's own purposes or commissioned by a third party. Figures net, without input tax.
Source: SV Wissenschaftsstatistik, Federal Statistical Office, corporate results for Germany. Calculations by CWS in Gehrke et al. (2020).
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C

# Innovation Behaviour in the Business Sector

C 3

The Europe-wide Community Innovation Surveys (CIS) conducted every two years form the data basis for the international comparison of the innovation behaviour of companies (C 3-1).[329] CIS are conducted by all EU Member States as well as by some other European countries on a harmonized methodological basis and under the coordination of Eurostat. They are based on a largely standardized questionnaire and are aimed at companies with ten or more employees in manufacturing industry and selected service sectors. In 2018, the innovation intensity, i.e., innovation expenditure in relation to total turnover, of research-intensive industry in Germany was 7.4 percent and thus above the rates of the comparative countries. In knowledge-intensive services, Sweden and Finland recorded the highest innovation intensities of the comparative countries, at 5.6 and 4.3 percent, respectively. In Germany, the rate was 3.2 percent.

The data on the innovation behaviour of the German economy in the period 2009 to 2019 presented in figures C 3-2 and C 3-3 are based on the innovation survey conducted annually since 1993 by the ZEW – Leibniz Centre for European Economic Research, the Mannheim Innovation Panel (MIP).[330] Data from the MIP represent the German contribution to the CIS. However, in addition to the data to be reported to Eurostat, the MIP also includes data for enterprises with five to nine employees.

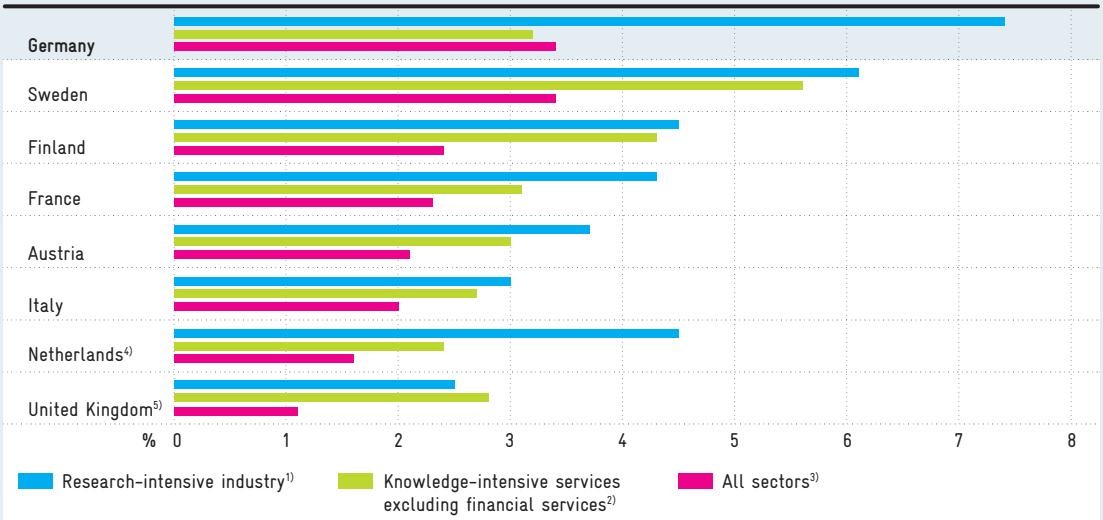
Innovation intensity (C 3-2) has shown only minor fluctuations in recent years in all the industry and business-oriented services sectors under consideration. In 2019, it was 8.9 percent in the R&D-intensive industry. Innovation intensity was significantly lower in other industry (1.4 percent), financial services (0.9 percent) and other services (0.6 percent). The knowledge-intensive service providers were able to continue the upward trend that has been observed since 2017 and achieved an innovation intensity of 6.1 percent in 2019. The share of turnover with new products (C 3-3) increased slightly for knowledge-intensive service providers compared to the previous year from 12.9 to 13.6 percent. R&D-intensive industry, on the other hand, recorded a decline from 33.0 to 31.2 percent, continuing the slight downward trend from the previous year. Slight declines were also seen in other industry (from 7.6 to 7.0 percent) and in other services (from 8.5 to 6.4 percent).

An important aspect in the commercialization of innovative technologies is standardization. At the international level, norms and standards are developed in the committees of the International Organization for Standardization (ISO). Through its involvement in these committees, a country can have a significant influence on global technical infrastructures (C 3-4).[331] In 2020, German companies were involved in the ISO's work significantly more often than representatives of other countries.[332] China was able to significantly increase the number of secretariats managed at the ISO in the period from 2010 to 2020, but still ranks sixth among the countries under consideration here.

Fig. C 3-1

Download data

## Innovation intensity in European comparison in 2018 in percent




Innovation intensity: innovation expenditure by companies as a percentage of their total turnover.
1) Research-intensive industry: divisions 19-22, 25-30 of WZ classification. Since data are not available for all sectors in all countries, the definition of research-intensive industries used in the European comparison differs from the definition normally used by the EFI.
2) Knowledge-intensive services excluding financial services: divisions 58-63, 71-73 of WZ classification. Since data are not available for all sectors in all countries, the definition of knowledge-intensive services used in the European comparison differs from the definition normally used by the EFI.
3) All sectors: divisions 5-39, 46, 49-53, 58-66, 71-73 of the WZ.
4) Reference year 2016. Research-intensive industry only divisions 25-30 of the WZ
5) Reference year 2016.
Source: Eurostat, Community Innovation Surveys 2018 and 2016. Calculations by ZEW.
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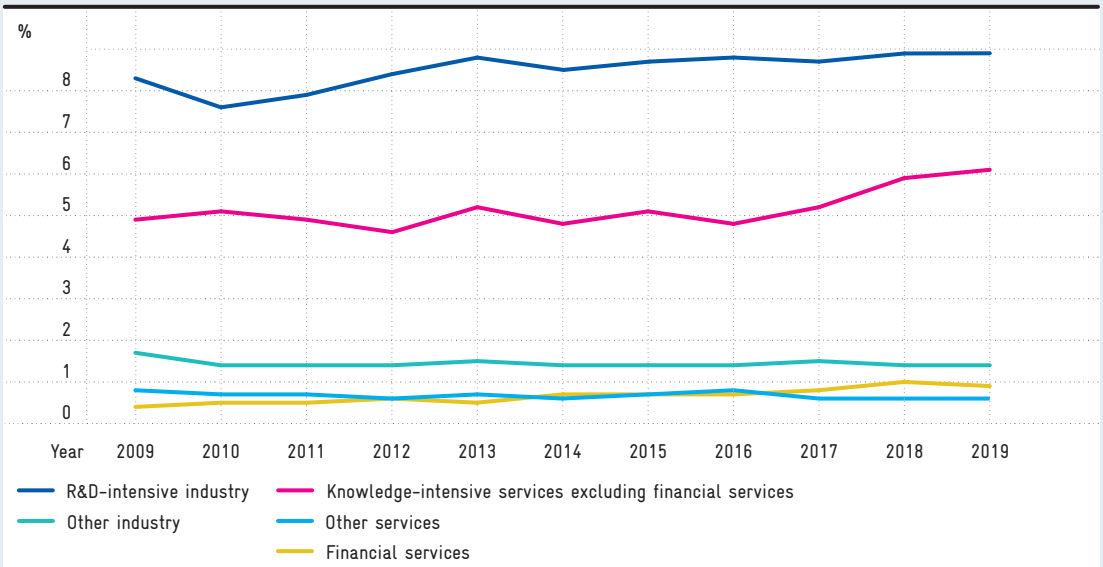
C

Fig. C 3-2

Download data

## Innovation intensity in industry and business-oriented services in Germany 2009–2019 in percent




Innovation intensity: innovation expenditure by companies as a percentage of their total turnover.
Data for 2018 partly revised.
Source: Mannheim Innovation Panel. Calculations by ZEW.
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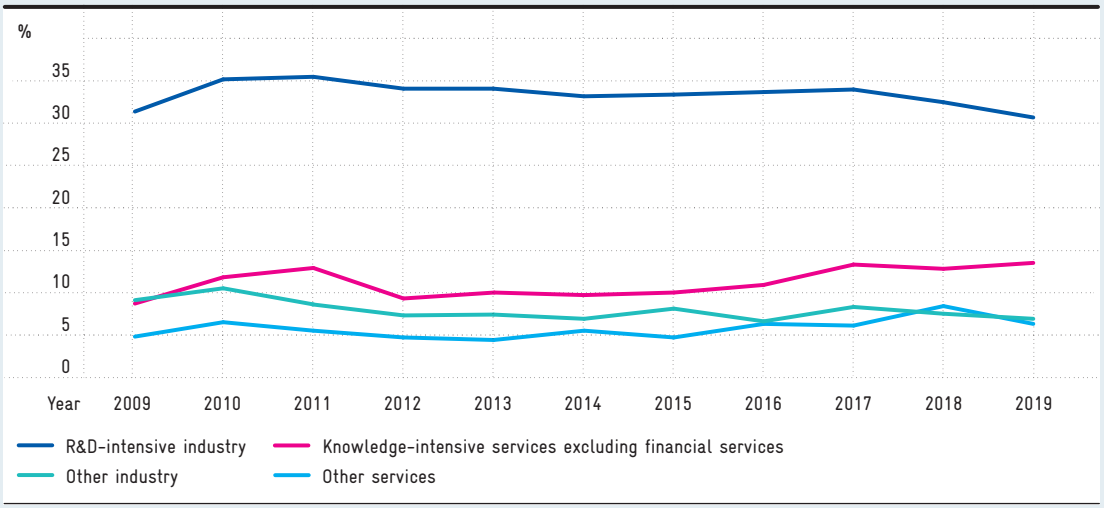
## Percentage of turnover generated by new products in industry and business-oriented services in Germany 2009–2019

Fig. C 3-3

Download data




Source: Mannheim Innovation Panel. Calculations by ZEW.
Data for 2018 partly revised.
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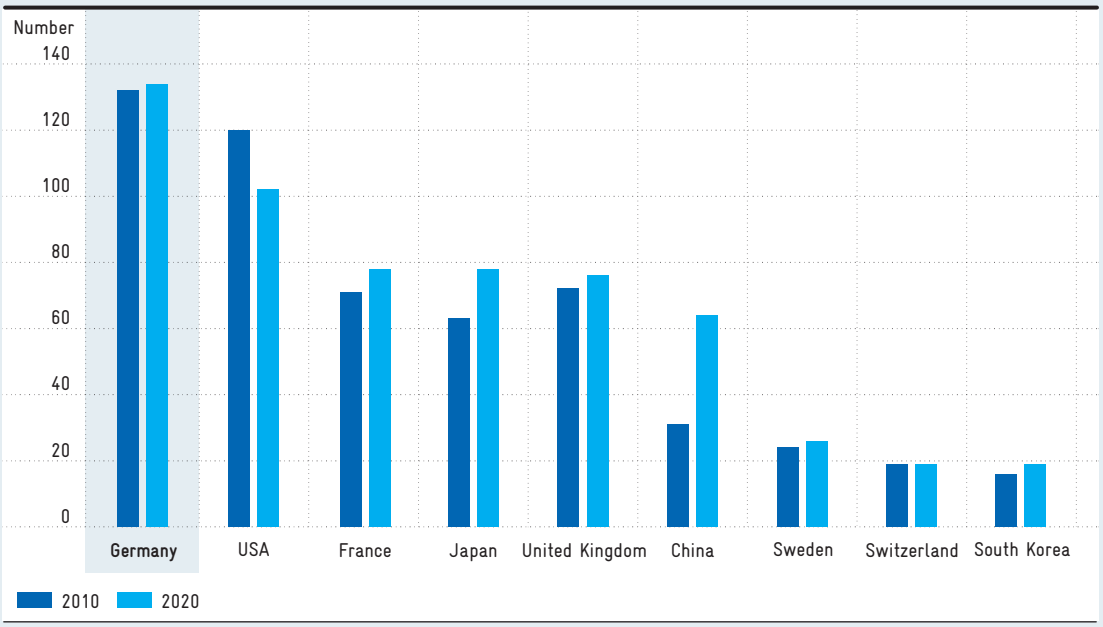
## Number of secretariats listed by the technical committees and subcommittees of the International Organization for Standardization (ISO) in 2010 and 2020

Fig. C 3-4

Download data




Source: Own representation based on ISO (2011) and https://www.iso.org/members.html (accessed on 17 December 2020).
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# C 4 Financing Research and Innovation[333]

Public funding of R&D in the business sector can take the form of direct R&D funding or indirect R&D funding (fiscal R&D funding). Figure C 4-1 shows the share of direct and indirect R&D funding in the business sector in the gross domestic product (GDP) in selected countries. The instrument of fiscal R&D funding was available to companies in most of the countries listed in the year under review (2017); Germany did not yet make use of this funding option in 2017. The Research Allowance Act (Forschungszulagengesetz) then came into force in Germany at the beginning of 2020.

Financing R&D and innovation projects is a key challenge for many companies in both the start-up and growth phases.[334] Young, innovative companies can often only establish themselves successfully on the market if private investors participate with venture capital in the start-up and development phase.

Figure C 4-2 provides an overview of the share of venture capital investments in the national GDP of selected countries. For the comparison, data from Invest Europe are used, which allow good international comparability due to the harmonized collection and processing.[335] The highest venture capital investments relative to GDP in 2019 were recorded in Finland and the UK. In an international comparison, Germany only occupies a mid-table position, even though the share of venture capital investments in GDP increased in 2019 compared to the previous year.

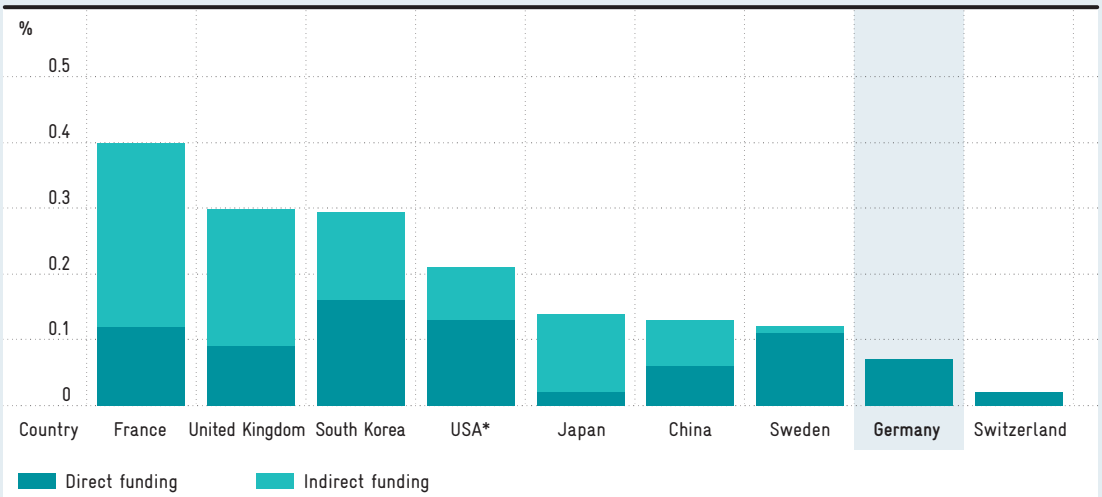
Since Invest Europe data only covers venture capital investments by companies organized in the association, there is a risk of underestimating the volume.[336] For the analysis of venture capital investments in Germany, data from transaction databases[337] are therefore used in addition to Invest Europe data. Their advantage is that the unit of observation is the individual transaction, which increases the probability that co-investments by atypical market participants[338] and non-European investors are also covered.

Figure C 4-3 provides an overview of the development of venture capital investments in Germany. Both Invest Europe data and transaction data show a significant increase in venture capital investment between 2009 and 2019. However, this is considerably larger for the transaction data. Based on this data, there is a clear change in the structure of venture capital investments. Indeed, such a change would probably also be observed for other countries. The expanded data basis therefore does not allow any conclusions to be drawn as to whether Germany's weak position in the availability of venture capital relative to other countries could be improved in an international comparison.

## Publicly funded R&D expenditure in the business sector as a percentage of the national gross domestic product of selected countries in 2017

Fig. C 4-1

Download data




The public funding of private-sector R&D is divided into direct R&D funding and indirect R&D funding (through tax incentives).
* 2016.
Source: OECD R&D Tax Incentive Database, research December 2020.
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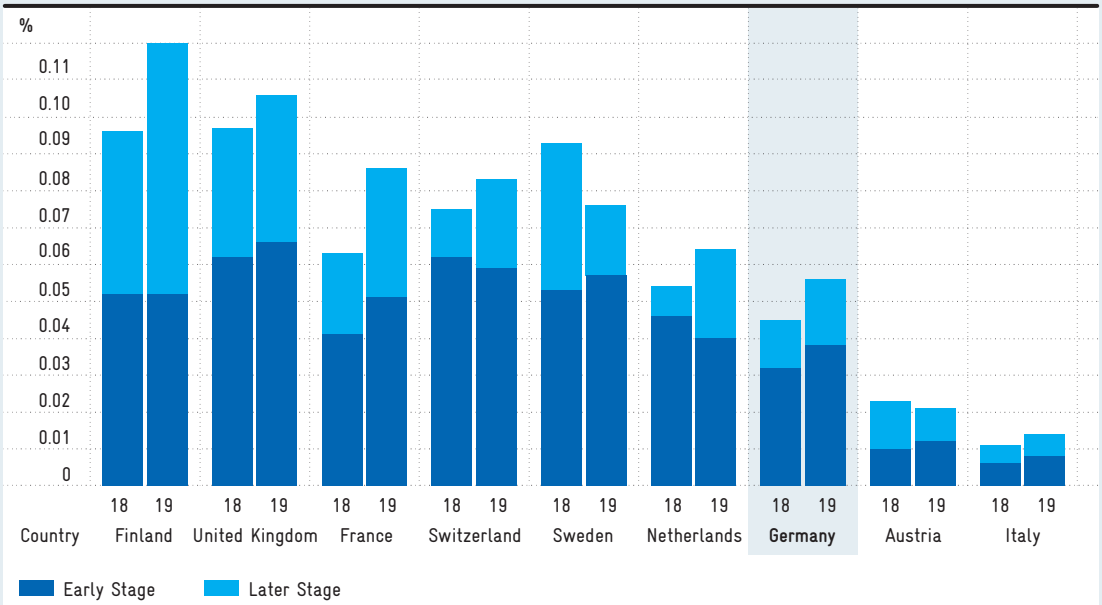
## Venture capital investments as a percentage of the national gross domestic product of selected countries in 2018 and 2019

Fig. C 4-2

Download data




Venture capital is defined here as temporary equity investments in young, innovative, non-listed companies.
Data for 2018 partly revised.
Investments are broken down according to the portfolio companies' head offices. Early stage comprises the seed phase and the start-up phase.
Source: Invest Europe. Calculations by ZEW in Bersch et al. (2021).
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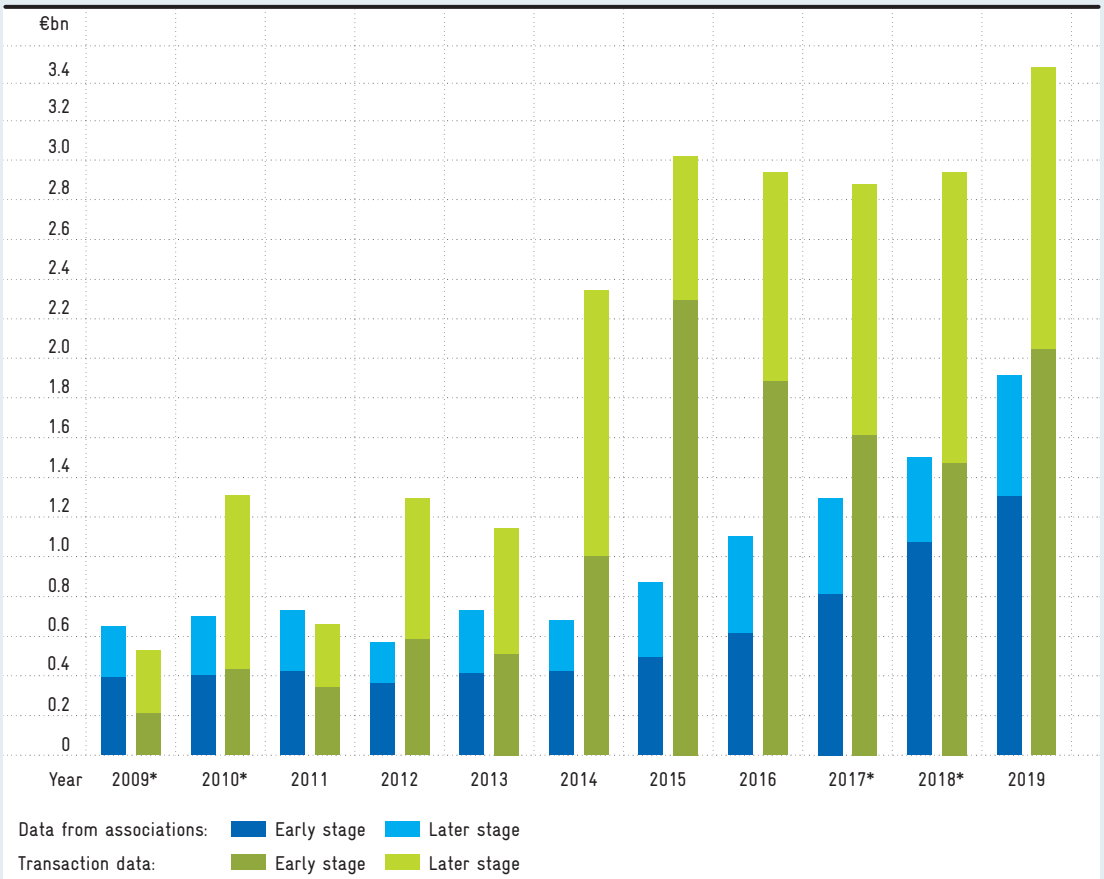
Fig. C 4-3

Download data

## Venture capital investment in Germany 2009–2019 in billion euros




Venture capital is defined here as temporary equity investments in young, innovative, non-listed companies.
* Data partly slightly revised.
Investments are broken down according to the portfolio companies' head offices. Early stage comprises the seed phase and the start-up phase.
Source of association data: Invest Europe. Calculations by ZEW in Bersch et al. (2021).
Source of transaction data: Bureau van Dijk, Majunke. Calculations by ZEW.
in Bersch et al. (2021).
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C

# New Businesses C 5

An international comparison of start-up rates, i.e., the number of enterprise births in relation to the total number of companies, is only possible at the European level.[339] For this purpose, Eurostat's Business Demography Statistics are used (C 5-1), which represent a subsection of the Structural Business Statistics (SBS) of the European Union. This official database is based on evaluations of the business registers in the individual Member States. The values for Germany come from the Business Demography Statistics of the Federal Statistical Office (Statistisches Bundesamt), which is an evaluation of the business register.[340] When comparing the start-up rates of eight selected European countries, Germany ranked sixth in 2018, both in terms of the economy as a whole (6.8 percent) and in knowledge-intensive services (8 percent).[341] In R&D-intensive industry (3.4 percent), Germany had the lowest start-up rate among the comparative countries under consideration.

The basis for the results on business dynamics in the knowledge economy presented in figures C 5-2 to C 5-4 is an evaluation of the Mannheim Enterprise Panel (Mannheimer Unternehmenspanel, MUP) conducted by the ZEW – Leibniz Centre for European Economic Research (ZEW). The MUP is the ZEW's panel data set on businesses in Germany that has been compiled in cooperation with Creditreform, Germany's largest consumer reporting agency, since 1992.[342] The term 'business' used in the MUP includes only economically active companies; only original start-ups are considered to be enterprise births.[343] The enterprise birth rate shown in figure C 5-2 is therefore calculated on a different data basis than in the Business Demography Statistics, so that no direct comparison is possible here.[344] This means that the values differ from the values given for Germany in figure C 5-1. After the financial and economic crisis, start-up rates initially fell in all sectors considered.[345] Afterwards, the values were relatively constant. Over the entire period, IT/telecommunications showed the highest start-up rates among the sectors considered (2019: 6.2 percent), while high-value technology and cutting-edge technology had the lowest start-up rates (2019: 2.8 percent each).[346]

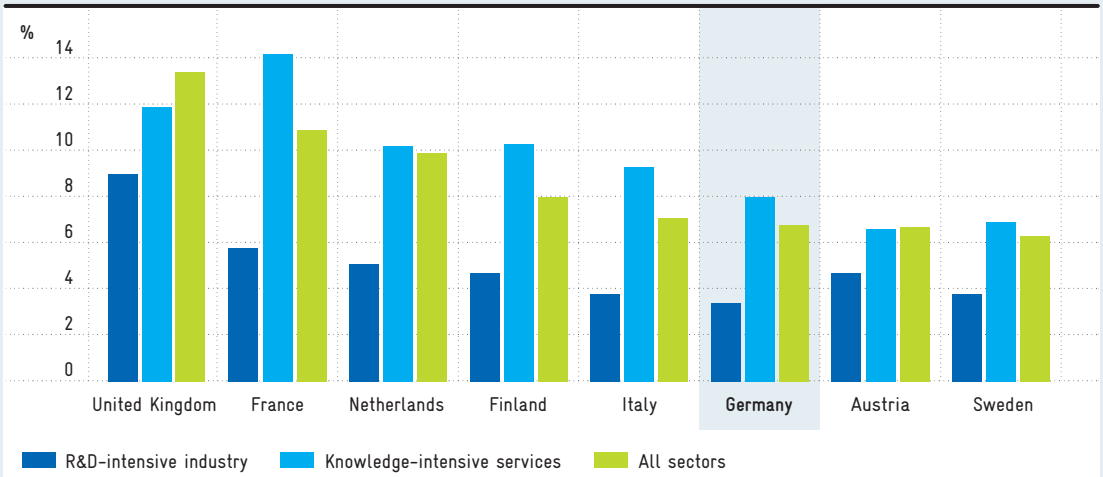
Closure rates showed a declining trend in the second half of the 2010s in all sectors considered (C 5-3).[347] In the knowledge-intensive sectors, they fell from 4.2 percent in 2014 to 2.8 percent in 2019.

In a comparison of the Länder, Berlin achieved the highest start-up rates between 2017 and 2019 in R&D-intensive industry (4.6 percent), in knowledge-intensive services (6.1 percent) and across the economy as a whole (6.1 percent) (C 5-4).[348] In R&D-intensive industry, Hamburg (4 percent) and Brandenburg (3.8 percent) took second and third place. In knowledge-intensive services, Saarland (5.2 percent) and Bremen (5.1 percent) had the highest start-up rates after Berlin, closely followed by Bavaria (5 percent).

Fig. C 5-1

Download data

## Start-up rates in selected countries in 2018 in percent




Start-up rate: number of start-up businesses as a percentage of the total number of companies.
Source: Business Demography Statistics (Eurostat). Calculations by ZEW.
in Bersch et al. (2021).
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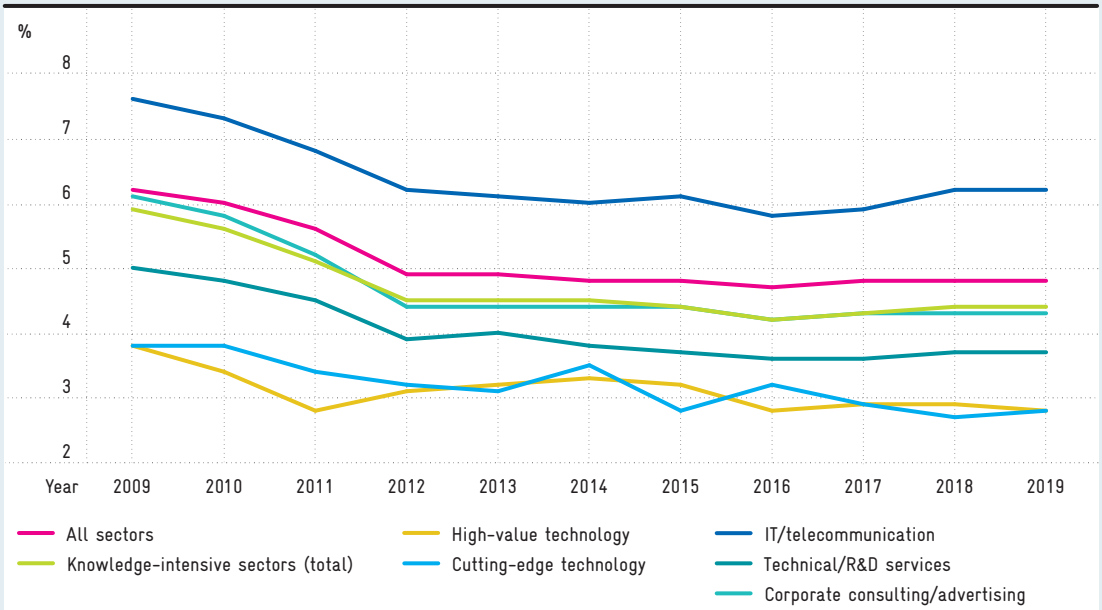
Fig. C 5-2

Download data

## Start-up rates in knowledge-intensive sectors in Germany 2009–2019 in percent




The knowledge-intensive sectors comprise the R&D-intensive industries (high-value technology and cutting-edge technology) and knowledge-intensive services.
Start-up rate: number of start-up businesses as a percentage of the total number of companies.
All figures are provisional.
Source: Mannheim Enterprise Panel. Calculations by ZEW in Bersch et al. (2021).
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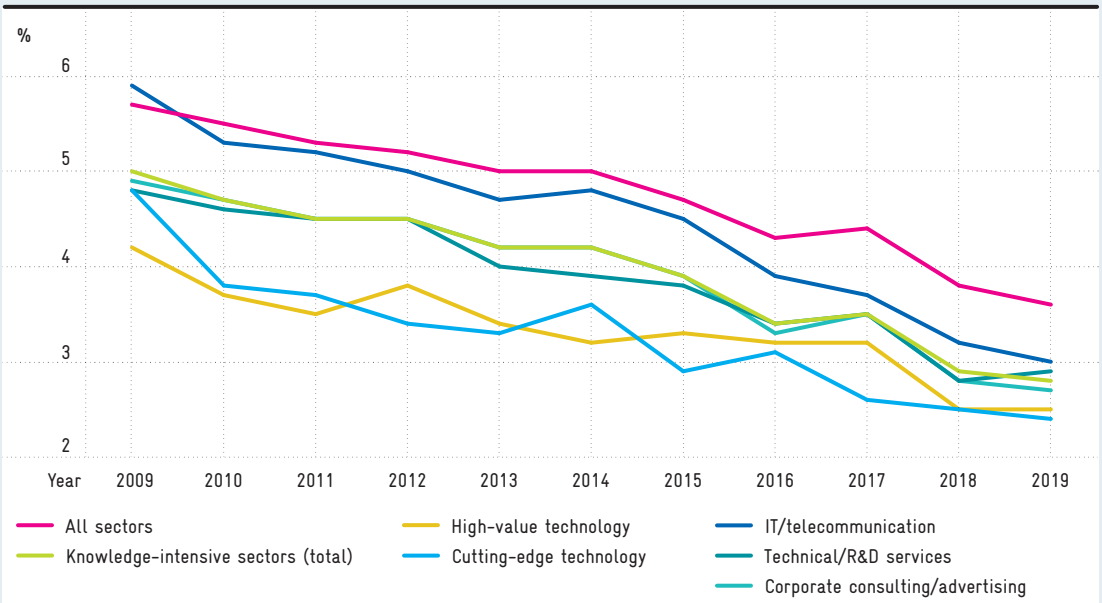
## Closure rates in knowledge-intensive sectors in Germany 2009–2019 in percent

Fig. C 5-3

Download data




The knowledge-intensive sectors comprise the R&D-intensive industries (high-value technology and cutting-edge technology) and knowledge-intensive services.
Closure rate: number of companies that close during a year as a percentage of all companies.
All figures are provisional.
Source: Mannheim Enterprise Panel. Calculations by ZEW in Bersch et al. (2021).
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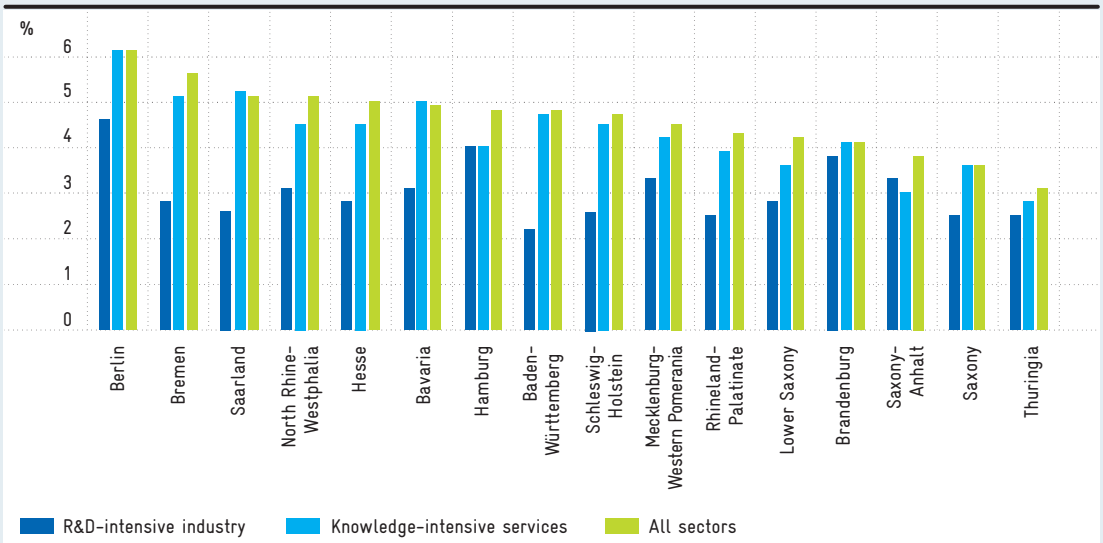
## Start-up rates by Länder 2017–2019 in percent

Fig. C 5-4

Download data




Start-up rate: number of start-up businesses as a percentage of the total number of companies.
All figures are provisional.
Source: Mannheim Enterprise Panel. Calculations by ZEW in Bersch et al. (2021).
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# C 6 Patents[349]

Since the mid-2000s, Germany's transnational patent applications have stagnated, as have those of other large European economies such as the UK and France (C 6-1). In contrast, China, South Korea, and Japan in particular show high growth rates here. China has now overtaken Germany and Japan and ranks second behind the USA in transnational patent applications.

While the USA is the leader in absolute applications in 2018, it does not occupy any top rank in terms of patent intensity (patent applications per million of the working population) (C 6-2). Here, Switzerland, Sweden and Japan are in the lead, followed by Finland, South Korea, and Germany. Patents are an important instrument for securing market shares in the context of international technology trade. A high patent intensity therefore reflects both a strong international orientation and a pronounced export focus of the respective economy.

Further conclusions about a country's technological performance can be drawn from patent activities in R&D-intensive technology. This area includes industry sectors that invest more than 3 percent of their turnover in R&D (R&D intensity). R&D-intensive technology comprises the areas of high-value technology (R&D intensity between 3 and 9 percent) and cutting-edge technology (R&D intensity above 9 percent).

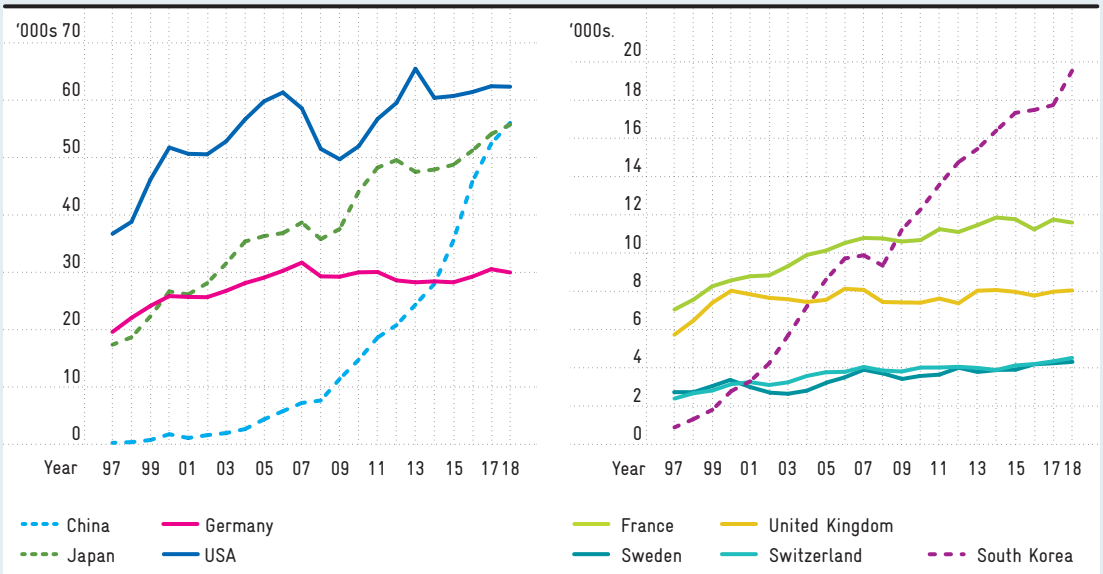
An international comparison reveals Germany's strong specialization in high-value technology (C 6-3), which can be explained by Germany's traditional strengths in the automotive industry, mechanical engineering, and the chemical industry. Germany records the highest value of the comparison group here.

In contrast, China, Sweden, and the USA specialize in cutting-edge technology (C 6-4), an area in which Germany underperforms.

## Number of transnational patent applications in selected countries 1997–2018

Fig. C 6-1

Download data




Transnational patent applications comprise applications in the form of patent families that include at least one application filed with the World Intellectual Property Organization (WIPO) via the Patent Cooperation Treaty (PCT) procedure, or one application filed with the European Patent Office.
Source: EPO (PATSTAT). Calculations by Fraunhofer ISI in Neuhäusler et al. (2021).
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## Number, intensity and growth rates of transnational patent applications in the field of R&D-intensive technology in selected countries in 2018

Tab. C 6-2

Download data

| | Number* | Intensity* | Intensity in R&D-intensive technology | Growth (2008 = 100)* | Growth in R&D-intensive technology (2008 = 100)* |
|---|---|---|---|---|---|
| **Total** | **299,636** | **–** | **–** | **152** | **151** |
| China | 56,035 | 73 | 51 | 733 | 699 |
| **Germany** | **29,959** | **715** | **416** | **102** | **107** |
| EU-28 | 79,699 | 356 | 204 | 108 | 110 |
| Finland | 1,962 | 772 | 437 | 107 | 95 |
| France | 11,595 | 428 | 255 | 108 | 109 |
| United Kingdom | 8,048 | 249 | 148 | 108 | 110 |
| Italy | 5,900 | 254 | 121 | 100 | 95 |
| Japan | 55,727 | 836 | 490 | 156 | 141 |
| Canada | 3,653 | 196 | 118 | 108 | 100 |
| Netherlands | 4,959 | 564 | 297 | 116 | 112 |
| Sweden | 4,311 | 846 | 572 | 116 | 123 |
| Switzerland | 4,517 | 966 | 488 | 117 | 105 |
| South Korea | 19,531 | 728 | 445 | 209 | 192 |
| USA | 62,335 | 400 | 261 | 121 | 120 |

The R&D-intensive technology sector comprises industries that invest more than 3 percent of their turnover in research and development. Intensity is calculated as the number of patents per million gainfully employed persons.
* Figures refer to all industries.
Source: EPO (PATSTAT), OECD (MSTI), World Bank. Calculations by Fraunhofer ISI in Neuhäusler et al. (2021).
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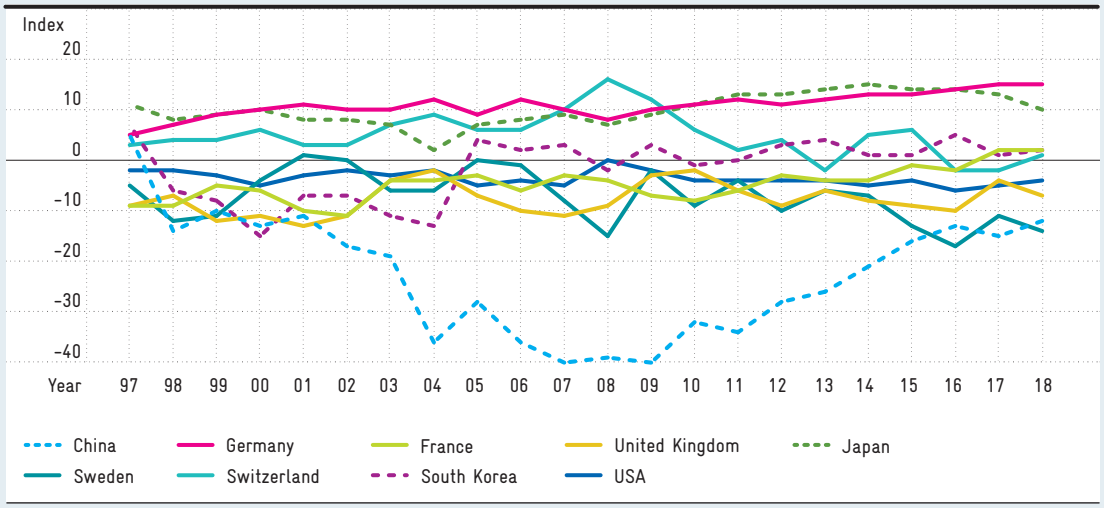
Fig. C 6-3

Download data

## Specialization index in selected countries in the field of high-value technology 1997–2018




The specialization index is calculated based on all transnational patent applications worldwide. Positive or negative values indicate whether the surveyed country's level of activity in each field is disproportionately high or low compared to the global average.
Source: EPO (PATSTAT). Calculations by Fraunhofer ISI in Neuhäusler et al. (2021).
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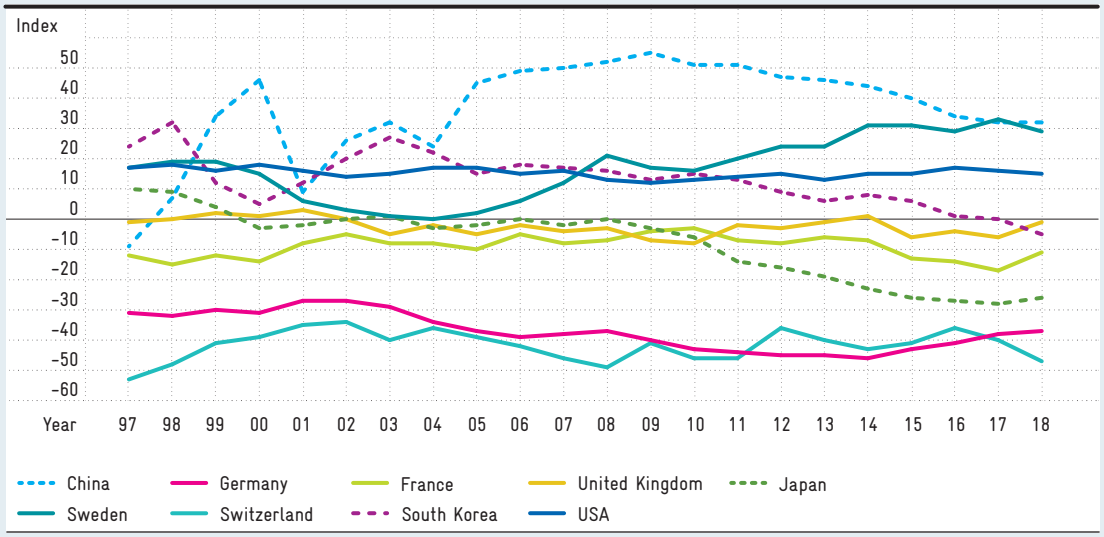
Fig. C 6-4

Download data

## Specialization index in selected countries in the field of cutting-edge technology 1997–2018




The specialization index is calculated based on all transnational patent applications worldwide. Positive or negative values indicate whether the surveyed country's level of activity in each field is disproportionately high or low compared to the global average.
Source: EPO (PATSTAT). Calculations by Fraunhofer ISI in Neuhäusler et al. (2021).
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# Scientific Publications[350] C 7

A large proportion of new technologies and services is based on developments and results from science. Bibliometric indicators and metrics are therefore used as a measure of scientific performance to assess the performance of a research and science system in quantitative and qualitative terms.

The bibliometric database Web of Science (WoS) records publications in scientific journals and citations of these publications worldwide. The research affiliation of scientists as referenced in the database makes it possible to assign individual publications to a specific country. If several authors from different countries are involved in a publication, they are included in the calculations in a fractioned counting method. Indicators regarding the quantity and quality of specialist publications can be used to assess the performance of a research and science system.

The publication shares of selected countries and regions in all publications in Web of Science (C 7-1) show significant changes for the comparative view of the years 2009 and 2019. Most countries, including the large western European nations of Germany, France, and the UK, as well as the USA, have lost publication shares. The German publication share has fallen from 5.3 to 4.1 percent, the British from 5.5 to 4.3 percent, the French from 3.8 to 2.5 percent and the USA's from 23.7 to 17.8 percent. This contrasts with an enormous increase in China's share of publications from 9.3 to 22.5 percent.

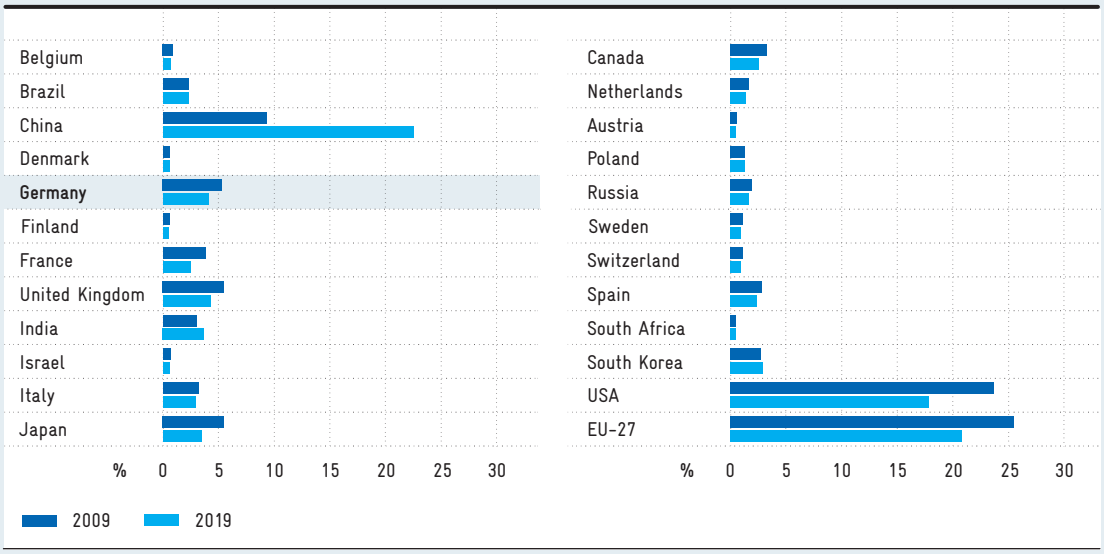
The international alignment (IA) of selected countries and regions in publications in Web of Science (C 7-2) is an indicator of the relative quality of scientific publications. Germany's index score was 10 in 2017, down from 14 in 2009. Publications by authors from Germany have thus relatively lost quality. The publication quality of almost all countries that performed above average in 2009 has declined in relative terms. China was again able to improve its relative publication quality, achieving an index value of 4 for 2017.

The scientific regard (SR) indicator of selected countries and regions for publications in Web of Science (C 7-3) shows that the index value for articles from Germany has fallen from 7 to 2. Articles from Germany were thus cited less frequently in 2017 compared to 2009 than other articles in the journals in which they appeared. This weakening trend is evident in most of those countries that had an above-average index value in 2009. Significant improvements to an above-average index score were achieved by China and Italy.

Fig. C 7-1

Download data

## Percentages of all publications from selected countries and regions in 2009 and 2019




Fractional counting.
Source: Web of Science. Research and calculations by DZHW in Stephen and Stahlschmidt (2021).
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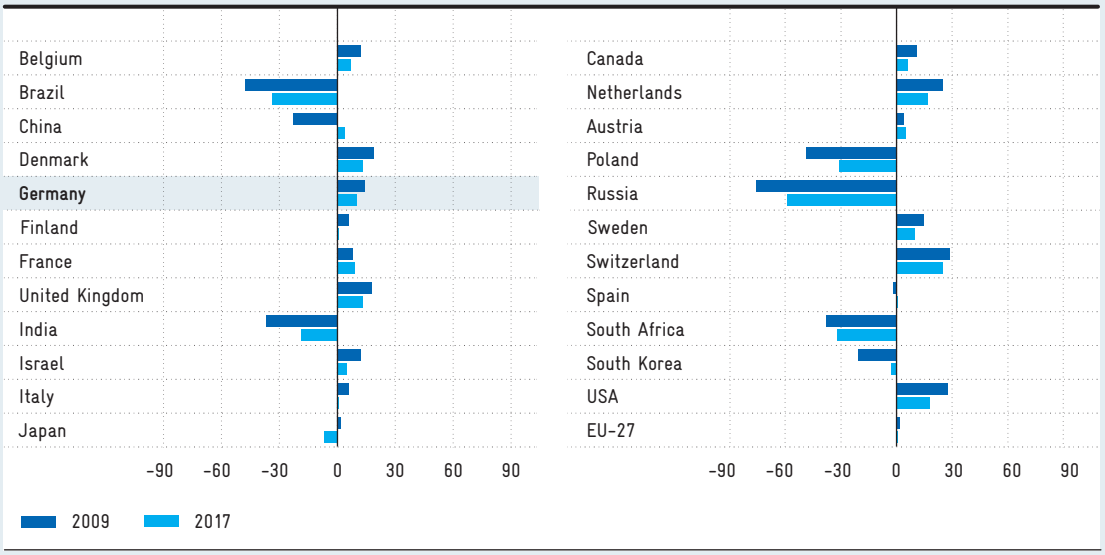
Fig. C 7-2

Download data

## International alignment (IA) of publications from selected countries and regions in 2009 and 2017 (index values)




The IA index indicates whether a country's authors publish in internationally more highly recognized or less highly recognized journals relative to the world average. Positive or negative values indicate an above-average or below-average IA.
Fractional counting.
Source: Web of Science. Research and calculations by DZHW in Stephen and Stahlschmidt (2021).
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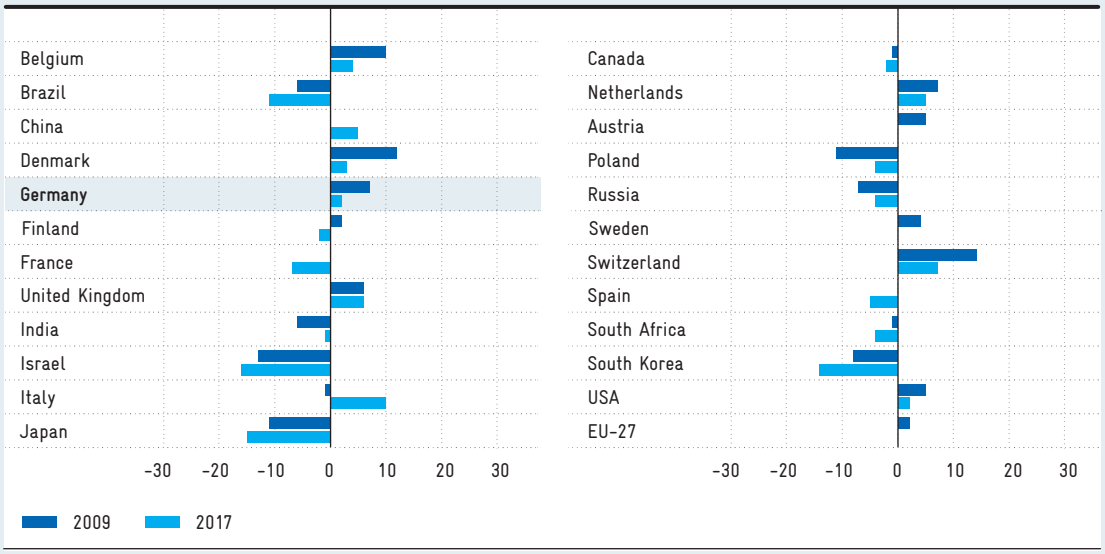
Fig. C 7-3

Download data

## Scientific regard (SR) of publications from selected countries and regions in 2009 and 2017 (index values)




The SR index indicates whether a country's articles are cited on average more frequently or more seldom than other articles in the journals in which they appeared. Positive or negative values indicate an above-average or below-average scientific regard. Fractional counting.
Source: Web of Science. Research and calculations by DZHW in Stephen and Stahlschmidt (2021).
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# C 8 Production, Value Added and Employment[351]

The specialization pattern of a country in foreign trade can be measured with the help of the RCA indicator.[352] It records the export/import ratio of a product group in relation to the export/import ratio of processed industrial goods in total. As in previous years, Germany had a comparative advantage in trade in R&D-intensive goods in 2019 (C 8-1). R&D-intensive goods consist of high-value technology goods and cutting-edge technology goods. However, a more detailed analysis of these two groups of goods shows that Germany's comparative advantage was only positive for trade in high-value technology goods, while it was negative for trade in cutting-edge goods, albeit with a slightly positive trend. France, the UK, Switzerland, South Korea, and the USA recorded positive values of the RCA indicator in cutting-edge technology; China and Japan showed a negative RCA indicator here over the entire period under review. Sweden has been recording negative values since 2010.

The share of research-intensive and knowledge-intensive industries in a country's value added allows conclusions to be drawn about its technological performance in an international comparison (C 8-2). In the area of high-value technology, Germany had the highest share of value added relative to the countries considered, amounting to 9.2 percent in 2018. In the area of cutting-edge technology, Germany was well behind the leaders South Korea (9.9 percent) and Switzerland (9.4 percent) at 2.8 percent. Knowledge-intensive services contributed significantly more to national value added than research-intensive industries in all countries considered. Yet with a value added share of 25.2 percent, they played a smaller role in Germany in 2018 compared to the other countries considered (exception: South Korea).

After the decline in gross value added in the various commercial business sectors in the crisis year 2009, value added in Germany has increased steadily again since 2010 (C 8-3). However, at 3.2 percent, growth in knowledge-intensive services in 2018 was lower than in the previous year (4.1 percent). There was also a lower increase in value added in non-knowledge-intensive services (4 percent versus 4.5 percent). While the increase in value added was also higher in the knowledge-intensive manufacturing sector in 2017 (4.9 percent) than in 2018 (1.1 percent), it was higher in the non-knowledge-intensive manufacturing sector in 2018 (4 percent) than in the previous year (2.5 percent).

The increase in employment subject to social security contributions in various commercial sectors of the economy in Germany between 2009 and 2019 is mainly due to the service sector (C 8-4). In the non-knowledge-intensive services, employment subject to social security contributions increased by 23.7 percent during this period, in the knowledge-intensive services by 27.7 percent. In the non-knowledge-intensive manufacturing sector, employment subject to social security contributions increased by 10.3 percent, in the knowledge-intensive manufacturing sector by 13 percent.

## Revealed comparative advantage (RCA) of selected countries in foreign trade in R&D-intensive goods 2005–2019 (index values)

Tab. C 8-1

Download data

| Year | China* | France | Germany | Japan | South Korea | Sweden | Switzerland | United Kingdom | USA |
|---|---|---|---|---|---|---|---|---|---|
| | | | | R&D-intensive goods | | | | | |
| 2005 | -29 | 7 | 10 | 42 | 17 | -1 | 18 | 14 | 17 |
| 2010 | -27 | 6 | 12 | 33 | 19 | -6 | 22 | 11 | 1 |
| 2015 | -27 | 5 | 13 | 31 | 13 | -5 | 28 | 3 | 2 |
| 2019 | -29 | 6 | 10 | 28 | 12 | 0 | 30 | 17 | -1 |
| | | | | High-value technology goods | | | | | |
| 2005 | 0 | 6 | 27 | 75 | 11 | -2 | 24 | 4 | -5 |
| 2010 | -16 | -2 | 30 | 61 | 7 | -3 | 21 | 15 | -10 |
| 2015 | -3 | -6 | 27 | 63 | 13 | 1 | 21 | 1 | -14 |
| 2019 | -1 | -11 | 19 | 64 | 13 | 7 | 23 | 11 | -17 |
| | | | | Cutting-edge technology goods | | | | | |
| 2005 | -53 | 8 | -34 | -14 | 24 | 1 | 4 | 33 | 55 |
| 2010 | -35 | 20 | -35 | -22 | 33 | -11 | 25 | 1 | 22 |
| 2015 | -46 | 21 | -23 | -35 | 12 | -22 | 41 | 8 | 27 |
| 2019 | -51 | 33 | -15 | -48 | 10 | -25 | 44 | 27 | 23 |

R&D-intensive goods comprise high-value technology goods and cutting-edge technology goods.
A positive RCA value means that the exp./imp. ratio for this product group is higher than for manufactured industrial goods as a whole.
* incl. Hong Kong.
Source: UN COMTRADE database, research November 2020. Calculations and estimates by CWS in Gehrke and Schiersch (2021).
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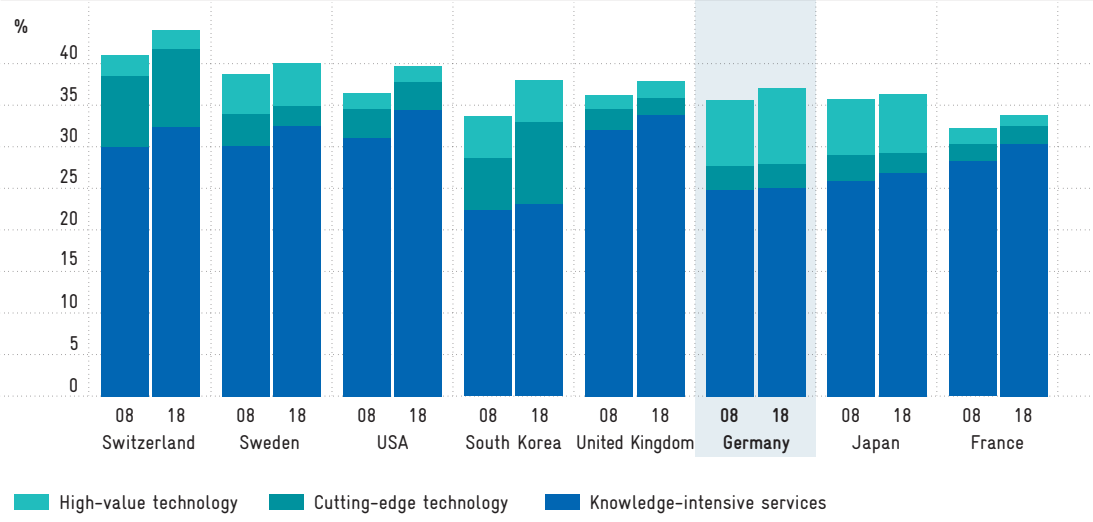
## R&D-intensive industries and knowledge-intensive services in selected countries as a percentage of value added in 2008 and 2018

Fig. C 8-2

Download data




R&D-intensive industries (high-value technology and cutting-edge technology) have an above-average R&D intensity. Knowledge-intensive services are characterized by an above-average proportion of employees with tertiary education qualifications.
Source: OECD-NA, OECD-STAN, OECD-SBS, Eurostat-NA, Eurostat-SBS, EU KLEMS. Calculations and estimates by DIW Berlin in Gehrke and Schiersch (2021).
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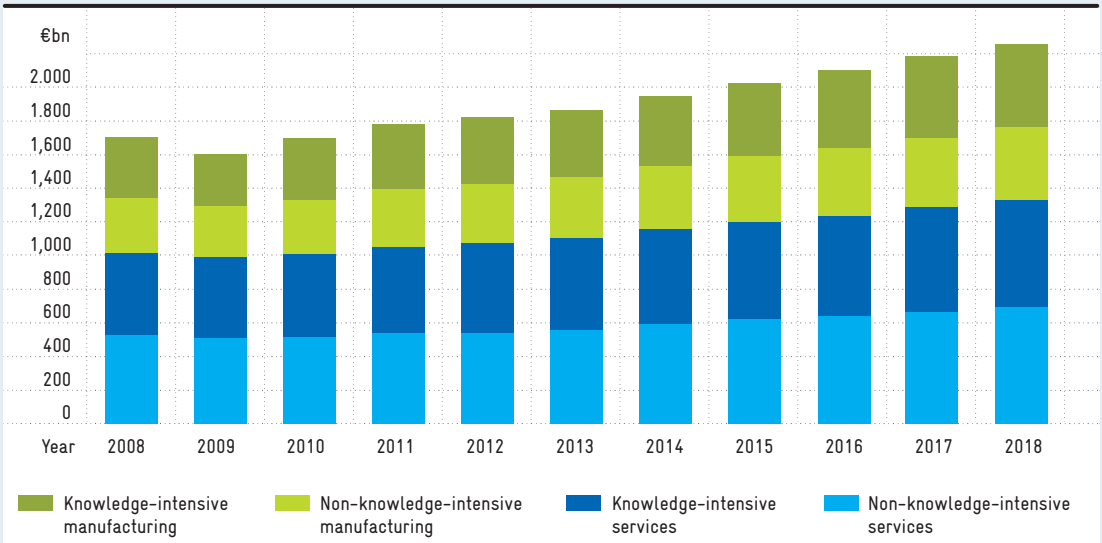
Fig. C 8-3

Download data

## Gross value added in different industrial business sectors in Germany 2008–2018 in billion euros




Gross value added is the difference between the total value of all goods and services produced and the intermediate inputs for their production. Not including agriculture, forestry, fisheries, public administration and services, real estate and housing, education, private households, social insurance, religious and other organizations, associations, and trade unions. Data for 2015 partly revised.
Source: Federal Statistical Office, Fachserie 18, Reihe 1.4, calculation status August 2020. Calculations by CWS in Gehrke and Schiersch (2021).
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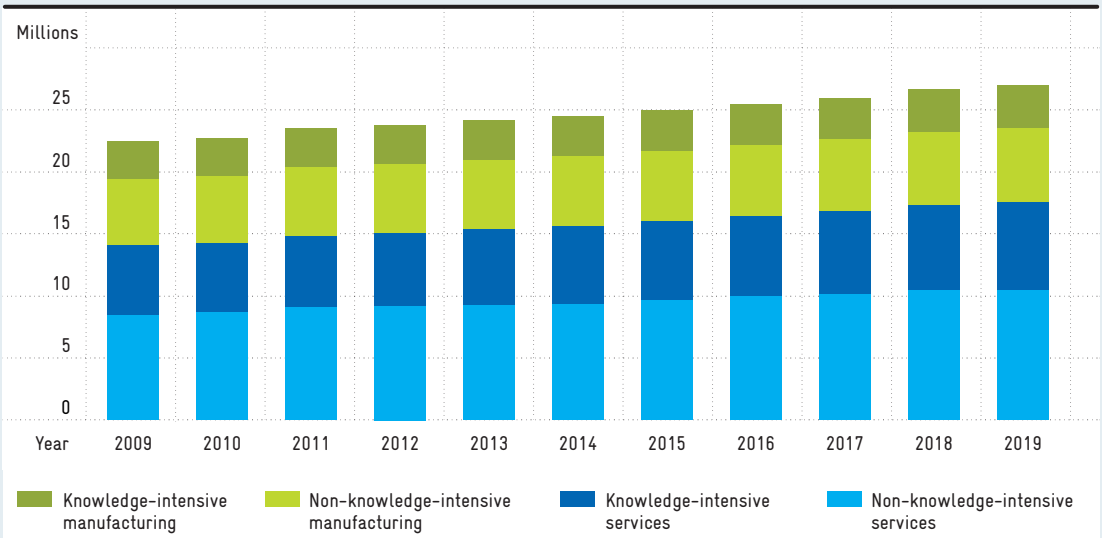
C

Fig. C 8-4

Download data

## Number of employees subject to social security contributions in different industrial business sectors in Germany 2009–2019 in millions




Not including agriculture, forestry, fisheries, public administration and services, real estate and housing, education, private households, social insurance, religious and other organizations, associations, and trade unions.
Source: Federal Employment Agency. Calculations by CWS in Gehrke and Schiersch (2021).
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# D 2 List of Abbreviations

| | |
|---|---|
| 5G | Fifth generation of mobile telephony |
| AES | Adult Education Survey |
| AI | Artificial intelligence |
| AiF | German Federation of Industrial Research Associations (Arbeitsgemeinschaft industrieller Forschungsvereinigungen „Otto von Guericke“ e.V.) |
| AISBL | Association Internationale Sans But Lucratif |
| ASCOT | Technology-based Assessment of Skills and Competences in Vocational Education and Training |
| AVGS | Activation and placement voucher (Aktivierungs- und Vermittlungsgutschein) |
| AZAV | Accreditation and Licensing Ordinance Employment Support (Akkreditierungs- und Zulassungsverordnung Arbeitsförderung) |
| BA | Federal Employment Agency (Bundesagentur für Arbeit) |
| BARDA | Biomedical Advanced Research and Development Authority |
| BBiG | Vocational Training Act (Berufsbildungsgesetz) |
| BIBB | Federal Institute for Vocational Education and Training (Bundesinstitut für Berufsbildung) |
| BMAS | Federal Ministry of Labour and Social Affairs (Bundesministerium für Arbeit und Soziales) |
| BMBF | Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung) |
| BMF | Federal Ministry of Finance (Bundesministerium der Finanzen) |
| BMFSFJ | Federal Ministry for Family Affairs, Senior Citizens, Women and Youth (Bundesministerium für Familie, Senioren, Frauen und Jugend) |
| BMI | Federal Ministry of the Interior, Building and Community (Bundesministerium des Innern, für Bau und Heimat) |
| BMWi | Federal Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie) |
| Cas | CRISPR-associated |
| CDI | Challenge Driven Innovation |
| CEPI | Coalition for Epidemic Preparedness Innovations |
| CERN | Conseil Européen pour la Recherche Nucléaire |
| CERTQUA | Gesellschaft der Deutschen Wirtschaft zur Förderung und Zertifizierung von Qualitätssicherungssystemen in der Beruflichen Bildung mbH |
| ChEM-H | Chemistry, Engineering & Medicine for Human Health |
| CIS | Community Innovation Surveys |
| CLA | Classification of Learning Activities |
| CLAIRE | Confederation of Laboratories for Artificial Intelligence Research in Europe |
| $CO_2$ | Carbon dioxide |
| COVID-19 | Coronavirus disease 2019 |
| CRISPR | Clustered Regularly Interspaced Short Palindromic Repeats |
| CVTS | Continuing Vocational Training Survey |
| CWS | Center for Economic Policy Studies (Center für Wirtschaftspolitische Studien) |
| DFG | German Research Foundation (Deutsche Forschungsgemeinschaft e.V.) |

| | |
|---|---|
| DG RTD | Directorate-General for Research and Innovation |
| DIW | German Institute for Economic Research (Deutsches Institut für Wirtschaftsforschung e.V.) |
| DLR | German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e. V.) |
| DNA | Deoxyribonucleic acid |
| DQR | German Qualifications Framework (Deutscher Qualifikationsrahmen) |
| DZHW-ICE | German Centre for Research on Higher Education and Science Studies – Information, Controlling, Decision (Deutsches Zentrum für Hochschul- und Wissenschaftsforschung GmbH – Information, Controlling, Entscheidung) |
| EASAC | European Academies Science Advisory Council |
| EEG | Renewable Energies Act (Erneuerbare-Energien-Gesetz) |
| EFI | Commission of Experts for Research and Innovation (Expertenkommission Forschung und Innovation) |
| E-government | Electronic government |
| EIA | Environmental impact assessment |
| ELLIS | European Laboratory for Learning and Intelligent Systems |
| EPO | European Patent Office |
| EU | European Union |
| EXIST | EXIST – University-Based Business Start-Ups (Existenzgründungen aus der Wissenschaft) |
| FDA | Food and Drug Administration |
| FEAM | Federation of European Academies of Medicine |
| FRM II | Research Neutron Source Heinz Maier-Leibnitz (Forschungs-Neutronenquelle Heinz Maier-Leibnitz) |
| FZulG | Research Allowance Act (Forschungszulagengesetz) |
| GbR | Partnership under civil law (Gesellschaft bürgerlichen Rechts) |
| GDP | Gross domestic product |
| GenTG | Genetic Engineering Act (Gentechnikgesetz) |
| GERD | Gross domestic expenditure on research and development |
| GMO | Genetically modified organisms |
| GMP | Good manufacturing practice |
| GSC | Grand societal challenges |
| GSW | Humanities and social sciences (Geistes- und Sozialwissenschaften) |
| GWS | Institute of Economic Structures Research (Gesellschaft für Wirtschaftliche Strukturforschung) |
| HIV | Human immunodeficiency virus |
| HTF | High-Tech Forum |
| HTS | High-Tech Strategy |
| HybOrg | Emergence and social impact of hybrid organizations in local crisis management (Entstehung und gesellschaftliche Wirkung hybrider Organisationen im lokalen Krisenmanagement) |
| IA | International alignment |
| IAB | Institute for Employment Research (Institut für Arbeitsmarkt- und Berufsforschung der Bundesagentur für Arbeit) |
| IAW | Institute for Applied Economic Research (Institut für Angewandte Wirtschaftsforschung e.V.) |
| IBM | International Business Machines Corporation |
| ICDL | International Certification of Digital Literacy |
| ICT | Information and communication technology |
| IGP | Innovation Programme for Business Models and Pioneer Solutions (Innovationsprogramm für Geschäftsmodelle und Pionierlösungen) |
| InnoVET | Shaping the Future – Innovations for Excellent Vocational Training (Zukunft gestalten – Innovationen für eine exzellente berufliche Bildung) |
| IP | Intellectual property, Internet protocol |
| ISCED | International Standard Classification of Education |
| ISI | Fraunhofer Institute for Systems and Innovation Research (Fraunhofer-Institut für System- und Innovationsforschung) |

| | |
|---|---|
| ISO | International Organization for Standardization |
| IW | German Economic Institute (Institut der deutschen Wirtschaft Köln e.V.) |
| KHK | Käte Hamburger Kolleg |
| KldB | Classification of occupations (Klassifikation der Berufe) |
| KMK | Standing Conference of the Ministers of Education and Cultural Affairs of the Länder in the Federal Republic of Germany (Kultusministerkonferenz) |
| KOINNO | Competence Centre for Innovative Procurement (Kompetenzzentrum innovative Beschaffung) |
| MBGen | Medium-sized holding companies (Mittelständische Beteiligungsgesellschaften) |
| MDG | Millennium Development Goal |
| MIP | Mannheim Innovation Panel (Mannheimer Innovationspanel) |
| MSTI | Main science and technology indicators |
| MUP | Mannheim Enterprise Panel (Mannheimer Unternehmenspanel) |
| NEPS | National Educational Panel Study |
| NFDI | National Research Data Infrastructure (Nationale Forschungsdateninfrastruktur) |
| NL | Netherlands |
| OECD | Organization for Economic Co-operation and Development |
| PATSTAT | Patent Statistical Database |
| PCT | Patent Cooperation Treaty |
| PEI | Paul-Ehrlich-Institute |
| R&D | Research and development |
| R&I | Research and innovation |
| RatSWD | German Data Forum (Rat für Sozial- und Wirtschaftsdaten) |
| RCA | Revealed comparative advantage |
| RNA | Ribonucleic acid |
| SARS-CoV-2 | Severe Acute Respiratory Syndrome Coronavirus Type 2 |
| SBIR | Small Business Innovation Research |
| SBS | Structural business statistics |
| SDG | Sustainable Development Goal |
| SGB | Social Code (Sozialgesetzbuch) |
| SINTEG | Smart Energy Showcases (Schaufenster für intelligente Energie) |
| SME | Small and medium-sized enterprise |
| SoliKris | Change through Crisis? Solidarity and Desolidarization in Germany and Europe (Veränderung durch Krisen? Solidarität und Entsolidarisierung in Deutschland und Europa) |
| SR | Scientific regard |
| STEM | Science, technology, engineering, and mathematics |
| TALEN | Transcription activator-like effector nuclease |
| ÜBS | Inter-company VET centres (Überbetriebliche Bildungsstätten) |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| VDI | Association of German Engineers (Verein Deutscher Ingenieure e.V.) |
| WEF | World Economic Forum |
| WeGebAU | Further training for low-skilled and employed older workers and employees in companies (Weiterbildung Geringqualifizierter und beschäftigter älterer Arbeitnehmerinnen und Arbeitnehmer in Unternehmen) |
| WHO | World Health Organization |
| WIPANO | Knowledge and Technology Transfer through Patents and Standards (Wissens- und Technologietransfer durch Patente und Normen) |
| WIPO | World Intellectual Property Organization |
| WoS | Web of Science |
| WZ | Economic sectors (Wirtschaftszweige) |
| WZB | Berlin Social Science Center (Wissenschaftszentrum Berlin für Sozialforschung gGmbH) |
| ZEW | ZEW – Leibniz Centre for European Economic Research (ZEW – Leibniz-Zentrum für Europäische Wirtschaftsforschung GmbH) Mannheim |

# Glossary

D 3

### Artificial intelligence (AI)
A general distinction is made between symbolic and neural AI. Symbolic AI is based on the concept of developing rules that allow a conclusion to be drawn from input values. In contrast, in neural AI these rules result from a matching of input values and inferences. Thus, symbolic AI is a deductive system, while neural AI is an inductive system.

### Bildungsinländer, Bildungsausländer
First-year students with foreign citizenship who have acquired their study entitlement in Germany are referred to as 'Bildungsinländer'; persons with a study entitlement acquired abroad who come to Germany to study are referred to as 'Bildungsausländer'.

### Closure rate
The percentage of closed enterprises in the annual average number of active enterprises in a country (enterprise stock) is called the closure rate.

### Cutting-edge technology
Cutting-edge technology goods are those R&D-intensive goods (cf. there) for whose production more than 9 percent of turnover is spent on research and development (R&D, cf. there) on an annual average.

### DigitalPakt Schule
DigitalPakt Schule (Digital Pact for Schools), which came into force in May 2019, is an agreement between the Federal Government and the Länder with which the Federal Government is to support the Länder and municipalities in investing in digital education infrastructure. The Federal Government is making €5 billion available for this purpose. The Länder contribute their own share of at least 10 percent to the financing of the investments supported with federal funds. In 2020, because of the school closures due to the pandemic, it was decided to add another €1.5 billion to the DigitalPakt Schule.

### Direct investment
Cross-border participations in the capital and reserves of enterprises, branches and permanent establishments are regarded as direct investments, provided that at least 10 percent of the capital shares or voting rights are directly attributable to the investor or more than 50 percent are directly and indirectly attributable to them.

### Early stage
Early stage describes the financing of the early development of a company, starting with the financing of research and product conception (seed phase), through the founding of the company, to the start of operational business activities including product development and initial marketing (start-up phase). The seed phase is limited to research and development (R&D) up to the maturity and first implementation of a business idea with a prototype, while within the start-up phase a business plan is drafted and the start of production and product marketing take place.

### E-government
E-government (electronic government) stands for the handling of government and administrative processes with the help of information and communication technologies via electronic media. In the context of e-government, government services and administrative matters are digitalized and offered online.

### Excellence Initiative
The Excellence Initiative, which expired in 2017, was based on a Federal Government-Länder agreement to promote science and research at German universities with the aim of improving international competitiveness. Support is provided within the framework of three funding lines: the graduate schools, the Clusters of Excellence, and the institutional strategies. The successor programme is the Excellence Strategy (cf. there).

### Excellence Strategy
The open-ended successor programme to the Excellence Initiative, which expired in 2017 (cf. there), is the Excellence Strategy. It comprises two funding lines: The funding line of the Clusters of Excellence is intended to serve the project-related funding of internationally competitive research fields at universities or university networks. The funding line of the Universities of Excellence is intended to permanently consolidate universities

or university networks as institutions and to expand their international top position in research based on successful Clusters of Excellence.

### Externalities
Externalities are defined as impacts of economic activities on third parties for which no compensation is provided.

### First-time graduates
First-time graduates are persons who have successfully completed a first degree programme.

### Foresight processes
Foresight processes are used for longer-term foresight regarding technological and societal changes.

### Future Fund
In November 2019, the coalition committee decided to make €10 billion available for a so-called Future Fund. With the passing of the 2021 budget law, the corresponding funds were made available for a ten-year period. In implementing the Future Fund, it is planned to both quantitatively and qualitatively expand existing financing measures and to develop new instruments.

### Future Package
The Future Package is a component of the economic stimulus programme adopted by the Federal Government to deal with the COVID-19 crisis. It particularly targets the promotion of future investments and investments in climate technologies and the advancement of innovations in the fields of hydrogen economy, quantum technology and artificial intelligence, among others.

### Future Skills Initiative
The Future Skills Initiative is a joint action programme of business and civil society that aims to improve the conditions for acquiring digital skills and other skills that will be relevant in the future.

### Germ line gene therapy
The term germ line gene therapy is understood to mean the use of genetic material to treat genetic diseases by correcting or replacing a defective gene in germ cells, which results in the genetic material introduced being passed on to subsequent generations.

### Green hydrogen
Hydrogen is produced by electrolysis, i.e., by splitting water into oxygen and hydrogen. In the production of green hydrogen, only electricity from renewable sources, such as wind and solar energy, is used for electrolysis. This means the production of green hydrogen is $CO_2$-free.

### Green power
Green power or green electricity is electricity that is generated entirely from renewables, such as wind and solar energy.

### Gross domestic product
Gross domestic product (GDP) is the value of all goods and services produced by a country's economy within one year. It is irrelevant whether nationals or foreigners are involved in the production of GDP, it only depends on the location of the value added. GDP is an indicator of the economic performance of an economy in international comparison.

### High-Tech Strategy 2025
The so-called High-Tech Strategy is the Federal Government's policy approach to integrating innovation funding across all federal ministries. The current High-Tech Strategy (HTS) 2025 was adopted by the Federal Cabinet in September 2018.

### High-value technology
High-value technology goods are those R&D-intensive goods (cf. there) for whose production more than 3 percent, but not more than 9 percent of turnover is spent on R&D on an annual average.

### Innovation intensity
The innovation intensity describes companies' innovation expenditure relative to turnover in a corresponding year.

### Key technologies
Key technologies are characterized by a wide range of applications and a high innovative potential.

### Knowledge economy
The knowledge economy comprises the R&D-intensive industries (cf. there) and the knowledge-intensive services (cf. there).

**Knowledge-intensive services**
Knowledge-intensive services are essentially characterized by the fact that the proportion of employees with a university degree is above average.

**Knowledge spillover**
In R&I activities, externalities occur in the form of knowledge outflows that the knowledge producer cannot prevent. For example, competitors can obtain knowledge by inspecting an innovative product without having to bear the full costs of knowledge production themselves. In this case, the private returns of the innovation diverge from the social returns and the innovator will, from a social perspective, invest too little in knowledge production.

**Lock-in effect**
A lock-in effect occurs when an economically sensible switch to a new system, such as from one Internet provider to another, is not made. This is a collective coordination failure: individually, the change is only worthwhile if all or many other users also make the change. Only when many people use the new system is the expected additional benefit for each user higher than the individual costs of the system change.

**Manufacturing sector**
Manufacturing is by far the largest part of the industrial sector, which includes all industries except energy and construction. Characteristic industries are, for example, the food industry, mechanical engineering, the manufacture of motor vehicles/vehicle parts, the manufacture of metal products and the chemical industry.

**Millennium Development Goals (MDGs)**
The MDGs are eight United Nations development goals for the year 2015, which were formulated in 2000. These are: Eradicate extreme poverty and hunger; Achieve universal primary education; Promote gender equality and empower women; Reduce child mortality; Improve maternal health; Combat HIV/AIDS, malaria, and other diseases; Ensure environmental sustainability; Global partnership for development.

**Multi-centre studies**
Multi-centre studies are studies that are conducted at different study centres at the same time.

**National Research Data Infrastructure (NFDI)**
The NFDI is a digital infrastructure currently under construction. In the NFDI, science and research data resources are systematically made accessible for the entire German science system, (inter)nationally networked and sustainably secured, and made qualitatively usable.

**National Skills Strategy**
The National Skills Strategy was adopted in June 2019 by the BMAS and BMBF together with the Länder, the business community, the trade unions, and the Federal Employment Agency. It bundles the activities of the Federal Government and the Länder in the area of job-related CET and is intended to lay the foundation for a new CET culture (cf. also box B 2-4).

**National Hydrogen Strategy**
With the National Hydrogen Strategy adopted in June 2020, the Federal Government is creating a framework for action for the future production, transport, utilization, and further use of hydrogen. It moreover defines steps that are necessary to contribute to achieving the climate goals and to create new value chains for the German economy.

**Neuronal AI**
See Artificial intelligence (AI).

**New Mission Orientation**
New Mission Orientation is an approach to R&I policy that focuses on addressing grand societal challenges and aims at transformative change in the economy and society. To this end, so-called missions are formulated that contain specific transformation goals to be implemented by way of R&I policy and complementary policy measures.

**Off-target effects**
With CRISPR/Cas, targeted changes can be made at previously defined points in the DNA. Off-target effects are when the DNA is also cut at other sites in the genome that are like the actual target sequence but are not themselves the target of the intervention.

**Open Access**
Open Access means free access to scientific results on the Internet.

### Open Government Data
Open Government Data refers to data sets that are made available to third parties for further use and dissemination. Whether the data provided can be described as open depends on various factors such as accessibility, formats, and the legal conditions under which the data may be used. Data relevant to data protection and security are excluded from public use.

### Open Science
Open Science describes the endeavour to enable free access to scientific results and thus make them reusable and comprehensible, e.g., through Open Data or Open Access..

### Patent family
A patent family means a group of patents or patent applications that are directly or indirectly linked by a common priority, have at least one common priority or have the same priority or combination of priorities.

### Policy mix
Policy mix describes a combination of coordinated political measures and initiatives.

### Randomization
Randomization is used to determine the causal effects of interventions whereby study participants are randomly divided into a treatment and a control group. This ensures that participants from the treatment and the control groups differ only by the measure.

### Red biotechnology
Red biotechnology refers to a field of biotechnology that focuses on the research and development of medically relevant products such as medicines, treatments, etc.

### Research and development (R&D)
Research and development (R&D) and research and innovation (R&I, cf. there) are not used synonymously. The OECD's so-called Frascati Manual defines R&D as systematic, creative work to increase the stock of knowledge – also with the aim of finding new applications. The term R&D covers the three areas of basic research, applied research and experimental development.

### R&D intensity
R&D intensity is the share of expenditure on research and development (R&D, cf. there) in the turnover of a company or an industry or in the gross domestic product of a country.

### R&D-intensive goods
R&D-intensive goods are composed of cutting-edge technology goods (cf. there) and high-value technology goods (cf. there).

### R&D-intensive industry
R&D-intensive industry comprises the cutting-edge technology (cf. there) and high-value technology (cf. there) sectors.

### Research and innovation (R&I)
Research and innovation (R&I) and research and development (R&D, cf. there) are not used synonymously. R&D is only one aspect of R&I activities. Innovation, as defined in the OECD's Oslo Manual, involves the introduction of new or significantly improved products (goods and services) or processes.

### Social innovations
Changes in the use of technologies as well as changes in lifestyles, business and financing models, ways of working and forms of organization are referred to as social innovations and basically include changes in social practices. Social innovations can be both complementary to and a consequence of a technological innovation, or completely independent of it.

### Somatic-cell gene therapy
The term somatic-cell gene therapy refers to the use of genetic material to treat genetic diseases by correcting or replacing a defective gene. The triggered genetic changes only affect the treated individual and are not passed on.

### Start-ups
Start-ups are newly established companies with an innovative business idea.

### Start-up rate
The start-up rate is the number of start-ups in relation to the overall number of enterprises.

### Sustainable Development Goals (SDGs)
In 2015, the global community adopted the 2030 Agenda, which contains 17 SDGs. These are: End poverty in all its forms everywhere; End hunger, achieve food security and improved nutrition and promote sustainable agriculture; Ensure healthy lives and promote well-being for all at all ages; Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all;

Achieve gender equality and empower all women and girls; Ensure availability and sustainable management of water and sanitation for all; Ensure access to affordable, reliable, sustainable and modern energy for all; Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all; Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation; Reduce inequality within and among countries; Make cities and human settlements inclusive, safe, resilient and sustainable; Ensure sustainable consumption and production patterns; Take urgent action to combat climate change and its impacts; Conserve and sustainably use the oceans, seas and marine resources for sustainable development; Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss; Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels; Strengthen the means of implementation and revitalize the global partnership for sustainable development.

**Symbolic AI**
See Artificial intelligence (AI).

**Three percent objective**
The European Council decided in Barcelona in 2002 to increase R&D spending in the EU to 3 percent of GDP by 2010. In addition, the private sector should finance two thirds of this expenditure.

**Transformation Failure**
Innovations can fundamentally help to overcome societal challenges and thus enable and accelerate transformative change to achieve socially desired goals. Yet there are various forms of transformation failure that lead to corresponding innovations not being made or not being applied to a sufficient extent (for further details cf. box B 1-2).

**Umbrella initiative Berufsbildung 4.0**
Berufsbildung 4.0 (Vocational Education and Training 4.0) is an initiative launched by the BMBF in 2016 which, in cooperation with the BIBB, bundles activities to align the structure and content of VET with the requirements of an increasingly digitalized and networked economy (cf. also box B 2-4).

**Venture capital**
Venture or risk capital is the seed capital for start-ups and young companies. This also includes funds that are used to support the equity base of small and medium-sized enterprises so they can expand and implement innovative, sometimes high-risk projects. For investors, the investment of venture capital is also high-risk, hence the term venture capital. Equity capital in the form of venture capital is often provided by special venture capital companies (capital investment companies). A distinction is made between the seed, start-up, and later stages.

# D 4 Economic Sectors in R&D-intensive Industries and Knowledge-intensive Commercial Services[353]

## R&D-intensive industries within the Classification of Economic Activities, 2008 edition (WZ 2008) (4-digit classes) n.e.c. = not elsewhere classified

**Cutting-edge technology**

20.20 Manufacture of pesticides and other agrochemical products
21.10 Manufacture of basic pharmaceutical products
21.20 Manufacture of pharmaceutical preparations
25.40 Manufacture of weapons and ammunition
26.11 Manufacture of electronic components
26.20 Manufacture of computers and peripheral equipment
26.30 Manufacture of communication equipment
26.51 Manufacture of instruments and appliances for measuring, testing and navigation
26.60 Manufacture of irradiation, electromedical and electrotherapeutic equipment
26.70 Manufacture of optical and photographic equipment
29.31 Manufacture of electrical and electronic equipment for motor vehicles
30.30 Manufacture of air- and spacecraft and related machinery
30.40 Manufacture of military fighting vehicles

**High-value technology**

20.13 Manufacture of other inorganic basic materials and chemicals
20.14 Manufacture of other organic basic materials and chemicals
20.52 Manufacture of glues
20.53 Manufacture of essential oils
20.59 Manufacture of other chemical products n.e.c.
22.11 Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres
22.19 Manufacture of other rubber products
23.19 Manufacture and processing of other glass, including technical glassware
26.12 Production of loaded electronic boards
26.40 Manufacture of consumer electronics
27.11 Manufacture of electric motors, generators and transformers
27.20 Manufacture of batteries and accumulators
27.40 Manufacture of electric lighting equipment
27.51 Manufacture of electric domestic appliances
27.90 Manufacture of other electrical equipment
28.11 Manufacture of engines and turbines, except aircraft, vehicle and cycle engines
28.12 Manufacture of fluid power equipment
28.13 Manufacture of other pumps and compressors
28.15 Manufacture of bearings, gears, gearing and driving elements
28.23 Manufacture of office machinery and equipment (excluding computers and peripheral equipment)
28.24 Manufacture of power-driven hand tools
28.29 Manufacture of other general-purpose machinery n.e.c.
28.30 Manufacture of agricultural and forestry machinery
28.41 Manufacture of metal forming machiner
28.49 Manufacture of other machine tools
28.93 Manufacture of machinery for food, beverage and tobacco processing
28.94 Manufacture of machinery for textile, apparel and leather production
28.95 Manufacture of machinery for paper and paperboard production
28.99 Manufacture of other special-purpose machinery n.e.c.
29.10 Manufacture of motor vehicles
29.32 Manufacture of other parts and accessories for motor vehicles
30.20 Manufacture of railway locomotives and rolling stock
32.50 Manufacture of medical and dental instruments and supplies

## Knowledge-intensive commercial services within the Classification of Economic Activities, 2008 edition (WZ 2008) (3-digit classes)

**Knowledge-intensive services**

*Emphasis on finance and assets*

411 Development of building projects
641 Monetary intermediation
642 Activities of holding companies
643 Trusts, funds and similar financial entitie
649 Other financial service activities, except insurance and pension funding
651 Insurance
652 Reinsurance
653 Pension funding
661 Activities auxiliary to financial services, except insurance and pension funding
663 Fund management activities
681 Buying and selling of own real estate
683 Real estate activities on a fee or contract basis
774 Leasing of intellectual property and similar products, except copyrighted worksEmphasis on communication
611 Wired telecommunications activities
612 Wireless telecommunications activities
613 Satellite telecommunications activities
619 Other telecommunications activities
620 Computer programming, consultancy and related activities
631 Data processing, hosting and related activities, web portals
639 Other information service activities n.e.c.

Emphasis on technical consulting and research

711 Architectural and engineering activities and related technical consultancy
712 Technical testing and analysis
721 Research and experimental development on natural sciences and engineering
749 Other professional, scientific and technical activities n.e.c.

*Emphasis on non-technical consulting and research*

691 Legal activities
692 Accounting, bookkeeping and auditing activities; tax consultancy
701 Activities of head offices
702 Management consultancy activities
722 Research and experimental development on social sciences and humanities
731 Advertising
732 Market research and public opinion polling
821 Office administrative and support activities

*Emphasis on media and culture*

581 Publishing books and periodicals; other publishing activities
582 Software publishing
591 Motion picture, video and television programme activities
592 Sound recording and music publishing activities
601 Radio broadcasting
602 Television programming and broadcasting activities
741 Specialized design activities
743 Translation and interpreting activities
823 Organization of conventions and trade shows
900 Creative, arts and entertainment activities
910 Libraries, archives, museums and other cultural activities

*Emphasis on health*

750 Veterinary activities
861 Hospital activities
862 Medical and dental practice activities
869 Other human health activities n.e.c.

# D 5 Recent Studies on the German Innovation System

The Commission of Experts for Research and Innovation (EFI) regularly commissions studies on topics that are relevant to innovation policy These studies can be accessed via the EFI website (www.e-fi.de/en/publications/studies) in the series 'Studies on the German innovation system' (Studien zum deutschen Innovationssystem). The findings are integrated into the Report of the Commission of Experts.

1-2021
Gehrke, B.; Kerst, C.; Wieck, M.; Weilage, I. (2021): Bildung und Qualifikation als Grundlage der technologischen Leistungsfähigkeit Deutschlands 2021. Fortschreibung der Indikatoren. Studien zum deutschen Innovationssystem. Berlin: EFI.

2-2021
Schasse, U. (2021): Forschung und Entwicklung in Staat und Wirtschaft. Studien zum deutschen Innovationssystem. Berlin: EFI.

3-2021
Bersch, J.; Berger, M.; Füner, L. (2021): Unternehmensdynamik in der Wissenswirtschaft in Deutschland 2019. Gründungen und Schließungen von Unternehmen, Gründungsdynamik in den Bundesländern, Internationaler Vergleich, Wagniskapital-Investitionen in Deutschland und im internationalen Vergleich. Studien zum deutschen Innovationssystem. Berlin: EFI.

4-2021
Neuhäusler, P.; Rothengatter, O.; Feidenheimer, A. (2021): Patent applications – Structures, trends and recent developments 2020. Studien zum deutschen Innovationssystem. Berlin: EFI.

5-2021
Stephen, D.; Stahlschmidt, S. (2021): Performance and structures of the German science system 2021. Studien zum deutschen Innovationssystem. Berlin: EFI.

6-2021
Gehrke, B.; Schiersch, A. (2021): FuE-intensive Industrien und wissensintensive Dienstleistungen im internationalen Vergleich. Studien zum deutschen Innovationssystem. Berlin: EFI.

7-2021
Polt, W.; Ploder, M.; Breitfuss, M.; Daimer, S.; Jackwerth, T., Zielinski, A. (2021): Politikstile und Politikinstrumente in der F&I-Politik. Studien zum deutschen Innovationssystem. Berlin: EFI.

8-2021
Weber, M.; Biegelbauer, P.; Brodnik, C.; Dachs, B.; Dreher, C.; Kovac, M.; Pulenkova, E.; Schartinger, D.; Schwäbe, C. (2021): Agilität in der F&I-Politik: Konzept, Definition, Operationalisierung. Studien zum deutschen Innovationssystem. Berlin: EFI.

9-2021
Bachmann, R.; Bode, E.; Görg, H.; Schmidpeter, B. (2021): Veränderungen von Tätigkeitsprofilen im Zuge des digitalen Wandels in Deutschland. Studien zum deutschen Innovationssystem. Berlin: EFI.

10-2021
Kirchmann, A.; Laub, N.; Maier, A.; Zühlke, A.; Boockmann, B. (2021): Technologische Innovationen und Wandel der Arbeitswelt in Deutschland: Herausforderungen für die berufliche Aus- und Weiterbildung sowie die Re-Qualifizierung im Zuge des digitalen Wandels. Studien zum deutschen Innovationssystem. Berlin: EFI.

11-2021
Elsner, M. (2021): Aktueller Stand der CRISPR-Technologie – Potenziale und Herausforderungen. Studien zum deutschen Innovationssystem. Berlin: EFI.

12-2021
Zyontz, S.; Pomeroy-Carter, C. (2021): Mapping of the research, innovation and diffusion activity of CRISPR across countries. Studien zum deutschen Innovationssystem. Berlin: EFI.

13-2021
Dederer, H.-G.; Frenken, G. (2021): Genom-Editierung am Menschen. Vergleich der regulatorischen Rahmenbedingungen für CRISPR-Gen-Editierung und ihre Auswirkungen auf Forschung und Innovation. Studien zum deutschen Innovationssystem. Berlin: EFI.

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# Endnotes

D 7

## A 1

1 These results are based on a business survey conducted by ZEW Mannheim in the context of the ZEW Business Survey of the Information Economy. The regular survey includes companies with at least five employees from the sectors information and communication technologies (ICT, consisting of ICT hardware and ICT services), media services and knowledge-intensive services (legal and tax consultancy, auditing, public relations and management consultancy, architectural and engineering offices, technical, physical and chemical investigation, research and development, advertising and market research as well as other freelance, scientific and technical activities). All these sectors together form the information sector. The survey was expanded to include manufacturing companies. This includes the sub-sectors of chemicals and pharmaceuticals, mechanical engineering, vehicle construction and other manufacturing. The survey was conducted in September 2020 as part of a combined written and online-based survey. In total, the extrapolated results are based on about 870 usable responses from the information sector and about 540 responses from manufacturing. To ensure the representativeness of the analyses, the answers of the survey participants were extrapolated by the ZEW to the number of all companies in the sectors under consideration. For more information on the ZEW Business Survey see ZEW (2020) and https://www.zew.de/publikationen/zew-gutachten-und-forschungsberichte/forschungsberichte/informationswirtschaft/zew-branchenreport-informationswirtschaft (last accessed on 15 January 2021).

2 Cf. https://www.bundesregierung.de/breg-en/issues/konjunkturpaket-1757640 and https://www.bmbf.de/de/zukunftspaket-fuer-das-innovationsland-deutschland-11825.html (last accessed on 15 January 2021).

3 Cf. Federal Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie, BMWi) (2020b).

4 Adjustments were made to the bridging aid in the second phase (funding period September to December 2020), which grants companies a subsidy in the event of COVID-19-related loss in turnover. In addition, the threshold whereby SMEs with up to five employees can receive a maximum of €9,000 and those with up to ten employees a maximum of €15,000 has been removed without substitution and the flat rate for staff costs has been increased from 10 percent of eligible costs to 20 percent. Cf. https://www.ueberbrueckungshilfe-unternehmen.de/UBH/Navigation/DE/Home/home.html (last accessed on 15 January 2021).

5 The adjustment refers to significant easements for the acquisition of shares by medium-sized holding companies. Similarly, the Federal Government's counter-guarantee statements were adjusted and improved. Cf. BMWi and Federal Ministry of Finance (Bundesfinanzministerium, BMF) (2020).

6 Cf. https://www.bmbf.de/files/090_20_Faktenblatt_Konjunkturpaket.pdf (last accessed on 15 January 2021).

7 Pursuant to Article 8 of the Second Act on the Implementation of Tax Relief Measures to Cope with the Corona Crisis (Second Corona Tax Relief Act (Zweites Gesetz zur Umsetzung steuerlicher Hilfsmaßnahmen zur Bewältigung der Corona-Krise (Zweites Corona-Steuerhilfegesetz)) adopted in June 2020, Section 3 (5) of the Research Allowance Act (Forschungszulagengesetz, FZulG) was amended and the amount of the maximum assessment base for eligible expenses incurred in the period from July 2020 to June 2026 was increased from €2 million to €4 million. This doubled the funding cap of the Research Allowance from €500,000 to €1 million for the period mentioned, with an unchanged funding rate of 25 percent. The coalition committee estimated a financial requirement of €1 billion for this. Cf. Deutscher Bundestag (2020), Deutscher Bundestag (2019b) and https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Schlaglichter/Konjunkturpaket/2020-06-03-eckpunktepapier.pdf?__blob=publicationFile&v=12 (last accessed on 15 January 2021).

8 The Commission of Experts had formulated alternative proposals in the run-up to the amendment of the FZulG. This included giving more support to commissioned R&D projects, increasing the assessment base for R&D personnel costs and/or increasing the funding rate for R&D personnel costs. Cf. Bertschek et al. (2020c).

9 Cf. Rammer et al. (2021).

10 Cf. Köhler-Geib (2020).

11 Cf. Bertschek et al. (2020b).

12 Cf. Bertschek et al. (2020a).

13 The special programme funds, among others, three companies (BioNTech, CureVac, IDT Biologika) that work with different technological approaches to vaccine development. Cf. https://www.bmbf.de/de/coronavirus-was-tut-das-bmbf-11069.html and https://www.bmbf.de/foerderungen/bekanntmachung-3035.html (each last accessed on 15 January 2021).

14 The BMBF also supports the German Center for Infection Research and the German Center for Lung Research. In addition, the BMBF has expanded the framework conditions around project funding in the short term to ensure liquidity for those already working in BMBF-funded projects. Cf. https://www.bmbf.de/de/coronavirus-was-tut-das-bmbf-11069.html (last accessed on 15 January 2021).

15 Cf. BMBF (2021).

16 Funding for funding projects is increased to expand the respective object of investigation to include the effects of the COVID-19 crisis (e.g., funding line Social Cohesion in Times of Crisis and Upheaval). In addition, support is provided for research in the humanities and social sciences on the social consequences and implications of the COVID-19 crisis, e.g. at the Käte Hamburger Kolleg Law as Culture Center for Advanced Study and at the Maria Sibylla Merian Centres for Advanced Studies, as well as for the establishment of a networking and discussion platform for academic communication in the humanities and social sciences (on the BMBF's internet portal for the humanities and social sciences). A working group of the Council for Social and Economic Data (Rat für Sozial- und Wirtschaftsdaten, RatSWD) acts as a focal point for numerous currently conducted small and large empirical surveys on the social impact of the COVID-19 crisis. Cf. https://www.konsortswd.de/ratswd/themen/corona/studien/ (last accessed on 15 January 2021).

17 Forthcoming publications are also recorded, hence the inclusion of 2021. Search keywords: Corona, -Covid-19, Pandemic*, Coronavirus, SARS-CoV-2, Lockdown, Epidemic, Respiratory disease. Articles can have several authors with different affiliations and are then assigned to several countries. Only articles attributable to the disciplines of medicine and others, social sciences and others, and engineering sciences and others are included.

18 Researchers with affiliations in Italy and India publish 8.25 percent and 6.1 percent of all COVID-19-related scientific publications, respectively..

19 Cf. Weber et al. (2021: 123).

20 Cf. https://www.phe.gov/about/barda/Pages/default.aspx (last accessed on 15 January 2021).

## A 2

21 Cf. here and below BMWi (2020d).

22 This tightening took place while adapting the existing German investment control rules to the EU Screening Regulation of October 2019. The EU Screening Regulation establishes, among other things, a new information and cooperation mechanism for screening foreign direct investment in its Member States. This leaves the responsibility for examination at the level of the Member State concerned, but at the same time aims to consider in the examination also effects on public policy and public security of other Member States as well as projects and programmes of Union interest. Cf. European Parliament and European Council (2019) and https://community.beck.de/2020/10/19/update-zum-investitionskontrollrecht-16-awv-aenderung-beschlossen/eu-screening-verordnung-anwendbar (last accessed on 15 January 2021).

23 It is necessary to examine not only the effects on Germany, but also on other EU Member States as well as on EU programmes and projects. Cf. https://community.beck.de/2020/10/19/update-zum-investitionskontrollrecht-16-awv-aenderung-beschlossen/eu-screening-verordnung-anwendbar (last accessed on 15 January 2021). Moreover, any company takeover subject to notification is to be suspended for the duration of the examination. In this way, the Federal Government wants to prevent the players involved from creating a fait accompli during the ongoing audit and undermining the objectives of the investment audit. Cf. Matthes (2020: 26f.) and https://www.bmwi.de/Redaktion/DE/Artikel/Service/Gesetzesvorhaben/erstes-gesetz-aenderung-aussenwirtschaftsgesetz.html (last accessed on 15 January 2021).

24 Cf. Die Bundesregierung (2020).

25 Cf. EFI (2020: 56ff.).

26 Cf. Die Bundesregierung (2020) and https://www.bmwi.de/Redaktion/DE/Artikel/Service/Gesetzesvorhaben/erstes-gesetz-aenderung-aussenwirtschaftsgesetz.html (last accessed on 15 January 2021).

27 Cf. Deutscher Bundestag (2019a)..

28 Cf. VdTÜV (2020).

29 According to § 2 of the Electromobility Act, electric vehicles include not only pure battery electric vehicles but also fuel cell vehicles and externally chargeable plug-in hybrid vehicles that emit a maximum of 50g of $CO_2$ per kilometre or can cover a distance of at least 40 kilometres purely electrically.

30 Cf. https://nationale-leitstelle.de/news/ (last accessed on 15 January 2021).

31 Cf. https://www.bmwi.de/Redaktion/DE/Pressemitteilungen/2020/12/20201203-altmaier-scheuer-spitzengespraech-ausbau-ladeinfrastruktur-elektrofahrzeuge.html (last accessed on 15 January 2021).

32 Cf. BMWi (2020a) and https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Schlaglichter/Konjunkturpaket/2020-06-03-eckpunktepapier.pdf?__blob=publicationFile&v=12 (last accessed on 15 January 2021).

33 Cf. https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Schlaglichter/Konjunkturpaket/2020-06-03-eckpunktepapier.pdf?__blob=publicationFile&v=12 (last accessed on 15 January 2021).

34 Cf. https://www.bmwi.de/Redaktion/DE/Artikel/Energie/eeg-stellungnahme-nationaler-wasserstoffrat.html (last accessed on 15 January 2021).

35 Cf. https://www.sinteg.de/ (last accessed on 15 January 2021).

36 Cf. https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Schlaglichter/Konjunkturpaket/2020-06-03-eckpunktepapier.pdf?__blob=publicationFile (last accessed on 15 January 2021).

37 Cf. Kagermann et al. (2020: 6).

38 Cf. Kagermann et al. (2020: 6).

39 Cf. https://www.bmbf.de/de/quantentechnologien-7012.html (last accessed on 15 January 2021).

40 Cf. https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Schlaglichter/Konjunkturpaket/2020-06-03-eckpunktepapier.pdf?__blob=publicationFile (last accessed on 15 January 2021).

41 Cf. Fraunhofer (2019).

42 Cf. https://www.bundesregierung.de/breg-de/aktuelles/fortschreibung-ki-strategie-1824340 and https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Schlaglichter/Konjunkturpaket/2020-06-03-eckpunktepapier.pdf?__blob=publicationFile (last accessed on 15 January 2021).

43 Symbolic AI is based on the concept of developing rules that allow a conclusion to be drawn from input values. In contrast, in neural AI these rules result from a matching of input values and inferences. Thus, symbolic AI is a deductive system, while neural AI is an inductive system. Cf. Cardon et al. (2018).

44 Cf. https://ellis.eu/ (last accessed on 15 January 2021).

45 Cf. https://claire-ai.org/about/?lang=de (last accessed on 15 January 2021).

46 Cf. Huber et al. (2020), https://www.handelsblatt.com/politik/deutschland/kuenstliche-intelligenz-bund-hat-bisher-kaum-neue-ki-professuren-eingerichtet/26287136.html?ticket=ST-19829798-rKPhmT9m1zsNX0fvH1i3-ap4 (last accessed on 15 January 2021). The figure of 28 AI-related professorships cited by the BMBF in a statement is based on all projects funded by the BMBF. The figure thus also includes professorships whose funding is not explicitly provided by the AI Strategy but by other funding programmes such as the Excellence Strategy or the Tenure Track Programme. Cf. https://annachristmann.de/wp-content/uploads/2020/10/Antwort_SF_10_78_KI_Professuren_Christmann.pdf and https://dip21.bundestag.de/dip21/btd/19/248/1924813.pdf (each last accessed on 15 January 2021).

47 Cf. EFI (2019: chapter A 2).

48 Cf. https://www.bmwi.de/Redaktion/DE/FAQ/Dateninfrastruktur/faq-projekt-gaia-x.html (last accessed on 15 January 2021).

49 The acronym AISBL stands for Association internationale sans but lucratif. In English: International association without lucrative purpose.

50 Cf. https://www.heise.de/news/Gaia-X-Grosse-US-Hyper--scaler-wollen-in-EU-Cloud-kraeftig-mitmischen-4965630.html?seite=3 and http://www.finanztreff.de/news/wirtschaftsministerium-200-millionen-euro-fuer-gaia-x/22534640 (last accessed on 15 January 2021).

51 Cf. https://background.tagesspiegel.de/digitalisierung/das-ist-die-datenstrategie (last accessed on 15 January 2021).

52 Cf. https://www.bmwi.de/Redaktion/DE/Artikel/Service/Gesetzesvorhaben/zweites-open-data-gesetz-und-datennutzungsgesetz.html (last accessed on 15 January 2021).

53 Cf. https://www.gwk-bonn.de/fileadmin/Redaktion/Dokumente/Papers/NFDI.pdf (last accessed on 15 January 2021).

54 Cf. https://www.nfdi.de/informationen-v2 (last accessed on 15 January 2021).

55 Cf. DFG (2020: 5).

56 Cf. Die Bundesregierung (2018: 48), EFI (2016: chapter A 1) and EFI (2017: 27). In the New High-Tech Strategy (HTS), the predecessor strategy of the HTS 2025, the concept of innovation was expanded to include not only technological but also social innovations. Cf. EFI (2017: 92).

57 Cf. Die Bundesregierung (2018: 11). The Federal Government has already promoted social innovations in recent years in the context of various measures and programmes. Examples include the funding programme Innovations for the Production, Service and Work of Tomorrow and the Innovation Programme for Business Models and Pioneer Solutions (Innovationsprogramm für Geschäftsmodelle und Pionierlösungen, IGP).

58 The competition is designed as a multi-stage, competitive procedure. In the first step, the BMBF, taking into account the results of a participatory online evaluation by citizens, awarded 30 ideas for the Ideas Prize for Social Innovation. With the prize money of €12,500 each, the ideas will be developed into a concept. The ten projects selected for the trial phase (with renewed participatory online evaluation) will be funded for up to two years with up to €200,000 each. Follow-up funding to put the five best projects into practice is planned, as is accompanying research and evaluation of the funding measure. Cf. Bundesanzeiger (2020). The BMWi, too, has recently announced a funding programme specifically aimed at social enterprises and social start-ups. Cf. https://www.bmwi.de/Redaktion/DE/Pressemitteilungen/2020/12/20201202-jarzombek-social-entrepeneurs-erhalten-kuenftig-speziell-auf-ihre-beduerfnisse-zugeschnittene-foerderung.html (last accessed on 15 January 2021).

59 In its 2016 annual report, the Commission of Experts already called for greater attention to be paid to social innovations and for experimentation with new formats of participation as well as new funding instruments, such as competitions or prize money. Cf. EFI (2016: 21).

## A 3

60 Cf. https://de.statista.com/statistik/daten/studie/1224/umfrage/arbeitslosenquote-in-deutschland-seit-1995/ (last accessed on 15 January 2021).

61 Cf. EFI (2017: chapter B 1-2).

62 Cf. EFI (2017: chapter B 1-4), EFI (2018: chapter A 1), EFI (2019: chapter A 1) and EFI (2020: chapter A 2).

63 Cf. BMBF (2006), BMBF (2010), Die Bundesregierung (2014), Die Bundesregierung (2018), EFI (2008: chapter C 5), EFI (2011: chapter A 5), EFI (2015: chapter A 3), EFI (2017: chapter B 5-1), EFI (2019: chapter A 1).

64 Cf. EFI (2020: chapter B 1).

65 Cf. https://www.umweltbundesamt.de/daten/klima/treibhausgas-emissionen-in-deutschland#treibhausgas-emissionen-nach-kategorien (last accessed on 15 January 2021).

66 Cf. EFI (2016: chapter B 2), EFI (2019: chapter A 2), EFI (2018: chapter B 3), EFI (2020: chapter B 2), EFI (2016: chapter B 4) and EFI (2019: chapter B 4).

67 In the EU's Digital Economy and Society Indicator, Germany ranked 21st out of 28 in digital public services in 2020. Cf. https://ec.europa.eu/digital-single-market/en/digital-public-services (last accessed on 15 January 2021). Cf. on e-government also EFI (2017: chapter B 6-2).

68 This is what happened, among other things, with report chapters on the importance of the higher education and vocational training system for the innovation system, on the development of skilled workers, on digital education, on the digitalization of higher education institutions and, in this report, on vocational and continuing education and training in digital transformation (chapter B 2). Cf. EFI (2014: chapter A 3), EFI (2017: chapter B 3-1), EFI (2018: chapter A 4), EFI (2019: chapter B 4).

69 In November 2018, the Federal Government presented a strategy for safeguarding skilled labour. Cf. https://www.bmwi.de/Redaktion/DE/Pressemitteilungen/2018/20181106-startschuss-fuer-umsetzung-der-fachkraeftestrategie-gefallen.html (last accessed on 15 January 2021).
70 Cf. Die Bundesregierung (2019).
71 Cf. Bloom et al. (2020).
72 Cf. EFI (2018: chapter B 1).
73 Cf. EFI (2018: chapter B 1).
74 Cf. EFI (2018: chapter B 1).
75 Cf. here and below EFI (2017: chapter A 2) and EFI (2019: chapter B 1).
76 The Federal Government is pushing the better use of knowledge gained at tertiary education institutions, for example, within the context of the programmes 'EXIST – Start-ups from Science' (EXIST – Existenzgründungen aus der Wissenschaft), 'WIPANO – Knowledge and Technology Transfer through Patents and Standards' (WIPANO – Wissens- und Technologietransfer durch Patente und Normen) and 'Research at Universities of Applied Sciences' (Forschung an Fachhochschulen).
77 Cf. EFI (2017: chapter B 7) and EFI (2020: chapter A 1).
78 Cf. EFI (2017: chapter A 5 and B 5-2).
79 The Commission of Experts also considers it useful to examine the introduction of a programme that, like the Dutch Small Business Innovation Research (SBIR) programme, supports companies in developing innovative solutions to societal problems (cf. box B 1-5).

## B 1

80 Cf. below Fier and Harhoff (2002), Gassler et al. (2006) and Polt et al. (2021).
81 The first research reactor in Munich, the so-called atomic egg, was commissioned in Garching in 1957. Operations were discontinued in 2000. In 2005, the Research Neutron Source Heinz Maier-Leibnitz (Forschungsreaktor München II, FRM II) went into operation. CERN was established in 1954. A complex of particle accelerators is maintained here, and cutting-edge research is conducted in basic physics. Cf. https://www.garching.de/mobile/Hochschul_+und+Forschungszentrum/Technische+Universit%C3%A4t+M%C3%BCnchen+%28TUM%29/Neue+Forschungs_Neutronenquelle+_+FRM_II-p-894.html, https://www.frm2.tum.de/ueber-uns/ and https://home.cern (each last accessed on 15 January 2021).
82 Cf. Fier and Harhoff (2002).
83 Cf. here and below Polt et al. (2021). In a study conducted by Joanneum Research and Fraunhofer ISI on behalf of the Commission of Experts, an attempt was made to find quantitative evidence based on text analysis (text mining) for the emergence of a new policy approach in available policy instruments. The textual analysis revealed that R&I policy in Germany has not yet embraced mission-oriented policy as a 'grand narrative' (own translation). Mission-oriented policy does not yet seem to have arrived in the broader debate. Cf. Polt et al. (2021: chapter 4).
84 Fraunhofer ISI has developed a typology of R&I policy missions as part of the BMBF-funded project 'High-Tech Strategy 2025 – Scientific support of missions and performance measurement in the context of accompanying the High-Tech Forum'. The typology includes accelerator and transformer missions, each with two subtypes. Accelerator missions aim at scientific innovations and technological breakthroughs. Type 1 accelerator missions are strongly related to basic research and are defined in terms of problems rather than solutions. They are intended to help correct market failures. Type 2 accelerator missions are more solution-oriented than problem-oriented, i.e., they focus on specific technological developments. In addition to correcting market failures, these missions also serve to overcome systemic failures, for example, by adjusting the legal framework. Transformer missions, on the other hand, aim at comprehensive change of socio-technical systems and serve to overcome transformation failures. Type 1 transformer missions are formulated in a solution-oriented way and do not directly affect the behaviour of end users. Type 2 transformer missions are characterized by stronger problem orientation and address the behaviour of the end users. For a typology of R&I policy missions, cf. Wittmann et al. (2020). Transformer missions are formative for the policy approach of New Mission Orientation.
85 On this, cf. also Weber et al. (2021) and Polt et al. (2021).
86 Cf. Mazzucato (2018).
87 On the catalytic R&I policy approach, cf. Cantner and Vannuccini (2018).
88 Cf. here and in the following EFI (2010: 20f.).
89 Cf. below Weber and Rohracher (2012).
90 Cf. below Weber and Rohracher (2012), Schot and Steinmueller (2018) as well as Cantner and Vannuccini (2018).
91 Cf. below https://ec.europa.eu/info/horizon-europe/missions-horizon-europe_en (last accessed on 15 January 2021), Mazzucato (2018) as well as Schot and Steinmueller (2018).
92 Cf. Rogge and Reichardt (2016).
93 Cf. below Weber and Rohracher (2012), Weber et al. (2021) as well as Schot and Steinmueller (2018).
94 Cf. here and below Weber and Rohracher (2012).
95 Cf. Haddad et al. (2019).
96 Cf. EFI (2019: 22).
97 Cf. https://www.hightech-strategie.de/de/missionen-1725.html (last accessed on 15 January 2021).
98 For a slightly sceptical view of mission-oriented policies, but with an understanding of the directionality argument, cf. Bloom et al. (2019). For a critique of transformational politics, cf. Giuliani (2018). For a critical view of the state also in environmentally oriented R&I policies and of the special relationship between the state and the private sector, cf. Tagliapietra and Veugelers (2020).
99 The key source in this context is Mazzucato (2018). For a comparative account, cf. Schot and Steinmueller (2018).
100 Cf. Mazzucato (2015).
101 Cf. Cantner and Vannuccini (2018).
102 Infrastructures that have the character of a public good and can only be provided by the public sector are to be excluded from pure start-up financing of infrastructures for innovative technologies. This can also apply to goods where excludability is technologically possible, such as transport routes and digital navigation and air traffic control systems. In such cases, it may be necessary for

the public sector to select a particular new technology and make it permanently available.

103 Cf. https://wirtschaftslexikon.gabler.de/definition/-agilitaet-99882 (last accessed on 15 January 2021), quoted in Weber et al. (2021: 18), own translation.

104 In this sense, the Commission of Experts has repeatedly called for an increase in the agility of public sector action in its reports. Cf. e.g., EFI (2010: 16).

105 Cf. OECD (2015: 18).

106 Cf. Weber et al. (2021: 49).

107 Such a policy approach shows traits of tentative governance and has agility as a central feature. The orientation of policy towards the principle of experiment and evaluation is also referred to as tentative governance. The concept of tentative governance was developed to deal with the consequences of the high degree of uncertainty regarding the governance of research, technology development and innovation, especially in relation to emergent developments in science and technology. Currently, tentative governance is of particular relevance in the context of the debate on mission-oriented innovation policy. Instead of technocratic planning concepts, as contained in the EU Commission's early papers on mission orientation, tentative governance approaches rely on accepting uncertainties and confronting them through open processes of consultation and negotiation. Experimental approaches, flexibility and learning are also highlighted as important elements. The concept of tentative governance has value for guiding policy as it helps to challenge unrealistic assumptions about the deterministic controllability of developments that are open to the future. Cf. Kuhlmann et al. (2019: 1091ff.).

108 Cf. https://www.bmbf.de/de/die-philosophie-dahinter--936.html (last accessed on 15 January 2021).

109 Cf. BMWi (2020c).

110 Cf. https://www.onlinezugangsgesetz.de/SharedDocs/kurzmeldungen/Webs/OZG/DE/2020/DigiLab20.html (last accessed on 15 January 2021).

111 Cf. https://www.bmbf.de/de/buergerdialog-zukunft--verstehen-330.html (last accessed on 15 January 2021).

112 Cf. Plattform Industrie 4.0 (2019).

113 Cf. https://work.4germany.org/ (last accessed on 15 January 2021).

114 Based on their experiences, the Work4Germany Fellows of the pilot year 2020 have, among other things, created a concept for building a new, more agile ministry. Cf. https://work.4germany.org/wp-content/uploads/2020/12/Das-neue-Ministerium.pdf (last accessed on 15 January 2021).

115 Agility criteria based on Weber et al. (2021: 52).

116 Cf. Weber and Rohracher (2012: 1043).

117 Cf. EFI (2017: 93ff.).

118 In Germany, the Competence Centre for Innovative Procurement (Kompetenzzentrum innovative Beschaffung, KOINNO), established in 2013 on behalf of the BMWi, is tasked with promoting innovation-oriented public procurement. Cf. https://www.bme.de/initiativen/koinno/ (last accessed on 15 January 2021).

119 Cf. NL Agency and Ministry of Economic Affairs, Agriculture and Innovation (2011).

120 Cf. NL Agency and Ministry of Economic Affairs, Agriculture and Innovation (2011).

121 Cf. Dekker (2013: 11ff.).

122 The BMBF has already introduced foresight processes with the Foresight Cycles (1st Cycle: 2007-2009; 2nd Cycle: 2012-2014) and with the current foresight process VORAUS:schau. Unlike the Finnish Government Foresight, however, this is an internal process of the ministry. Cf. https://www.bmbf.de/de/mit-foresight-in-die-zukunft-schauen-930.html and https://www.bmbf.de/de/die-philosophie--dahinter-936.html (last accessed on 15 January 2021).

123 Cf. Weber et al. (2021).

124 The division of labour within the ministries traditionally takes place in hierarchically structured specialist units that are distributed horizontally across several departments. Here, the specialized units have clearly defined areas of responsibility and are essentially concerned with the design and implementation of their respective programmes and measures. Since the budgets of the ministries are allocated to the respective departments and these can be used autonomously to the greatest possible extent under the reservation of management, strategic and interdepartmental activities must be institutionally enshrined for an overarching orientation. Cf. Weber et al. (2021: 67).

125 Finnish: Valtioneuvoston Kansli. Cf. https://vnk.fi/en/government--report-on-the-future (last accessed on 15 January 2021).

126 Cf. https://vnk.fi/en/foresight-activities (last accessed on 15 January 2021) and Weber et al. (2021: 128f and 130).

127 Cf. Weber et al. (2021: 131f.).

128 The appointment period of previous Mission Board members may be extended for this purpose. Cf. https://www.kooperation-international.de/aktuelles/nachrichten/detail/info/horizont-europa-mission-boards-legen-vorschlaege-fuer-eu-missionen-vor/ (last accessed on 15 January 2021).

129 Since 2018, the programme has been increasingly aligned with the Sustainable Development Goals. Cf. Weber et al. (2021: 186).

130 The BMBF is already pursuing a similar approach, for example, in the context of the energy transition with its Copernicus projects. Cf. https://www.kopernikus-projekte.de/ (last accessed on 15 January 2021).

131 Cf. Weber et al. (2021: 186ff.).

132 Cf. Weber et al. (2021: 131).

133 Cf. EFI (2017: chapter B 5-2).

134 Cf. Huber et al. (2019) https://www.experimentierraeume.de/die-idee/was-sind-experimentierraeume/ (last accessed on 15 January 2021).

## B 2

135 For an overview of the state of research on the employment effects of digitalization, cf. OECD (2019: chapter 2) and Gregory et al. (2019).

136 Cf. Goos et al. (2014) and Arntz et al. (2016).

137 Technical and spatial flexibility in a digitalized work environment can improve the reconciliation of work and family life and thus especially the labour market

integration of women. Cf. BMFSFJ (2016). In addition, from the company's point of view, digitalization also offers new opportunities for the inclusion and employment of people with disabilities. Cf. Flüter-Hoffmann and Kurtenacker (2020).

138 The Commission of Experts already dealt with these digital skills in detail in its 2018 Report and, as before, urged the increased teaching of skills in the use of digital technologies from the ground up. Cf. EFI (2018: chapter A 4).

139 Cf. http://www.future-skills.net/initiative (last accessed on 15 January 2021).

140 Across countries, the surveyed companies rated insufficient skills as the most important factor hindering the introduction of new technologies. Cf. WEF (2020: 35).

141 The Commission of Experts has long since stated that qualification and innovation are dynamically interrelated. On the one hand, innovation changes the skill needs of employees. On the other hand, the supply of suitable human capital is, with a time lag, a significant driver of the innovation process. Cf. EFI (2008: 36f.), EFI (2012: 60) and EFI (2014: 30).

142 Cf., for example, Frey and Osborne (2017) as well as Brynjolfsson and McAfee (2011). However, professions are made up of different tasks, each of which can be automated to different degrees. For instance, interactive non-routine tasks, unlike routine tasks, are relatively difficult to automate. According to estimates, only 12 percent of jobs in Germany are characterized by a range of tasks that include a share of at least 70 percent of easily automatable tasks. These jobs are therefore highly likely to be replaced by digital technologies. Cf. Bonin et al. (2015). Similar findings emerge for several OECD countries. Cf. Arntz et al. (2017). In many other workplaces, the range of tasks is likely to change significantly as automation advances. According to OECD estimates, almost 36 percent of all jobs in Germany have a share of 50 to 70 percent of tasks that can be easily automated. Cf. OECD (2019: figure 2.6) based on Nedelkoska and Quintini (2018). When automation potentials are realized, some of these jobs may be displaced as a result of the realized productivity gains. For those jobs that are retained, the job profile may shift towards new tasks that are harder to automate.

143 Cf., among others, Hüther (2020) and Schallmo et al. (2017).

144 Cf. Autor and Salomons (2018), Acemoglu and Restrepo (2018c), Acemoglu and Restrepo (2020) and Bessen (2019).

145 Cf. Gregory et al. (2019).

146 Cf. Dauth et al. (2017). Acemoglu and Restrepo (2020), however, find net negative employment effects of the increased use of industrial robots for the USA. Yet these effects determined for the past cannot be easily transferred to further digital transformation. The relative importance of the factor labour could deteriorate if innovations in automation are used that are only just profitable but hardly contribute to productivity increases. Under this condition, labour can be displaced without substantially creating new labour demand elsewhere. Cf., for example, Acemoglu and Restrepo (2018a). However, the OECD considers aggregate employment losses due to digitalization to be unlikely also in the future. Cf. OECD (2019).

147 Cf. Acemoglu and Autor (2011) and Acemoglu and Restrepo (2018b). In many countries, wage and employment growth in recent years have been comparatively strong in occupations with higher skill requirements, where new technologies tend to have a complementary effect. In contrast, wage and employment growth in occupations with medium skill requirements, which are characterized by a higher degree of substitutable manual and routine tasks, have been relatively weak. Cf. OECD (2018). At the same time, wages and employment in segments with low skill requirements also tended to increase, which is probably related to the high share of non-routine tasks in this segment that are difficult or inefficient to automate. The extent of polarization has not been the same in all countries. In the past, this development was less pronounced in Germany than in other European countries or in the USA. Cf. Goos et al. (2014) and Eurofound (2015).

148 These are carried out on behalf of the BMAS by the Federal Institute for Vocational Education and Training (Bundesinstitut für Berufsbildung, BIBB) and the Institute for Employment Research (Institut für Arbeitsmarkt- und Berufsforschung, IAB) in cooperation with the Institute of Economic Structures Research (Gesellschaft für Wirtschaftliche Strukturforschung, GWS) on the basis of a complex macroeconomic model that also maps endogenous transition processes between numerous occupational labour markets. Cf. Maier et al. (2017), Maier et al. (2014), Schnur and Zika (2009) and Meyer et al. (2007).

149 Cf. here and below Wolter et al. (2019: 36).

150 There is also a Digitalized World of Work scenario which, in comparison to the Economy 4.0 scenario, assumes a stronger change in consumer behaviour due to digitalization and the further development of public administration towards e-government. Under these conditions, the gross turnover of jobs will increase by a further 300,000 by 2035. Cf. Zika et al. (2019).

151 When interpreting these changes, it should be noted that the consequences of Economy 4.0 for the labour market and the economy are determined by comparing the sectoral, occupational and skill specialization structures projected for a scenario of advancing digitalization with the results of the baseline projection, which assumes that only the technological changes of the recent past will continue. So, this is only about the additional effects of increased digitalization of the German economy. Cf. Wolter et al. (2019).

152 In addition to occupational specialization, the level of skill specialization is a second central structuring dimension for the Classification of Occupations 2010 (Klassifikation der Berufe, KldB 2010). It refers to the complexity of the tasks to be performed and is closely guided by the required occupational qualifications but does not directly correspond to them. For example, work experience or informally acquired skills can also be an adequate substitute. The classified occupations are assigned one of four different skill specialization levels. Cf. Paulus and Matthes (2013: 9ff.).

153 Cf. Wolter et al. (2019: 30) and Paulus and Matthes (2013).

154 Cf. Spitz-Oener (2006).
155 Cf. here and below Bachmann et al. (2021).
156 This observation is also found in some studies on the development of job profiles over time in Germany since the mid-2000s. Cf. Bachmann et al. (2019), Fedorets (2019) and Storm (2020).
157 Cf. Gordon and Sayed (2020) and Bachmann et al. (2021).
158 Cf. here and below Bachmann et al. (2021).
159 Cf. Arntz et al. (2016).
160 Cf. http://www.future-skills.net/initiative (last accessed on 15 January 2021).
161 Cf. Zinke (2019: 12f.). The study was prepared as part of the initiative Vocational Education and Training 4.0 – Skilled Worker Qualifications and Competences for the Digitalized Work of Tomorrow (Berufsbildung 4.0 – Fachkräftequalifikationen und Kompetenzen für die digitalisierte Arbeit von morgen), which the BIBB designed and implemented together with the Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF).
162 Cf. Kirchmann et al. (2021: 98).
163 Cf. https://de.statista.com/statistik/daten/studie/72005/umfrage/entwicklung-der-studienanfaengerquote/ (last accessed on 15 January 2021).
164 In addition to the changeover to Bachelor's and Master's degree courses, the increasing diversity of degree courses is due to increasing specialization and differentiation within the subjects as well as a growing number of private tertiary education institutions offering applied specializations. Cf. Autorengruppe Bildungsberichterstattung (2020: 177ff.) and Kirchmann et al. (2021: 63). A recently published study shows that the Bologna Reform, i.e., the switch to Bachelor's and Master's degrees, has reduced the number of new apprentices in Germany by an average of 3 to 5 percent. Cf. Thomsen and Trunzer (2020).
165 Cf. Autor et al. (2003), Spitz-Oener (2006) and Bachmann et al. (2021).
166 Cf. Weinert (2002), https://www.bibb.de/de/8570.php and https://www.dqr.de/content/2325.php (each last accessed on 15 January 2021) for definitions of the terms that guide the working definitions described here.
167 Cf. Almlund et al. (2011) and Specht et al. (2011).
168 Cf. https://www.dqr.de/content/2325.php and https://www.kodekonzept.com/blog/de/2019/04/24/qualifikationen-vs-kompetenzen-worin-liegt-der-unterschied/ (each last accessed on 15 January 2021).
169 Cf. Kirchmann et al. (2021: 49).
170 Cf. https://www.bibb.de/dienst/berufesuche/de/index_berufesuche.php/new_modernised_occupations_by_year (last accessed on 15 January 2021).
171 There is, however, a need to catch up in the commercial professions. Cf. Kirchmann et al. (2021: 47f.).
172 Cf. Kirchmann et al. (2021: 46f.) and https://www.bmbf.de/de/digitalisierung-und-nachhaltigkeit---was-muessen-alle-auszubildenden-lernen-12244.html (last accessed on 15 January 2021). Standard occupational profile positions are training contents that are identical in all dual system training occupations. They are to be understood as minimum requirements in each individual training occupation, are taught during the entire training period and are subject to examination. Cf. https://www.bmbf.de/de/karliczek-digitalisierung-und-nachhaltigkeit-kuenftig-pflichtprogramm-fuer-auszubildende-11049.html (last accessed on 15 January 2021).
173 Cf. Gesamtmetall et al. (2017).
174 These regulatory means ('Ordnungsmittel') are the regulations governing the structuring of vocational training courses. They include the official Ordinance on Vocational Education and Training (Verordnung über die Berufsausbildung), which defines the occupational profile, specifies the content of in-company vocational training, and describes the examination requirements, as well as the framework curriculum, which specifies the content to be taught in vocational school instruction. These regulatory means ensure that vocational education and training (VET) takes place at the same level everywhere in Germany and leads to comparable qualifications. Cf. https://www.wbv.de/berufenet/ordnungsmittel-was-ist-das.html (last accessed on 15 January 2021).
175 In an online survey conducted by the BIBB, as many as one third of the trainers, skilled workers and supervisors of skilled workers surveyed said that the training in their company is poorly or rather poorly prepared for the requirements of digitalization. In 30 percent of companies, in-company training has not been redesigned in recent years in response to digitalization. Cf. Zinke (2019: 77ff.).
176 Cf. Risius et al. (2020).
177 Cf. Zinke (2019: 77ff.).
178 Cf. Kirchmann et al. (2021: 85f.).
179 Cf. Risius and Seyda (2020: 4).
180 Additional qualifications were introduced when the Vocational Training Act (Berufsbildungsgesetz, BBiG) was amended in 2005. According to § 5 Para. 2 No. 5 and § 49 BBiG, additional qualifications are understood to be additional vocational skills, knowledge and capabilities that supplement or expand professional action capability as required. They are not part of the minimum content of the respective VET occupation profile and are tested and certified separately. Examples are the additional qualification Financial Management for the occupation bank clerk and the additional qualifications Process Integration and System Integration for industrial metal occupations. The European Computer Driving Licence (ECDL), replaced last year by the International Certification for Digital Literacy (ICDL), as well as additional qualifications that impart foreign language skills and business knowledge (the latter, for example, in the case of skilled trades) are also included. Cf. https://www.bibb.de/ausbildungplus/de/34711.php (last accessed on 15 January 2021) and BIBB (2018a: 16). Elective qualifications, which were already introduced in 2000, must be seen as distinct from this. Their use is mainly considered for highly specialized industries that require specialization beyond disciplines. Cf. BIBB (2019a: 80).
181 Cf. Flake et al. (2019: 14).
182 A lack of suitable examination staff could also contribute to this. Since the examination is conducted as part of the final examination, the examination board must also be qualified to conduct the examination of the additional qualification. This is easier to ensure for additional qualifications that have a close connection to the recognized VET occupation. Cf. BMBF (2016b: 52).

183 Cf. Kirchmann et al. (2021: 88).
184 Cf. Zinke (2019: 104f.).
185 SMEs are less well equipped with (expensive) technology. Still, not all vocational schools have their own Wi-Fi network. Cf. Kirchmann et al. (2021: 56 and 84f.).
186 Cf. Flake et al. (2019: 12).
187 Cf. here and below Kirchmann et al. (2021).
188 Cf. Seyda et al. (2018: 111) and written information by the IW from 7 October 2020.
189 The European Classification of Learning Activities (CLA) is a person-centred concept and distinguishes three forms of educational and learning activities: formal educational activities, non-formal educational activities, and informal learning activities. Non-formal educational activities include educational activities that are not classified as formal educational activities, i.e., do not lead to a qualification as per the German Qualifications Framework (Deutscher Qualifikationsrahmen, DQR), but are embedded in an organized teaching/learning arrangement in the sense of a teacher-student relationship. However, teachers and students do not have to be present in person. Informal learning activities include all learning activities that are neither formal nor non-formal, i.e., do not take place in institutionalized contexts. The participation of people in continuing education and training (CET) is measured here and below by participation in non-formal educational activities based on data from the Adult Education Survey (AES). Cf. BMBF (2019c), BIBB (2020: 300ff.) and Autorengruppe Bildungsberichterstattung (2020: 215). The AES specifically asks about the following forms of non-formal learning activities: Courses and training courses, short-term educational or training events (e.g., lectures, seminars), training in the workplace and private lessons during leisure time. The participation rate describes the percentage of participants in all surveyed persons who have participated in at least one non-formal CET measure in the twelve months prior to the survey. Cf. BIBB (2020: 300ff.). The participation rates here refer to the population aged 25 to 64. In this age group, it can be assumed that most people have already completed their initial education.
190 Cf. BIBB (2020: 303).
191 In-house CET activities include all CET activities that take place entirely or predominantly during paid working hours or paid time off for educational purposes or where direct CET costs are borne at least proportionally by the employer. Individual job-related CET includes all remaining CET activities that are predominantly undertaken for job-related reasons. The logging of CET rates in 2018 differed slightly from that of previous years. As a result, however, the participation rate in job-related CET hardly changes overall. At the lower level, however, a slightly higher participation rate is measured in the area of in-house CET and a slightly lower participation rate in the area of individual job-related CET. Yet the significant increase in the rate of participation in in-house CET in 2018 cannot be attributed to this survey effect. Cf. BIBB (2020: 300ff.). The figures given here on individual participation in CET differ slightly from those in chapter C 1 due to different data bases.
192 The participation rate in job-related CET for persons without completed VET was 29 percent in 2018, for persons with an apprenticeship or a vocational school qualification 42 percent, for persons with a master craftsman's diploma or comparable qualification 63 percent and for persons with a university of applied sciences or tertiary education institution degree 62 percent. Cf. here and below BIBB (2020: 304f.).
193 The data basis here is the National Educational Panel (NEPS). The NEPS is an annual panel survey of people living in Germany with a focus on educational processes and skills development over the entire life course. Cf. Heß et al. (2019).
194 Cf. Heß et al. (2019).
195 These results are based on data from the IAB Establishment Panel. The IAB Establishment Panel is an annual survey of around 16,000 businesses in Germany on a wide range of topics related to employment policy. In the IAB Establishment Panel, a company is considered to be actively engaging in CET if employees are released for CET measures or if the costs of CET are borne in whole or in part by the company. The reference period is the first half of the financial year of each of the years presented here. Cf. Gehrke et al. (2021: 108), BIBB (2020: 307ff.) and Janssen and Leber (2015). Other company surveys show a significantly higher participation of companies in CET. However, due to differences in the survey units and the concept of CET, the surveys are only comparable with each other to a limited extent. According to the fifth European Continuing Vocational Training Survey (CVTS5), which surveys companies with ten or more employees, 77 percent of companies in Germany were actively engaging in CET in 2015. Cf. BIBB (2018b: 351f.). According to the IW Continuing Education Survey 2020, the participation of German companies in CET was even around 88 percent in 2019. Cf. Seyda and Placke (2020: 107).
196 Cf. Gehrke et al. (2021: 108). It is important to note, however, that according to both the IW Continuing Education Survey and the CVTS5 small enterprises invested more time in CET than medium-sized and large enterprises. Cf. Seyda and Placke (2017: 7ff.).
197 This is illustrated, for example, by the IW Continuing Education Survey 2020. Cf. Seyda and Placke (2020). Cf. also Gehrke et al. (2021), Gehrke et al. (2019) and Janssen et al. (2018).
198 Cf. here and below Kirchmann et al. (2021: 76).
199 16 percent of in-house CET activities were provided by community providers, 14 percent by commercial providers, 4 percent by government providers and 2 percent by other providers. Cf. Autorengruppe Bildungsberichterstattung (2020: 211f.).
200 5 percent of individual job-related CET activities were accounted for by other providers. Cf. Autorengruppe Bildungsberichterstattung (2020: 211f.).

201 In 2018, only 4 percent of 18 to 64-year-olds participated in non-formal education offered by a tertiary education or other academic institution. Participation in non-job-related CET activities is included here. Cf. BMBF (2019c: 63).

202 Cf., among others, WR (2019) and High-Tech Forum (2020).

203 The AZAV, which came into force on 6 April 2012, is a legal ordinance of the BMAS based on § 184 SGB III (Social Code III). The education vouchers or activation and placement vouchers (Aktivierungs- und Vermittlungsgutscheine, AVGS) issued to jobseekers by the employment agencies or job centres can only be redeemed for education measures certified according to AZAV at correspondingly certified education providers.

204 In 2017, according to the Continuing Education Monitor, 80 percent of CET providers had at least one quality management system, a good third of which did not have external certification. Cf. BIBB (2019b). Commonly used is certification as per ISO 9001 and ISO 29990 for labour market and education service providers by CERTQUA. CERTQUA was founded in 1994 as a company of the leading associations of the German economy and the industry association Wuppertaler Kreis e.V. It is an ISO 17021 and ISO 17065 accredited certification organization for the specialized areas of labour market, education, and services.

205 For example, voluntary customer reviews typically exhibit significant selection bias. Cf. Marinescu et al. (2018).

206 Cf. Kirchmann et al. (2021: 66 and 85). An IT security audit is partly seen as an obstacle to rapid adaptation.

207 Cf. Kirchmann et al. (2021: 67f.).

208 Cf. Kirchmann et al. (2021: 71f.).

209 Cf. here and below Kirchmann et al. (2021: 66f.) and Autorengruppe Bildungsberichterstattung (2020: 228). In 2016, 84 percent of companies actively engaging in CET already used digital learning programmes. Cf. Seyda et al. (2018: 118).

210 Cf. Kirchmann et al. (2021: 67).

211 In order to join forces, the Federal Government, the leading organizations of German industry, the trade unions, the Federal Employment Agency and the Länder initially formed the Alliance for Initial and Further Training (Allianz für Aus- und Weiterbildung) for the years 2015 to 2018. In 2019, the partners signed a new alliance agreement until 2021. It is committed to ensuring that dual system VET is geared to the needs of an increasingly digitalized and networked economy. Cf. https://www.aus-und-weiterbildungsallianz.de/AAW/Navigation/DE/Home/home.html and https://www.bmwi.de/Redaktion/DE/Dossier/ausbildung-und-beruf.html (each last accessed on 15 January 2021).

212 There are also initiatives at the European level: In 2020, the European Union adopted the European Skills Agenda for sustainable competitiveness, social fairness, and resilience, based on the 2016 Skills Agenda. In the new European Skills Agenda, twelve education policy goals are formulated, which relate in particular to the improvement of existing skills (CET) and the acquisition of new skills (retraining). The goals are to be achieved by 2025. Cf. https://ec.europa.eu/social/main.jsp?langId=de&catId=1223 and https://ec.europa.eu/social/main.jsp?langId=de&catId=89&newsId=9723&furtherNews=yes (each last accessed on 15 January 2021).

213 Cf. Esser et al. (2016) and Zinke (2019).

214 The strategy Education Offensive for the Digital Knowledge Society, which was formulated by the BMBF in 2016, provides a systematic framework for action across educational sectors to promote digital education in Germany. It identifies the following five fields of action: imparting digital education, expanding efficient digital infrastructures, creating an up-to-date legal framework, supporting strategic organizational development, and exploiting the potential of internationalization. For these five fields of action, concrete target scenarios of the 'Educational World digital 2030' (Bildungswelt digital 2030) are identified, an overview of ongoing and new activities is given and, in addition, existing needs for action are formulated. Cf. BMBF (2016a).

215 Cf. here and below BMBF (2017) and https://www.bmbf.de/de/dachinitiative-berufsbildung-4-0-11808.html (last accessed on 15 January 2021). The umbrella initiative Berufsbildung 4.0 is also part of the BMBF's Digital Strategy. The BMBF's Digital Strategy specifies five key areas of society in which the BMBF will help shape the digital transformation. One of these areas is Strengthening Digital Education and Training and its Institutions. Cf. BMBF (2019b).

216 For an overview of the programmes within the umbrella initiative Berufsbildung 4.0 cf. https://www.bmbf.de/de/dachinitiative-berufsbildung-4-0-11808.html (last accessed on 15 January 2021). In its Annual Report 2018, the Commission of Experts presented the programmes of the umbrella initiative Berufsbildung 4.0. Cf. EFI (2018: 36). The umbrella initiative has since been further developed and supplemented with more programmes.

217 Cf. https://www.bmbf.de/de/nationale-weiterbildungsstrategie-8853.html (last accessed on 15 January 2021).

218 Cf. here and below BMAS and BMBF (2019).

219 Cf. here and below https://www.bmas.de/DE/Presse/Pressemitteilungen/2019/forschungsprojekt-kompetenz-kompass-gestartet.html and https://www.bmas.de/SharedDocs/Downloads/DE/Thema-Aus-Weiterbildung/presseinfo-kompetenz-kompass.pdf?__blob=publicationFile&v=1 (each last accessed on 15 January 2021). In the research project, two procedures were developed and tested based on employer and employee data. The first method compares the competence profiles of employees in companies where modern technologies have already been introduced to a greater extent with those in companies with a lower degree of digitalization. The results have not yet been published. In the second method, the development of the importance of competence requirements was estimated based on job advertisements. The results show that the evaluation of job advertisements is in principle suitable for tracing the development of competence requirements with a high degree of topicality

and validity along occupations, requirement levels and regions. Cf. Stops et al. (2020).

220 Cf. Rüschoff (2019: 5).

221 For an overview of the ASCOT+ projects cf. BIBB (2020: 385) and https://www.ascot-vet.net/de/ascot-projekte.html (last accessed on 15 January 2021). ASCOT+ is the successor programme to the ASCOT research initiative, which was funded from 2011 to 2015, and is intended to further develop its results and transfer them to VET practice. In ASCOT, IT-supported, valid measurement procedures have been developed for selected occupational fields that make professional action competences, including social competences, of apprentices visible. Cf. BMBF (2017: 11).

222 Cf. https://www.qualifizierungdigital.de/de/-programm---23.php and https://www.qualifizierungdigital.de/de/foerderbekanntmachungen-106.php (each last accessed on 15 January 2021). For instance, practicable solutions for teaching and learning with mobile technologies are to be developed and the media competence of apprentices and training staff improved. Cf. EFI (2018: 36).

223 Cf. here and below https://www.bmbf.de/de/qualifizierungsinitiative-digitaler-wandel---q-4-0-10065.html, https://www.foraus.de/de/seminarkonzept-medien-und-it-kompetenz-fuer-ausbildungspersonal-mika-119648.php and https://netzwerkq40.de/de/ (each last accessed on 15 January 2021).

224 Cf. here and below BMBF (2019a) and BMBF (2017). Other programmes in the context of the umbrella initiative Berufsbildung 4.0 to promote the modernization of VET by SMEs are the special programme Promotion of Digitalization in Inter-company VET Centres (Förderung von Digitalisierung in überbetrieblichen Berufsbildungsstätten – ÜBS-Digitalisierung) and the funding line Shaping the Future – Innovations for Excellent Vocational Education and Training (Zukunft gestalten – Innovationen für eine exzellente berufliche Bildung, InnoVET) launched in 2019. The former promotes digital equipment and the use of innovative (digital) VET concepts in inter-company training, which is predominantly used by SMEs. InnoVET promotes the creation of innovation clusters in which local or sectoral stakeholders develop and test innovative and permeable education and training formats. In particular, SMEs are supported in providing excellent training opportunities with the aim of ensuring the attractiveness and equivalence of VET. Cf. BMBF (2019d), https://www.bmbf.de/foerderungen/bekanntmachung-2217.html and https://www.bmbf.de/de/innovet.html (each last accessed on 15 January 2021).

225 Cf. Autorengruppe Bildungsberichterstattung (2020: 224f.).

226 The Skills Development Opportunities Act expands the BA's programme for the further training for low-skilled and employed older workers and employees in companies WeGebAU (Weiterbildung Geringqualifizierter und beschäftigter älterer Arbeitnehmerinnen und Arbeitnehmer in Unternehmen). In this programme, the entry requirements were linked to the qualification and age of the employees to be supported and the size of the company. Cf. Pfeiffer et al. (2019).

227 Cf. Bundesanzeiger (2018): https://www.bmas.de/DE/Schwerpunkte/Nationale-Weiterbildungsstrategie/qualifizierungsoffensive.html and https://www.bmas.de/DE/Themen/Aus-und-Weiterbildung/Weiterbildungsfoerderung/weiterbildungsfoerderung.html (each last accessed on 15 January 2021).

228 BMAS (2020b) and https://www.bmas.de/DE/Themen/Aus-und-Weiterbildung/Weiterbildungsfoerderung/weiterbildungsfoerderung.html (last accessed on 15 January 2021).

229 Cf. IG Metall (n.y.).

230 Cf. BMAS (2020a).

231 Cf. also EFI (2018: 34 and 37).

## B 3

232 Cf. Elsner (2021: 21ff.).

233 Cf. Elsner (2021: 23f.).

234 For example, researchers at the Broad Institute under the leadership of CRISPR pioneer Feng Zhang have developed a COVID-19 antigen test that was fast-tracked by the Food and Drug Administration (FDA) on 6 May 2020. The test is based on a method developed in 2017 called SHERLOCK (Specific High Sensitivity Enzymatic Reporter Unlocking), which relies on the ability of the CRISPR method to localize specific gene sequences. First, a lead molecule that attaches to a specific section of the SARS-CoV-2 genome is programmed. If the lead molecule finds a match, the CRISPR enzyme generates a signal that can be detected either as a fluorescent glow or as a dark line on a paper dipstick.

235 With the help of so-called CRISPR screening, it is possible, for example, to decipher the genes that are responsible for certain cell behaviour. Cf. Sharma and Petsalaki (2018).

236 Cf. Deutscher Bundestag (2017).

237 Cf. acatech (2017: 8f.).

238 A gene is a section on the DNA of a chromosome that encodes for certain protein building blocks or has a specific regulatory function.

239 Cf. Doudna (2020).

240 Cf. here and below Elsner (2021).

241 In a palindromic sequence, the same base sequence is present in the two DNA strands, oriented in opposite directions.

242 CRISPR systems can also consist of more than two components. Natural CRISPR systems usually use at least three components.

243 Cf. Cathomen and Puchta (2018: 154).

244 Medical applications of CRISPR/Cas can be classified into interventions that only affect the individual being treated (somatic-cell gene therapy) and interventions where the genetic alteration is passed on (germ line interventions). While somatic-cell gene therapy is ethically unobjectionable, the ethical justifiability of germ line gene therapy is controversially discussed by experts. Cf. Reich et al. (2015: 12) and Leopoldina et al. (2015: 4). The first germ line interventions on humans, which took place in China, were sharply criticized internationally, and sanctioned in China because of the risks they posed at the time. Cf. Cyranoski (2020) and Lander et al. (2019).

245 Within the context of germ line gene therapy, the treatment of genetic diseases is carried out by correcting or replacing

the defective gene either in germ cells or in embryos or embryonic cells of an early developmental stage or in pronuclear stages, with the result that the introduced genetic material is passed on to the subsequent generations. Cf. Dederer and Frenken (2020: 1f.).

246 The different treatment approaches each have advantages and disadvantages. One difficulty with gene therapies is that every cell that is the target of the intervention must also be reached. One way to do this is to treat germ cells in vitro. This is technically easier to achieve than introducing CRISPR/Cas into the respective target cells within an organism. Methods that can reach a large number of cells in patients do not yet exist for most organs. This is partly because CRISPR/Cas could be recognized and rejected by the immune system. However, an intervention in germ cells means the genetic changes are passed on and thus also unintended changes in the genetic material through so-called off-target effects.

247 Cf. Elsner (2021: 14ff.).

248 By 2026, the global CRISPR/Cas gene editing market is estimated to be worth over US$7 billion. Cf. https://www.bloomberg.com/press--releases/2019-05-06/global-crispr-and-cas-gene-marketto-surpass-us-7-603-8-million-by-2026 (last accessed on 15 January 2021).

249 The field of medicine and health includes, among other things, papers regarding the treatment and research of diseases and pharmaceutical applications such as antibodies and vaccinations. The differentiation follows Martin-Laffon et al. (2019), whereby the fields of medicine and pharmaceutical applications are combined in the field of industrial applications. Cf. Zyontz and Pomeroy-Carter (2021: 20).

250 Papers in the technical improvement category contribute to the improvement of CRISPR/Cas as a technology and are not limited to one of the other fields (health and medicine, agriculture, industrial applications). Examples of technical improvements include improvements in methods to deliver CRISPR/Cas into cells, to use nucleases other than Cas9 and to reduce off-target effects. Cf. Martin-Laffon et al. (2019).

251 Cf. Jinek et al. (2012). While various Cas proteins can in principle be used for CRISPR/Cas, the work mentioned above is based on the use of Cas9.

252 Cf. Cong et al. (2013) and Mali et al. (2013). While various Cas proteins can in principle be used for CRISPR/Cas, the work mentioned above is based on the use of Cas9.

253 Cf. Doudna (2020).

254 For beta-thalassaemia and sickle cell anaemia, the only treatment so far is regular blood transfusions, which are associated with potentially life-shortening side effects, such as iron overload of major organs. CRISPR/Cas enables new treatment approaches for these diseases, which are currently being tested in clinical trials. The aim of gene therapy is for patients to have normal blood counts after treatment and no longer require blood transfusions. First results of the clinical trials are positive. Cf. CRISPR Therapeutics and Vertex (2019).

255 For clinical trials cf. https://ir.editasmedicine.com/news-releases/news-release-details/allergan-and-editas medicine-announce-dosing-first-patient (last accessed on 15 January 2021).

256 Cf. Mühlbäck et al. (2020) for a discussion of new treatment approaches and preclinical studies using CRISPR/Cas.

257 Cf. Cathomen and Puchta (2018: 174).

258 Cf. Cathomen and Puchta (2018: 150f.).

259 Cf. Cathomen and Puchta (2018: 150f.).

260 The database consists of publications in the Web of Science Core Collection with the term 'CRISPR' in the title, abstract or keywords. To assign publications to countries, the locations of the authors' institutions are used. In the analysis, publications are not counted fractionally, i.e., one publication is attributed to each country involved in a publication. With this counting method, international co-publications result in the sum of the countries' publications being greater than the total number of publications recorded.

261 The assignment of publications to fields is based on Martin-Laffon et al. (2019). For the purposes of these analyses, some fields were aggregated from Martin-Laffon et al. (2019). The field of health and medicine aggregates the areas medicine and pharmaceutical applications in the field of industrial applications in Martin-Laffon et al. (2019). The field of technical improvements aggregates the areas technical improvements and other in vitro applications in Martin-Laffon et al. (2019). The field of agriculture aggregates the areas crops, livestock, and aquaculture in Martin-Laffon et al. (2019). The field of industrial applications includes the area of industrial applications in Martin-Laffon et al. (2019), but without pharmaceutical applications. Cf. Zyontz and Pomeroy-Carter (2021: 20).

262 Each publication is assigned to exactly one field. The overall publication landscape is characterized by intense concentration. In three of the four fields, one country accounts for about half of all publications worldwide. In the field of agriculture, China accounts for about half of all publications, while in the fields of health and medicine and technical improvements, the USA accounts for about half of all publications. In all four fields, researchers in Germany are in the top 5 in terms of the number of publications. In the field of technical improvements, Germany achieves its highest rank in the country comparison with third place. In the field of health and medicine, Germany comes in fifth place, its worst result.

263 Looking at the growth in the number of publications, broken down into the fields of agriculture, health and medicine, industrial applications and technical improvements, a strong increase in all fields can be observed. Until 2015, most publications could be assigned to the fields of technical improvements. Since 2016, most publications have been in the field of health and medicine.

264 Cf. Zyontz and Pomeroy-Carter (2021: 22).

265 Cf. LaManna and Barrangou (2018).

266 Cf. Kamens (2015) and https://blog.addgene.org/-addgene-depositors-get-more-citations (last accessed on 15 January 2021). In addition, the free availability of research data makes it possible, for example, to search for new CRISPR proteins in these data or to use them to improve the processes for optimizing guide RNAs.

267 The Broad Institute is a biomedical research centre of the Massachusetts Institute of Technology and Harvard University. Cf. https://www.broadinstitute.org/ (last accessed on 15 January 2021).

268 Cf. Zyontz and Pomeroy-Carter (2021: 14ff.) and https://www.sciencemag.org/news/2020/09/latest-round-crispr-patent-battle-has-apparent-victor-fight-continues (last accessed on 15 January 2021).

269 Differences in the legal framework (e.g., restricted research on embryos) can have an impact on the quantitative and qualitative publication opportunities for scientists in the respective countries.

270 The percentage of publications published in highly cited journals is the ratio of the number of publications in highly cited journals to the number of all publications. For countries with a low number of publications, this percentage cannot be interpreted meaningfully.

271 CRISPR patent families have been identified on Lens.org. The same search strategy was used for identification as in Martin-Laffon et al. (2019). For that, the search term [CRISPR OR Cas9 OR Cpf1 OR gRNA* OR sgRNA* OR 'RNA* guide*' OR 'guide* RNA*'] was applied to the title, abstract and claim of patents with priority dates until 31 December 2019. The patent families identified in this way were manually checked to delete duplicate entries and remove hits that were not directly related to CRISPR systems. Cf. Zyontz and Pomeroy-Carter (2021: 21). As different patent jurisdictions publish patents according to different deadlines, the 3,652 CRISPR/Cas patent families with a priority date of 31 December 2018 form the data basis of the analysis. Cf. Zyontz and Pomeroy-Carter (2021: 22).

272 The definition of the fields is equivalent to the definition of the fields in the previous analysis of publications. It is based on the classification by Martin-Laffon et al. (2019), adapted by Zyontz and Pomeroy-Carter (2021). Cf. also endnote 260.

273 At 1.7 percent of all CRISPR patent families, the share of patent families with inventors in Germany is lower than the share of patent families with inventors in Germany of all patent families worldwide. Measured by patent families recorded in the WIPO IP Statistics Data Center, this share amounts to 3.2 percent.

274 Almost 40 percent of the patents by inventors in Germany recorded here were filed in 2018. No CRISPR/Cas patents were filed by inventors in Germany before 2015. Although the dynamics of patent applications from Germany may have increased since 2018, it is not possible to make a reliable judgement based on the data currently available. Also, a higher dynamic in patent applications from Germany should not hide the fact that inventors from Germany continue to produce only a fraction of the patent applications that are filed by inventors from the USA, for example.

275 The database on CRISPR/Cas companies may be incomplete. Based on the search strategy, it is not possible, for example, to identify companies that have not applied for a patent and have not yet gone public with a website on their CRISPR work. Companies might refrain from going public with their company in view of the ongoing patent disputes and to protect intellectual property. Cf. Zyontz and Pomeroy-Carter (2021: 23).

276 This restriction reduces in particular the number of Chinese companies considered, for which in 258 cases only information on patents is available. More detailed information is available only for eight Chinese companies. Cf. Zyontz and Pomeroy-Carter (2021: 55).

277 Due to differences in counting methods, the company figures in this analysis differ from the company figures in Zyontz and Pomeroy-Carter (2021). In contrast to Zyontz and Pomeroy-Carter (2021), the category Ownership, which contains companies that hold shares in CRISPR/Cas companies, is omitted here. Only the CRISPR/Cas companies themselves are counted here.

278 Since some companies are active in several fields, the sum of companies in the fields is greater than the total number of 278 identified CRISPR/Cas companies.

279 Employee figures are only available for 115 of the 134 companies in the USA.

280 Data on the year of establishment is available only for eight of the total of nine German CRISPR/Cas companies. Cf. Zyontz and Pomeroy-Carter (2021).

281 This impression is also confirmed by conversations with experts.

282 The clinical trial databases searched are https://www.clinicaltrials.gov/ and https://apps.who.int/trialsearch/ (each last accessed on 15 January 2021). The information listed therein was supplemented by way of data from the Dimensions database https://www.dimensions.ai/ (last accessed on 15 January 2021). Cf. Zyontz and Pomeroy-Carter (2021: 24).

283 Cf. https://www.drks.de/drks_web/-navigate.do?navigationId=trial.HTML&TRIAL_ID=DRKS00019110 (last accessed on 15 January 2021).

284 Besides Germany, these are China, France, the UK, Japan, Switzerland, South Korea, and the USA.

285 Advanced Therapy Medicinal Products, ATMPs.

286 A gene therapy medicinal product is a biological medicinal product whose active substance contains or consists of DNA or RNA. Cf. https://www.pei.de/DE/arzneimittel/atmp/gentherapeutika/gentherapeutika-node.html (last accessed on 15 January 2021). Biopharmaceuticals are therapeutic drugs whose active ingredients are produced with the help of genetically modified organisms. Cf. Lücke et al. (2020: 9).

287 Cf. Dederer and Frenken (2021: 1).

288 With regard to the regulation of somatic-cell gene therapy, focus is on consideration of the relevant drug or (bio) medical law regulations of the respective countries.

289 In addition, animal experiments in the context of basic and preclinical research are covered by the provisions of the Animal Protection Act (Tierschutzgesetz, TierSchG). Cf. Dederer and Frenken (2021: 2)

290 Cf. Dederer and Frenken (2021: 7).

291 Cf. Dederer and Frenken (2021: 79).

292 Cf. Dederer and Frenken (2021: 79).

293 Cf. Lücke et al. (2020: 4 and 55).

294 Cf. Dederer and Frenken (2021: 4 and 11).

295 In China, Japan, South Korea and the USA, there are certain deviations in the system of preventive control. Cf. Dederer and Frenken (2021: 92).

296 The application must also include an environmental impact assessment (EIA). Similarly, the responsibility under genetic engineering law for the closed system lies with the Länder. Cf. Dederer and Frenken (2021: 12f. and 99).

297 Cf. Dederer and Frenken (2021: 93).

298 In the USA, too, application of the GMP standard adapted to the stage of development of the gene therapy drug can be observed. There, the requirements for composition,

manufacture and control of the investigational medicinal product are flexible but become increasingly strict during product development. The same applies to Japan, where the GMP standard for investigational medicinal products tends to be lower than for finished products. Cf. Dederer and Frenken (2021: 93).

299 Gene therapy medicinal products used in clinical trials in Germany must comply with the GMP standard without restriction from phase I and II onwards. Cf. Dederer and Frenken (2021: 80).

300 In addition, the application must be accompanied by information on the subject matter and objectives of the clinical trials as well as the protocol. Cf. Dederer and Frenken (2021: 15).

301 Multi-centre studies are studies that are conducted at different study centres at the same time.

302 Cf. Dederer and Frenken (2021: 97).

303 Cf. Deutscher Ethikrat (2019: 44).

304 Cf. Deutscher Ethikrat (2019: 44 and 177) and https://www.who.int/news/item/19-03-2019-who-expert-panel-paves-way-for-strong-international-governance-on-human-genome-editing (last accessed on 15 January 2021).

305 Cf. Deutscher Ethikrat (2019: 174 and 234).

306 In the USA, approval for clinical trials is deemed to have been granted after a 30-day period has elapsed, i.e., although not legal doctrine, it is in fact a notification procedure. Cf. Dederer and Frenken (2021: 27 and 92f.).

307 Cf. Dederer and Frenken (2021: 92f.).

308 Cf. Dederer and Frenken (2021: 86 and 112).

309 While only three applications for approval of clinical trials for gene transfer medicinal products or GMOs were registered with the PEI in 2013, their number increased to 31 in 2019. This is partly due to the rapid development of science in the field of regenerative medicine. Cf. EASAC and FEAM (2020: 1), Dederer and Frenken (2021: 112) and https://www.pei.de/DE/regulation/-klinische-pruefung/bearbeitungsstatistik/statistik-node.html (last accessed on 15 January 2021).

310 Simplification of the authorization procedure would only be achievable by amending the law on the level of the European Union.

311 Cf. EFI (2015: 69) and WR (2018: 15f.).

312 Cf. WR (2018: 8f. and 22). For a detailed differentiation between commercial and non-commercial clinical trials, see Bührlen et al. (2010).

313 Cf. WR (2018: 5 and 22) and https://www.bfarm.de/DE/Arzneimittel/Arzneimittelzulassung/KlinischePruefung/Nicht-kommerzielle Pruefungen/_node.html (last accessed on 15 January 2021).

314 Cf. WR (2018: 9).

315 Cf. Dederer and Frenken (2021: 108).

316 Cf. WR (2018: 41 and 44).

317 Cf. acatech (2017: 9). The lack of venture capital and other sources of financing applies to the entire biotechnology sector in Germany. Cf. Bauernhansl et al. (2019); KfW Research (2020); Lücke et al. (2020).

318 Cf. acatech (2017: 50), Dederer and Frenken (2021: 108), https://www.handelsblatt.com/politik/deutschland/milliardenpaket-koalition-will-mehr-wagniskapital-fuerstart-ups-mobilisieren/26264566.html and https://www.bundesregierung.de/breg-de/aktuelles/zukunftsfondsstart-ups-1827526 (each last accessed on 15 January 2021).

319 Go-Bio initial complements the BMBF's Go-Bio programme, which was launched in 2005 and supports researchers with innovative ideas from the life sciences who are willing to start a business.

320 Cf. https://www.bmbf.de/foerderungen/bekanntmachung-2722.html and https://www.go-bio.de/de/go-bioinitial-1702.html (last accessed on 15 January 2021).

321 Cf. https://chemh.stanford.edu/ (last accessed on 15 January 2021).

322 Cf. IOM (2010: 22).

323 Cf. WR (2018: 12 and 18).

324 Cf. Dederer and Frenken (2021: 83).

325 Cf. Dederer and Frenken (2021: 82f.) and https://ct.catapult.org.uk/ (last accessed on 15 January 2021).

## C 1

326 Cf. Gehrke et al. (2021).

## C2

327 Cf. Schasse (2021).

328 Switzerland only data for 2017.

## C3

329 Cf. here and below Rammer and Hünermund (2013).

330 Cf. here also https://www.zew.de/publikationen/zew-gutachten-und-forschungsberichte/forschungsberichte/innovationen/innovationserhebung (last accessed on 15 January 2021).

331 Cf. Blind (2002).

332 ISO (2011) and https://www.iso.org/members.html (last accessed on 17 December 2020).

## C4

333 This section and the following figures are based on Bersch et al. (2021).

334 Internal financing is hardly possible, as the enterprises generate no or hardly any turnover at the beginning from which they can make investments and pay current expenses. Debt financing in the form of bank loans is also difficult, as it is difficult for banks to assess the companies' prospects of success.

335 Invest Europe is the European association of private equity and venture capital investors and operates the European Data Cooperative (EDC), a platform for collecting private equity and venture capital data. Based on the information in the EDC database as well as data from Eurostat and the International Monetary Fund, Invest Europe provides updated data on venture capital investments at regular intervals. This is based on information from the national venture capital associations, which obtain their information through member surveys. The harmonized collection and processing of data ensures good international comparability.

336 This is the case if investing market participants are not registered as members of Invest Europe or if it is a non-European investor.

337 The Zephyr M&A database contains information on mergers and acquisitions (M&A), separated into private equity, venture capital and business angel investments. The information includes the investment sum, the company in which the investment was made (portfolio company) and the investor. As the Zephyr M&A database primarily contains larger investments, the information from this database is supplemented by that from the Majunke transaction database. This database is provided by Majunke Consulting and covers venture capital investments in Germany, Austria, and the German-speaking part of Switzerland. It likewise contains information on the investment sum, the portfolio company, and the investor, and includes small investments. Since both databases also contain several other investments in companies in addition to venture capital investments, each transaction is checked to determine whether it actually is a venture capital investment with a sufficiently high probability. For this, information from the Mannheim Enterprise Panel (MUP) on the (natural and legal) persons involved in a company is used.

338 Atypical investors are all those market participants who make direct venture capital investments but whose core business is different. These include, for example, asset managers, umbrella funds, banks, and insurers as well as established companies.

## C5

339 However, the comparability of individual country data is not without reservation. Cf. here in detail Müller et al. (2014).

340 Cf. here and in detail Müller et al. (2013).

341 Cf. here and below Bersch et al. (2021).

342 The MUP comprises the total stock of economically active enterprises in Germany, insofar as they are recorded by Creditreform. It covers all company information available at Creditreform and includes companies that no longer exist. In total, the MUP contains information on more than eight million companies that are economically active in Germany or were economically active in the past. The ZEW puts these data into a panel structure and carries out various quality controls (e.g., deletion of multiple entries, imputation of missing values to the business sector, identification of closing characteristics). For the calculation of the total number of start-ups at the current margin, extrapolations are made to consider the time lag between a start-up event and its recording by Creditreform. Cf. Bersch et al. (2021) and https://www.zew.de/-forschung/mannheimer-unternehmenspanel/ (last accessed on 15 January 2021).

343 The MUP has a much narrower definition of economically active enterprises, so that rather small-scale entrepreneurial activities are not covered by the MUP. In addition, market entries and exits are defined differently in the MUP. In the MUP, a start-up is deemed to have taken place if a previously not executed business activity is taken up, the extent of which corresponds at least to the main gainful activity of a person. A closure occurs when a company does not carry out any economic transactions in a year and does not offer any goods for sale in the market. Cf. Müller et al. (2013) on the various data sources.

344 Cf. here and below Bersch et al. (2021).

345 Cf. here and below Bersch et al. (2021).

346 Cf. here and below Bersch et al. (2021).

347 Cf. here and below Bersch et al. (2021).

## C 6

348 Cf. Neuhäusler et al. (2021).

## C 7

349 Cf. Stephen and Stahlschmidt (2021).

## C 8

350 This section, the following table and the following figures are based on Gehrke and Schiersch (2021).

351 For a methodological explanation of the RCA indicator, cf. Schiersch and Gehrke (2014: 74f.).

## D

352 Cf. Gehrke et al. (2013).

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