RESEARCH, INNOVATION
AND TECHNOLOGICAL
PERFORMANCE IN GERMANY

COMMISSION OF EXPERTS
FOR RESEARCH
AND INNOVATION

EFI

REPORT

2019

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2022 2023 2024
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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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This report is also the result of the highly competent and dedicated work of the staff of the Commission of Experts' coordination office and the staff of the Commission Members.

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Foreword

After a delayed start, the Federal Government has presented numerous plans for research and innovation policy in the new legislative period. The Commission of Experts comments on some of the most significant plans in chapter A 1. In the new High-Tech Strategy 2025, the Federal Government has once again committed itself to the target of spending 3.5 percent of gross domestic product on R&D by 2025. However, the funds currently budgeted are not sufficient to meet this target. The Commission of Experts therefore once again calls for the introduction of tax-based support for R&D, focused on SMEs. It also recommends that the Federal Government grants considerable freedom to the proposed Agency for Disruptive Innovations. Unless it is granted independence from political control, the agency will be unable to meet the expectations placed upon it.

The Federal Government's Artificial Intelligence Strategy (chapter A 2) documents the high regard in which it holds this field of research. The funding volume of €3 billion (by 2025) appears to be appropriate. The current version of the AI Strategy, however, remains vague on numerous points and must be substantiated without delay. The Commission of Experts expressly warns against adopting a scatter-gun approach to research funding. However, the Commission of Experts considers a wide-ranging transfer of knowledge to be necessary. It supports the systematic expansion of European collaborations so that, as part of the association of EU partner countries, Germany can keep pace with the USA and China as the leading nations in the field of AI research.

In chapter A 3, the Commission of Experts examines the funding structures implemented by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG), Germany's largest research funding organization, and compares them with those of key research funding organizations in the United Kingdom, the Netherlands, Switzerland and the USA. This examination shows that the DFG places strong emphasis on funding programmes intended to foster collaboration and structural development. It also highlights that the average funding provided by the DFG for new single project applications is comparatively low, and the average funding duration relatively short. The Commission of Experts suggests that a review be conducted to examine whether the high weighting given to structural funding formats should be adjusted in favour of single project funding.

In chapter B 1, the Commission of Experts acknowledges the importance of start-ups in the innovation system. In Germany, a vibrant start-up scene has developed in recent years that is highly concentrated in regional terms. To promote globally visible start-up ecosystems, it is important not to counteract this geographical concentration but, instead, to expand existing and emerging ecosystems. Start-ups in Germany – particularly those in the growth phase – still have problems in accessing sufficient venture capital. With this in mind, the conditions for private investments in start-ups must be further improved; in particular, incentives should be created to encourage institutional investors to invest more heavily in start-ups.

In chapter B 2, the Commission of Experts investigates the contribution that research and innovation policy can make to the energy transition. Important innovative technologies and business models for decarbonisation of the German energy system are already market-ready, or will be so in the near future. However, their diffusion is hampered by CO_2 prices set too low as well as by regulatory requirements. In order to remove these barriers, taxes and levies on energy across all sectors of the economy should be geared to the damage energy sources inflict on the environment or to their CO_2 content. To avoid putting the success of the energy transition at risk, political actors should structure potential reforms in a socially sustainable manner – without curtailing the steering effect of climate-protection measures.

In chapter B 3, the Commission of Experts discusses blockchain technologies, which provide an immutable, forgery-proof way to store and transfer digital data. Germany is well positioned to exploit the economic and social potential of such technologies. However, it is important to promote the use and further development of blockchain technologies with a flexible regulatory framework, such as by setting up regulatory test beds. It will also be necessary to develop skills and knowledge in society and administration in order to reliably assess the opportunities and risks involved in the use of these technologies.

In chapter B 4, the Commission of Experts analyses the digitalization of German tertiary education (TE) institutions. The German TE institutions surveyed ascribe a high level of importance to digitalization, but this is yet to be reflected in the level of digitalization achieved. The Commission of Experts therefore considers there to be significant potential for development, especially in the areas of teaching and administration. The governance structures currently in place in TE institutions hamper the progress of the digitalization process. To ensure that digitalization can succeed on the whole, TE institutions must continue to modernize their administration. The Commission of Experts recommends supporting TE institutions in this process by introducing a lump-sum digitalization payment.

The Commission of Experts perceives the numerous initiatives in recent months as a clear signal that the Federal Government is building on its commitment to research and innovation policy in past years and that it continues to regard the topic as a high priority. The Federal Government should now seek to back up its announcements with actions in the near future and implement its ambitious plans with dynamism and intelligent coordination.

Berlin, 27 February 2019

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EXECUTIVE SUMMARY

Executive Summary

A Current developments and challenges

A 1 Commentary on current research and innovation policy

The High-Tech Strategy 2025 (HTS 2025) was adopted by the German Federal Cabinet in September 2018. This Strategy sets a target of expending the equivalent of 3.5 percent of gross domestic product on R&D by 2025. The Commission of Experts calls upon the Federal Government to make adequate funds available in this legislative period as a contribution towards the step-by-step achievement of the 3.5 percent target.

The Commission of Experts expressly welcomes the prominent consideration afforded in HTS 2025 to digital transformation, but urges that the measures announced should be swiftly implemented.

The Commission of Experts also once again calls for the prompt introduction, as already previously recommended by the Commission, of tax incentives for R&D activities with particular attention being paid to SMEs.

In August 2018 the Federal Cabinet resolved to establish an Agency for Disruptive Innovations. In order to achieve the desired objectives, this agency must have considerable freedom and be able to conduct its day-to-day business with the maximum independence from political control. The current restricted budget is to be increased over the medium term.

The Joint Science Conference is currently consulting on agreements to succeed the Pact for Research and Innovation (PFI) and the Higher Education Pact. In carrying forward the PFI, greater attention should be paid to the transfer of knowledge and technology. With regard to the distribution of funds for tertiary education, the agreement which succeeds the Higher Education Pact should in addition to considerations of capacity also take note of quality indicators.

A 2 Artificial Intelligence – The AI strategy of the German Federal Government

The Federal Government's Artificial Intelligence strategy was adopted by the Government on 15 November 2018. The Commission of Experts welcomes the Federal Government's intention to provide substantial funding for this important technology at the amount of €3 billion (by 2025). However, in the opinion of the Commission of Experts the current version of the AI strategy is still vague on many points and requires substantial further development. Above all there is a need for an implementation plan with clearly defined goals.

The Commission of Experts is sceptical of the Government's intention to establish at least 12 AI competence centres. The Federal Government should use the budgeted funds primarily to strengthen the already existing AI centres in order to create high-performance, internationally visible AI ecosystems.

In view of the overheated employment market for AI specialists, it also appears questionable as to whether there will be sufficient high-quality candidates to meet the Government's target of 100 professorships. These funds should instead be staggered over a longer period and used to fill both permanent as well as tenure-track professorships. European cooperation in research and transfer must urgently be strengthened. Here too, there is currently an absence of details regarding the measures announced.

The machine learning methods currently in use require large datasets for training purposes. This favours AI research in countries such as the USA and China. The Federal Government should therefore take steps to improve the availability of data. On the other hand, support should be more strongly focused on Germany's specific locational advantages. These include the high availability of machine-oriented data, and relatively high quality datasets.

A 3 Basic research funding structures and publications in international comparison

In terms of competitive financing for basic research, the central research funding organization in Germany is the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG). The funding structures of the DFG and publications deriving from DFG-funded projects are compared with those of the most important research funding organizations in Great Britain, the Netherlands, Switzerland and the USA. International comparison indicates that the DFG attaches more weight to funding programmes intended to foster cooperation and structural development. At the same time, in terms of single project funding, the average funding amounts involved in new applications to the DFG are comparatively low and the funding durations relatively short. The heavy weighting of funding programmes intended to foster cooperation and structural development should be critically reviewed. In addition, it could be useful to increase the average funding amount and the maximum funding duration of single project funding.

Also striking is the below-average rate of international cooperation measured by the co-authorship of publications referencing the DFG. This raises the question as to whether international cooperation should not be more strongly promoted by the DFG.

If one considers the quality of publications deriving from DFG-funded projects, based on publications with funding-provider references, it is apparent that this is lower than in the comparison countries. The Commission of Experts suggests that the reasons for this pattern should be investigated. The Commission therefore recommends that greater use should be made of causal analyses according to latest scientific standards.

B Core topics 2019

B 1 The role of start-ups in the innovation system

The term start-ups refers to young enterprises with innovative business ideas and high growth potential. A vibrant start-up scene has developed in Germany, where it is highly regionally concentrated.

Start-ups pursue new business models, and through their innovations, they expand and modernize the range of available products and services. New companies spun off from the scientific institutions play an important role in the transfer of knowledge and technology in practice. Start-ups are also trend scouts and provide momentum for established companies. As partners in cooperation with established businesses, start-ups contribute to the joint development and marketing of innovations.

Start-ups in Germany – particularly in the growth phase – still have problems in accessing venture capital. In addition, in view of their size and their business models, they face specific challenges which are to some extent posed or influenced by the legal environment. With this in mind, the Commission of Experts makes the following recommendations:

– In order to promote start-ups from the world of science, the start-up culture at tertiary education institutions must be strengthened still further. Start-up training should be a constituent part of all courses. To enable founders to obtain licenses quickly, tertiary education institutions and non-university research institutions should develop standard license agreements for the purpose of transferring rights to spin-off companies.
– Start-ups, particularly in the high-tech sector, profit from geographically concentrated ecosystems in which they are able to locate in the immediate vicinity of research institutions, investors, established businesses and other start-ups. In order to promote globally visible start-up ecosystems, it is essential not to counteract their geographical concentration, but instead broaden already existing or developing start-up ecosystems.
– The conditions for private investments in start-ups must be further improved. Given the shortage of anchor investors in Germany, the Commission of Experts advocates the creation of incentives for institutional investors to invest more heavily in venture capital. In addition, the mandatory imposition of VAT on the management services provided by fund managers should be repealed.
– Employee share schemes are an important instrument with which to recruit skilled workers and ensure their longer-term loyalty to a start-up company. However, the legal and particularly tax-law requirements to be considered in formulating the necessary contracts are frequently a source of considerable uncertainty for start-ups and their investors. In order to increase the legal certainty for start-ups in the introduction of employee share schemes, trade associations with close links to start-ups should in coordination with the federal authorities jointly develop standard contracts for such schemes that offer a maximum of legal security.
– In dynamic fields of technology – such as Blockchain or AI – the Federal Government should be proactive in establishing a reliable legal framework in order to reduce the uncertainties experienced by start-ups. In the interests of developing an innovation-friendly environment, increasing use should be made of regulatory test beds.

B 2 Innovations for the Energy Transition

Germany shares the climate policy goal set by the international community of limiting global warming to below 2 degrees centigrade. To this end, the energy system in Germany must become largely greenhouse gas-neutral by 2050. As a consequence, an Energy Transition will be required from fossil fuels to greenhouse gas-neutral renewable energy sources.

Innovative technologies and business models can make a decisive contribution to a cost-effective Energy Transition. It is not primarily a question of inventing new technologies. Many important technologies and business models are already market-ready. However, their diffusion is hindered by low CO_2 prices and regulatory constraints.

Higher CO_2 prices which are central to the decarbonisation of the energy system will lead to higher prices for diesel, petrol, heating oil and natural gas. To attenuate undesired distributional effects, a CO_2-oriented tax reform must compensate low-income households, e. g. by means of income transfers.

The Commission of Experts recommends that the Federal Government should take the following measures:

- In order to make innovative and climate-friendly technologies and business models more competitive, taxes and levies on energy across all sectors of the economy should be based on the CO_2 content of energy carriers. The government should use additional tax revenues from a CO_2-oriented tax reform to compensate low-income households who will be particularly burdened by higher energy prices.
- The incentive regulation (ARegV) for electricity grid operators must be modified so as to ensure the profitability of innovative technologies and business models that stabilize the grid.
- To make flexibility options in the supply and demand for electricity profitable, grid charges must be reformed in order to reflect the actual costs of grid usage over time and space.
- Given the outstanding importance of sector coupling for the Energy Transition, R&D (support) should be better oriented towards the organizational principle of sector coupling.

B 3 Blockchain

Blockchain is a technology which enables the immutable, tamper-proof digital storage and transfer of data. Data are stored not by any one individual institution, but by numerous participants simultaneously. There is therefore no central instance which has control over the stored data.

Blockchain technologies are currently being developed, tested and transitioned into marketable products by various participants. It is hoped that the decentralized data storage that can be achieved with Blockchain will reduce the level of market concentration in data-driven industries and lower the barriers to market entry. In this way, Blockchain technologies can lead to radical changes in existing industries.

Germany is in a promising position to help shape the development of Blockchain technologies and realize both economic and social potential. This current locational advantage should be used by the political community as a lever to promote the on-going development and application of Blockchain technologies.

The Commission of Experts regards Blockchain technologies as holding considerable potential benefits for businesses, the population and administration. In order to realize this potential, the Commission of Experts recommends that the Federal Government should take the following measures:

- The Federal Government's planned Blockchain strategy should include an analysis of the strengths and weaknesses of Germany as a Blockchain centre. This should incorporate analyses of current legal and regulatory conditions which inhibit innovation.
- The strategy should include proposals for regulatory test beds in which solutions to the identified obstructions can be tested in order to prepare necessary amendments to the legal situation.
- The strategy should designate interfaces with other digital policy strategies of the Federal Government such as the AI strategy or the implementation strategy. Likewise the combined effects of the various strategies should be identified and utilized.
- Legal uncertainties for businesses should also be reduced by promoting the development of competencies on the part of contacts at ministries and authorities. This increase in competencies should also be utilized to analyse concepts for the use of Blockchain technologies in government administration and, where meaningful, launch pilot projects.
- Finally, members of the public as well as businesses should be made aware of the advantages and disadvantages of Blockchain technologies to enable them to deal confidently with Blockchain applications.

B 4 Digitalization of tertiary education institutions

German tertiary education institutions according to their own statements attach great importance to digitalization. However, this is not reflected equally well in the levels of digitalization achieved in research, teaching and administration. Significant development potential therefore exists for the continuing digitalization of German tertiary education institutions, above all in teaching and in administration.

In the digitalization of the tertiary education institutions, a technically complex task is compounded by inadequately developed governance structures. For digitalization to succeed, the tertiary education institutions must continue to modernize their administration.

- The Commission of Experts recommends that the tertiary education institutions should develop a digitalization strategy with clearly defined goals and a suitably coordinated implementation plan. This digitalization strategy should go hand in hand with the profile-building of tertiary education institutions repeatedly called for by the Commission of Experts. The need for extra-occupational training should be taken into account in particular.
- Tertiary education institutions should increase their negotiating power by aggregating the purchase of licenses on an inter-university basis. The Ministries of Science and Culture of the Länder can provide support for this process.
- The digitalization of Germany's structurally under-financed tertiary education system is an on-going task which requires sustainable financing. The Commission of Experts recommends that the tertiary education institutions should be supported through the introduction of a lump-sum digitalization payment. The tertiary education institutions should receive a specific amount per student with which to develop and maintain their digital infrastructure and applications and expand their digital teaching and learning offer.
- The support for tertiary education institutions digitalization via competitively awarded project funding should continue.

- In order to make it easier for tertiary education institutions to recruit IT specialists, the Commission of Experts recommends that the Länder in their capacity as public service employers should introduce some flexibility into the existing pay regulations with an orientation towards the Collective Agreement for the Public Service (Tarifvertrag für den öffentlichen Dienst, TVöD).
- The Commission of Experts suggests that smaller tertiary education institutions in particular should be supported through the creation of IT service centres and by strengthening existing advisory and support institutions

CURRENT DEVELOPMENTS AND CHALLENGES

A

A 1 Commentary on current research and innovation policy

High-Tech Strategy 2025

In its High-Tech Strategy 2025 (HTS 2025), the Federal Government formulated inter-departmental targets and areas of focus for R&I policy in the current legislative period.[1] The HTS 2025 was adopted by the German Federal Cabinet on 5 September 2018.[2] It heralds the fourth phase of the strategic process in the field of R&I policy initiated in 2006.[3]

The primary focus of the HTS 2025 lies in three fields of action: "Societal Challenges", "Germany's Future Competencies" and "An Open Culture of Innovation and Entrepreneurship" (cf. figure A 1-1).

Societal challenges

The Federal Government has stated its aim to put people at the heart of R&I policy and provide targeted support in response to societal needs.[4] The HTS 2025 specifies six societal challenges (cf. figure A 1-1) which require qualitative leaps forward "that make a visible and tangible difference to people's day-to-day lives".[5]

The major societal challenges outlined in the HTS 2025 tie in closely with the priority challenges identified in the third phase of the HTS.[6] However, a new emphasis is set in the HTS 2025 by assigning the topic "City and Country" to the societal challenges. In this regard, the aim is "to develop all regions, both urban and rural, into sustainable and future-ready locations in which to live and work".[7] The HTS 2025 details, for instance, plans to reinforce the innovative power of structurally weak regions, promote sustainable urban development within the meaning of the 2030 Agenda for Sustainable Development, and create more resilient regional economic structures and infrastructure. The Commission of Experts welcomes the intention to enhance the innovative power of rural regions. It warns, however, that considerations

Fig. A 1-1

Download data

Structure of the HTS 2025

Societal Challenges	Germany's Future Competencies	An Open Culture of Innovation and Entrepreneurship
- Health and Care - Sustainability, Energy and the Climate - Mobility and Transport - City and Country - Security - Economy and Work 4.0	- The Technological Foundation - The Base of Skilled Workers - Societal Participation	- Bringing Science to Bear - Strengthening Entrepreneurial Spirit - Using Knowledge and Innovation Networks

Source: own depiction following BMBF (2018: 8).

of structural development should not dominate the Federal Government's R&I policy.

Germany's Future Competencies

The Federal Government's view is that, in order to combat the specified societal challenges, competencies must be developed in order to further establish Germany as a location for science, research and innovation.[8] In the HTS 2025, the "Germany's Future Competencies" field of action comprises three components (cf. figure A 1-1):

- The first component, the "Technological Foundation", aims to promote skills in relation to central key technologies that make it possible to realize wide-ranging – and also disruptive – innovation potential.[9] The Commission of Experts welcomes the explicit inclusion of technologies with cross-sectional character in the HTS 2025.
- Skilled workers with a good level of suitable qualifications are a central basis for Germany's ability to innovate and be competitive.[10] The "Base of Skilled Workers" is therefore an important topic area in the HTS 2025. The Commission of Experts welcomes the high importance assigned to digital education in the HTS 2025.
- The third component of the HTS 2025, "Societal Participation", links with the core element of "Transparency and Participation" from the third phase of the HTS. The Commission of Experts has already advocated the systematic implementation of approaches to enable citizens and groups of players from civil society to play a greater role in the development of R&I policy.[11] Ultimately, however, taking decisions on state innovation policy remains the duty of representatives democratically elected by the people.[12] Increased public participation should be accompanied by intensive communications work by the BMBF to introduce issues from the field of research and innovation into general societal discourse. In doing so, it may be prudent to intensify collaborative endeavours in scientific communication with academies, tertiary education institutions and non-university research institutions (außeruniversitäre Forschungseinrichtungen, AUFs). The Commission of Experts deems the support for accompanying research in social sciences and the humanities outlined in HTS 2025 to be appropriate.

An Open Culture of Innovation and Entrepreneurship

Global innovation and value-creation chains are becoming increasingly complex as innovation cycles become ever shorter. In light of this, the Federal Government aims to establish an open and agile culture of innovation.[13] "An Open Culture of Innovation and Entrepreneurship" is a field of action comprising three topics (cf. figure A 1-1):

- In "Bringing Science to Bear", the Federal Government intends to intensify the transfer research findings into practice.[14] The Federal Government's plans in this regard include promoting new transfer methods and structures and developing new, highly innovative clusters emerging from basic research. Furthermore, it operates a transfer initiative to identify barriers "on the path from the concept to market" and develop solutions to overcome them.[15] An entirely novel aspect of the HTS 2025 is the creation and use of disruptive innovations. This will comprise two distinct approaches (see below). In a joint initiative of the BMBF and the BMWi, the Agency for Disruptive Innovations will be established to promote disruptive innovations for application in civil society. In parallel, the BMI and BMVg will collaborate to found the Agency for Innovation in Cybersecurity.[16] In the HTS 2025, the Federal Government also announces that the state will take its role as a driver of innovation into account in public sector procurement, e-government and in the field of open data. The Commission of Experts shares the view that these areas harbour immense potential for innovation and that the public purse must at last make significant progress in this regard. In view of the considerable volume of orders placed, public procurement can play an important role in the formation and development of innovation-oriented markets.[17] e-government should enhance the quality of public authorities' services for both citizens and private companies.[18] Making authorities' databases accessible can enable start-ups and established companies to realize new value-creation potential.[19] It would be advisable to conduct a systematic investigation in this regard to examine whether legal regulations would obstruct such access and whether they could be amended without impairing privacy protections.

A

- In the topic area of "Strengthening Entrepreneurial Spirit", the HTS 2025 includes measures aimed at supporting small and medium-sized enterprises.[20] The intention is for universities and AUFs to function increasingly as research and innovation partners of SMEs; it also aims to promote the internationalization of SMEs and to maintain and enhance the competitiveness and innovative power of SMEs.[21] The strategy advocates promoting start-up funding, in particular in the world of science, further developing the range of instruments to finance the foundation and growth of young companies, and reinforcing start-up ecosystems (cf. chapter B 1 on funding for start-ups).[22] Furthermore, the HTS 2025 refers to the introduction of tax-based R&D funding, in particular for SMEs. The Commission of Experts – which has argued in favour of tax-based R&D funding for several years,[23] considers it very important that the Federal Government finally pushes ahead with such an instrument. The Commission presented potential courses of action and recommendations in its 2017 report.[24]
- In the topic area of "Using Knowledge and Innovation Networks", collaboration at both national and international level is the centre of attention in the HTS 2025. Among other aspects, the strategy includes support for structural measures such as clusters, networks, competence centres and innovation labs. There are also plans to fund the development of a national infrastructure for research data. Germany's inclusion in global knowledge flows and value-creation chains is to be further reinforced, as is educational and research cooperation at the European level.

Cross-cutting issues

The HTS 2025 is characterized by a series of cross-cutting issues.

- In the past, the Commission of Experts has on numerous occasions called for digitalization to be incorporated more closely in R&I policy and to be considered in all areas of support. The Commission is therefore pleased to note that the topic of digitalization is a common theme in all areas of the HTS 2025.
- In contrast to the third phase of the HTS, framework conditions are not considered a topic area in their own right in the HTS 2025; instead, these conditions are addressed in the context of the individual fields of action. In this context, the Commission of Experts regrets that the overarching significance of framework conditions is not afforded sufficient consideration.
- The HTS 2025 features a new aspect: so-called missions are formulated in all fields of action.[25] Examples of these missions are "Fighting Cancer", "Sustainable Economic Activity in Cycles", "Bringing Artificial Intelligence to Bear" and "New Sources for New Knowledge". These missions will be pursued as part of a systematic approach in the fields of action, within which it will only be possible to find solutions to major challenges with the cooperation of all participations and which will involve several departments.[26] The Commission of Experts welcome the fact that a new approach has been ventured with the outlined missions.
- Unlike the third phase of the HTS, the HTS 2025 includes rough schedules for research and innovation policy initiatives. The Commission of Experts welcomes this commitment to timely implementation by the Federal Government.

Implementation of High-Tech Strategy 2025

Coordination across departments and policy areas has been a characteristic element of HTS from the outset.[27] The establishment of a round-table of state secretaries should further advance this coordination in the current legislative period.[28] The Commission of Experts praises the efforts to strengthen inter-departmental coordination compared to the third phase of the HTS. The stated missions of the HTS 2025 also represent starting points for intensified inter-departmental cooperation.

As in the last three phases of the HTS, an advisory body is again included in the HTS 2025.[29] The High-Tech Forum, as it is known, includes representatives from the worlds of science and business as well as from civil society.[30] Its role is to analyse important topics and provide impetus for the round-table of state secretaries in respect of the implementation and further development of the HTS 2025. As was the case in the third phase of the HTS, there is little more than two years in the current legislative period for the advisory body to conduct active work.[31]

It plans to undertake work to develop the HTS for the next legislative period before the current period has run its course.[32] The Commission of Experts considers this a positive move, as valuable time was lost at the start of this legislative period – and the one before it – before the HTS advisory body was able to begin its work. The Commission also recommends conducting an evaluation into what was achieved in previous phases of the HTS measured against objectives set in each case. The results of this evaluation should be presented in time for the new legislative period, so that they can be incorporated in future work.

The Commission of Experts specifically welcomes the recent announcement of evaluations for all major support measures and work to continually develop evaluation praxis.[33] The Commission refers to its past statements on the structure of evaluations.[34] Despite some progress, however, the Federal Government's R&I policy remains a far cry from systematically evidence-based evaluation praxis.

The 3.5 percent target

In 2017, Germany achieved its target of investing 3 percent of GDP in R&D.[35] In the HTS 2025, the Federal Government has set a new target of stepping up investment for R&D to 3.5 percent of GDP by 2025. The Commission of Experts welcomes the fact that this takes up one of its recommendations from 2013.[36] However, the Commission urges the Federal Government to increase significantly the financial resources set aside in the budget for R&D in order to achieve this target. In the coalition agreement forged between the CDU, CSU and SPD, it was agreed that a total of €2 billion would be provided from 2018 to 2021 in order to achieve the 3.5 percent target incrementally.[37] Yet even in the event that GDP fails to increase in nominal terms in this period, the Federal Government will have to make cumulated additional expenditure of around €3.3 billion between 2018 and 2021 in order to reach the 3.5 percent target incrementally.[38] In the event of nominal economic growth of 1.5 percent per year, this sum would almost double.

Promoting disruptive innovations

While the German innovation system features effective support for evolutionary innovation processes, there are no funding structures in place at present that are explicitly focused on engendering disruptive innovations. Disruptive innovations are new creations that entail wide-reaching transformations in markets, organizations and societies and which harbour significant added-value potential. The HTS 2025 is the Federal Government's first innovation strategy which aims to develop and exploit disruptive innovations by means of specifically designed approaches (see above). On 29 August 2018, the Federal Cabinet agreed to establish the Agency for Disruptive Innovations (Agentur zur Förderung von Sprunginnovationen) for civil applications as well as the Agency for Innovation in Cybersecurity (Agentur für Innovationen in der Cybersicherheit) (cf. box A 1-2). The Commission of Experts emphatically welcomes the move to promote disruptive innovations outside of established funding structures.

It is the view of the Commission of Experts that the Agency for Disruptive Innovations is fundamentally capable of advancing disruptive innovations by means of innovation competitions and high-profile projects (cf. box A 1-2). These instruments have already proven their worth in the USA when used by the Defense Advanced Research Projects Agency (DARPA) (cf. box A 1-3). Crucial factors in the new agency's success will be the independence the organization is afforded, as well as its ability to attract entrepreneurially minded figures with excellent technical and scientific qualifications to serve in leading roles. As the agency will promote projects which, despite harbouring considerable potential, are also characterized by a high degree of risk, an inherent aspect of this concept is that many of its projects will fail. The Commission of Experts notes at this juncture that such failures will not be indicative of a failure of the Agency for Disruptive Innovations. In addition, the institution will not be an overnight success; a sufficiently high number of projects will need to be initiated to achieve success. Measured against these requirements, the budget that the Federal Government has so far set aside for the Agency for Disruptive Innovations is too limited.

The Agency for Disruptive Innovations is focused on civil applications. The Agency for Innovation in Cybersecurity, on the other hand, aims to source new cybertechnologies. The Commission of Experts therefore considers it sensible that the two institutions are to be kept separate in organizational terms.

A

Box A 1-2

Approaches pursued by the Federal Government to promote disruptive innovations

The Federal Government is pursuing two approaches to promote disruptive innovations.

Agency for Disruptive Innovations for civil applications

According to the Federal Government, the purpose of the Agency or Disruptive Innovations is to promote research ideas with the potential to produce disruptive innovations to solve specific problems of relevance for civic society and potential users.[39] It should lead to highly innovative products, processes and services being created with the potential to transform entire markets, create added value and benefit society.[40] The agency should serve three primary purposes: it should act as an idea scout for topics with disruptive potential, promote R&D, and act as a transfer hub.[41] It will be jointly established by the BMBF and the BMWi in the legal form of a private limited company (Gesellschaft mit beschränkter Haftung, GmbH) and is set to be afforded a high level of independence.[42]

A central feature of the Agency for Disruptive Innovations, promoting innovations for civil application, is a person-oriented, entrepreneurial approach – unlike classic support instruments. In this context, fixed-term innovation managers will play a prominent role: possessing exceptional technological and market knowledge, they must be afforded sufficient independence when handling projects.[43] The agency will promote disruptive innovations on the basis of two instruments:[44] Firstly, innovation competitions will compare the methods used by participating teams to solve pre-determined challenges. Secondly, high-profile projects will revolve around a specific user-related problem. This will create a corresponding R&D project, providing support for three to five years with the aim of bringing the solution to market once the funding term ends. Innovation competitions and high-profile projects are instruments that have already proven their worth in the USA when used by the Defense Advanced Research Projects Agency (DARPA) (cf. box A 1-3).

The Federal Government has set aside €151 million as the budget for the agency's launch phase.[45] It estimates funding requirements of a further €1 billion for the ten-year period from 2019.[46]

Agency for Innovation in Cybersecurity

By establishing the Agency for Innovation in Cybersecurity, the Federal Government hopes to initiate projects in the field of cybersecurity.[47] The aim is to retain security technologies in Germany and to achieve speed advantages in comparison to previous procurement processes. The Agency for Innovation in Cybersecurity is to be founded as an in-house private limited company (GmbH), owned by the Federal Government and jointly overseen by the BMI and BMVg. Around €215 million has been made available to the agency for the period 2018-2022 – an amount in the region of €40-50 million per year.

Science policy

The decision to fund the excellence clusters promoted as part of the Excellence Strategy was taken in September 2018.[48] At 57, the number of funding cases is considerably higher than the 45 to 50 cases envisaged in the Federal-Länder agreement on the Excellence Strategy.[49] The Commission of Experts is critical of the retrospective decision to deviate from important assessment parameters and the fact that the number of funding cases was increased due to political considerations. As the funding was not increased, the number of funding cases limited to financial support available to exceptional excellence cluster projects.

The Federal-Länder agreements on the Pact for Research and Innovation (Pakt für Forschung und Innovation) and the Higher Education Pact (Hochschulpakt) expire in 2019. The Joint Scientific Conference (Gemeinsame Wissenschaftskonferenz, GWK) plans to conclude its deliberations on

Box A 1-3

DARPA as a role model for a disruptive innovation agency

The Advanced Research Projects Agency (ARPA) – later renamed the Defense Advanced Research Projects Agency (DARPA) – was established in the USA in 1968 as a response to the 'Sputnik Shock'.[50] At present, DARPA has a budget of over USD 3 billion and employs around 100 programme managers. DARPA organizes innovation competitions and promotes high-profile projects. Examples of its work include the innovation competitions for autonomous vehicles and the development of ARPANET:

- In 2004, 2005 and 2007, DARPA organized innovation competitions centred around autonomous vehicles. The Grand Challenges set in 2004 and 2005 involved vehicles navigated a predefined route in the desert, avoiding obstacles in doing so.[51] The aim of the subsequent DARPA Urban Challenge in 2007 was to develop vehicles capable of navigating an urban environment. The innovation competitions demonstrated that autonomous driving is fundamentally possible. They accelerated the development of technologies in this field.[52] German innovator Sebastian Thrun – who won the 2005 Grand Challenge with his Stanford Racing Team and finished second in the 2007 Urban Challenge – was entrusted with Google's self-driving car project.[53] DARPA innovation competitions are also closely linked to the foundation of start-ups, such as the sensor manufacturer Velodyne LiDAR.[54]

- Starting in the 1960s, DARPA (and its predecessor, ARPA) supported the development of ARPANET, a network to enable geographically separate computers to share resources.[55] ARPANET was the precursor to the modern Internet, which of course opened up entirely new added-value potential – and continues to do so to this day.

successor agreements for these pacts in Spring 2019. It will present its findings to the Federal and Länder Governments in its June 2019 session.[56]

- The Commission of Experts supports the continuation of the Pact for Research and Innovation as it provides the planning security that scientific organizations urgently need. In the past, the Commission has spoken out in favour of updating the research policy objectives to be implemented by AUFs to include a greater emphasis on the transfer of knowledge and technology.[57] Individual AUFs should develop and systematically implement a strategy to this end.
- Current plans foresee stabilizing the Higher Education Pact on the basis of the recently passed Article 91b of the German Constitution (Grundgesetz).[58] The Commission of Experts welcomes the fact that the Federal Government will provide the Länder with long-term support in funding teaching and that the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) programme allowance will continue to be financed.
  The Commission of Experts is in favour of increasing federal funding for teaching in order to facilitate quality improvements. This must not, however, lead to a situation in which the Länder reduce their contributions to science funding in other areas. Tertiary education institutions need substantial improvements to their basic funding. In terms of allocating funds from the Higher Education Pact to tertiary education institutions, the Commission of Experts considers it sensible to use both capacity-related and quality-related indicators.[59]

The Commission of Experts has repeatedly referred to the central importance of suitable mentoring relationships in providing high-quality teaching, and has therefore called for curricular standard values to be raised.[60] Adjusting the teaching workload of staff can also free up time in which staff could develop and implement innovative teaching formats.

Recommendations

High-Tech Strategy 2025

- The Commission of Experts calls on the Federal Government to make sufficient funding available in the current legislative period as a contribution to reaching the 3.5 percent target incrementally.
- In the HTS, the Federal Government announced that the state will take its role as a driver of innovation into account in public sector procurement, e-government and in the field of open data. This must be implemented without undue delay.
- The Commission of Experts also proposes evaluating the measures taken to date in the field of public procurement. This could lead to successful approaches being identified and subsequently intensified.
- The tax-based R&D funding activities discussed in the HTS must be introduced in the near future, with a focus on SMEs. Whether this funding should then be gradually extended to include large companies can then be examined once further experience has been gathered.[61] he Commission of Experts advocates implementing tax incentives for R&D activities as a tax credit for R&D personnel expenses offset against payroll tax. A reasonable alternative to this would be a tax credit for all R&D expenses, offset against companies' income tax. In the latter case, the tax credit should be converted to a subsidy if a company has no tax liabilities.
- The missions and measures pursued in the HTS 2025 should be underpinned with milestones; progress in reaching these milestones should also be clearly documented. The missions pursued in the field of action entitled "Societal Challenges" should be approached in a technology-agnostic manner.
- Against the backdrop of rapid technological development, the legal framework conditions must come under greater political focus than is made clear in the HTS 2025. In the short term, the Federal Government should identify fields in which technological developments necessitate changes to legal framework conditions.
- The Commission of Experts therefore considers it necessary to examine issues of security and liability in relation to AI applications and questions of data protection in the field of Industry 4.0 (cf. chapter B 1).
- The Commission of Experts once again calls for more agile federal R&I policy so that new developments can be picked up at an early stage.

Agency for Disruptive Innovations

- The Agency for Disruptive Innovations to promote innovations with civil applications should be afforded considered freedom and be able to go about its day-to-day operations with the maximum possible independence from political control. Another pressing matter is the recruitment of entrepreneurially minded and highly qualified figures from the worlds of industry and science to serve in leading roles. The agency's budget should be expanded in the medium term.

Science policy

- In terms of updates to the research policy targets to be implemented by AUFs, greater emphasis must be placed on the transfer of knowledge and technology. Individual AUFs should draw up and subsequently implement a strategy to this end.
- The successor agreement to the Higher Education Pact should include increased federal funding for teaching, such as for the purpose of digitizing teaching in universities. In addition to capacity-related indicators, quality-related indicators should also be considered in the allocation of funding.
- To improve teaching quality, the Commission recommends raising curricular standard values and adjusting teaching workloads.
- In recent years, the Federal Government has invested considerable sums in higher education – such as through the Excellence Initiative, the Higher Education Pact, the Teaching Quality Pact and by undertaking all costs incurred by the Federal Training Assistance Act (Bundesausbildungsförderungsgesetz, BAföG). The Commission of Experts encourages the Federal Government to examine how this compares to the financial commitments made by the Länder in relation to higher education.

Artificial intelligence – The Federal Government's AI Strategy

A 2

The Federal Government adopted its Artificial Intelligence Strategy on 15 November 2018. It was drawn up following an online consultation procedure jointly implemented by the BMBF, BMWi and BMAS. The high importance the Federal Government ascribes to artificial intelligence and associated technologies is demonstrated by its plans to set aside some €3 billion for the implementation of the strategy by 2025.

Definition, applications and development

The term artificial intelligence (AI) denotes procedures, algorithms and technical solutions that make it possible to transfer complex tasks once performed by humans to machines and software capable of learning. There is, as yet, no universally accepted definition of AI.[62] Even today, AI procedures can be successfully deployed in the fields of image and voice recognition, to control autonomous systems in domestic and industrial settings, to perform medical diagnostic tasks[63] and, increasingly, to create autonomous vehicles. Despite their impressive ability to perform specific tasks, these systems remain a long way from matching human intelligence. Nevertheless, AI still holds significant economic importance. In its 2018 Report, the Commission of Experts explored the fields of smart home, industrial production, autonomous vehicles and hostile environments.[64] Artificial intelligence is a key technology for such autonomous systems.

The development of AI is supported by various scientific traditions. One recent contribution makes a distinction between so-called symbolic AI and neural AI.[65] Neural AI has gained major significance since 2012.This is demonstrated by the number of publications for the two forms of AI (cf. figure A 2-1).

Triggers for the rapid development of neural AI include breakthroughs in improving the precision and speed of image recognition algorithms.[66] These and other successes have cleared the way for neural AI to triumph in a variety of applications.

Countries around the world have seized upon the impetus behind neural AI to differing degrees. In Germany, the Federal Government persevered with almost exclusive support for symbolic AI for a long time. It only championed neural AI at a later stage in 2017, as part of the call for tenders for Machine Learning Competence Centres – despite such methods becoming increasingly prominent since 2012.[67] In this contest, the locations of Munich, Berlin, Tübingen and Bonn/Dortmund were each allocated funding in the amount of around €2 million per year.[68]

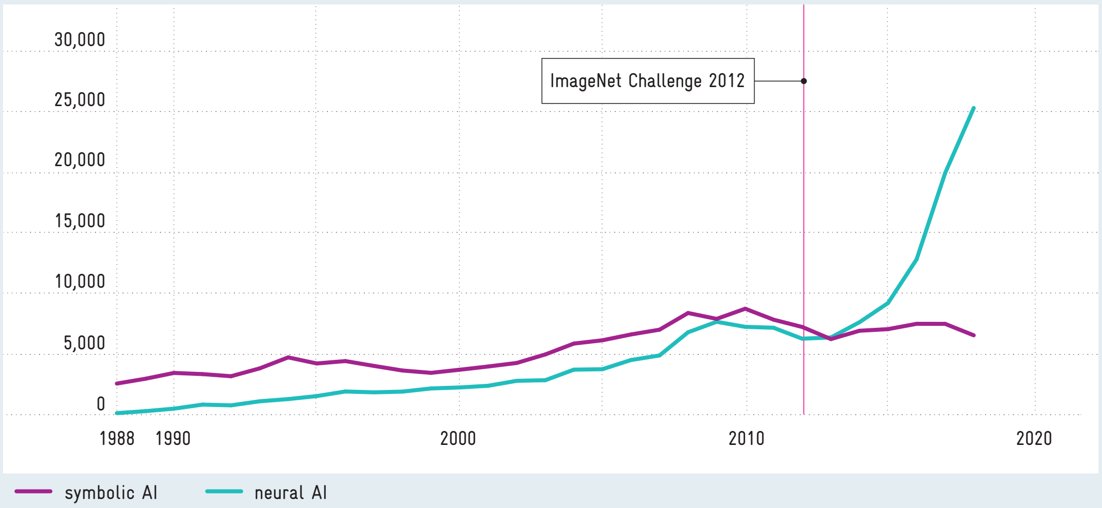
Classifying the publications depicted in figure A 2-1 according to country and AI approach produces interesting contrasts (cf. figure A 2-2). China and the USA record the highest numbers of publications. However, Chinese research in recent years has primarily concentrated on neural AI. The United Kingdom, Germany and France are the leading European counties in terms of the number of publications. Taken together, EU member states enjoy a good starting position in the field of AI research; however, this aggregation would only be justifiable if all friction was removed in the European Research Area and the Single Market.

A

Fig. A 2-1

Download data

Number of publications in the fields of symbolic and neural AI 1988–2018



The ImageNet Challenge is a contest for image recognition. In 2012, the winning team used neural AI; the enhanced methods enabled them to markedly improve image recognition performance. This success instigated a wealth of further research in the field of neural AI.
Source: own calculations based on Scopus data. API query with keywords based on Cardon et al. (2018).

Economic and societal significance of artificial intelligence

Many economists consider AI a technology that can be deployed in almost all sectors of the economy and which has the potential to enhance productivity considerably. At present, there are still no reliable scientific studies into the economic impact of AI.[69] Nevertheless, consultancy firms have identified effects on a very significant scale.[70] In its role as a location for innovation, Germany simply cannot afford to neglect AI's value-added potential.

AI also holds considerable societal significance. In the first instance, this is due to its potential impact on labour markets. Learning systems will become increasingly able to carry out tasks that at present only humans can perform. Despite this, concerns that workforces will be made redundant en masse are without firm scientific foundation.[71] Other important issues for society include the ethical discussion of which decisions people should delegate to machines, which rules should be applied to form algorithmic decisions and how intelligent systems can avoid distorted and unfair decisions.[72] In addition, there are – quite justifiably – demands that decision-making processes be transparent.[73] Ethical considerations of AI have wide-ranging consequences for the regulation, authorization and certification of AI as well as for issues relating to liability. The Commission of Experts expressly welcomes the fact that, as suggested in the EFI Report 2018, a Bundestag Committee of Inquiry named "Artificial Intelligence – Social Responsibility and Economic, Social and Ecological Potential" has been set up, tasked in particular with discussing social and ethical aspects of the use of AI processes. It is hoped that the committee's work can provide crucial momentum to stimulate a societal discussion of AI in Germany and Europe.

The Federal Government's AI Strategy

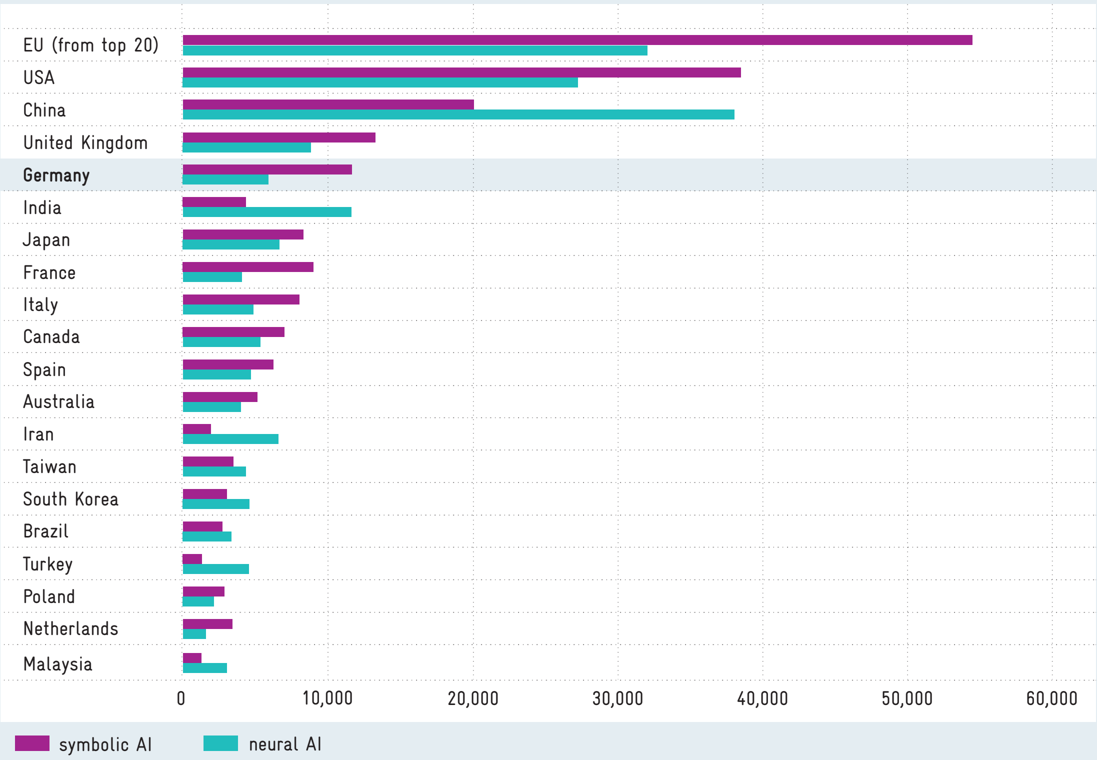
Political discussions surrounding the importance of AI were primarily inspired by a report produced by the Obama administrated in late 2016 containing recommendations for US scientific and economic policy.[74] National AI strategies have since been drawn up by China, France, the United Kingdom, Finland, the European Union and various other countries.[75] In Germany, the topic was referenced in the coalition agreement[76] concluded between the CDU, CSU and SPD in early 2018. The coalition agreement emphasizes the crucial significance of AI technology and sets the target of making "Germany a world-leading location for research into artificial intelligence". The Federal Government again

Fig. A 2-2

Download data

A

Number of publications in the fields of symbolic and neural AI by country (top 20) 1988–2018



Listed in order of total publications in the fields of symbolic and neural AI.
Source: own calculations based on Scopus data. API query with keywords based on Cardon et al. (2018).

demonstrated the importance it ascribes to the topic with its AI Summit in April 2018.

In its strategy paper, the Federal Government specifies three overarching targets. It aims to make Germany a leading location for the development of AI technologies and ensure the country's competitiveness. The second target in the paper is to secure responsible development and use of AI for the common good. Finally, the Government aims to embed AI in German society through a broad societal dialogue and active policy work. The AI Strategy also describes the technology's current situation in Germany. However, this view is not backed up with data. It then names a series of fields of action on which the Federal Government hopes to focus.[77] In its 2019 budget, the Federal Government made an initial sum of €500 million available for 2019 and the following year. The Federal Government plans to make around €3 billion available for implementation of its AI Strategy by 2025. In making these commitments, the Federal Government hopes to achieve high leverage effects and expects that business, science and the Länder will at least match the funding from federal level.

To ensure that research and business remain competitive and serve the common good, the AI Strategy also comprises a series of AI-specific measures. For instance, in order to support young scientists, research and teaching in the field of AI, the strategy foresees recruitment of at least 100 new professors to ensure AI has a solid foothold in universities. In addition, existing competence centres for AI research are to be developed across regions in order to create a national network of at least twelve centres and application hubs. The Federal Government also hopes to establish a virtual Franco-German research and innovation network together with French institutions and further develop cooperation across Europe. Moreover, it plans to reinforce support for small and medium-sized enterprises in the field of AI through the Mittelstand 4.0 competence centres.[78]

The Federal Government has also emphasized the importance of responsible development and use of AI to serve the common good. Several AI-specific measures have also been proposed in this regard. Among others, these include establishing a German artificial intelligence observatory. The working population's AI skills are to be developed as part of a national training strategy and the skilled labour situation is to be monitored. In addition, 50 lighthouse AI applications will be pushed forward for the benefit of the environment and climate.

The Federal Government has also stressed the need to initiate a wide-ranging societal dialogue around the political design of framework conditions for AI. The measures include a round-table of data protection authorities and trade associations on AI issues, as well as activities to explain and clarify AI and support privacy.

Despite the protracted nature of the process to develop the Federal Government's AI Strategy, it now represents an important basis for AI research, transfer and applications in Germany. The Commission of Experts explicitly welcomes the fact that, by publishing its AI Strategy, the Federal Government has laid the foundation for measures that will enable Germany to improve its competitive position, accompany the societal discussion and offset pending changes to labour markets – and even exploit such changes to benefit workers. The funding set aside for these measures, which totals €3 billion (by 2025), appears appropriate.[79]

The fact that an interdepartmental strategy has been undertaken is also a positive development; in principle, it can now be used as the basis for collaboration between the ministries involved. The Commission of Experts also praises the work to consider social and ethical aspects of AI. Doing so makes it possible to create a holistic response to these novel challenges.

Need for further development and recommendations

There is considerable need to further develop the current edition of the Federal Government's AI Strategy: it remains vague in many aspects and, at present, fails to describe the envisaged measures in concrete terms. The Commission of Experts therefore makes the following recommendations:

– A reliable, quantitative analysis of strengths and weaknesses should be conducted to facilitate Germany's development as an AI location. No such analysis has been carried out to date. Instead, the starting situation is described without evidence or data.
– An AI implementation plan is urgently required: it should provide a schedule for the individual AI Strategy measures (including milestones) and specify the envisaged resource requirements. The Commission of Experts recommends formulating specific timescales and implementation paths for the various measures.
– To date, no metrics have been specified which can be used to evaluate the success of the proposed measures. The Commission of Experts recommends defining these assessment standards as a matter of urgency. Initial deliberations in this regard are already underway.[80]
– The Commission of Experts views the Federal Government's intention to establish at least 12 AI competence centres with scepticism. The Federal Government should use the proposed €3 billion to reinforce existing AI locations and to create productive and internationally visible AI ecosystems.
– The labour market for AI experts is currently overheated. With that in mind, it is doubtful whether it will be possible to achieve the target of recruiting 100 new, high-calibre professors. It would appear prudent to stagger this funding over a longer period of time and use it to support both permanent professorships and those awarded through tenure track procedures. The Commission of Experts also recommends that the BMBF award 1,000 international doctoral scholarships over the coming five years in order to attract additional talented and internationally mobile young scientists to Germany. The BMBF should support efforts to recruit talented young scientists with international information resources.These proposals should be coordinated with existing plans for international graduate programmes such as ELLIS and Claire.[81]
– The Commission of Experts advises that monitoring of AI Strategy measures is implemented by an independent body with international comparisons in order to ensure the maximum degree of objectivity and transparency.
– At present, the AI Strategy contains numerous indications of generic measures such as funding for start-ups, consultancy for newly founded companies and public funding schemes in the

field of venture capital and venture debt. It is the view of the Commission of Experts that these elements dilute the Strategy as a whole.

- The AI Strategy includes the announcement that AI is to be a key focus of the proposed Agency for Disruptive Innovations. This thematic requirement contradicts the target set by the Government itself to give the agency considerable free reign. The Commission of Experts warns that the agency will only be able to fulfil the expectations placed upon it if it can act independently of political specifications (cf. chapter A 1).
- To date, the AI Strategy only refers to vague notions of collaborative endeavours with French institutions. These ideas must be substantiated forthwith. The Commission of Experts also emphasizes that – in light of British research efforts (cf. figure A 2-2) – the potential for cooperation with institutions in the United Kingdom should not be ignored.
- In principle, a European collaborative endeavour can either be established at EU level or through intergovernmental collaboration agreements between individual EU member states.[82] The European Molecular Biology Laboratory (EMBL)[83] represents a successful intergovernmental organizational form that already exists and which could also be used in the field of AI research. Such a structure would also make it possible to realize intensive, post-Brexit collaborations with research institutions in the United Kingdom.
- At present, standard machine learning procedures require large sets of training data. This affords AI research in countries such as China and the USA an advantage. In these countries, companies have been able to collect large volumes of data – and continue to do so – thanks to relatively weak data protection requirements. This currently results in a geographical disadvantage for European players, in particular those involved in R&D relating to deep learning. To begin with, therefore, the Federal Government should implement measures to improve data availability in general – such as by improving the conditions for creating data pools. For another thing, promotion efforts must place greater emphasis on specific benefits of Germany as a location for AI. These include the high availability of machine-related data and relatively high-quality datasets. In addition, the Federal Government should examine the potential of non-data-intensive AI.

The measures vaguely described by the Federal Government in its AI Strategy[84] must be further clarified as a matter of urgency.

A

A 3 Basic research funding structures and publications in international comparison

Financing for basic research can take various forms. In Germany, funding is provided through basic financing of tertiary education institutions (universities and universities of applied sciences) and non-university research institutions (außeruniversitäre Forschungseinrichtungen, AUFs) on the one hand, and in competitive processes through research funding organizations on the other. In its previous annual reports, the Commission of Experts has examined research at tertiary education institutions (2012) and AUFs (2010) in considerable detail. The present analysis investigates the funding structures in competitive basic research funding, which in Germany is allocated by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG).

International comparisons show that competitive research funding can take place through various funding lines, allowing the same overall level of funding to be structured in entirely different ways. This analysis compares the DFG's funding structures with the most prominent research funding organizations in the United Kingdom (UKRI), the Netherlands (NWO), Switzerland (SNF) and the USA (NIH and NSF).[85] Available data from the ten-year period 2008 to 2017 is taken as the basis for this comparison. The comparison takes the following structural characteristics into account: the total amounts awarded for individual funding lines, average funding amounts, maximum funding durations for specific programmes, distribution of approved funding across subject groups and success rates. The assumption is that different structures will result in different research results. Consequently, this analysis also makes an international comparison of the structure of research results (publication quality and quantity) which could be attributed to funding allocated through the research funding organizations considered here.

Funding and funding structures of the DFG

The DFG is Germany's central research funding organization for competitive financing of basic research. According to its statutes, the DFG "serves all branches of science and the humanities by funding research projects and facilitating national and international collaboration among researchers".[86] The specific tasks of the DFG also include: selecting "the best projects by researchers at universities and research institutions on a competitive basis"; funding "excellent science without regard to extra-scientific factors"; awarding "the best researchers with funding"; providing "the means and freedom necessary for successful research", and facilitating "the advancement and training of early career researchers".[87] "In principle, every scientist working in Germany or at a German research institution located abroad who has completed their academic training (a doctorate as a rule) is eligible to submit a proposal".[88]

In addition, basic research in Germany is funded through basic financing of AUFs, whose researchers can only submit applications to the DFG in cooperation with tertiary education institutions (cf. box A 3-1).

By far the largest proportion of all DFG subsidies (around €3.1 billion in 2017)[89] was granted to applicants at universities (91.3 percent in 2017).[90] In addition to direct project costs, programme allowances also finance indirect project expenses related to funding (also known as overheads, such as accommodation, administration and energy costs). At present, programme allowances account for 22 percent.[91]

A

Box A 3-1

Non-university research institutions as further pillars of publicly financed research in Germany

In addition to the DFG, Germany finances an independent sector of AUFs, each of which has specific missions. Max Planck Institutes conduct knowledge-oriented basic research in natural sciences, life sciences, the humanities and social sciences. The Helmholtz Association performs top-level research in strategic programmes in the fields of natural sciences, technology and biomedicine. The Fraunhofer-Gesellschaft conducts application-oriented research in the fields of health, security, communications, mobility, energy and the environment. The Leibniz Association conducts knowledge-oriented and application-oriented basic research into issues of societal, economic and ecological importance.[92]

The sector of AUFs – which may only submit applications to the DFG under specific conditions – is unique to Germany. The Federal and Länder governments provide total funding of €6.82 billion for AUFs (2017 target).[93] When scientists at AUFs[94] nevertheless wish to apply for funding from the DFG, they can only do so in cooperation with tertiary education institutions. This mechanism is also known as the duty to cooperate.[95]

The DFG is jointly financed by the Federal Government (58 percent) and the Länder governments (42 percent).[96] The level of financial support is granted on the basis of an economic plan proposed by the Joint Committee (Hauptausschuss) of the DFG and approved by the Joint Science Conference (Gemeinsame Wissenschaftskonferenz, GWK).[97] The Pact for Research and Innovation (Pakt für Forschung und Innovation, PFI) sets down research policy objectives to be implemented by the DFG. In return, the DFG receives financial planning security in the form of annual funding increases.[98] From 2006 to 2010, this increase in funds amounted to 3 percent per year; from 2011 to 2015, it amounted to 5 percent per year, and annual increases of 3 percent are planned for the period 2016 to 2020.[99] Additional funding was made available to the DFG as part of the Excellence Initiative. In 2005, the Federal Government and the Länder concluded the agreement on the Excellence Initiative's first financial support period from 2006 to 2011. As part of this, the DFG was awarded additional funding totalling €1.9 billion.[100] In the second Excellence Agreement for the period 2011 to 2017, signed in 2009, the DFG received total funding of €2.7 billion.[101]

In 2017, the DFG awarded total funding in the amount of €3.15 billion[102] (including the Excellence Initiative). In 2008, this figure stood at €2.23 billion, representing a significant funding increase of more than 40 percent over the entire ten-year period from 2008 to 2017.[103] This growth can be traced back in part to the programme allowance, introduced in 2007 and financed from the Higher Education Pact. Since 2013, a further portion is attributable to significant financial allocations as part of the second round of the Excellence Initiative.[104] The distribution of approved funds across the individual funding lines has remained broadly stable over the last ten years. The main recipient groups of DFG funding, the average funding amounts and the maximum funding duration of programmes have changed only slightly.[105]

The DFG system comprises various programme lines. There are 39 funding lines which cover a wide spectrum of objectives and target groups. According to the DFG itself, the portfolio of funding schemes is composed of the instruments divided into Individual Grant Programmes,[106] Coordinated Programmes,[107] the Excellence Initiative of the Federal Government and the Länder (2005 to 2017), the Excellence Strategy of the Federal Government and the Länder from 2018,[108] Research Infrastructure, Scientific Prizes and International Programmes.[109]

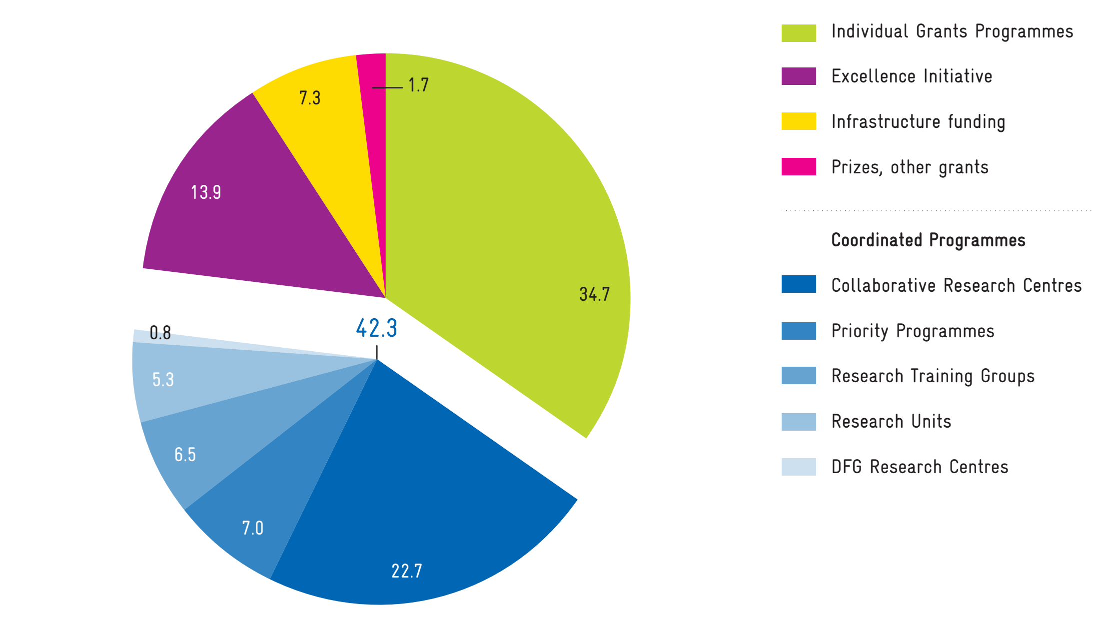
The single largest share of funding in 2017 went on Individual Grant Programmes at approximately 35 percent, followed by Collaborative Research Centres at almost 23 percent (cf. figure A 3-2). The five most important Coordinated Programmes (Collaborative Research Centres, Priority Programmes, Research Training Groups, Research Units and DFG Research Centres) account for around 42 percent of funding awarded.[110] The aim of Coordinated Programmes is to promote "cooperation and structural innovation".[111] The DFG aims to achieve this "by encouraging national and international collaboration in areas of current relevance and by concentrating scientific potential at a university".[112] In doing so, DFG funding

A

Fig. A 3-2

Download data

Annual total funding volume for ongoing projects awarded by each programme in 2017 as a percentage of all funding



Source: DFG data. Calculations by Fraunhofer ISI in Kroll (2019).

places major emphasis on supporting collaboration between researchers. The Excellence Initiative and Research Infrastructure programmes also account for significant proportions of spending (at 13.9 percent and 7.3 percent respectively). The ranking of funding lines has also broadly remained stable since 2008.[113]

In 2017, the average funding amount in the Individual Grants Programmes category was approximately €200,000 across all new applications in the same category.[114] The success rate for the Individual Grants Programmes category was around 30 percent in 2017; however, this figure has fluctuated significantly over the course of time. The lowest figure was 23 percent, recorded in 2013; the highest stood at 35 percent in 2009.[115] The funding period for new applications in Individual Grants Programmes is usually between two and three years (in fact, the average for 2017 was 31.6 months).[116] Coordinated programmes are generally longer – for instance, Collaborative Research Centres can run for up to twelve years, while Research Training Groups can run for up to nine.[117]

International comparison of funding structures

The following section compares the funding structures of the DFG with those of the most important research funding organizations in the United Kingdom (UKRI), the Netherlands (NWO), Switzerland (SNF) and the USA (NIH and NSF). In doing so, reference is made to a study conducted by the Austrian Institute of Economic Research (Österreichisches Institut für Wirtschaftsforschung, WIFO) on behalf of the Commission of Experts.[118]

In all these countries, the funding awarded by the aforementioned research funding organizations only represents a proportion of total research funding for tertiary education institutions. At 18 percent, the proportion of overall research funding for tertiary education institutions awarded by the DFG is at the lower end in international comparison.[119] The same is true for the funding amounts provided by the DFG per scientist in the tertiary education sector.[120] In the international comparison, the cumulative average growth rate of 6.8 percent for DFG funding in the period 2005 to 2016 ranks in the middle of the table.[121]

Box A 3-3

A

Classification of funding lines and instruments

Categories of funding lines for international comparison	**Description** (selected examples from DFG funding lines)[122]
Project funding	**Project funding**
Single project funding	Standard funding for single principal investigator-led research projects (Research Grants)
Single project funding early career	Single project funding for early career researchers, i.e. fixed-term staff and/or first-time applicants
Single project funding high-risk	Single project funding with a specific focus on high-risk projects (Reinhart Koselleck Projects)
Networks and multi-project funding	Funding for collaborations between scientists/research directors, usually from different research institutions (e.g. Research Units)
Interdisciplinary research	Funding for research projects with interdisciplinary collaboration or interdisciplinary approach
Priority areas	**Larger-scale, coordinated funding lines**
Structural priority area	Funding with the aim of reinforcing scientific excellence and boosting international visibility (Collaborative Research Centres, DFG Research Centres, Excellence Initiative)[123]
Thematic priority area	Support for research on predefined topics (Priority Programmes)
Infrastructure	**Funding for research equipment (outwith funding in single project funding)** (Scientific Instrumentation and Information Technology, Scientific Library Services and Information Systems)
Funding of people	**Promotion of people**
Education and training	Funding for potential scientists not holding a doctorate with the aim of preparing them for or guiding them towards a scientific career (Research Training Groups)
Career	Funding for post-doctoral researchers with the aim of improving their career prospects (e.g. Emmy Noether Programme, Heisenberg Programme)
Mobility	Funding to facilitate researchers' international mobility and support exchange programmes (e.g. Research Fellowships)
Diversification	Funding for researchers with the aim of improving diversity in terms of gender, origin or type of tertiary education institution (Project Academies)
Prizes	Prizes for researchers (e.g. Gottfried Wilhelm Leibniz Prize, Heinz Maier-Leibnitz Prize)
Translation	**Funding with the aim of using basic research for specific applications**
Applied research	Funding for applied research within the tertiary education system (e.g. Clinical Trials)
R&D collaboration with firms	Funding for collaborative R&D projects
Commercialisation	Funding for commercialization of research results
R&D value chain	Funding for the entire research cycle, from basic research to applied research and experimental development through to commercialization
Scientific communication	**Funding to communicate research findings to a non-scientific audience**
International cooperation	**Funding for bilateral research collaboration between different countries** (e.g. establishing international collaborations, submitting joint applications for D-A-CH)

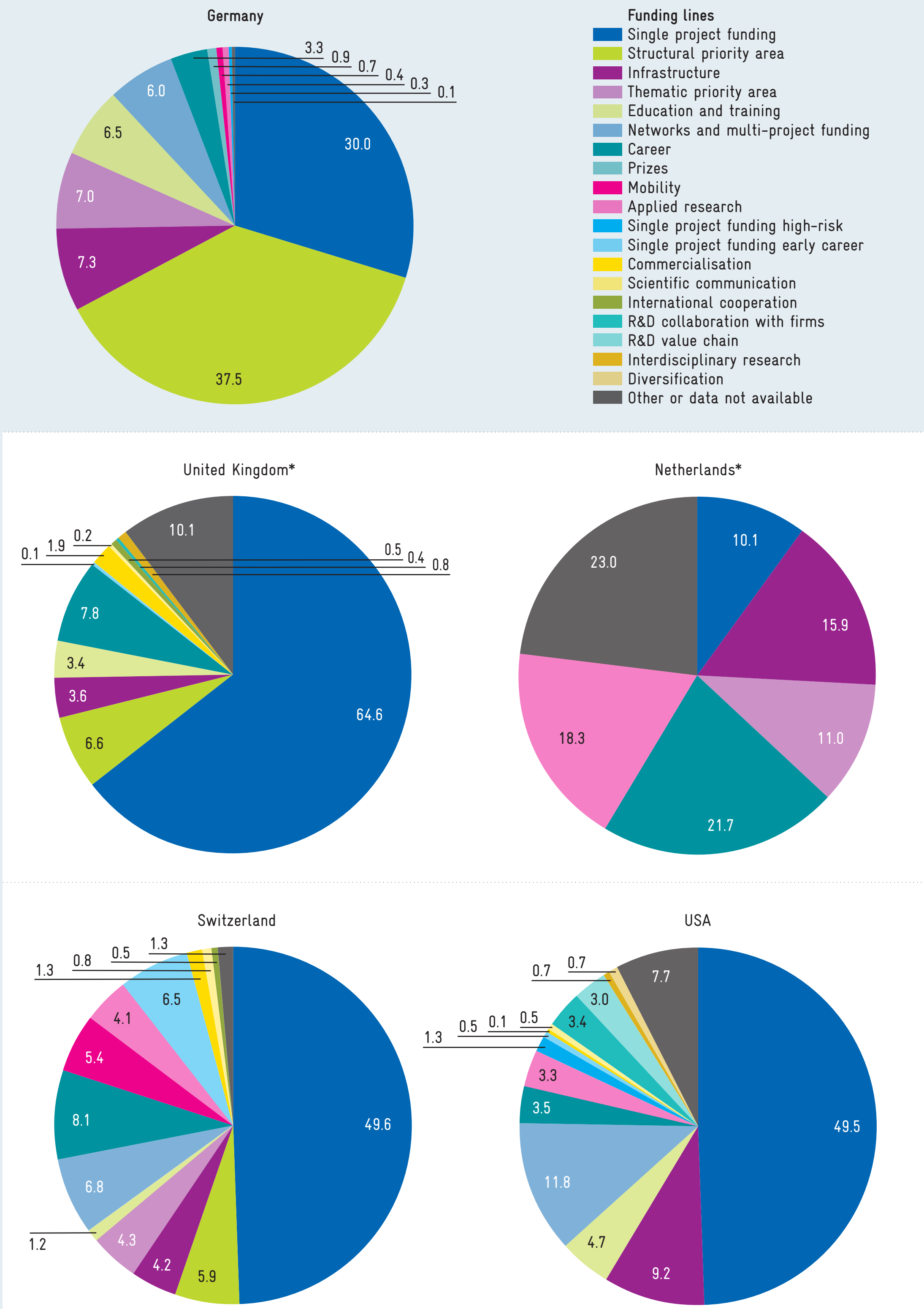
Source: Janger et al. (2019: 23f.).

A

Fig. A 3-4

Download data

Structure of funding lines in international comparison in 2017 as a percentage of all funding



* 2016
United Kingdom: weighted average of the AHRC, BBSRC, EPSRC, ESRC, MRC, NERC and STFC. Data taken from financial reports.
USA: weighted average of the NIH and NSF.
Source: research funding organizations' data. Germany, the Netherlands, Switzerland: WIFO calculations in Janger et al. (2019).
United Kingdom, USA: own calculations based on Janger et al. (2019).

To make it possible to compare the complex funding structures of different countries' research funding organizations, the various funding lines – the finer details of which differ – are allocated to broader (but internationally comparable) categories. Box A 3-3 outlines the funding line classification method that the international comparison is based on.[124]

One aspect shared by research funding organizations in almost all of the countries examined here is that single project funding is one of the most important funding lines (cf. figure A 3-4). Following the above classification method, single project funding from the DFG includes Research Grants. In the United Kingdom, Switzerland and the USA, single project funding is the largest funding line, representing 50 to 65 percent of total funding in these countries. It is striking that the proportion of structural priority area funding is higher for the DFG than in comparative countries; structural priority areas concern funding with the aim of reinforcing scientific excellence and boosting international visibility. Based on the above classification, structural priority areas include three DFG funding lines: Collaborative Research Centres, DFG Research Centres and the Excellence Initiative (cf. box A 3-3). This pattern has remained comparatively stable in recent years; in Germany, it has even been further reinforced by the Excellence Initiative.[125] DFG funding is therefore more concentrated on larger-scale, coordinated funding lines than is the case for research funding organizations in other countries. However, international empirical studies show that such coordinated funding lines are not always more successful. In particular, their success appears to differ depending on the subject area.[126] The following section examines whether there are systematic differences in the publications of projects funded by the respective research funding organizations in an international comparison.

In terms of the distribution of funding across subjects, the largest proportion of funding was allocated to projects in the natural sciences in the countries examined here – with the exception of the USA.[127] Due to the funding activities of the NIH, the largest proportion of funding in the USA on average went to the field of medicine. In Germany, the field of engineering sciences receives more funding than in the comparison countries.[128]

The results of the WIFO study suggest that, in this international comparison, Germany has the lowest average funding amount and a rather low maximum

Tab. A 3-5

Download data

International comparison of funding characteristics of single project funding on the basis of new applications in 2017

Country	Research funding organization	Average funding amount (in €m)	Maximum funding duration (in years)[2]	Success rate (in percent)
Germany	DFG	0,28	3	30
Netherlands	NWO	0,33	6	22
Switzerland	SNF	0,50	1–4	48
United Kingdom	AHRC	0,64	5	25
	BBSRC	N/A	5	24[4]
	EPSRC	0,98	N/A	29
	ESRC	N/A	N/A	23[4]
	MRC	N/A	5	22
	NERC	N/A	N/A	31[4]
	STFC	N/A	N/A	N/A
USA	NIH	0,41[1]	3–5	19[1]
	NSF	0,34	2,9[3]	21

N/A: data not available. AHRC, BBSRC, ESRC, MRC, NERC and NWO: 2016.
[1] On the basis of new applications, applications for renewal and applications for amendments. [2] 2018 or last available applicable documents without specific year stated. [3] Average duration. [4] Overall success rate.
Source: research funding organizations' data. WIFO calculations in Janger et al. (2019).

A

funding duration in terms of single project funding on the basis of new applications (cf. table A 3-5).[129] No comparable data on other funding lines was available to the Commission of Experts. Regarding the effects of different funding durations, empirical studies suggest that shorter funding durations tend to lead to less excellent publications, partly due to less freedom for research.[130] In terms of the effects of increasing funding amounts on research results, the empirical evidence is controversial; however, there tends to be good evidence of a positive correlation between the funding amount and the results of the funded research.[131] At 30 percent, the DFG's success rate for single project funding is quite high compared to other countries – with low average funding amounts at the same time (cf. table A 3-5). In summary, both the funding duration and the average funding amount appear to be structural characteristics that merit more detailed analysis and examination in future.

There is also a difference between the eligibility of indirect costs in single project funding programmes. While the DFG applies a rate of 22 percent – similar to the SNF (20 percent) – the NWO does not fund

Box A 3-6

Operationalization and measurement concept for research council acknowledging publications (RCAPs)[132]

Scientific publication results are one method by which to measure the results of research projects. Publications are allocated to research funding organizations based on the details in the acknowledgement sections of journal articles. Not all research funding organizations make such acknowledgements a legal obligation. However, for some time now, they have been the standard query for many scientific journals when submitting articles via the corresponding institution tools. According to both Thomson Reuters (Web of Science) and Elsevier (SCOPUS), funding information has been collected as standard since 2009 and is reliably interpretable.[133] Data from Web of Science was used as the basis for comparisons in this regard, as it provided more robust funding reference data for the period under examination. Nevertheless, a comparative analysis with SCOPUS – which still contains incomplete funding references but includes data from a wider range of subjects – provided almost identical results, at least in the case of research council acknowledging publications within individual scientific disciplines.

A total of around 5.6 million publications were analyzed using Web of Science data for the period 2010 to 2017. Publications that acknowledge one of the key research funding organizations included in the analysis are referred to briefly as research council acknowledging publications (RCAPs).

The number of RCAPs of the respective country and the number of national and international co-publications among the RCAPs are taken as quantitative indicators. These publication-based indicators are available for the period 2010 to 2017.

The excellence rate and the crown indicator (CI) are used as qualitative indicators.

The excellence rate is defined as the proportion of a country's publications that are among the 10 percent of the world's most-cited publications in the respective scientific discipline. The CI compares a country's citation rates with those of the rest of the world, normalized for specific disciplines.[134] The CI is normalized to 1.0. For example, a CI of 1.4 would indicate that the publications of the country in question are cited 40 percent more frequently than the international average.

The excellence rate and the CI are calculated on the basis of citations. These citation-based indicators are based on a citation window of three years (including the year of publication), meaning that only publications with a corresponding time interval until the current margin can be recorded. These indicators are available for the period 2010 to 2015. In order to satisfy the various starting situations of qualitative indicators of all publications, the difference between the RCAP excellence rate and the excellence rate for all publications is taken as a further qualitative indicator for the research funded in a respective country (with the same approach applied for the CI).

any indirect costs, while the NIH and NSF fund all indirect costs (30 to 69 percent). The UKRI finances 80 percent of all costs incurred (direct and indirect costs); the remaining 20 percent must be borne by the research institution.[135]

International comparison of research results: publications from funded projects

Assessing research results on the basis of publication performance and taking publications which acknowledge funding from national research funding organizations (referred to here in short as research council acknowledging publications, RCAPs) as an indicator of the results of funded research produces clear, country-specific patterns. Box A 3-6 explains how publications can be allocated to research funding organizations.

The publication analysis results outlined in the following originate from a Fraunhofer ISI study commissioned by the Commission of Experts. This study shows that the proportion of RCAPs among all national publications is highest in the USA at the end of the period (2017), at 31 percent. The figure in Germany was 23 percent, in Switzerland 21 percent, in the United Kingdom 20 percent and in the Netherlands 14 percent.[136] While the number of RCAPs rose for all countries from 2010 to 2017,[137] the growth rate of RCAPs in Germany (37 percent) was lower than in European comparison countries.[138]

In almost all countries, RCAPs occur less frequently in co-authorship than publications as a whole.[139] If co-authorship is divided into national and international co-authorship, it can be seen that RCAPs are produced more frequently with co-authors from the same country than publications as a whole (in Germany, for instance, 23 percent of RCAPs were co-authored with a national partner and 20 percent of all publications were co-authored with a national partner in 2017).[140] However, in Germany, as in most other countries, RCAPs are produced with international co-authors less frequently than for all publications (in Germany, for instance, 53 percent of RCAPs were co-authored with an international partner and 59 percent of all publications were co-authored with an international partner in 2017).[141] Moreover, the proportion of international co-publications has grown less sharply for RCAPs than for publications as a whole – a trend evident across all countries.[142]

In terms of the quality of the research results, measured using the citations of respective publications, there are clear country-specific differences.[143] The excellence rate can be applied as the primary indicator (cf. table A 3-7) – that is to say, the proportion of publications that are among the 10 percent of the most-cited publications in the respective discipline (cf. box A 3-6).

The results of the Fraunhofer ISI study make clear that each country's RCAP excellence rate is higher than the excellence rate for respective countries' publications as a whole. In Germany, for example, the RCAP excellence rate is recorded at 17 percent and the excellence rate for all publications is 14 percent. This figure places Germany at the lower end of both rankings. Germany also falls behind the comparative

Tab. A 3-7

International comparison of excellence rates and crown indicators of RCAPs as well as excellence rates and crown indicators of all publications and differences in 2015[144]

Download data

Country	Excellence rate for RCAPs (in percent)	Excellence rate for all publications (in percent)	Difference in excellence rates (in percentage points)	Crown indicator for RCAPs	Crown indicator for all publications	Difference in crown indicators
Germany	**17**	**14**	**+3**	**1.4**	**1.3**	**+0.1**
Netherlands	22	17	+5	1.8	1.6	+0.2
Switzerland	22	19	+3	1.8	1.7	+0.1
United Kingdom	21	15	+6	1.8	1.4	+0.4
USA	20	14	+6	1.7	1.3	+0.4

The term RCAP denotes a publication which acknowledges one of the research funding organizations considered in this analysis.
Cf. Box A 3-6.
Source: Thomson Reuters – Web of Science. Calculations by Fraunhofer ISI in Kroll et al. (2019).

countries examined here using the excellence rate for all publications determined by the OECD.[145] At the same time, Germany has the second-lowest number of publications per scientist in the tertiary education sector (in full-time equivalent positions) after the United Kingdom. The proportion of excellent publications among RCAPs is therefore not simply low because there is a disproportionately high number of other publications.[146] At 3 percentage points, the excellence rate increase for DFG-funded RCAPs compared to all publications is also rather low in the international comparison. Only in Switzerland is the rate of increase equally low – but the Swiss figure is an increase on a significantly higher excellence rate across all publications.[147]

For the purpose of classification, it is also useful to compare the excellence rate of DFG-related RCAPs used here to the excellence rates for all publications from tertiary education institutions and AUFs. This comparison can be conducted on the basis of an earlier study for the year 2012.[148] It is clear that the excellence rate for DFG RCAPs (17 percent) is higher than the rates for the Fraunhofer-Gesellschaft (10 percent), tertiary education institutions (13 percent), the Leibniz Association (13 percent) and the Helmholtz Association (16 percent). However, the excellence rate of the Max Planck Society (23 percent) is significantly higher than for DFG RCAPs – as is to be expected, given the Max Planck Society's concentration on excellent basic research. The results of the comparisons indicate that, in terms of the excellence rate, competitively funded research still has considerable scope for improvement.[149]

The crown indicator (CI) can be applied as an alternative qualitative indicator (cf. table A 3-7); it compares a country's citation rates with those of the rest of the world on the basis of a discipline-specific normalization (cf. box A 3-6). This measure of quality also shows that, in all countries, the CI for RCAPs is higher than the CI for all publications in the respective country.[150] When compared to other countries, with 1.4 in 2015, Germany has the lowest CI for RCAPs and – together with the USA – also has the lowest CI for all publications (1.3). The difference between the CI of RCAPs and that of all publications also puts Germany at the lower end of the ranking compared to the other countries examined here.

Taken as a whole, it is clear that DFG RCAPs display a relatively low increase in terms of their excellence rate and CI when compared to the figure for all publications in Germany and that this cannot be justified by the latter already returning above-average figures.

Another of the DFG's objectives is to promote cooperation and structural innovation. To date, no evaluations have been conducted into whether it achieves this objective. As a result, it is also not possible to evaluate whether the heavy focus of financing on funding programmes aimed at promoting cooperation and structural innovation compared to the funds allocated to single project funding is actually productive. For those submitting applications, this entails considerable additional effort in giving systematic consideration to structural innovation and collaborative elements when planning their research. Evidence that such efforts generally provide sufficient benefit to justify them is yet to be provided.

Conclusions and recommendations

The DFG as well as the research funding organizations in the comparison countries have differentiated funding structures in basic research, which are based on different objectives and target groups and are often comparable. Germany places a higher than average emphasis on funding for structural priority area programmes (Collaborative Research Centres, DFG Research Centres and the Excellence Initiative) compared with other countries – a pattern that has become yet more pronounced in recent years. This means that the DFG concentrates more heavily on larger-scale, coordinated funding schemes than other countries' research funding organizations. At the same time, it is clear that the total funding amount provided by the DFG in relation to the number of full-time scientists employed in the tertiary education sector is rather low compared to other countries. The results also indicate that for single project funding, the DFG has the lowest average funding amounts and among the shortest maximum funding durations per new application. The DFG's success rate is, by contrast, comparatively high.

Assessing the research results on the basis of research council acknowledging publications, it can be determined that the excellence rate and CI of publications which acknowledge the DFG are lower than for RCAPs in comparison countries. Meanwhile, the difference in quality between publications with funding acknowledgements and those without is among the smallest in the international comparison.

- The Commission of Experts suggests that the reasons for these patterns should be investigated more closely. It therefore recommends that greater use should be made of causal analyses according to the latest scientific standards.[151] The Commission also proposes preparing the underlying data, making it freely available to the scientific community and having more in-depth quantitative and qualitative analyses conducted by the scientific community for example as part of a specific research priority programme.[152] Scientific insights into the effects of various structures gained through this research should then be integrated by the DFG when examining its funding and support portfolio.
- The international comparison indicates that the DFG places heavy emphasis on funding programmes that aim to promote cooperation and structural innovation. At the same time, the average funding amounts awarded by the DFG to new applications for single project funding are rather low and the funding durations rather short. In addition, the overall level of DFG funding in relation to the number of scientists in the German tertiary education sector is rather low. Empirical findings suggest that the innovative content of funded projects and the quality of research results could be improved by increasing funding durations. In light of these results and the DFG objective of promoting excellence, it may be advisable to increase the average funding amounts and maximum funding durations for single project funding. As the heavy emphasis on funding programmes aimed at promoting cooperation and structural innovation represents a distinctive feature in the international comparison, it should be subjected to critical examination based on detailed DFG data.
- The below-average level of international cooperation measured by the co-authorship of publications referencing the DFG (RCAPs) is also striking. This finding is questionable as the mission of promoting international collaboration among researchers is a specific mission of the DFG, embedded in its statutes. This therefore raises the question of whether international cooperation should not be more strongly promoted by the DFG.
- The present analysis is unable to provide conclusive answers to every question due to problems with data availability. Further analyses should be conducted, in particular to examine whether the DFG should not be more rigorous in its single project funding when selecting projects but, in return, award more generous funding amounts and durations. Beyond that, a discussion is required into whether larger-scale, coordinated funding should be downsized for the benefit of excellent individual projects.
- The international comparison also shows that the programme allowance offered by the DFG is rather low. The increase in the DFG programme allowance to 30 percent – as embedded in the coalition agreement[153] – is therefore to be welcomed, as it also improves the general conditions and the basis for research at universities.

CORE TOPICS 2019

B

B 1 The role of start-ups in the innovation system

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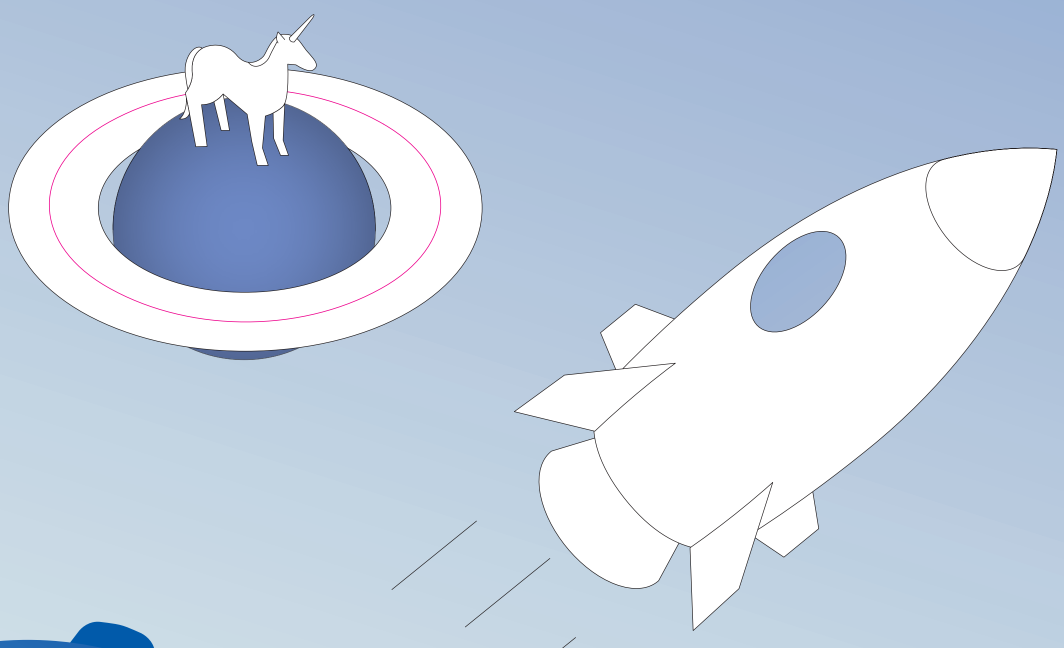
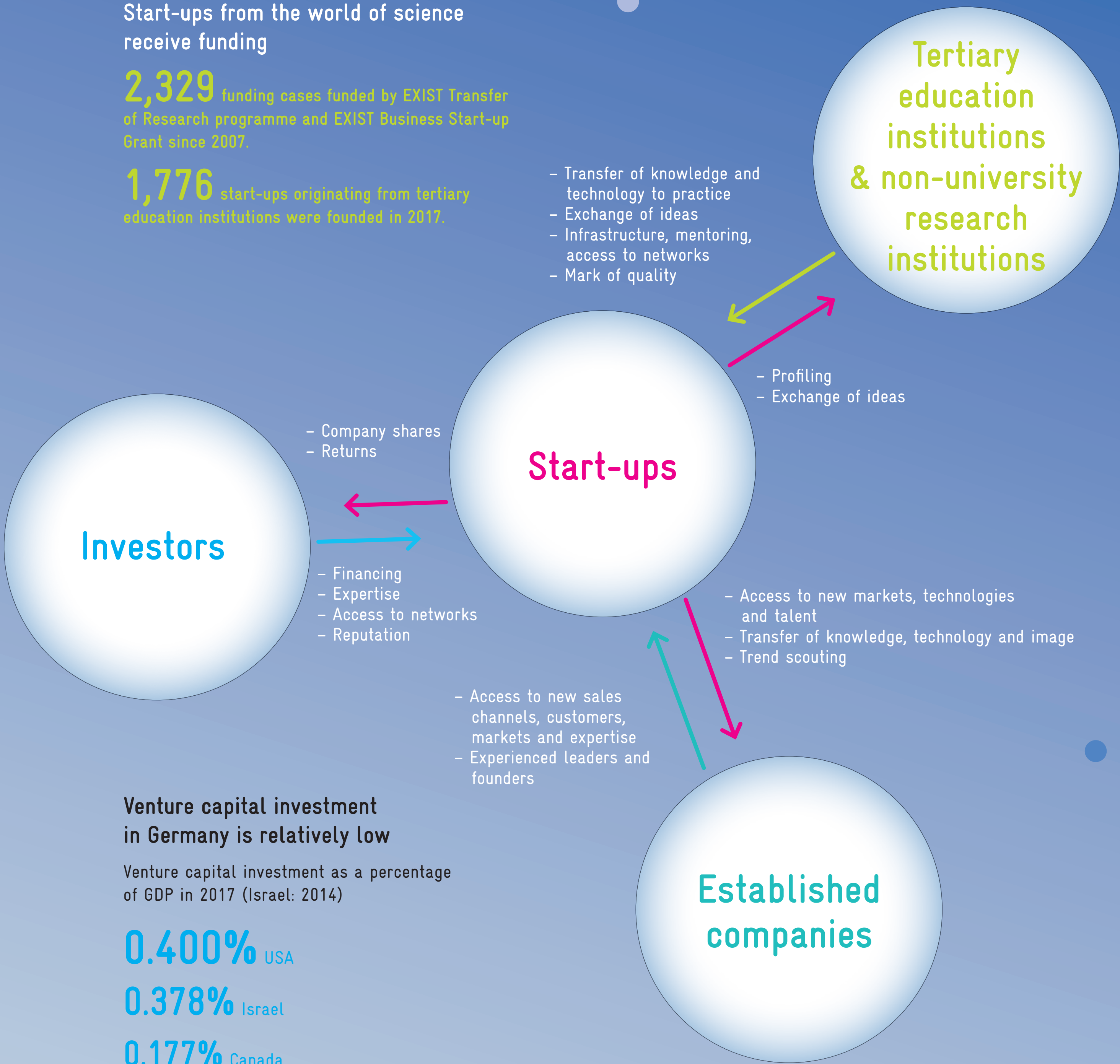
Start-ups explore new business models and produce innovations, thereby both augmenting and modernizing the array of products and services on offer. Start-ups from the world of science play an important role in the transfer of knowledge and technology into practice. Start-ups are also trend scouts and provide crucial impetus for established companies that are always challenged anew by the competition with start-ups. As cooperation partners of established companies, start-ups contribute to the joint development and marketing of innovations.



Start-ups from the world of science receive funding

2,329 funding cases funded by EXIST Transfer of Research programme and EXIST Business Start-up Grant since 2007.

1,776 start-ups originating from tertiary education institutions were founded in 2017.



Venture capital investment in Germany is relatively low

Venture capital investment as a percentage of GDP in 2017 (Israel: 2014)

0.400% USA

0.378% Israel

0.177% Canada

0.083% South Korea

0.076% United Kingdom

0.035% Germany

Established companies' interest in start-ups is clear

84% Proportion of German accelerators operated by established private companies.

48% Proportion of large family-owned companies in Germany cooperating with at least one start-up in 2018.

Source: number of EXIST funding cases: BMWi/PtJ data. Number of start-ups originating from tertiary education institutions founded in 2017: Frank and Schröder (2018: 5). Proportion of German accelerators operated by established private companies: Zinke et al. (2018: 60). Proportion of large family-owned companies cooperating with start-ups: Löher et al. (2018: 6). Venture capital investment in international comparison: OECD (2018a: 15).

B 1 The role of start-ups in the innovation system

Start-ups are young companies with innovative business ideas and considerable potential for growth.[154] They explore new business models and produce innovations, thereby both augmenting and modernizing the array of products and services on offer. In light of their specific capabilities and their incentives, start-ups are often better able to take up disruptive ideas and implement them in the form of market-ready solutions. As newcomers to the market – and in contrast to established companies – they do not need to worry about disruptive ideas cannibalizing their existing business model. Start-ups from the world of science play an important role in the transfer of knowledge and technology into practice. Start-ups are also trend scouts and, by exerting competitive pressure, stimulate established companies and challenge them to explore new approaches. Start-ups also contribute to the joint development and marketing of innovations as cooperation partners to established companies.

This chapter illustrates the geographical distribution of start-ups in Germany, discusses the various contributions start-ups make to the innovation system and highlights potential ways to further boost such contributions.

B 1-1 Geographical distribution of start-ups in Germany

A vibrant start-up scene has developed in Germany. However, reliable data on the growth of the German start-up population is currently not available.

Estimating the evolution of the number of start-ups based on the overall number of business foundations is problematic. The overall number of business foundations in Germany is in decline (cf. chapter C 5).[155] However, considering the favourable economic environment, it seems plausible that this is driven by a fall in the number of businesses founded to secure livelihoods – that is to say, due to unemployment or a lack of suitable alternatives.[156] Such motives are not typical reasons behind the foundation of a start-up. A study of the USA has shown that the development trends of company foundations in general and for start-ups in particular do not always run parallel.[157] The evolution of venture capital investment in Germany (cf. chapter C 4) indicates that the number of start-ups in Germany is higher today than it was five year ago.

Yet it is not only the overall number of start-ups that is interesting but also their geographical distribution within Germany. One point of reference for this distribution is venture capital investments and state funding for start-ups from the world of science, even though not all start-ups receive venture capital or government funding.[158]

Start-ups are often financed through state funding and by business angels in the early phase and receive external capital from venture capitalists during the subsequent growth phase.

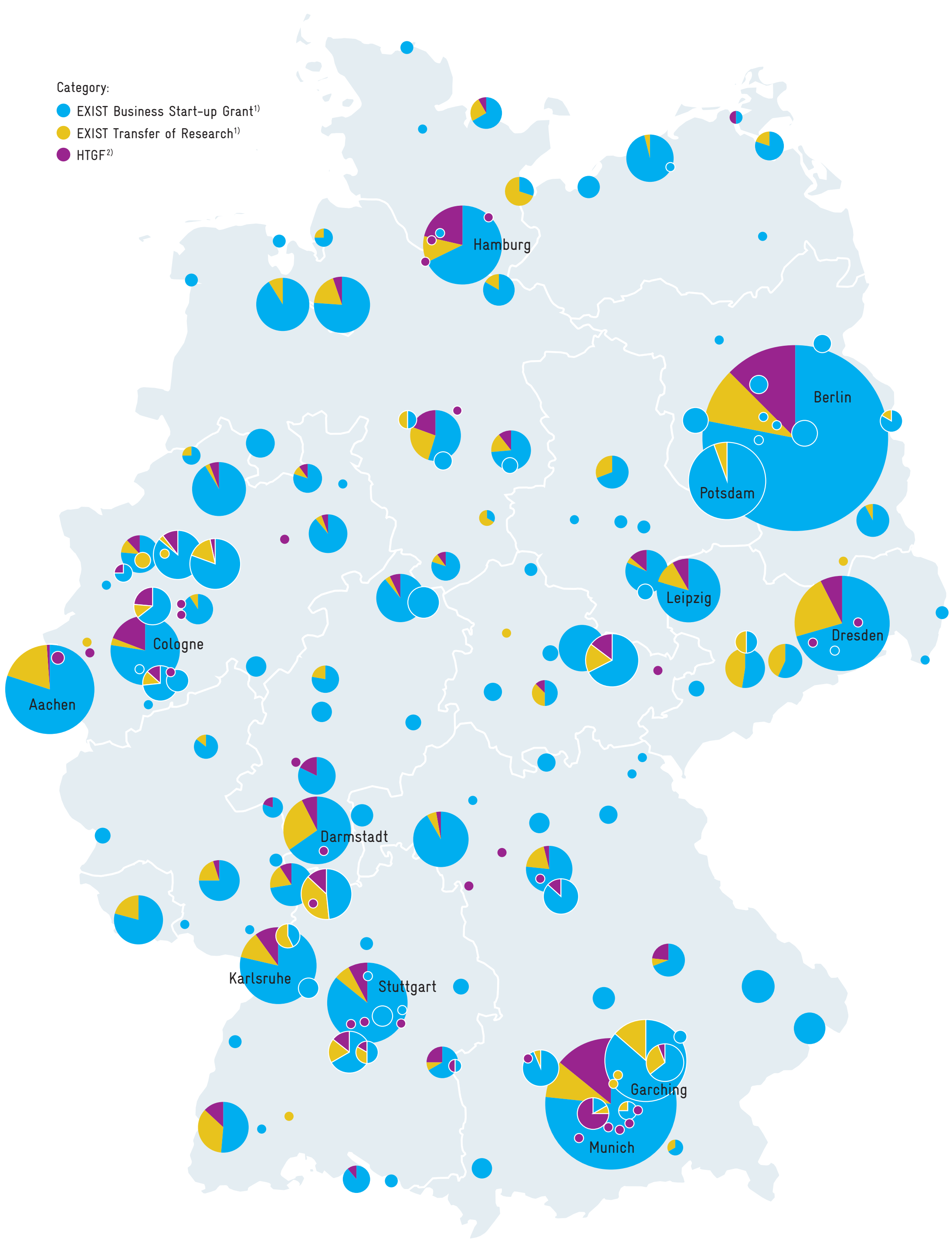
For the early phase of start-ups originating from academic institutions, the geographical distribution can be described using funding data from the EXIST programme, which supports start-ups from the world of science (cf. box B 1-5). In this regard, the number of funding cases supported by the EXIST Business Start-up Grant and EXIST Transfer of Research programme is examined since these funding lines were launched in 2007.

The High-Tech Gründerfonds (HTGF) is an important provider of venture capital for early-phase start-ups (cf. box B 1-9). The locations of start-ups that currently form part of the HTGF's active portfolio therefore make it possible to draw conclusions as to the geographical distribution of early-stage start-ups.

Fig. B 1-1

Download data

Geographical distribution of funding cases for the EXIST Business Start-up Grant and the EXIST Transfer of Research programme as well as start-ups in the portfolio of the HTGF



1) Period from 2007 to 2018.
2) Active portfolio of HTGF I, II and III as of November 2018.
The pie charts' size increases proportionate to the number of funding cases for the EXIST Business Start-up Grant and the EXIST Transfer of Research programme as well as start-ups in the portfolio of the HTGF.
It is possible that isolated start-ups and start-up projects may be included in more than one category.
Sources: Data from the BMWi/PtJ and the HTGF (2018). Own calculations.

Tab. B 1-2

Download data

Distribution of funding cases for the EXIST Business Start-up Grant and the EXIST Transfer of Research programme as well as start-ups in the portfolio of the HTGF across the Länder

	EXIST Business Start-up Grant[1]		EXIST Transfer of Research[1]		HTGF[2]		Venture capital investments by companies organized in the BVK[3]	
	Number of funding cases	Funding amount in €m	Number of funding cases	Funding amount in €m	Number of start-ups in portfolio	Estimated investment volume (early phase) in €m	Number of portfolio companies	Investment volume in €m
Baden-Württemberg	228	22.7	52	36.1	35	21.0	43	78.8
Bavaria	401	37.4	49	31.1	56	33.6	104	215.8
Berlin	325	33.0	39	23.7	52	31.2	174	490.2
Brandenburg	108	11.1	7	2.9	5	3.0	27	29.4
Bremen	32	2.7	8	3.9	2	1.2	2	1.1
Hamburg	51	5.4	8	6.0	16	9.6	26	60.1
Hessen	102	9.6	18	11.0	10	6.0	16	12.8
Lower Saxony	104	10.7	20	11.3	11	6.6	12	12.4
Mecklenburg-West Pomerania	42	3.9	3	2.0	1	0.6	4	2.3
North Rhine-Westphalia	294	28,4	43	28.2	36	21.6	58	84.0
Rhineland Palatinate	32	3.0	5	2.6	2	1.2	10	7.8
Saarland	23	2.4	6	3.8	–	–	5	1.6
Saxony	145	14.1	48	30.7	15	9.0	27	22.1
Saxony-Anhalt	34	3.3	5	2.5	3	1.8	4	3.3
Schleswig-Holstein	15	1.4	10	4.6	3	1.8	38	4.4
Thüringen	62	5.9	10	6.2	7	4.2	16	5.9

[1] Period from 2007 to 2018.
[2] Active portfolio of HTGF I, II and III as of November 2018. This includes the assumption that investment in the early phase totals €600,000 per start-up. The estimate does not include any ongoing finance.
[3] Investments in 2017.
Sources: Data from the BMWi/PtJ and the BVK as well as the HTGF (2018). Own calculations.

The venture capital investments documented by the German Private Equity and Venture Capital Association (Bundesverband Deutscher Kapitalbeteiligungsgesellschaften, BVK) covers both the early and growth phases. However, these investments are only documented at Länder level.

As illustrated in figure B 1-1, particularly high numbers of start-up projects supported by the EXIST programmes can be found in Berlin and Munich. The HTGF also invests particularly heavily in these two locations.

This geographical concentration is also reflected in the distribution of venture capital investment across the German Länder, as documented by the BVK (cf. table B 1-2), in which Berlin and Bavaria again lead the way.

A glance at other countries makes clear that such a geographical concentration is far from a German phenomenon.[159] In all countries, start-ups are founded and develop particularly well in locations that feature an effective start-up ecosystem with tertiary education institutions and non-university research organizations (außeruniversitäre Forschungseinrichtungen, AUFs), established companies and investors, as well as other start-up founders and skilled workers. The following sections cast light on how start-ups interact with these actors.

B 1-2 Start-ups from the world of science as a transfer channel

A core component of the contribution made by start-ups from the world of science is the transfer of knowledge and technology to the market. In this context, start-ups from the world of science are start-ups founded by current or former scientists applying the knowledge and insights they gained through their research activities in tertiary education institutions and AUFs. In all developmental stages, start-ups originating from research institutions are more innovative than other new businesses.[160] An assessment of the IAB/ZEW Start-up Panel – conducted by the ZEW on behalf of the Commission of Experts – indicates that start-ups from the world of science conduct an above-average level of R&D activities and develop a relatively higher number of product innovations that are new to the market than is the case for new businesses overall.[161]

Despite intensified efforts by tertiary education institutions and AUFs to promote start-ups from the world of science, such as through an increasing supply of incubator programmes,[162] the number of start-ups originating from tertiary education institutions and AUFs in Germany remains low (see below).[163] In its 2017 report, the Commission of Experts already warned that the potential of start-ups from the world of science was not being sufficiently exploited.[164]

Start-ups from non-university research institutions

When considering start-ups originating from AUFs in the period 2005 to 2017, it is clear that start-up activities were highly volatile across this period and have not systematically increased (cf. figure B 1-3).[165] The average number of all start-ups originating from the entire Fraunhofer-Gesellschaft or the Helmholtz Association is comparable with the

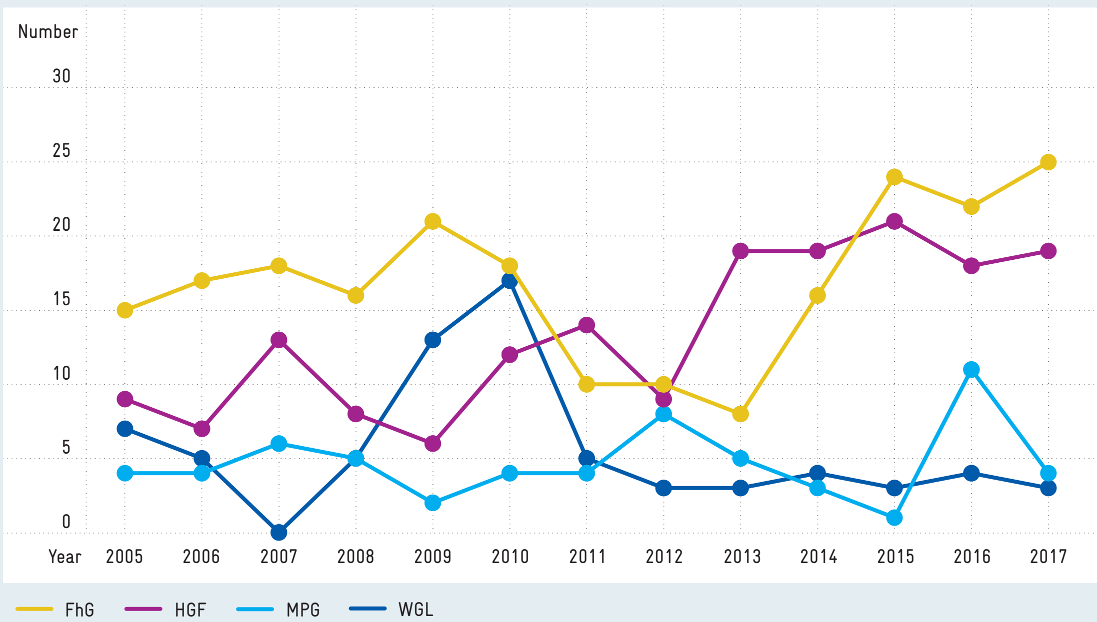
B

Fig. B 1-3

Download data

Start-ups from non-university research institutions 2005–2017

Number of start-ups established in the calendar year for the exploitation of intellectual property or expertise developed at the institution following conclusion of a formal agreement.



FhG: Fraunhofer-Gesellschaft, HGF: Helmholtz Association, MPG: Max Planck Society, WGL: Leibniz Association.
Source: own diagram based on GWK (2018a: 113).

number of all start-ups from individual universities such as ETH Zürich or Stanford University.[166] In light of the stagnating rate of start-ups from AUFs, the Commission of Experts welcomes the commitment from AUFs to intensify measures to promote start-ups as part of the Pact for Research and Innovation (Pakt für Forschung und Innovation, PFI) III.[167]

A look at the revenue generated by AUFs from intellectual property rights agreements or licences in the period from 2005 to 2017 shows an overall increase of almost 11 percent (cf. figure B 1-4). The Fraunhofer-Gesellschaft recorded by far the highest licensing revenue over the entire period; its licensing income for 2017 was €143 million. The Max Planck Society, the Helmholtz Association and the Leibniz Association recorded licensing revenues in 2017 of €20 million, €15 million and €7 million respectively.[168] The high stability of licensing income could indicate that AUFs purposefully focus on a stable income stream from licensing agreements with established companies. Similarly stable revenues can only partially be collected from start-ups as founders initially have only limited resources with which to pay licensing fees.

Start-ups from tertiary education institutions

Far more start-ups originate from tertiary education institutions than from AUFs.[170] A survey conducted as part of the Gründungsradar showed that 1,776 start-ups originating from tertiary education institutions were founded in 2017.[171] Of these, 767 start-ups transferred knowledge or technology from tertiary education institutions to the newly founded company. 232 start-ups were based on specific intellectual property rights (e.g. patents or registered designs).[172] Between 2012 and 2017, the number of recorded start-ups at tertiary education institutions rose by around 40 percent.[173]

The EXIST programme (cf. box B 1-5) has contributed to the positive evolution of the start-up culture at German tertiary education institutions.[174] In light of the break in funding following the second round of competition in EXIST IV,[175] the new EXIST Potentials programme – launched in November 2018 as part of the EXIST Culture of Entrepreneurship initiative – is to be welcomed. The EXIST Potentials programme is intended in particular to help small and medium-sized tertiary education institutions

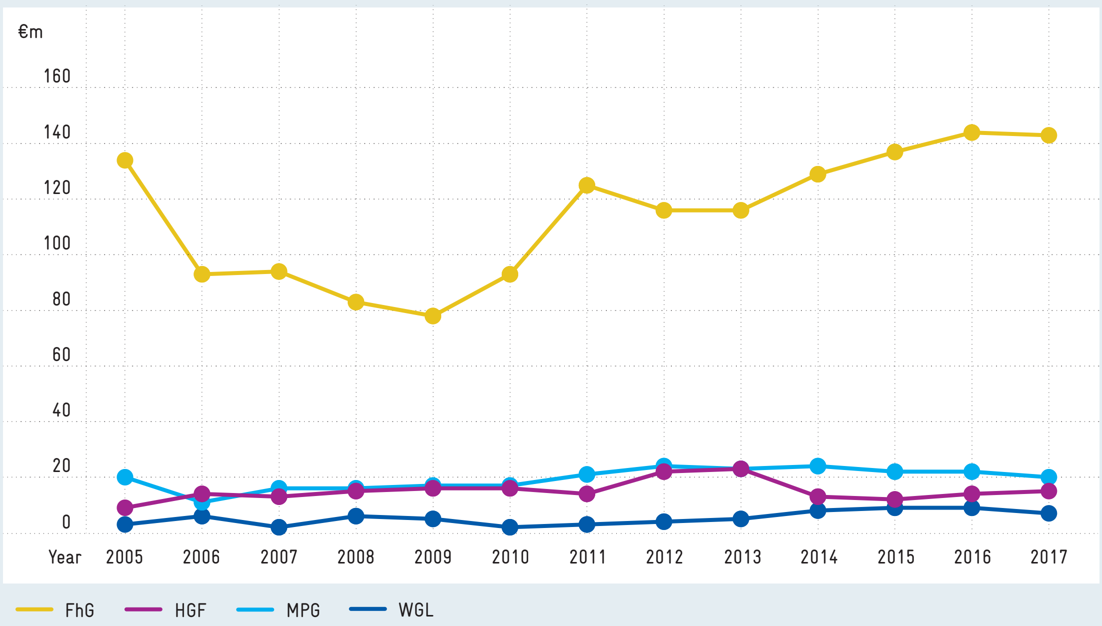
B

Fig. B 1-4

Download data

Revenues from intellectual property rights 2005–2017 in €m

Revenues received in the calendar year from intellectual property contracts/licences.[169]



FhG: Fraunhofer-Gesellschaft, HGF: Helmholtz Association, MPG: Max Planck Society, WGL: Leibniz Association.
Source: own diagram based on GWK (2018a: 111f.).

to implement measures that promote start-ups.[176] However, the Commission of Experts regrets that the EXIST Potentials programme has been allocated only moderate funding.[177] Some German Länder have also set about promoting start-ups from tertiary education institutions which, in light of the fact that tertiary education institutions financing is a matter devolved to the Länder, appears logical. North Rhine-Westphalia, for example, is providing a total of €150 million to up to seven universities over five years as part of its competitive Exzellenz Start-up Center initiative.[181] At the same time, as is always the case when the Federal Government and Länder intervene in the same field, it must be asked how well coordinated the various start-up support measures actually are.

Box B 1-5

EXIST funding programme[178]

Through its EXIST – University Based Business Start-Ups programme, launched in 1998, the BMWi funds start-up activities at tertiary education institutions and AUFs and helps research organizations to spread entrepreneurial spirit. The programme comprises three funding lines: EXIST Culture of Entrepreneurship (launched 1998), EXIST Business Start-up Grant (launched 2007, formerly EXIST Seed) and EXIST Transfer of Research (launched 2007). The EXIST Culture of Entrepreneurship scheme supports tertiary education institutions in formulating and implementing a comprehensive and sustained institution-wide strategy to increase entrepreneurial culture and spirit. The EXIST Culture of Entrepreneurship funding line features several programme phases: EXIST I (1998 to 2005), EXIST II (2002 to 2006), EXIST III (2006 to 2011), EXIST IV, also known as the EXIST Culture of Entrepreneurship – Entrepreneur University (2011 to 2018) – and the new EXIST Potentials programme, launched in November 2018 (2018 to 2023).[179] The EXIST Business Start-up Grant is a line of funding which supports innovative technology-based and knowledge-based start-up projects in the preparatory phase. The EXIST Transfer of Research programme funds resource development measures that are necessary to prove the technical feasibility of research-based start-up ideas. Recent evaluations of the funding programme, as well as the Gründungsradar 2018 report, attest to the positive impact of this funding. The tertiary education institutions supported as part of the EXIST Culture of Entrepreneurship – Entrepreneur University show a clear increase in the level of support for start-ups. Moreover, EXIST supports the emergence of an array of start-ups in highly diverse technological fields and sectors. The survival rate of the created start-ups is comparably high.[180]

Barriers to start-ups from the world of science

On behalf of the Commission of Experts, the Technical University of Munich (TUM) surveyed 50 people who had founded, led or advised a start-up in the last ten years, either in their own right or as part of a team. As part of this survey, the lack of practice-oriented qualifications, heavy administrative burdens and a shortage of resources (e.g. capital, office space) were named as barriers to start-ups from tertiary education institutions.[182] Another challenge is the potential competition between the commercial use of scientific knowledge and its distribution in the form of publications if the company founders remain active at the research organization.[183]

Legal framework conditions and uncertainty may also represent barriers to entrepreneurship. Start-ups from the world of science are complicated by protracted licensing negotiations between their founders and transfer organizations. In the USA, for instance, numerous technology transfer organizations at universities offer founders optional so-called express licence contracts to expedite licensing.[184] If founders find the conditions of express licence contracts unattractive, they can also conduct specific negotiations with the respective technical transfer organization. Express licence agreements could also help to accelerate the process of founding a start-up in Germany and lower the hurdles for start-ups from the world of science.[185]

Start-ups as drivers of innovation in established companies B 1–3

Start-ups provide crucial impetus and drive innovation in established companies. By competing, start-ups exert pressure on established companies to continuously improve in order to maintain their market position.[186] However, start-ups can also serve as trend scouts for new technologies and innovations.[187] Statements from start-up founders confirm that large companies take great interest in monitoring start-ups – allowing them, for instance, to discover new markets and commercial channels. Start-ups can help small and medium-sized enterprises (SMEs) to accurately appraise the future viability of technologies and innovations.

However, start-ups can also be effective cooperation partners for established companies. In addition, it can be part of the innovation strategy of established companies to buy up innovative start-ups.

Collaborations between established companies and start-ups

Collaborations can help to promote new innovations, expedite the diffusion of knowledge and technologies and test the marketability of technologies more quickly.[188] In recent years in particular, established German companies' interest in cooperating with start-ups has markedly increased, meaning that companies increasingly compete over attractive start-ups (in part by necessity).[189] A survey of 248 large, family-owned companies in Germany conducted by the Institut für Mittelstandsforschung (IfM) Bonn suggests that almost half of those companies surveyed were in cooperation with at least one start-up.[190] The number of incubators and accelerators offered by companies in Germany has risen continuously in recent years. Some 84 percent of all German accelerators (121 in 2017) are now operated by established companies.[191]

Collaborations are established in particular where companies and start-ups offer complementary products. The results of the study carried out by the TUM conducted on behalf of the Commission of Experts indicates that start-ups and established companies in partnerships particularly aim to facilitate both partners' access to sales and supply markets or enhancing their offering to customers.[192]

– In a partnership that aims to tap into new markets, the cooperation partners benefit from an exchange of information on customers, suppliers and/or capital investors. The reasons given for pursuing joint market development include increased overall turnover, an upgraded product portfolio and an enhanced public image for the participating cooperation partners (cf. box B 1-6).

– By jointly expanding the offerings made to customers, start-ups and established companies can together develop new, complementary products and services. In many cases, a new technology developed by the start-up is integrated into the established company's existing products. Start-ups can access the resources and infrastructure of their more established cooperation partner. The primary reasons given for such collaborations are the continuous improvement of a company's own products and a sustained positive impact on the culture of established companies.

Box B 1-6

Cooperation for market expansion[193]

The Karlsruhe-based start-up Cubuslab manufactures an adapter that extends the functionality of laboratory equipment. This adapter makes it possible to export and transfer data, allowing laboratory equipment to transfer measurements to other devices more quickly and more easily. Cubuslab uses the sales channels of its cooperation partner, a laboratory equipment manufacturer. Prototypes of the adapter can therefore be tested on the market more quickly – and non-viable prototypes then adapted to customer requirements. At the same time, the laboratory equipment manufacturer also benefits from the fact that its products are digitized to a greater extent and made more competitive.

However, collaborations also present start-ups and established companies with challenges.[194] In this regard, start-up founders with experience of collaborations particularly highlight the unbalanced power relationships due to the asymmetric allocation of resources, conflicts when cooperative relationships become competitive and differences in corporate cultures. SMEs are in need of support in terms of how to initiate cooperative relationships with start-ups, suitable means of exchange and what information to offer.[195] With this in mind, the Digital Hub Initiative – launched in 2017 by the BMWi and tasked with promoting cooperation between start-ups and companies – as well as plans to intensify networking between start-ups and established companies as part of the ministry's Start-up Initiative are to be welcomed.[196] However, industry experts have criticized the resources allocated to the Digital Hubs as being insufficient. An interesting international example from experience of making information available to potential cooperation partners is the Israeli information platform Start-Up Nation Central (cf. box B 1-7).

Box B 1-7

Start-Up Nation Central[197]

Start-Up Nation Central is an online platform providing information on the start-up ecosystem in Israel. The platform presents start-ups (including their business model, location, year founded), hubs, investors, established SMEs, scientific institutions and multi-national corporations. It allows users to search purposefully for potential cooperation partners; by creating a company profile of their own and providing information, users can also present themselves to potential business partners. The platform also provides information on new technological trends. It reduces the effort required to find players in the start-up ecosystem while simultaneously boosting the visibility of Israeli start-ups – including for international investors.[198] The volume of company profiles created on the platform is evidence of its acceptance as a medium for companies to share information and present themselves. A systematic evaluation of the platform's success has not yet been carried out.

Acquisition of start-ups by established companies

Acquiring start-ups can enable established companies not only to accelerate their innovation projects but also to reduce the costs of technology procurement and market entry.[199] A ZEW study has shown that established companies from knowledge-intensive sectors acquire innovative companies more often than companies from other sectors. They are also more likely to acquire start-ups from outside their own sector.[200] Consequently, companies from knowledge-intensive sectors expand their portfolio more than companies from other sectors. This trend is most pronounced in the field of cutting-edge technology.[201]

Acquisitions by well-financed Chinese and US corporations have attracted particular attention in recent years. Some commentators have voiced concerns that technologies developed in Germany – and the added value they entail – could be lost overseas. As a basic principle, the Commission of Experts considers an open, international transfer of capital and technology to be a crucial driver of innovation and growth. It shares the concern, however, that unequal market access conditions and market distortions caused by state-financed companies, such as in China, could impair the market opportunities of German companies.

The acquisition of start-ups by powerful digital giants from the USA is also contentious. In this case, the fear is that market giants are systematically removing start-ups from the market, which, over the long-term, might have the potential to threaten large corporations' business models.[202] In Germany, lawmakers have sought to address these competition concerns in the 9th Amendment to the Act against Restraints of Competition (GWB). In future, mergers will also be subject to pre-emptive merger control in cases where the purchased company records a turnover of less than €5 million in Germany but the return (usually the purchase price) is in excess of €400 million. In future, the Federal Cartel Office (Bundeskartellamt, BKartA) will therefore be able to examine mergers through which large, established companies seek to gain or reinforce market control by acquiring young, innovative companies with a high commercial value.[203]

Start-up entrepreneurs have responded to this change with some scepticism. From their point of view, selling their start-up to an established company can be an attractive option – for instance, it can be an effective method by which to gain access to capital or the customers of their new parent company. They fear that the new competition regulation could restrict the financing and exit options available to them.

The Commission of Experts believes that the concerns expressed by start-up entrepreneurs are understandable. When the situation as a whole is considered, however, there is much to be said in favour of efforts to counter strong concentration tendencies following mergers because they can act as barriers to innovation. In addition, the amendment will not inhibit acquisitions in general; it will only subject acquisitions to examination by the competition authorities in cases where the purchase price exceeds a high threshold. Their task is then to assess the potential consequences of the planned corporate acquisition on competition.

B 1-4 Start-up financing using equity capital

Start-ups are heavily depending on equity capital to finance their investments.[204] Most start-up projects require significant financing and entail a high degree of risk – but, if successful, can generate considerable growth.[205] Venture capitalists acquire holdings in start-ups with the aim of achieving the maximum possible returns from the company's growth. To increase the expected returns on their investments, venture capitalists often not only provide financial support but also offer strategic consultancy to start-up managers, monitor their operating performance and support them in establishing networks, sourcing additional financing and recruiting senior staff.

Typical actors on the venture capital market include business angels[206] and venture capital funds. The average sum invested by business angels is markedly lower than that of venture capital funds.[207] Business angels are primarily engaged in the early phases; venture capital funds are generally more reticent to invest funds in risky early-phase financing, and instead mainly play an important role in financing the growth phase.[208]

Germany has become an increasingly attractive investment location for international venture capitalists.[209] A recent analysis showed that, between 1993 and Q3 2018, around one-fifth of German start-ups financed by venture capital had at least one investor from the USA.[210]

Following the financial and economic crisis, venture capital investment in Germany has risen – not least due to the low level of interest rates (cf. figure C 4-3). However, venture capital investment as a percentage of GDP remains low compared to other key countries (cf. infographic and figure C 4-2). German start-ups still face difficulties when it comes to sourcing venture capital, especially during the growth phase. Financing options are restricted by a range of factors. The following sections examine several of these in further detail, namely: the lack of anchor investors, the modest size of venture capital funds, inadequate fiscal regulations and weak exit channels.[211]

Lack of anchor investors and modest size of venture capital funds

In Germany, there is a lack of institutional investors who act as anchor investors in the venture capital market and give important signals to domestic and international investors. Due to the predominantly pay-as-you-go structure of its public pension system, Germany lacks a class of institutional investors that play a significant role in other countries: pension funds.

The fact that relatively few major venture capital funds exist in Germany is a further problem.[212] However, institutional investors are loath to invest in small-volume funds. Insurance companies, for instance, therefore often look to make venture capital investments in the USA and Asian markets due to their size.[213] This is further reinforced by the tendency of investors to base their investment decisions on funds' previous success, sometimes referred to as their track record. Unfortunately, European funds' track records are usually decidedly short. Yet it is not only in terms of the size of its venture capital funds, but also with respect to the number of business angels where Germany has ground to make up.[214]

In recent years, both the Federal Government and the Länder have developed and created various programmes that offer incentives for investors considering venture capital funds and start-up investments (cf. box B 1-9 for more information on Federal Government programmes). In 2015, the KfW (a German state-owned development bank) returned to the market as an investor for venture capital funds as part of the ERP Venture Capital Fund Financing programme. This move aimed to help attract further institutional investors both within Germany and from abroad.[215] KfW Capital, a KfW subsidiary operational since 15 October 2018, focuses and expands KfW's financing activities in the field of venture capital.[216] Plans for KfW Capital include an increase in the investment volume in venture capital funds and

Box B 1-8

Dansk Vækstkapital

Dansk Vækstkapital is a joint project of the Danish state and Danish pension funds. It aims to make equity capital available to start-ups and SMEs with potential to grow.[217] Dansk Vækstkapital is comprised of two independent umbrella funds – Dansk Vækstkapital I and Dansk Vækstkapital II – which invest in small-cap and mid-cap funds, venture capital funds and mezzanine funds. The investment phase of Dansk Vækstkapital I was from 2011 to 2015. Dansk Vækstkapital II is currently in its investment phase. Both umbrella funds feature two sources of financing.

Source 1: Pension funds lend the state-established but independent Vækstfonden a determined share of the investment volume and, in return, receive a fixed rate of interest. Vækstfonden invests this capital in the umbrella fund.

Source 2: The pension funds invest other financing in the umbrella fund directly.

In the case of Dansk Vækstkapital I, three-quarters of the capital was invested in the Vækstfonden, with one-quarter invested in the umbrella fund directly. In the case of Dansk Vækstkapital II, the pension funds were given the option of investing one-third in Vækstfonden and two-thirds directly in the umbrella fund – or vice versa. The third option is for the pension funds to invest 100 percent of the capital in private equity.

venture-debt funds to an average of €200 million per year by 2020. In an effort to attract further institutional investors, the Federal Government is currently in dialogue with the insurance industry.[218] The intention is to develop models to facilitate an increase in venture capital investment from this sector. In this context, the Commission of Experts believes that Denmark's Dansk Vækstkapital programme could be an interesting model to encourage institutional investors to invest venture capital in start-ups (cf. box B 1-8).[219]

Inadequate fiscal conditions

While the fiscal conditions for venture capital investments were improved by the changes to regulations governing the offsetting of losses in 2016,[220] it still does not provide sufficient incentives for venture capital investment. In contrast to many other European countries, fund managers' administrative services are subject to VAT.[221] This makes the prospect of establishing and managing venture capital funds in Germany less attractive than doing so elsewhere.

Weak exit channels

The most important exit channels for holdings in start-ups include selling to a strategic investor (cf. Acquisition of start-ups by established companies, p. 53 ff.) and initial public offerings (IPOs).[222] In Germany, exit routes for investors are complex.[223] To invigorate stock markets as a source of financing for young, growing companies and to provide a crucial exit channel for investors, the Deutsche Börse Venture Network was set up in June 2015.[224] Since its launch, USD 2.4 billion has been invested in its member companies and seven IPOs carried out.[225] Furthermore, Scale – a new segment for SMEs – was opened on the Frankfurt Stock Exchange in March 2017.[226] Euronext, the European stock exchange operator, is also trying to attract young German technology companies.[227] The first IPO by a company financed by the HTGF (NFON, in May 2018) and Home24's IPO in June 2018 can be seen as positive signals for the exit environment.[228]

Box B 1-9

Federal Government programmes relating to venture capital and venture debt

Foundation phase[229]

High-Tech Gründerfonds: The High-Tech Gründerfonds (HTGF) is an early-phase fund established in 2005 as a public-private partnership.[230] Following the expiry of the HTGF I investment phase, HTGF II began in 2011.[231] HTGF III commenced operations in 2017.[232] Investors in HTGF III, which comprises capital of €316.5 million, include the Federal Government (ERP Special Fund, ERP-SV), KfW Capital,[233] the Fraunhofer-Gesellschaft and 32 private companies.[234] Acting as lead investor or in collaboration with partners, the HTGF finances innovative technology start-ups by either granting convertible loans or buying shares in companies.[235]

IINVEST – Grant for Venture Capital: Through its INVEST – Grant for Venture Capital programme, launched in 2013, the BMWi encourages private investors (and business angels in particular) to invest in young, innovative companies. The programme currently comprises two components:[236] The investment grant affords business angels a tax-free grant on top of their investment. The exit grant represents fixed compensation for the taxes due on the gains realized by a sale.

German Micro-Mezzanine Fund: The German Micro-Mezzanine Fund, launched by the BMWi in 2013 and financed by the ERP Special Fund (ERP-SV) and the European Social Fund (ESF), aims to increase the equity base of micro-enterprises and start-ups through silent participations.[237] The silent participation is overseen by the Mittelständische Beteiligungsgesellschaft (MBG) of the federal state in which the investment is made.[238] The German Micro-Mezzanine Fund had initial capital of €35 million, which was then gradually increased to €75 million (Fonds I). A further €85 million is now available in the new ESF funding period (Fonds II).

Growth phase

Coparion: Coparion, a co-investment fund jointly overseen by the Federal Government (ERP-SV), KfW Capital and the EIB, started operations in 2016. Together with private lead investors, Coparion invests in innovative start-ups that develop new products, processes and services and/or bring them to market and thereby perform their own R&D activities.[239] Coparion started operations with capital of €225 million. In December 2018, this figure increased by €50 million to €275 million after the EIB joined the fund.[240] The Federal Government provided €180 million while KfW Capital's share is €45 million.[241]

ERP/EIF Fund of Funds: The European Investment Fund (EIF) and the ERP Special Fund together finance a fund of funds which participates in venture capital funds that invest in young technology companies, primarily those based in Germany.[242] The initial resources of the ERP/EIF Fund of Funds, which was established in 2004, amounted to €500 million; this was increased to €1 billion in May 2010 and to €2.7 billion in July 2017.[243] A proportion of the funding made available for the ERP/EIF Fund of Funds is allocated to the European Angels Fund (EAF) (see below).[244]

European Angels Fund: Established in 2012, the European Angels Fund (EAF) provides co-financing for selected experienced business angels and other non-institutional investors who invest in innovative companies.[245] The EAF's funding was increased by €130 million to €285 million in 2015. The ERP/EIF Fund of Funds provides €270 million of this funding, while a further €15 million stems from the EIF's equity facility with the LfA Förderbank Bayern.

ERP Venture Capital Fund Financing: By launching ERP Venture Capital Fund Financing programme in 2015, the state-owned KfW development bank returned to the market as a venture capital fund investor with a budget of €400 million.[246] KfW Capital took over control of programme operations in October 2018. At the risk of the ERP Special Fund, KfW Capital participates in venture capital funds that invest primarily in Germany and finance technology-oriented start-ups and young, innovative companies.[247]Since 2017, the programme has also been open for participations in venture debt funds.

ERP/EIF Growth Facility: Launched in 2016 and funded by the ERP Special Fund and the EIF, the ERP/EIF Growth Facility aims to boost venture capital support for fast-growing companies.[248] Venture capital funds and fund managers receive funding to refinance co-investment funds they manage.[249] In total, some €500 million of funding is available for individual co-investment funds, of which €330 million comes from the ERP Special Fund and €170 million from the EIF.[250]

ERP/EIF/Länder Mezzanine-Fund of Funds: Set up in 2013 by the EIF, the BMWi/ERP Special Fund, LfA Förderbank Bayern and NRW.BANK, the ERP/EIF/Länder Mezzanine-Fund of Funds participates in private professional mezzanine funds that invest in German SMEs, including younger growth-phase companies.[251] The ERP/EIF/Länder Mezzanine-Fund of Funds was initially given a budget of €200 million.[252] In 2016, a second mezzanine fund was set up with an investment period of five years and a budget of €400 million.[253]

Venture Debt

The Federal Government's aim is to make venture debt financing – that is to say, loans with equity-like elements – available to companies, especially those in the growth-phase.[254] This includes venture debt fund finance as part of the ERP Venture Capital Fund Financing programme (see above) and ERP/EIF/Länder Mezzanine-Fund of Funds (see above). A new feature introduced in 2018 was the use of the EIB's InnovFin MidCap guarantee for the KfW Loan for Growth programme. There KfW also has plans to introduce co-venture debt financing with private partners in the form of smaller individual commitment volumes and EIB venture debt deals in which the KfW participates at its own discretion (with EIB underwriting). There are also plans to create a new segment in the ERP/EIF/Länder Mezzanine-Fund of Funds to enable the facility to offer larger-scale venture debt financing.

Challenges for start-ups B 1–5

Due to their small size and their business model, start-ups face specific challenges, some of which are caused or influenced by the legal framework.

Difficulty accessing R&D funding

Start-ups develop innovative products and business ideas that often require R&D activities. The public purse funds R&D activities at companies in order to stimulate innovations.[255] However, start-ups often find it more difficult than established companies to obtain R&D funding.

– Applying for funding entails significant administrative effort. This represents a barrier to start-ups, who have less experience of submitting such applications. Another problematic aspect is that companies are required to demonstrate their ability to remain solvent for the duration of the project.[256] Start-ups often find this condition difficult to fulfil. The formal requirements of the solvency check – and how they are interpreted – vary depending on the funding provider or project sponsor and, in some cases, from one funding programme to the next.[257] This creates serious uncertainty for start-ups who, in some cases, are forced to forgo innovation projects as a result.
– The German fiscal system still lacks any tax incentives for R&D activities. However, such incentives are set to be introduced in the current legislative period (cf. chapter A 1). Nevertheless, whether start-ups conducting R&D work will be able to benefit from tax incentives for R&D activities depends very much on how such measures are structured. In its 2017 report, the Commission of Experts presented options for tax incentives for R&D activities.[258] During the initial phase, start-ups have little to no income and therefore have little to no tax liabilities. Therefore, if a tax credit instrument were to be implemented, in the event that the credit exceeds a start-up's tax liabilities, it should be possible to disburse the amount exceeding the tax liability directly. Alternatively, start-ups should be able to carry the residual credit forward to the following year.

Barriers to recruiting skilled workers

In order to realize demanding R&I projects, start-ups need qualified and motivated workers. However, in light of their limited liquidity and low turnover, start-ups are usually not able to offer skilled workers competitive salaries in the classical form of fixed monthly remuneration.

- Employee participation programmes are one method by which a start-up can attract and retain skilled workers (cf. box B 1-10). Compared to alternative employment opportunities, employees are cutting back on their fixed monthly remuneration, but have the opportunity to share in a start-up's success. Employee participation programmes are particularly common among start-ups financed by venture capital. However, the start-up often has to contend with major uncertainties in terms of the legal interpretations of specific regulations in employee participation programmes.[259]
- Recruiting skilled workers from abroad can help overcome staff shortages and develop competencies that promote the internationalization of the company. According to the German Start-up Monitor (DSM), start-ups are very internationally positioned in terms of their workforces.[260] In start-ups that took part in the 2017 DSM survey, 23 percent of employees came from other EU countries, with a further 6 percent from non-EU countries. In Berlin, Hamburg and Munich, the proportions of employees from non-EU countries were particular high at over 20 percent.[261] Around one-third of start-ups that took part in the 2017 DSM survey found it (somewhat or very) difficult to recruit staff from abroad.[262] The Commission of Experts welcomes the Federal Government's efforts to prepare a skilled worker immigration law for well-qualified workers from third countries. Nevertheless, there will still be bureaucratic hurdles to overcome even if this new law comes into force. Such hurdles place a particular burden on start-ups.

Box B 1-10

Employee participation programmes

A distinction can be made between two basic models of employee participation programmes.[263] In an employee stock ownership plan (ESOP), employees gain an ownership interest in the company; a virtual stock option plan (VSOP) allocates virtual shares (sometimes known as phantom shares). A transfer of shares as part of an ESOP must be recorded in the commercial register. Employees become shareholders and therefore also receive corresponding rights to co-determination and information. However, this aspect may not be desirable to start-up founders and venture capitalists. For employees, on the other hand, one negative aspect of an ESOP is that tax authorities consider a transfer of shares to be remuneration and tax it directly – even if the shares are yet to yield returns. Virtual shares awarded as part of a VSOP do not represent a participating interest but instead constitute an entitlement to payment that does not entail co-determination or information rights. Employees are then entitled to a payment in the event of an exit. Taxation only occurs when proceeds are generated, i.e. in the case of an exit or a dividend pay-out. In practice, VSOPs are far more common.[264]

Companies implement employee participation programmes with the aim of retaining staff. With this in mind, it would render the programme futile if employees were to leave the company as soon as the shares had been transferred. To solve this issue, employee participation programmes usually entail cliffs and vesting. Vesting is an agreement by which an employee forfeits their share entitlement either in whole or in part if they leave the company before working for the company for a pre-determined period of time. A cliff is an agreed period of employment after which vesting actually comes into effect.

Legal uncertainties in dynamic technology areas

A significant proportion of start-ups are currently internet-based.[265] However, start-ups are increasingly active in other technology areas. The Global Startup Ecosystem Report 2018 analysed start-ups' activities in various technology areas.[266] The four areas currently seeing the highest growth rates in terms of early stage deals, exits and start-up rates are "Advanced Manufacturing & Robotics", "Agtech & New Food", "Blockchain" and "Artificial Intelligence, Big Data & Analytics". In total, 8.4 percent of start-ups around the world operate in these technology areas.

For German start-ups which operate in these fields and drive technological developments forward, the challenge is to assert themselves in the global competition. Their chances of success are influenced by the German and European legal frameworks. Such regulations relate, for instance, to issues of security and liability when using AI applications (cf. chapter A 2), the potential users of blockchain technologies in regulated markets such as the energy industry (cf. chapter B 3), and the protection of personal and company data in Industry 4.0.[267]

Setting up Regulatory Test Beds (RTBs) makes it possible to obtain insights into the effect of alternative approaches to regulation. Regulatory Test Beds are a research concept in which potential solutions to a problem are tested within a defined framework.[268] The objective is to gather experience of complex social dynamics and form a basis upon which decisions can be taken, such as in relation to the make-up of legal framework conditions. The German political sphere has seized on the idea of Regulatory Test Beds: they are explicitly referenced as an instrument in the HTS 2025 and the AI Strategy.[269] An inter-departmental working group (Arbeitsgruppe "Reallabore") has been established to examine the topic and convened for the first time on 27 November 2018. The BMBF already funds a series of Regulatory Test Beds in the energy field.[270] The BMWi presented a Regulatory Test Beds Strategy on 14 December.[271]

Recommendations B 1–6

Start-ups play a crucial role in the innovation system. Not only do they provide innovative products, processes and business models, they also act as a catalyst and cooperation partner for innovations in established companies

Promoting start-ups from the world of science

- Efforts to promote a culture of entrepreneurship at tertiary education institutions through the Federal Government's EXIST programmes and Länder initiatives have begun to yield results. Nevertheless, the culture of entrepreneurship at tertiary education institutions must still be strengthened. Start-up training should be anchored in all courses of study.
- In the continuation of the PFI, start-ups from the world of science as a transfer channel should again be addressed under the science policy objectives.
- The management of technology transfer organizations should not be guided solely by financial objectives but should also take into consideration the wider economic and social implications of the transfer. Even if start-ups are unable to generate licensing revenue, they create added value for society that is afforded little attention at present.
- Tertiary education institutions and AUFs should develop express licence contracts to transfer rights to spin-off companies to reduce uncertainties and to enable founders to licence products and services swiftly. The express licence contracts already offered by certain US technology transfer organizations could be examined as examples of good practice in this regard.
- To ensure that scientists are not forced to contend with the conflicting goals of the academic and commercial applications of research results, a grace period should be introduced into patent law.[272]

Strengthening start-up ecosystems and collaborations

- Start-ups – and particularly those originating in the high-tech sector – benefit from geographically concentrated ecosystems in which they enjoy close proximity to research institutions, investors, established companies and other start-ups. Rather than being an issue requiring resolution, the regional concentration of innovation actors is symbolic of a successful innovation system. In order to promote globally visible start-up ecosystems in cutting-edge technologies, the challenge now is not to counteract this geographical concentration but instead to foster and expand existing and emerging start-up ecosystems.
- Internet-based approaches (such as cooperation platforms) and other techniques can enable companies outside of these ecosystems to access cooperation opportunities and the knowledge and technologies these sites generate. The Federal Government should therefore move to support the setup of central platforms that service to facilitate initiation of business relationships and collaborations. The Israeli platform Start-Up Nation Central can serve as a role model in this regard.
- In addition, supporting individual start-ups outside of geographically concentrated start-up ecosystems is also a worthwhile means of leveraging innovation potential and exploiting the positive effects of start-ups for established companies outside these centres.

Further improving the framework conditions for private investment in start-ups

- As Germany suffers from a lack of anchor investors, the Commission of Experts is in favour of creating incentives to encourage institutional investors to invest in venture capital funds. The Commission of Experts recommends that, as part of its ongoing dialogue with the insurance industry, the Federal Government examine to what extent Denmark's Dansk Vækstkapital model could be applied in Germany.
- The fiscal framework conditions for venture capital funds are in need of further improvement. The fact that fund managers' administrative services are subject to turnover tax should be reversed.

Enhancing start-ups' means of accessing R&D funding

- Opportunities for start-ups to share in project funding should be further extended. The formal requirements of start-ups' solvency checks should be more favourably structured and uncertainty in their interpretation removed.
- Start-ups' demands should be afforded particular consideration in the introduction of tax incentives for R&D activities. If this tax incentive took the form of a tax credit, in the event that the credit exceeds a start-up's tax liabilities, it should be possible to disburse the amount exceeding the tax liability directly. Alternatively, the start-up should be able to carry the remaining credit forward to the following year.

Helping start-ups to recruit skilled workers

- Employee participation programmes are an important instrument by which start-ups can attract skilled workers and retain them for the long term. However, the legal (and, more importantly, fiscal) interpretation of the contracts start-ups and investors require to implement such programmes often entails significant legal uncertainty. To increase the legal certainty for start-ups introducing employee participation programmes, associations that represent start-ups should coordinate with federal authorities to develop standard contracts for employee participation programmes that provide the greatest possible degree of legal certainty.[273]
- Although start-ups often rely on skilled workers from abroad, various bureaucratic hurdles complicate the process of recruiting employees from third countries. Start-ups should be supported in overcoming these hurdlers.

Adjusting regulation in dynamic technology areas

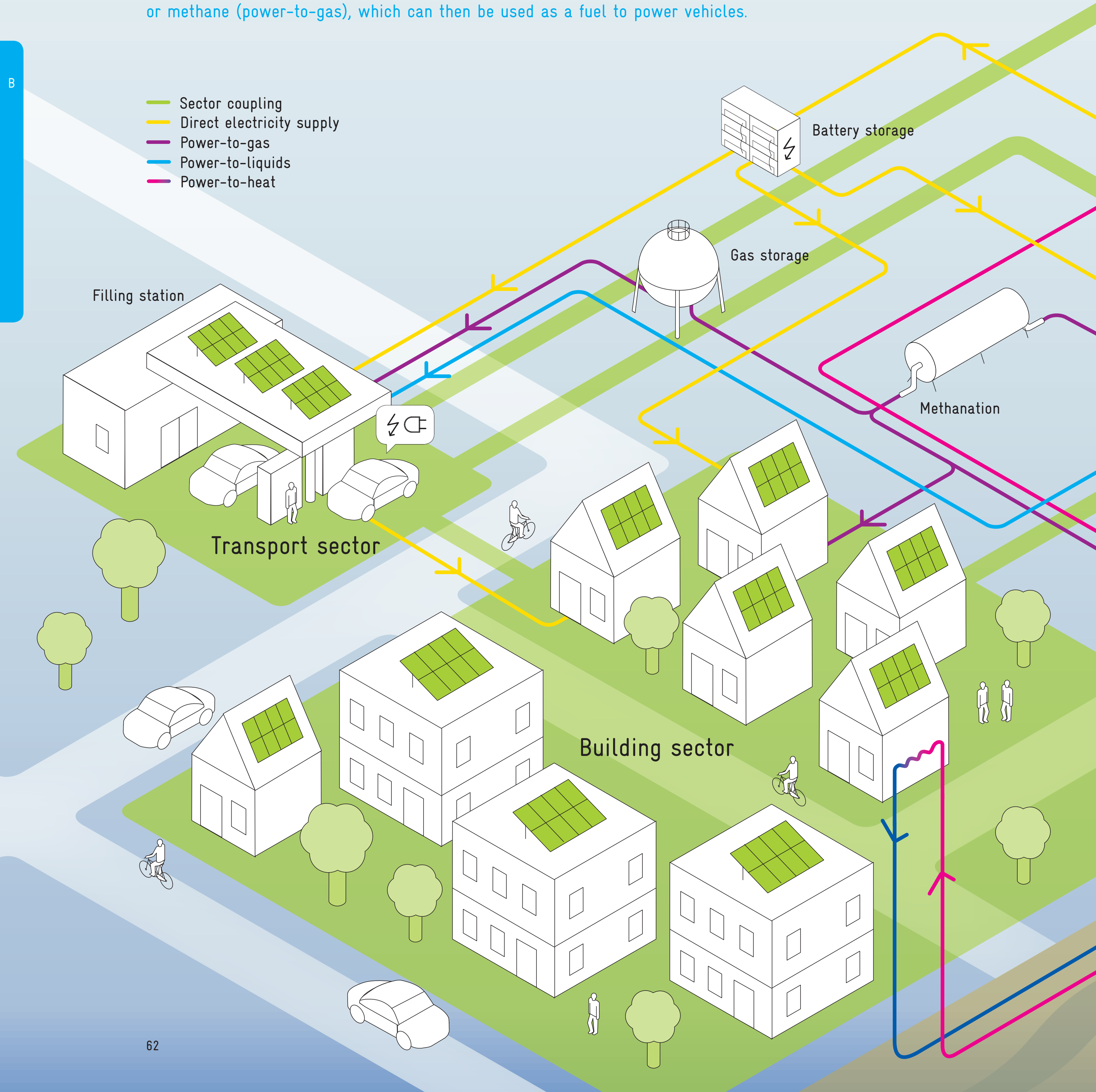
- In dynamic technology areas – such as blockchain applications and AI – the Federal Government should be proactive and work to establish a reliable legal framework that reduces uncertainty for start-ups.
- Regulatory Test Beds (RTBs) represent an effective experimental instrument to allows legislators to develop innovation-friendly framework conditions. The Commission of Experts therefore

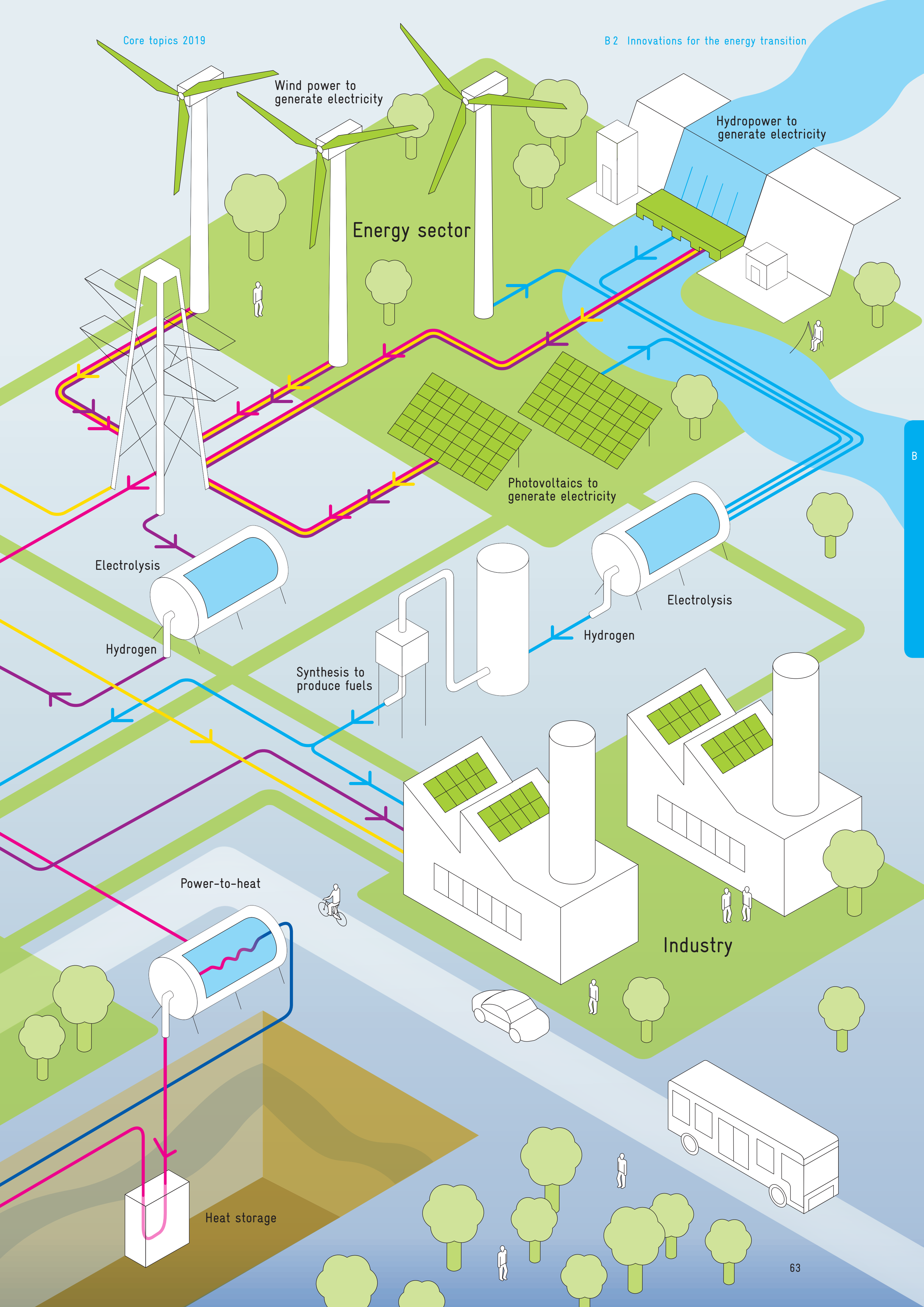
expressly welcomes the Federal Government's increased use of Regulatory Test Beds. The task now is to move quickly to identify suitable areas of application.

B 2 Innovations for the energy transition

Download data

Sector coupling will play a pivotal role in the energy transition. It is based on direct and indirect electrification. In the case of direct electrification, fossil energy sources are directly replaced by electricity – such as using electric cars rather than vehicles with a combustion engine. Indirect electrification involves converting electricity into other energy sources. Electrolysis, for example, is a process by which electricity can be used to produce hydrogen or methane (power-to-gas), which can then be used as a fuel to power vehicles.




Wind power to
generate electricity
Hydropower to
generate electricity
Energy sector
Photovoltaics to
generate electricity
Electrolysis
Hydrogen
Electrolysis
Hydrogen
Synthesis to
produce fuels
Industry
Power-to-heat
Heat storage

B 2 Innovations for the energy transition

B 2-1 The Federal Government's ambitious greenhouse gas emission targets

At the 2015 UN Climate Change Conference in Paris, Germany signed up to an international commitment to keep global warming below 2 degrees Celsius. This aims to curb the drastic damage caused by climate change. As a result of the Paris Agreement, the German energy system will have to become largely greenhouse gas-neutral by the year 2050.

Back in 2010, the German Federal Government committed to reduce greenhouse gas emissions[274] (GHG emissions) by 80-95 percent by the year 2050 compared to 1990 levels. In late 2016, the Federal Government adopted the Climate Action Plan 2050, which sets down specific GHG reduction targets for various sectors of the German economy.[275] Figure B 2-1 illustrates German GHG emissions by sector[276] for the reference year 1990 and for 2017 in millions of tonnes of CO_2 equivalents. These figures are accompanied by the Federal Government's GHG reduction targets for 2020, 2030 and 2050.[277]

Germany is, in all likelihood, set to miss the interim target of reducing GHG emissions by at least 40 percent by 2020 compared with 1990 levels.[278] In order to achieve the reduction target for 2030, GHG emissions will have to be 55 percent lower than in 1990.[279] However, reaching this target will only be possible if annual reductions in GHG emissions between 2017 to 2030 are around fourfold greater than annual reductions over the last ten years.

The drastic reductions in GHG emissions proposed by the Federal Government are to be achieved through an energy transition from fossil fuels to GHG-neutral, renewable forms of energy. At the same time, however, secure supplies must be guaranteed and the affordability of energy ensured.[280]

Over the last decade, high levels of state funding for renewable energy (RE) for electricity generation[281] have led to a situation in which more than one-third of electricity consumption is now covered by RE sources.[282] The energy sector, however, is only responsible for a little over one-third of climate-damaging GHG emissions produced in Germany. In addition to further efforts to replace fossil fuels with RE sources as a means of generating electricity[283] it is obvious that considerable effort is required to reduce GHG emissions in other sectors – in particular in buildings, industry and transport.[284] In this context, the use of renewable electricity across all sectors – known as sector coupling – will be of pivotal importance.

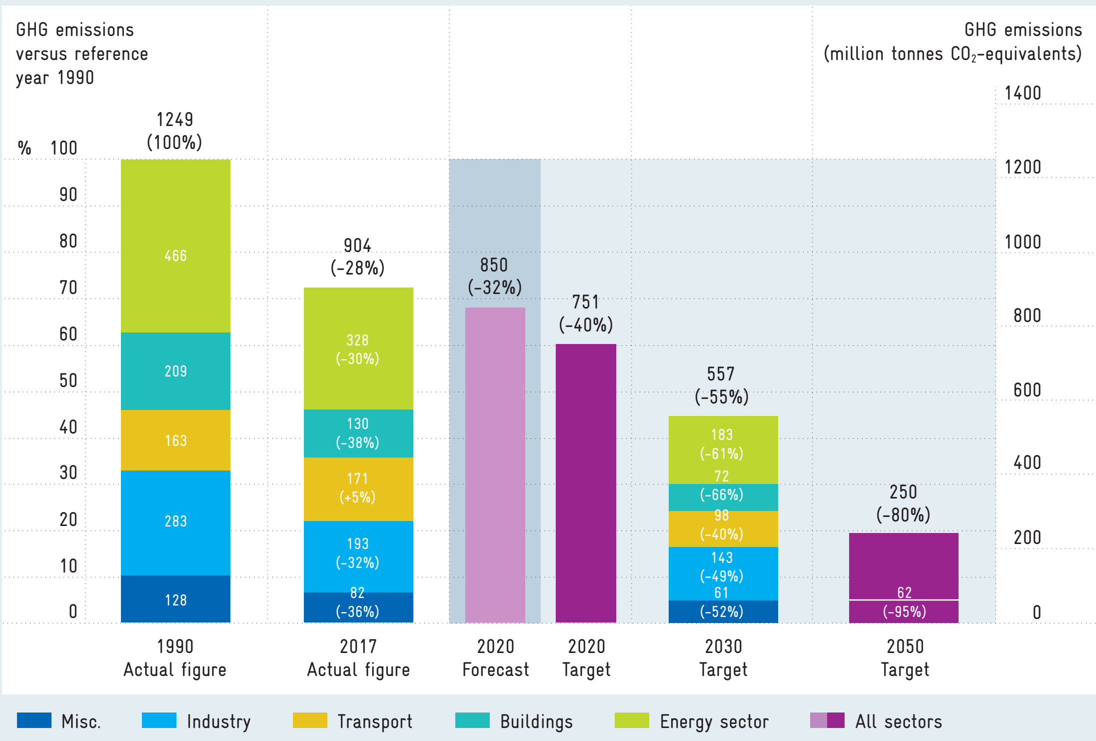
Sector coupling is based on direct and indirect electrification. In the case of direct electrification, fossil fuels are directly replaced by electricity. Examples of this include replacing an oil-fired heating system with an electrical heat pump (known as power-to-heat) or using electric motors in vehicles (power-to-mobility) in the place of petrol or diesel engines.[285] Indirect electrification is the conversion of electrical power into another energy carrier. Electrolysis, for example, is a process by which electricity can be used to produce hydrogen or methane (power-to-gas), which can then be used as fuels to power vehicles. Direct and indirect electrification both contribute to reducing GHG emissions when the electricity used is generated from GHG-neutral, renewable sources, such as wind or solar energy.

However, the energy transition must not simply be restricted to expanding the use of electricity from RE sources to electrify the energy system. A simple calculation makes this clear: in 2017, final energy consumption in Germany amounted to 2,591 TWh.[286] To cover the overall energy consumption for 2017

Fig. B 2-1

Download data

GHG emissions in Germany for 1990 and 2017, forecast of GHG emissions in Germany for 2020 and GHG emissions targets for Germany for 2020, 2030 and 2050



Absolute values in million tonnes of CO_2-equivalents. Figures in brackets show change versus reference year 1990.
Source: own diagram based on BMUB (2014), BMUB (2016), BMU (2018a) and BMU (2018b).

using only electricity from RE sources, Germany would require RE capacity of more than 1,400 GW[287] However, by the end of 2017 – following many years of sustained support for RE applications[288] the country had installed capacity of just 112 GW.[289] Not only is there too little time to expand the country's capacity to 1,400 GW, there is quite simply not enough land available upon which to build the required wind and solar installations. Specialists have therefore assumed that RE capacity will not exceed 500 GW in light of the spatial constraints.[290] Even for an expansion target of 500 GW, 12 GW would have to be added annually by 2050, while the average annual expansion of renewables in the period 2007 to 2017 was just 7.3 GW.[291] One thing is clear: even optimistic projections of RE expansion will not be enough to reach emission reduction targets on their own.Instead, the expansion of RE technologies must be combined with energy savings and energy efficiency improvements.

Innovative technologies and business models can help to force progress on the cost-effective generation of electricity from RE sources and encourage its use across sectors, while also realizing the potential for energy savings and energy efficiency improvements. Against this background, this chapter will examine three core issues:

i. Which innovative technologies and business models are of central importance for the energy transition in different sectors?
ii. What barriers to innovation do different sectors face?
iii. What reform options are available to policy-makers?

To answer these questions, a survey of domain experts has been carried out (cf. box B 2-3). The evaluation of its results shows that key innovative technologies and business models are, in principle, available today. However, their market diffusion is curbed by market externalities, regulatory requirements and lock-in effects. Box B 2-2 highlights the most significant externalities in the context of the energy transition: GHG externalities and network externalities.[292] Furthermore, existing regulatory requirements often heavily influence which technologies and business models succeed in the market. Moreover, switching to new technologies often entails significant costs – which can create situations in which the most economical technology over the longer term fails to gain acceptance (lock-in effect). Such issues present barriers to the use of innovative, climate-friendly technologies and business models as part of the energy transition.

In the following, the four core sectors in the energy transition – energy, buildings, transport and industry – will be examined in further detail. The section on each sector will illustrate the initial situation, followed by i) the central technologies and business models in use, ii) barriers to innovation and iii) potential routes for reform.

Box B 2-2

Market externalities in the context of the energy transition

Externalities are generally defined as the effects of economic activities on third parties for which no compensation is paid.[293]

GHG externalities:

GHGs are emitted when oil, coal and gas are burned. These emissions amplify the earth's natural greenhouse effect and lead to global warming and climate change. As a result, sea levels are rising and extreme weather events are becoming increasingly common. The negative consequences of climate change, such as floods and droughts, affect large numbers of people around the world. These damages are not considered by GHG emitters if they are not compelled to pay for them. In this case, more GHGs are emitted than is societally viable. Charging for GHG emissions[294] at a level corresponding to the damage caused would force each and every person to consider the harm they are causing to the environment. Doing so would internalize the negative externalities of GHGs. Such a system could be achieved, for instance, by taxing energy sources on the basis of their GHG content.[295] The German Environment Agency (Umweltbundesamt, UBA) calculates the societal costs of GHG externalities to be €180 per tonne of CO_2.[296]

At present, the level of taxes and charges on energy sources such as electricity, coal, oil and gas are not based on their respective negative GHG externalities; in comparative terms, energy sources with high GHG emissions are too cheap. This creates a particular competitive disadvantage for climate-friendly technologies based on renewable electricity, such as electric cars and heat pumps. This hampers the use of electricity from RE sources in the transport and building sectors and thereby also hinders sector coupling as a core element of the energy transition.

Network externalities:

The attraction of using a technology can depend on how many other actors already use it.[297] This is referred to as a network externality. The cost-effectiveness of developing infrastructure to use specific technologies is dependent on there being a critical mass of users. The market diffusion of electric and hydrogen-powered cars, for instance, is curbed by the lack of comprehensive charging and refuelling infrastructure. By contrast, the required refuelling infrastructure for existing technologies (combustion engines powered by fossil fuels) is already in place. This favours the continued use of existing technologies and hampers the transition to new, alternative drive systems – a so-called lock-in effect.

Box B 2-3

Survey of experts on technologies for the energy transition

On behalf of the Commission of Experts, a survey of renowned experts in the energy sector has been conducted to gather their views on technologies for the energy transition. The experts assessed the maturity level of these technologies and their significance for the energy transition. The survey concerned the energy sector, industry, transport and buildings. The experts assessed both the significance of technologies and their maturity level on a four-point scale, based on the target of full decarbonization of the German energy system by 2050. In addition, the experts had the opportunity to propose additional technologies and business models they consider important for the energy transition but which had not been included in the survey.

In total, 36 experts took part in the survey, resulting in a response rate of around 50 percent.

In the analysis, a technology is considered to have a high degree of maturity if the experts assign one of the two highest levels of maturity to it on average. A technology was identified as having a high degree of significance for the energy transition if at least 70 percent of the experts surveyed said they considered it important or very important for the energy transition.[298]

B 2-2 Energy sector

Initial situation

The energy sector has successfully reduced GHG emissions by 30 percent compared to 1990 levels (cf. figure B 2-1). However, this represents just half of the sector's target for 2030 – a reduction of 61 percent. Achieving this amount will require a massive increase in electricity generation from RE sources. Fossil fuel power stations and nuclear power stations made redundant by the nuclear phase-out will have to be replaced.[299] This migration poses considerable challenges for the energy sector due to the volatility and decentralized nature of renewable generation. For many years, the energy industry was characterized by largely centralized power generation that could be effectively controlled, based on fossil fuels and nuclear energy. It was also possible to select power plant sites with proximity to major consumption centres, which made it comparably easy to coordinate the expansion of the power grid. The massive expansion of renewable energies is leading to a weather-dependent electricity generation system that is more varied in terms of location and generation time, which is very difficult to control, and which is spread across many decentralised plants.

The rise of geographically shifting electricity generation, at changing times and from decentralized systems, necessitates the expansion of power networks on a massive scale at all voltage levels.[300] Expanding and upgrading the power grid will place growing importance on efficient grid management – a field in which digitization of the energy industry will be key.[301]

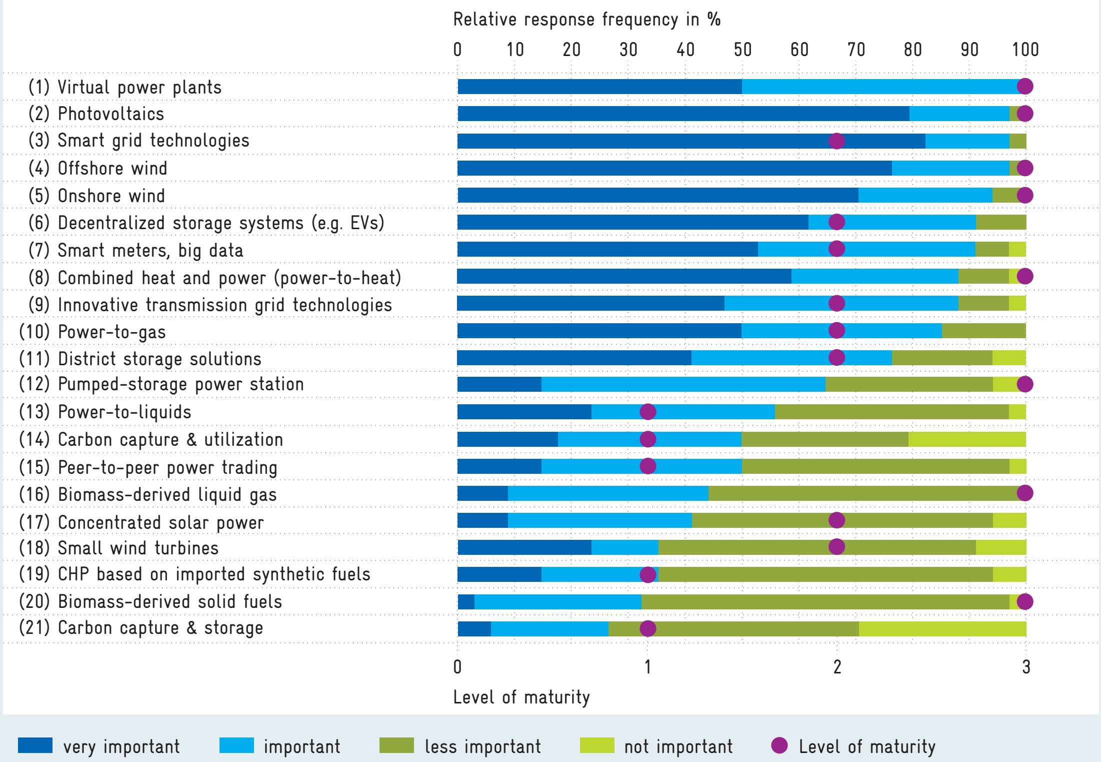
The ever-increasing proportion of electricity from RE sources, along with advancing direct and indirect electrification of the entire energy system, presents new challenges for supply reliability. To ensure a reliable supply of electricity, the generation and demand of electricity must be matched at all times. Flexibility options are therefore required in order to compensate for short-term peaks in generation and consumption. Such options include electricity storage systems and converting electricity into other energy carriers, such as gas, fluids or heat (power-to-X). It must also be ensured that the system is capable of covering longer periods with low levels of energy generation, gloomily referred to in German as "Dunkelflauten" – dark doldrums. Sufficient reserve capacities must be set up to safeguard against this. In future, supply reliability requirements will become increasingly important, particularly in light of the advancing electrification of further sectors such as transport and heating.

Increasing the capacity of electricity from RE sources must therefore be accompanied by further expansion of power grids and the use of innovative flexibility options and sector coupling technologies. Flexibility options and sector coupling technologies can make a decisive contribution to the economic viability of the energy transition by maintaining a very high level of supply security.

Fig B 2-4

Download data

Technologies in the energy sector – significance for the energy transition and level of technological maturity



In the first instance, the technologies are listed in descending order according to the absolute number of "very important" and "important" responses. If this total is shared by more than one technology, the technology with more "very important" responses is listed higher. The bars show the relative frequency of answers as a percentage. The level of maturity is classified as follows: 0=Initial research, 1=Technology under development, testing and piloting, 2=Product concept and business plan exist, 3=Market-ready product exists.
The values in the diagram represent the median value of the experts' assessments.
Source: Gatzen and Pietsch (2019).

B

Important technologies and business models for the energy transition

Figure B 2-4 presents how the surveyed experts assessed the significance of various technologies in the energy sector for the energy transition and their level of technological maturity (cf. box B 2-3). Listing the results in descending order, the experts consider the most significant technologies to be virtual power plants (1), photovoltaics (2), smart grid technologies (3), offshore and onshore wind (4 and 5), decentralized storage systems (6), smart meters and big data (7), combined heat and power (CHP) (8), innovative transmission grid technologies (9), power-to-gas (10) and district storage solutions (11). Most of the experts surveyed said that product concepts have at least been produced for these technologies, while some even feature market-ready products. However, the experts surveyed do not believe there are market-ready products to date in the areas of smart grid technologies (3), decentralized storage systems (6), smart meters and big data applications (7), innovative transmission grid technologies (9), power-to-gas or district storage solutions (11).[302]

A key requirement for the success of the energy transition is seen – in addition to generation technologies such as photovoltaics (2) and wind (4 and 5) – in virtual power plants (1), smart grid technologies (3), smart meters (7) and innovative transmission technologies (9) which make use of (intelligent) digital technologies to manage power grids, power generation and power consumption.

It is clear that the digitalization of the energy industry is a key requirement for (increased) use and implementation of innovative technologies and business models. In this way, digitization makes

Box B 2-5

The European Union Emissions Trading System

The European Union Emissions Trading System (EU ETS) has been a cornerstone of European efforts to combat climate change since its introduction by the EU in 2005. In addition to the 28 EU member states, the Emissions Trading System also includes Norway, Iceland and Liechtenstein. The EU ETS operates on what is known as the 'cap and trade' principle, which sets an upper emissions threshold for the energy sector and energy-intensive industries.[303] This covers around 12,000 installations around Europe which together produce around 45 percent of GHG emissions in Europe.

Within the emissions cap, companies receive or buy emission allowances which they can trade as required. Trading these allowances in the EU ETS makes it possible to reduce emissions where it costs least to do so.

The price of emission allowances is currently around €20 per tonne of CO_2, though this figure was for a long time less than €10 per tonne of CO_2. The previously low pricing in the EU ETS can be traced back to various factors– including the high initial quantity of emission allowances created by the EU ETS, reduced economic activity as a consequence of the 2008 economic crisis and the subsidization of renewable energies to generate electricity.

The latest reform of the EU ETS significantly reduced the permitted emission levels and removed excess certificates from the market.[304] Allowance trading prices have increased in its wake. Nevertheless, these prices remain far below the societal cost of pollution, which the German Environment Agency (UBA) states is €180 per tonne of CO_2.

Box B 2-6

Business model for distribution network monitoring

Brief description
Gridhound is an entrepreneurial company founded in 2015. It uses machine learning to monitor medium-voltage and low-voltage networks in real time. Such approaches allow distribution system operators to identify problematic network states and thereby optimize network operation.

Service offering and business model
A sensitivity analysis determines the optimal points at which to integrate measurement technology in the field. Based on that, an assessment of the network status and real-time monitoring of medium-voltage and low-voltage networks provide network data, such as forecasts of future network status. The software used to do this is based on machine learning methods.

Pilot projects to determine the optimal measuring points in the field and analyses of small parts of the network will be offered on a project-by-project basis. The assessment of the network status and real-time monitoring are offered in the form of software-as-a-service and can be charged based on the services used.

Relevance for the energy system
IThere are over 800 distribution system operators in Germany. In 2016, the compensation payments made by distribution system operators for power outages totalled over €370 million. Dynamic feed-in management could reduce compensation costs which would, in turn, lead to a reduction in electricity prices for end customers.

Regulatory barriers
Regulation currently in force makes it more appealing to invest in hardware such as power cables than to invest in digital solutions such as real-time monitoring.[305]

it possible, for instance, to collect consumption data and use it to identify potential savings, control power consumption or make consumption more flexible. Companies can implement smart grid technologies (3) to enable network operators to conduct real-time monitoring and supplement their operations with forecasts of future network status (cf. box B 2-6). This could significantly reduce costs for network operators. Digitalization and decentralization could also lead to the formation of new value-creation networks.[306] An example of this is business models based on blockchain technology (box B 2-7).

Barriers to innovation

In the energy sector, barriers to innovation primarily stem from the lack of internalization of GHG externalities (cf. box B 2-2) as well as regulatory barriers.

Until now, negative GHG externalities have not been sufficiently reflected in the price for emission allowances in the EU ETS. While the German Environment Agency (UBA) considers a price of €180 per tonne of CO_2 to be a reasonable guide for the cost of GHG emissions to the climate, the price for emission allowances fluctuated between €15 and €25 per tonne of CO_2 in Q4 2018.[307] As a result, there is relatively little financial incentive to invest in climate-friendly, low-carbon technologies.

To date, network charge regulation has created a situation in which the majority of customer groups are not subject to the actual, geographically different and time-dependent costs of power grid use.[308] Price signals required for the efficient flexibilization of power supply and demand are not currently in place. Consequently, innovative technologies – such as decentralized storage systems or power-to-X – cannot sufficiently monetarize their contribution to the flexibilization of the energy system and are impeded in their market diffusion.

By failing to sufficiently consider the scale of operating expenditure in relation to capital expenditure, the German Incentive Regulation Ordinance (Anreizregulierungsverordnung, ARegV) lacks incentives for network operators to invest in innovative concepts for power shortage management (cf. box B 2-6). From the perspective of network operators, investing in network expansion is generally more lucrative, even though power shortage management without network expansion may be more cost-efficient on a macroeconomic level.[309] As a result, the spread of technologies such as power-to-heat and storage systems[310] – as well as business models for innovative network management – is significantly curbed.

Options for reform

There are a range of options for reform to overcome barriers to innovation in the energy industry; due to the asymmetric nature of their distributive effects, some of these options will be controversial and require political assessment. Key options for reform include:

- reinforcing the price signals from the EU ETS by further reducing the number of emission allowances;
- adjusting network charges to integrate geographical and time-related shortages in the power network's price signal, and,
- revising the ARegV to increase the incentive for network operators and other market players to use systems that benefit grid stability.

Buildings — B 2–3

Initial situation

GHG emissions from buildings in 2017 were 38 percent lower than in 1990. The sector is therefore well over halfway to achieving its target of a reduction of 66 percent by 2030 (cf. figure B 2-1).

The primary uses of energy in buildings are room heating and air conditioning (85 percent) as well as hot water generation (15 percent).[311] In 2017, some 75 percent of building heating was produced using fossil fuels in oil or gas heating systems.[312] Due to the long service life of heating systems, these figures remain fairly stable over time; migrations to other energy sources are therefore a slow process. As a result, measures involving low-CO_2 and CO_2-free heating technologies will not be sufficient to achieve the sector target for 2030 as they are generally limited to newly constructed buildings.[313]

Box B 2-7

Blockchain technologies in the energy industry[314]

Evolving the energy industry to organize small-scale, decentralized systems will require increased coordination of transactions, both physical (in terms of electricity generation, transport and consumption) and financial (in terms of electricity trading). On a fundamental level, blockchain technologies make it possible to coordinate an array of transactions in a safe and efficient manner (see chapter B 3). Such technologies therefore also have the potential to play a vital role in the energy transition with decentralized electricity generation and supply structures.[315]

The costs for network operation are passed on to consumers in the form of network charges. However, such charges are only transparent to a certain degree; this is because not enough network status data is available and can be distributed between various actors. One solution to this would be to combine sensors that indicate network status with blockchain technologies that automatically collect and store data without the risk of manipulation. On that basis, performance and cost indicators could then be determined in the network directly and communicated reliably via the blockchain. This would make it possible to set fair and transparent usage-based network charges.

B

Energy efficiency also has a decisive role to play in achieving sector targets. The Federal Government has formulated a long-term target of 40 kWh/m^2 for annual consumption in residential buildings.[316] In 2016, the final energy consumption in private households was 126.2 kWh/m^2.[317] It will therefore be necessary to promote the development and construction of buildings that produce more (CO_2-free) energy than they consume.

Important technologies and business models for the energy transition

Figure B 2-8 presents innovative technologies in the building sector and depicts the surveyed experts' assessments of them for the energy transition and their respective level of technological maturity (cf. box B 2-3). Listing the results in descending order, the experts consider the most significant technologies to be heating pump systems (1), energy-efficient construction and renovation (2), smart meters (3), renewable CHP and district heating (4), innovative heat and cold storage systems (5), district solutions and landlord-to-tenant electricity supplies (6), building automation technologies (7), technologies for energy-saving building use (8), solarthermics (9), heat recovery (10) and powertoheat (11). Most of the experts agreed that market-ready products – or at least product concepts – currently exist for these technologies. The majority of experts indicated that the step of producing market-ready products still had to be taken for smart meters (3), innovative heat and cold storage (5), district solutions and landlord-to-tenant electricity supplies (6), building automation technologies (7), energy-saving building use (8) and heat recovery (10).[318]

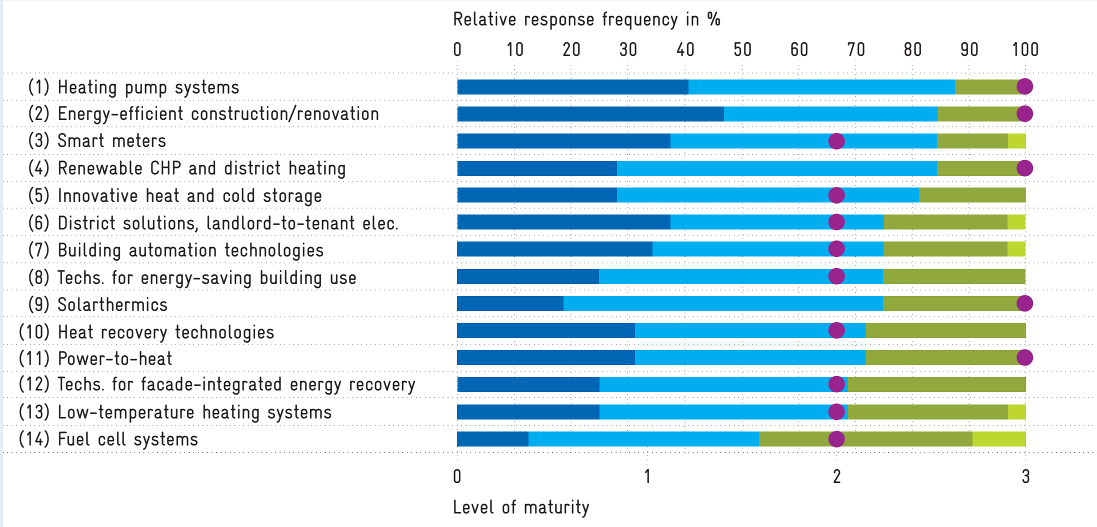
The technologies the experts consider to be significant can be divided into two categories: efficient and climate-friendly energy provision on the one hand, and technologies to reduce consumption on the other. The first category includes heating pumps (1) and other power-to-heat applications, renewable CHP and district heating (4), solarthermics (9), innovative heat and cold storage (5) as well as district solutions and landlord-to-tenant electricity supply models (6). Technologies to reduce energy consumption relate to energy-efficient construction and renovation (2), building automation (7) and energy-saving building use (8).

The building sector also features innovative services that can be offered in the form of digital business models (cf. box B 2-9). Companies offer green electricity in combination with domestic power optimization or landlord-to-tenant electricity supply models. Landlord-to-tenant electricity and district electricity systems denote electricity produced locally by a landlord and offered to tenants directly. Suppliers generate revenues from monthly charges for green electricity supplies or contributions to landlord-to-tenant supply associations.

Fig. B 2-8

Download data

Technologies in the building sector – significance for the energy transition and level of technological maturity



In the first instance, the technologies are listed in descending order according to the absolute number of "very important" and "important" responses. If this total is shared by more than one technology, the technology with more "very important" responses is listed higher. The bars show the relative frequency of answers as a percentage. The level of maturity is classified as follows: 0=Initial research, 1=Technology under development, testing and piloting, 2=Product concept and business plan exist, 3=Market-ready product exists.
The values in the diagram represent the median value of the experts' assessments.
Source: Gatzen and Pietsch (2019).

Box B 2-9

Business model for landlord-to-tenant electricity

Brief description

Polarstern GmbH was founded in Munich in 2011. The energy supplier offers energy products such as green electricity and eco-gas from 100 percent renewable sources. In addition, Polarstern offers special tariffs for heating pumps and electric cars as well as decentralized electricity supply products for private homes and apartment buildings, such as landlord-to-tenant supply models.

Service offering and business model

In its operations, Polarstern uses both the central, public power network and locally generated electricity to supply energy to buildings. Polarstern creates and organizes landlord-to-tenant and domestic electricity models to enable the use of locally generated electricity. Furthermore, it offers services to optimize domestic power consumption.
Polarstern generates revenues from monthly green energy supply charges as well as levies for the use of locally generated electricity.

Relevance for the energy transition

All of the company's products and services are based entirely on renewable energies. The integration of decentralized storage systems, such as electric cars, makes it easier to balance electricity supply and demand in the network.

Regulatory barriers

The German Landlord-to-Tenant Electricity Act (Gesetz zur Förderung von Mieterstrom) was adopted in 2017. To date, however, the law only permits the use of photovoltaic technology. Limiting the scheme to just one technology makes it impossible to exploit the full potential of landlord-to-tenant energy.

Barriers to innovation

Barriers to innovation in the building sector can be traced back to GHG externalities (cf. box B 2-2) and lock-in effects.

Energy sources used to power households vary significantly in terms of the taxes, charges and levies placed on them, sometimes referred to as state-imposed price components. Electricity is subject to significantly larger state-imposed price components than natural gas and fuel oil. Considering these energy sources in relation to the GHG emissions they produce shows major differences from uniform CO_2 pricing. The implicit CO_2 price for electricity is far higher than that of natural gas or light heating oil.[319] This results in significant competitive disadvantages for electricity-based sector coupling technologies in the building sector (incl. heating pumps).

Lock-in effects occur in the building sector because the costs of migrating from an established technology to a new one are too high (in part due to irreversible investments and sunk costs). This can curb the spread of innovative, climate-friendly heating systems that would be more cost-effective over the long term.[320]

Options for reform

There are a range of options for reform to overcome barriers to innovation in the building sector; due to the asymmetric nature of their distributive effects, some of these options will be controversial and require political assessment. Key options for reform include:

– revising taxes, charges and levies – so-called state-imposed price components – on energy sources and using the costs of the GHG externalities caused by respective energy sources to dictate these components in future;
– expanding fiscal incentives or depreciation schemes in addition to funding programmes in order to create further incentives to use innovative technologies,[321] and
– extending regulatory measures relating to existing buildings in order to overcome lock-in effects.[322]

Transport B 2-4

Initial situation

Rather than falling, GHG emissions in the transport sector actually rose slightly between 1990 and 2017. As a result, the Federal Government's target of reducing GHG emissions in the transport sector by 40 percent compared with 1990 levels by the year 2030 remains distant.[323] This adverse development can primarily be ascribed to the rise in traffic volumes, which has more than negated energy efficiency increases of 25 percent in passenger transport and 12 percent in goods transport.[324, 325] Drastic measures are required if the sector is to meet its target for 2030.

At present, cars are responsible for 61 percent of GHG emissions in the transport sector, followed by goods vehicles on 35 percent, domestic flights on 1.4 percent and diesel engine trains on 0.6 percent.[326] The proportion of renewable energy used in the transport sector has been stagnant at around 5 percent since 2008.[327] Alternative drive systems[328] are yet to make an appreciable contribution to defusing the critical GHG situation in the transport sector. In 2018, they accounted for only 1.7 percent of the total vehicle stock in Germany.[329]

In addition to e-mobility, hydrogen and synthetic fuels can play an important role in the transport sector's future energy mix and help to achieve the strict GHG reduction requirements by 2030 and beyond. The use of different technologies would appear sensible, particularly in light of the differing mobility requirements (in terms of range) and vehicle dynamics in goods and passenger transport. Furthermore, concepts to avoid and shift traffic – such as expanding and developing local public transport networks, sharing models and traffic avoidance measures in traffic planning – are gaining in importance.[330]

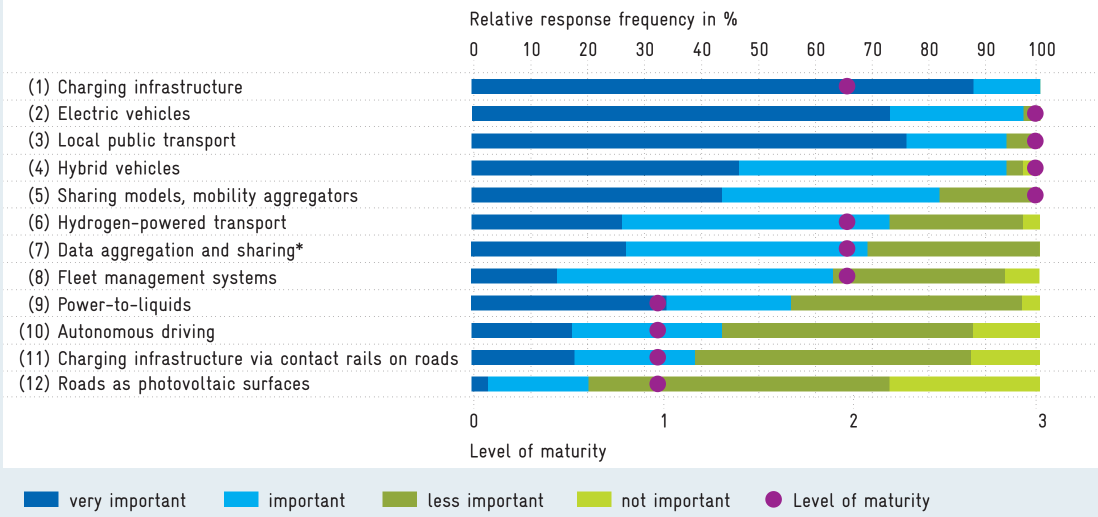
Important technologies and business models for the energy transition

Figure B 2-10 presents innovative technologies in the transport sector and depicts the surveyed experts' assessments of them for the energy transition and their respective level of technological maturity (cf. box B 2-3). Listing the results in descending order,

Fig. B 2-10

Download data

Technologies in the transport sector – significance for the energy transition and level of technological maturity



In the first instance, the technologies are listed in descending order according to the absolute number of "very important" and "important" responses. If this total is shared by more than one technology, the technology with more "very important" responses is listed higher. The bars show the relative frequency of answers as a percentage. The level of maturity is classified as follows: 0=Initial research, 1=Technology under development, testing and piloting, 2=Product concept and business plan exist, 3=Market-ready product exists.
The values in the diagram represent the median value of the experts' assessments.
* Aggregation and sharing of data for the purpose of traffic flow optimization
Source: Gatzen and Pietsch (2019).

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the experts consider that the most significant technologies relate to charging infrastructure (1), electric vehicles (2), local public transport (3), hybrid vehicles (4), sharing models and mobility aggregators (5) and hydrogen-powered transport (6). Most of the experts surveyed stated that product concepts have at least been produced for these technologies, while some even feature market-ready products. The majority of experts believe that charging infrastructure (1) and hydrogen-powered mobility (6) are not yet market-ready solutions.[331]

Electric vehicles (2) will take on a key role in the transport sector of the future.[332] By enabling the direct use of electricity from renewable sources and with particularly high energy efficiency levels, electric vehicles can make a decisive contribution to the decarbonization of the transport sector.[333] To expand the operating ranges of electric vehicles, however, charging infrastructure must be further expanded.[334] Furthermore, battery systems need to be further developed in order to increase their power density and thereby extend their range and reduce their cost.[335]

Hybrid vehicles and plug-in hybrids[336] – which feature both an electric motor with a high-performance battery and a combustion engine – are expected to contribute to decarbonization of the transport sector in the transition phase.

In addition to electric battery-driven vehicles, hydrogen-powered vehicles (which use hydrogen that can be generated through electrolysis using renewable electricity) will become increasingly important. Hydrogen-powered vehicles benefit from a greater range as well as faster refuelling, though their energy efficiency is significantly lower than that of electric vehicles.[337] Significant investment in infrastructure will also be required to facilitate the fuelling of hydrogen-powered vehicles.[338]

Avoiding and shifting traffic can also contribute to reducing GHG emissions. Such measures include expanding local public transport to provide greater network coverage, increasing service frequency and promoting travel by foot and by bicycle. In addition, new business models (such as car-sharing services) can reduce the number of vehicles required and better

Box B 2-11

Business model for smart traffic management and sensor systems

Brief description
Sonah UG was founded in Aachen in 2016. Sonah develops flexible optical sensors for a range of applications relating to smart cities, such as in the fields of parking space monitoring, EV charging station monitoring and intelligent traffic management systems. Their sensors can be installed in existing infrastructure, such as streetlights and buildings.

Service offering and business model
Sonah is developing a decentralized sensor network to combat issues such as parking space issues, EV charging point monitoring and traffic management. To achieve this, the company is working to develop optical sensors. These optical sensors make it possible to analyse and interpret on-street situations in conformity with data protection regulations and send relevant metadata for various application cases. This data is evaluated using machine learning algorithms and processed in new business models.

Sonah generates revenue through the sale of these sensors and monthly charges for parking space monitoring. It can generate further income by supplying data on parking and traffic behaviour.

Relevance for the energy transition
Traffic made up on vehicles hunting for a parking space is today responsible for a significant proportion of urban air pollution. Monitoring parking space availability and making this data available in navigation applications will make it possible to reduce this traffic and, therefore, air pollution.

Regulatory barriers
Data-driven business models encounter difficulties when applied in the public realm, as it is not clear to whom the data actually belongs. This uncertainty hampers potential innovation projects.

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use the capacity of vehicles on the road.[339] Moreover, mobility aggregators make it possible to combine a range of transport services in a single app. Intelligent transport optimization technologies can also play a role in making traffic flow management more efficient.

Cloud-based mobility platforms can make it possible, for instance, for companies to offer their employees so-called shared mobility services. Fleet vehicles can be digitized and used privately by employees after work. The transport platform therefore forms an interface between the suppliers and consumers of transport services. In this case, the business model is a software-as-a-service package, with usage charges payable per vehicle and unit of time.

Barriers to innovation

Barriers to innovation in the transport sector can be traced back to GHG externalities (cf. box B 2-2) and regulatory obstacles. Electric and hydrogen-powered vehicles require spatially inclusive and comprehensive charging and fuelling infrastructure respectively; due to network externalities, such infrastructure is yet to be established in Germany. These externalities are intensified because a comprehensive charging infrastructure has to be aligned with the expansion of the distribution network infrastructure.[340]

While car manufacturers are subject to CO_2 fleet targets for new vehicles, hardly any measures are in place that aim to change driving behaviour or transport usage and thereby realize effective reductions in GHG emissions from existing vehicles. This will cement the status quo for private car transport that discriminates against innovative technologies such as mobility aggregators, traffic avoidance or public transport.[341]

Support for alternative drive systems based on CO_2 fleet targets is not open to different technologies. If the proportion of electric vehicles in a manufacturer's fleet of new cars exceeds a certain threshold, this dilutes the CO_2 requirements for the fleet as a whole. This focus on electric vehicles is to the detriment of other alternative drive system concepts, such as hydrogen-powered vehicles. A critical appraisal of government activities in the transport sector must not ignore the fact that the Federal Government is pursuing industrial policy on the international stage that protects the German automotive industry. At the European level, for example, the German government has advocated for greater weakening of the reduction targets for new cars than a majority of EU member states would have supported.[342] Such policies inhibit innovations for alternative drive system concepts and could backfire in the long term and actually weaken Germany's position as a core location for the automotive industry.

Options for reform

There are a range of options for reform to overcome barriers to innovation in the transport sector; due to the asymmetric nature of their distributive effects, some of these options will be controversial and require political assessment. The options for reform comprise:

- increasing the price of GHG emissions by adjusting taxes on vehicles and fuel;
- promoting climate-friendly drive concepts and their charging/refuelling infrastructure through a technology-agnostic approach;
- implementing more coordinated expansion of traffic, charging and refuelling infrastructures, and
- charging private vehicles for road usage as a further incentive to transition from individual transport in cars to other modes of transport with lower GHG emissions.

B 2-5 Industry

Initial situation

The manufacturing industry is responsible for around 20 percent of GHG emissions in Germany. That being said, GHG emissions in this sector fell by 30 percent between 1990 and 2017 (cf. figure B 2-1). However, to achieve the sector's target for 2030, GHG emissions from the manufacturing industry must fall by 50 percent compared to 1990 levels.

In the manufacturing industry, reducing GHG emissions poses particular technical challenges where very high temperatures are involved, in basic industry (e.g. lime and cement production) and in the chemicals sector.[343] In such cases, fossil fuels are required in part due to the specific material properties of such fuels[344] and CO_2 is sometimes created as a direct by-product even when non-fossil materials are used.[345]

Important options for GHG reductions in the manufacturing industry include improving industrial processes' energy efficiency and migrating to renewable electrical power where possible, as well as the capture, use and storage of CO_2.[346] In addition, fossil resources can be replaced in applications that do not burn them but instead relate to their material use. Examples of this include the use and production of ethylene or ammonia using power-to-X technologies for the chemical industry or using hydrogen produced through renewable-powered hydrolysis in steel production.[347]

Important technologies and business models for the energy transition

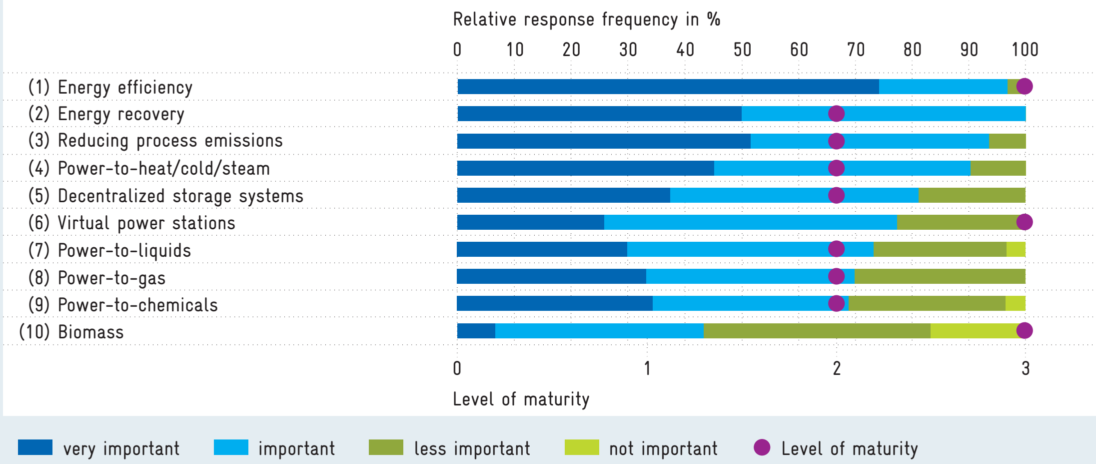
Figure B 2-12 presents innovative technologies in industry and indicates the surveyed experts' assessments of them for the energy transition and their respective level of technological maturity (cf. box B 2-3). Listing the results in descending order, the experts consider that the most significant technologies relate to increasing energy efficiency (1) and energy recovery (2), reducing process emissions (3), power-to-heat/cold/steam (4), decentralized storage systems (5), virtual power stations (6), power-to-liquids (7) and power-to-gas (8). Most of the experts surveyed stated that product concepts have at least been produced for these technologies, while some even feature market-ready products. However, they indicated that technologies relating to energy recovery (2), reducing process emissions (3), power-to-heat/cold/steam (4), decentralized storage systems (5), power-to-liquids (7) and power-to-gas (8) are not yet mature enough to be market-viable.[348]

In industry, innovative climate-friendly technologies are primarily aimed at increasing efficiency. Among other things, innovative business models for the analysis of energy data are used here (cf. box B 2-13). In addition to more economical use of resources, energy efficiency can also be increased through energy recovery.[349]

Fig. B 2-12

Download data

Technologies in the industry – significance for the energy transition and level of technological maturity



In the first instance, the technologies are listed in descending order according to the absolute number of "very important" and "important" responses. If this total is shared by more than one technology, the technology with more "very important" responses is listed higher. The bars show the relative frequency of answers as a percentage. The level of maturity is classified as follows: 0=Initial research, 1=Technology under development, testing and piloting, 2=Product concept and business plan exist, 3=Market-ready product exists. The values in the diagram represent the median value of the experts' assessments.
Source: Gatzen and Pietsch (2019).

Furthermore, migrating to low-carbon energy sources is a highly effective measure by which to reduce GHG emissions. In power-to-X processes, electricity (from renewable sources) is converted into new energy carriers such as gases, liquid fuels, chemicals or heat. This makes it possible to reduce the use of fossil fuels. For instance, hydrogen can be produced through electrolysis using water and (renewable) electricity instead of using natural gas.

Barriers to innovation

In the manufacturing industry, barriers to innovation are primarily caused by a lack of or insufficient internalization of GHG externalities (cf. box B 2-2). On the one hand, the CO_2 price for facilities covered by the EU ETS is too low; on the other hand, electricity use is disadvantaged compared to other energy sources in terms of taxes, charges and levies. This inhibits the introduction of innovative low-CO_2 or CO_2-free technologies in the manufacturing industry.

Options for reform

Options for reform to overcome the barriers to innovation in the manufacturing industry aim to internalize THG externalities. The options for reform include:

– reinforcing the EU ETS by further reducing the number of emission allowances, and
– revising taxes, charges and levies – so-called state-imposed price components – on energy sources and using the costs of the GHG externalities caused by respective energy sources to dictate these components in future.

Using the sector coupling principle to guide R&D funding B 2–6

The energy transition must also be supported through R&D investments in innovative, climate-friendly technologies.[350] R&D not only contributes to the creation of new technologies but is also beneficial to

Box B 2-13

Business model for industrial electricity supply

Brief description
EnergyCortex was founded in Aachen in 2018 and works to develop a cloud-based, cross-sector energy data platform for industrial customers, municipal utilities and operators of decentralized systems (e.g. renewable energy and CHP systems).

Service offering and business model
EnergyCortex collects and visualizes data from sources such as smart meters and then processes and prepares this data on behalf of its customers. The prepared data makes it possible to offer services that reduce costs and improve performance.

EnergyCortex provides its services on the basis of fixed-tariff, pay-as-you-use and profit-sharing models.

Relevance for the energy transition
Visualizing and evaluating consumption data makes it possible to identify measures to reduce energy consumption.

technologies which, in the opinion of the surveyed experts, are ready for the market today. The aim in this regard is to increase their market potential and accelerate their market diffusion. In light of the outstanding potential sector coupling harbours for the energy transition, R&D programmes should not consider the innovation potential of technologies and business models for the energy transition in isolation but rather on a cross-sectoral basis.

Research efforts to support the energy transition are being funded by the Federal Government, in particular by the BMBF and BMWi.[351] In its 7th Energy Research Programme,[352] the Federal Government set down the basic approaches and focuses of its support for energy research; it also referenced these in its High-Tech Strategy 2025 (HTS 2025).[353]

The Commission of Experts welcomes the Federal Government's increasing consideration of the principle of sector coupling in R&D funding.[354] However, the coordination of funding across departments must be made more effective in order to tap further synergies. The Commission of Experts therefore suggests that in these research activities – as in the entire portfolio of funding measures and in the coordinating work of the HTS 2025 – the aspect of sector coupling should be further strengthened.

Recommendations B 2–7

The Federal Government has assigned the energy transition a prominent position in its policy goals. Innovative technologies and business models can make a decisive contribution to the success of the energy transition. Decarbonizing the German energy system in the most cost-effective manner possible is inconceivable without the use of innovative technologies and business models. The primary challenge ahead, however, is not to create new technologies – domain experts believe that key technologies and business models are ready for the market today. However, their market diffusion is curbed by insufficient internalization of externalities and existing regulatory requirements.

Removing these obstacles will lead to considerably higher CO_2 pricing and, therefore, higher prices for diesel, petrol, heating oil and natural gas. These price increases will be necessary to achieve the required steering effects. However, they also entail unfavourable distribution effects. The reforms must therefore be accompanied by socio-political measures such as income transfers.

The Commission of Experts recommends that the Federal Government implement the following measures:

- In order to help innovative, climate-friendly technologies to prevail in market competition, energy charges and levies should be determined by the damage caused to the environment by – and CO_2 content of – respective energy carriers across all sectors of the economy. As part of such CO_2-oriented fiscal reform, it is crucial that the state use tax revenues generated in this regard to compensate and support economically disadvantaged households most severely affected by energy price increases.
- The German Incentive Regulation Ordinance (ARegV) should be amended for power network operators to make operating innovative systems

and pursuing business models that stabilize and support the power network worthwhile.

- To ensure that the overall economic benefits of flexibilization options in the supply and demand of electricity also make commercial sense, network charges should be reformed in order to better represent the actual costs of power network use in terms of both geography and time.
- In order to encourage digital business models for the energy transition, legal issues relating to the collection and use of data should be clarified without delay.
- In light of the outstanding potential sector coupling harbours for the energy transition, R&D activities and their funding should be structured with a greater emphasis on the organizational principle of sector coupling.

B 3 Blockchain

B 3-1 Blockchain technologies: Greater security for decentralized applications

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Blockchain is a recent technology that enables data to be digitally stored and transmitted in a process that renders it both immutable and tamper-proof.[355] Rather than being stored by a single institution, in blockchains, data is stored by numerous actors simultaneously. As a result, there is no central authority that has control over the stored data (cf. figure B 3-2).

Box B 3-1 demonstrates the significance of this technological accomplishment using the example of international supply chains.

Besides the transactions of goods along the supply chain, blockchains can also store numerous other types of transactions and render them tamper-proof. Current uses of blockchain technologies include processing financial transactions, organizing decentralized electricity trading, administrating digital identities, facilitating the flow of information between public authorities and helping regulatory bodies and companies to comply with reporting requirements.

However, blockchain technologies and their applications are still in an early developmental stage. The majority of example applications are yet to move beyond the pilot stage. Nevertheless, domain experts expect the technology and its applications to develop successfully in future. The ongoing development of blockchain technologies could engender substantial cost savings and substantially simplify transaction processes. As a result, there is huge potential for both further innovation and significant upheaval in existing economic structures. One reason for this is the crucial importance of data for business and wider society combined with the novel approach to data storage provided by blockchain technologies. There is no longer any need for a central, mediating authority.

Barriers to the future development of blockchain technologies arise from unanswered technological issues, uncertain legal and regulatory framework conditions and a lack of acceptance at both political and societal levels. Germany is in a promising position for shaping the development of blockchain technologies and realizing potential economic and societal benefits. Berlin in particular is a location of global significance for the blockchain developer community. Political actors should leverage this location advantage to promote the future development and application of blockchain technologies.

Key features of blockchain technologies B 3-2

The design and operating principle of blockchain technologies create a series of features that potentially influence the success and diffusion of these technologies. These features include blockchain governance, security, the distinction between blockchains as infrastructure and as an application, and the economic incentives for various actors in the blockchain ecosystem.

The absence of a single, central authority is not only the objective of blockchain technology applications but also serves as the guiding principle for their future development.[356] Decisions on the direction of this development require either the formation of an informal process or definition of a formal one. Informally, for example, the most active developers might come to decisions on the technology's future direction, which are then adopted by others involved in the process. A formal process, on the other hand, could require a system in which every user of a specific blockchain technology has a voice to help shape direction-dictating decisions. These options are discussed as part of blockchain governance (for further aspects of blockchain governance, cf. box B 3-4). Governance can therefore influence issues such as the quality and pace of the development of blockchain technologies.

The aforementioned features and economic incentives (cf. box B 3-3) mean that blockchain technologies offer a high level of security. However, absolute security is not possible. As a result, there have been repeated cases in which cryptocurrencies have been stolen – such thefts are estimated to have amounted to almost €1 billion in the first half

Box B 3-1

Blockchain applications for supply chains

Every year, goods worth €16 trillion are shipped internationally. 80 percent of the goods we consume every day are the result of international trade.[357] The supply chains this entails are highly complex. For instance, to transport a shipment of avocados from Mombasa to Rotterdam, 30 institutions and over 100 people might be involved in over 200 distinct exchanges of data.[358] This high degree of complexity leads to high administrative costs throughout the supply chain. Such costs can significantly exceed the physical costs of delivering the goods. It is also difficult to trace the overall make-up of such supply chains. Tests with packaged fruit have shown that it can take several days to trace a supply chain and identify the origin of a product. Recent food scandals have highlighted the importance of being able to trace supply chains. Only then is it possible to correctly identify the source of contaminants – which could include pathogens. The objective must therefore be to make it as easy to trace and understand international supply chains with numerous actors as it is to track and trace a package shipped by a courier.

To document a supply chain and the various actors it comprises, all events during a shipment must be recorded and stored in one place.[359] In the past, however, companies have been loath to work together to map supply chains, as it would mean entrusting information on business processes to other companies and relying on a third party's security provisions. If a single company were made the central institution for supply chain information, they would have detailed insights into the transactions made by the companies involved and could then attempt to profit from this information.

Blockchain technologies can render such a central institution superfluous. Rather than having a central institution collect and store the data, the companies involved save information on supply chain processes in a digital ledger: the blockchain. The companies involved can then each store a copy of the blockchain, so that the data is not concentrated in a single, central institution. At the same time, the access rights to the blockchain can be specified; doing so allows only companies involved in a specific shipment to read and write entries in the blockchain. Furthermore, technological features of the blockchain prevent data from being manipulated at a later point in time (cf. box B 3-3).

As a result, blockchain technologies offer a high degree of transparency and security with regard to the stored data; they also help to remove barriers and make tracing supply chains more straightforward. A pilot project has demonstrated that, after introducing a blockchain to track supply chains, the origin of packaged fruit can be tracked in just a few seconds – a task that can otherwise take several days. In another case, improved transparency made it possible to reduce the time required to transport a shipment of packaging material to a US production line by 40 percent.[360]

In August 2018, the technology firm IBM and container shipping company Maersk introduced a blockchain for supply chains following a twelve-month test period. At that time, 94 organizations were involved in the project, including various port operators, shipping companies, customs authorities and logistics providers.[361]

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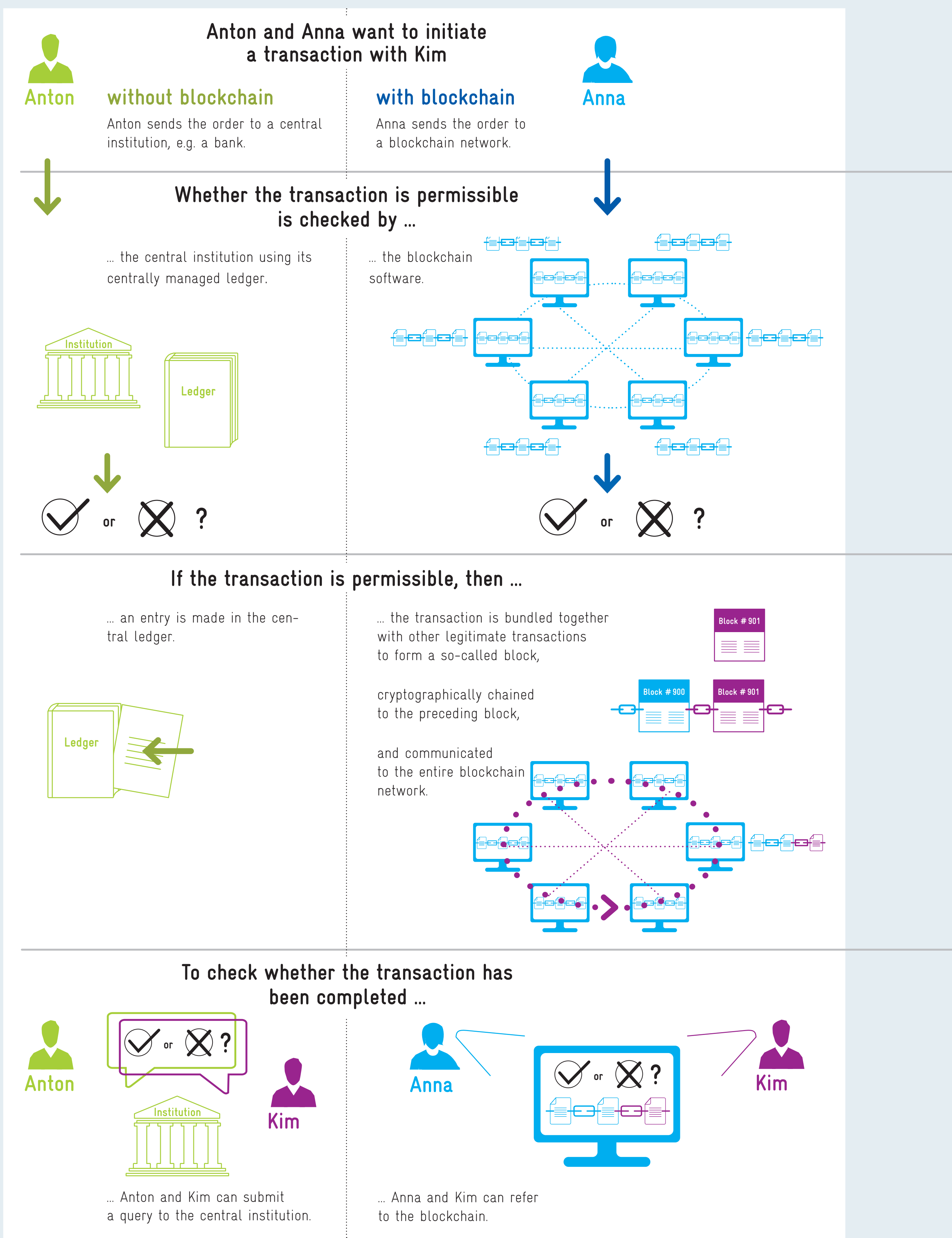
Fig. B 3-2

Download data

How a transaction works – both with and without blockchain technology



Transaction process	Differences between the transactions
Anton and Anna each agree a transaction with Kim in which Kim is to receive €50. Anna makes the transaction using a blockchain, while Anton uses a central authority such as a bank.	In the case of transactions without blockchain technology, the central institution has to be trusted to carry out the transaction reliably, keep data secure and only use data for the authorized purposes. Such services often incur high fees. When using blockchain technologies, one has to be confident that the blockchain technology works properly.
Anton instructs the bank to transfer €50 to Kim. The bank uses its central cash book to check whether the transaction can be permitted. Anna sends the value of €50 via the blockchain. In the blockchain, the participants check whether the transaction is permissible.	Blockchain technologies clearly define and state which transactions are permitted. In transactions without blockchain technology, the central institution's conditions of use need to be examined and interpreted to understand which transactions are legitimate. However, the central institution might interpret these conditions differently – and can change them unilaterally. The computers of the blockchain network have to build a consensus. The necessary consensus mechanisms, however, can consume a lot of energy, as in the case of the Bitcoin blockchain.
The bank executes Anton's transaction, debiting Anton's account with the amount of €50 and crediting €50 to Kim's account. The transaction is recordedin the ledger. Anna's transaction is combined with other transactions in a block, marked with a digital fingerprint (known as a hash) and then communicated to the entire blockchain network. The new block is chained to the previous block by referring to the hash of its predecessor.	Transactions stored in a blockchain cannot be changed at a later date. A central institution, on the other hand, is able to change or delete transactions. In addition, a successful cyber-attack on a central institution can result in its services being unavailable. In a blockchain, the ledger is stored on many different computers, meaning that data remains available even if some computers fail. Recording a transaction in a central ledger is a quick process that requires few resources. Recording a transaction in a blockchain, on the other hand, requires more resources because the transactions are sent to and stored by all computers in the network. This also requires greater memory capacity.
To review the transaction with Anton, Kim can check her bank account. To review the transaction with Anna, Kim can check the block with her transaction.	To inspect the current status of stored transactions, a request has to be sent to the central institution. Blockchain participants can directly access and view the transactions stored in a blockchain. In addition to transactions, a central institution also stores data about its users, such as their names, passwords and credit card details. While these institutions do have security features in place to protect against theft, various hacks have shown that such provisions do not offer complete security.

Glossary:

A **ledger** records and stores transactions (potentially digitally). A transaction is a sequence of steps that form a logical unit. The nature of transactions can vary considerably – and include tasks such as transferring money from one person to another, posting on social media or sharing information between companies or authorities.

A **central institution** maintains the ledger. As a result, the institution holds sole control over the recording and storing of transactions. Examples of central institutions include banks, legal advisers and social media.

A **network** is composed of computers that are connected and therefore able to exchange information.

A **blockchain** is a digital ledger simultaneously stored on numerous different computers. A blockchain is composed of blocks connected in a chain.

Blocks bundle transactions, similar to a page in a ledger. In addition, each block contains information that connects it to the previous block and thereby renders its content immutable. This renders both the transactions within a block and the sequence of blocks immutable.

Consensus describes a situation in which all computers agree on the correct state of the blockchain and the transactions stored in it.

Consensus mechanisms ensure that the computers form a consensus, even if there might be computers within the network seeking to disrupt it, such as by sending false information.

Box B 3-3

Operating principle of blockchain technologies

Blockchain is a technology that enables the digital storage and transmission of data. All transactions are stored by numerous computers[362] and information about new transactions is shared between the computers in the blockchain network. New transactions are compiled in a block of a specific size and cryptographically connected with all previous blocks in a chain (cf. figure B 3-2).[363]

This process does not feature a central authority – such as a bank – that checks that transactions are correct. Therefore, no trust is required between the participants ex ante. This is ensured by technical functions and economic incentives.

Blockchains can either be open to everyone (public) or limited to a specific group of participants (private or permissioned). Examples of public blockchains include the Ethereum and Bitcoin blockchains.[364] In consortium blockchains, only a specific group of people are authorized to view or save transactions. This could include various companies who want to record transactions together but wish to ensure that such transactions do not become publicly accessible. In a private blockchain, the access rights are further restricted, for example to allow only one specific company to save transactions in the blockchain.

The high level of security that blockchains offer rests, among other things, upon the consistent and systematic use of cryptographic processes. These processes are used to ensure that the identity of the transaction partners and the transactions themselves are correct, i.e. that they have not been falsified, and to make sure that past transactions cannot be altered.[365] When checking the legitimacy of a transaction, the network ensures, among other aspects, that only new transactions can be added to the blockchain and that the resources to be transferred actually exist. Transactions which have already been saved cannot be manipulated. As a result, the entries in a blockchain are immutable. This feature is ensured by cryptographic hash functions that allocate an easily identifiable fingerprint (known as a hash) to transactions within a block. If just one character within the transaction is changed, it would be obvious that the hash is not correct. The hash function SHA-256 would give the transaction

Anna sends €50 to Kim.

the following hash:

bfc31d9b353de84eb1ddaf1aa13bf02a34dae95287498b5d5653fa10c086812a.

This hash is stored in the original block with the transaction between Anna and Kim. If Anna wished to change the transaction at a later date and debit Anne instead, the same hash function would give the transaction

Anne sends €50 to Kim.

the following hash:

cc00ae6db2eedfbc703f95de9a82700a9778281c67ef8a7d9d2a592abf24ea08.

This hash is obviously in conflict with the hash saved in the original block. Furthermore, the following block includes its predecessor's hash as a reference – thereby the blocks are chained to each other. Therefore, a transaction can only be successfully manipulated if all subsequent blocks are also changed accordingly.

This is why the legitimation of new blocks by computers in the blockchain network is so important. The rules for this constitute so-called consensus mechanisms. The choice of the consensus mechanism depends to a large extent on the access rights of the computers in the network. In a consortium blockchain in which the participants know each other's identities, security and reliability can also be enforced outside the blockchain. This makes it possible to use other consensus mechanisms, such as those based on plurality voting systems. By contrast, the users of public blockchains by and large remain anonymous. This means that, as the security of such blockchains cannot be enforced

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outside of the blockchain, such provisions need to be integrated in their protocols. There are various approaches to achieve this, such as proofofwork (PoW) and proofofstake (PoS). These approaches use economic incentives and financially penalize misconduct, such as confirming non-legitimate blocks.

To create a new block for a PoW blockchain, a computing-intensive cryptographic problem must be solved. This process is known as mining. The task is to find a number, known as the nonce, so that the block's hash starts with a specific number of zeroes. The nonce, like the target value for the number of zeroes, is stored in the block. This makes it possible to check straight away whether the work to create the block has actually been carried out – hence the name proofof-work. The first miner to create a correct block and find an applicable nonce receives a fee in the corresponding blockchain currency (e.g. Bitcoin) as payment for their work.

The computing power required to solve this cryptographic problem consumes high levels of electricity. Electricity costs form an economic incentive that prevents many new blocks of the blockchain from being generated to manipulate an earlier transaction in the blockchain. The incentive for manipulation arises from weighing the profit of manipulation and the associated costs of mining – in this case the costs for electricity and computers.

PoW is a very secure consensus mechanism that can also enforce the rules of a blockchain when participation is unrestricted and when the network could contain faulty computers or participants with malicious intentions. However, such mechanisms require so much power that, in 2018, the Bitcoin blockchain consumed about as much energy as Austria.[366]

An alternative to PoW in public blockchains is the PoS consensus mechanism. PoS consumes markedly less energy than PoW and includes incentives to discourage mistakes by requiring a deposit to be paid before a user can validate blocks.

Once a new block has been created, it has to be sent to the entire network and saved by the participating computers. This process is considerably more demanding than saving a transaction in a central ledger because it has to be repeated for all computers in the network. The eschewal of a central storage system means that blockchain technology is also less susceptible to malfunctions.

In addition to the fundamental operating principle of blockchain technologies, there are a range of extensions with varying degrees of maturity. The aims of current development projects include increasing transaction throughput[367] and creating a connection between different blockchains. Another extension has already been introduced with the introduction of the Ethereum Blockchain: the automatic execution of processes on the blockchain by so-called smart contracts. Smart contracts are computer programmes that are also stored in the blockchain.[368] They make it possible, for instance, to implement if-then relationships, such as: "If Kim delivers the shipment of gummi bears to Anna, then €50 will be transferred from Anna to Kim". Smart contracts have the potential to reduce transaction costs by formalizing the conditions for transactions and executing them automatically. This gives rise to a further motivation to dispense with central institutions.

of 2018.[369] However, the security precautions of blockchain technologies are usually not overcome in these thefts. Instead, such thefts often occur in central cryptocurrency exchanges.[370] Nevertheless, there have been repeated cases in the past in which small blockchain networks – i.e. blockchains in which the miners (cf. box B 3-3) have relatively little computing power – have been the victims of so-called 51 percent attacks.[371] Blockchains with high levels of computing power are significantly less likely to become victims of 51 percent attacks. The security that blockchain applications provide (cf. also box B 3-3) is a key reason for their use. The notion that blockchain technologies may not be secure can therefore negatively impact their diffusion.

An important distinction must be made between a blockchain such as Ethereum, which represents infrastructure, and the applications which build on it. This distinction is comparable to the difference between TCP/IP internet protocols on the one hand and applications, such as the World Wide Web with its webpages and email, on the other. Decentralized applications that build on a blockchain are known as dApps (decentralized apps). For example, dApps acting as a browser or wallet facilitate the interaction with a blockchain. Furthermore, they provide applications such as social networks, trading platforms or identity management. dApps thereby make it possible to use blockchain technologies without an in-depth technical understanding. They also generate additional functionalities for users and thereby contribute to the technology's diffusion.

The most important actors in the blockchain ecosystem include: institutions behind certain blockchains, such as the Ethereum Foundation; miners, who undertake validation in proof-of-work blockchains; companies that offer applications on the basis of blockchain technologies, and companies that provide complete blockchain solutions. The latter group includes major technology firms such as IBM, Amazon, SAP and Microsoft, that offer blockchain solutions in the form of software-as-a-service.

In the past, start-ups that develop blockchain applications or blockchain infrastructure have often used a new financing instrument known as initial coin offering (ICO). An ICO involves selling digital tokens that can later be used, for instance, to use the services of the blockchain application. Such methods are supplemented by rounds of classic financing using venture capital to finance blockchain companies.

Blockchain applications generate revenue from their users by applying usage charges such as freemium or subscription models. Miners receive payments for their work in the cryptocurrency of the blockchain for which they confirm a block.

Applications and potential of blockchain technologies B 3–3

Blockchain applications can be found in many different fields. The motivation for using or testing blockchain technologies is often a combination of three distinct considerations: i) securing transactions, ii) automating transactions and iii) decentralized data storage and access management.

The use of blockchain technologies in international supply chains (cf. box B 3-1) is an example of cross-company (and therefore decentralized) data storage. Public authorities can also deploy blockchain technologies to intensify the exchange of information, automate process steps and thereby improve cooperation between authorities. Box B 3-5 provides an example of the successful use of blockchain technologies in the asylum process.

When regulatory authorities and companies implement blockchain technologies, this can lead to enhanced transparency and lower the costs involved in fulfilling transparency requirements. This was demonstrated by a pilot project conducted by the UK Financial Conduct Authority (FCA) in cooperation with two global banks.[372] The banks in question were able to fulfil their reporting obligations for mortgages much more easily than in the past.[373] So far, banks and regulatory authorities have spent up to four weeks preparing and providing data. By using blockchain technologies, the banks were able to significantly reduce the time taken up by reporting processes. This new approach also made it possible to produce reports almost in real-time; previously, reports were only made available on a quarterly basis at most.[374]

Data saved in blockchains cannot be deleted or changed. Consequently, blockchain technologies are suitable for making information verifiable and reliable.[374] The immutability of data is used to file tax-relevant information, as for example invoices in the online trade, in a forgery-proof form. In medical research, this aspect is used to secure automatically generated data from analysis systems. This rules out the possibility that the data will be manipulated.[376]

An example of process automation through sart contracts can be found in the insurance sector. By taking publicly accessible data on flight times as a basis, a major international insurance company offers insurance against flight delays. Due to

Box B 3-4

Blockchain governance

Governance describes the manner in which an organization – in this case the blockchain and its stakeholders – is managed or governed. For blockchains, governance includes the set of rules contained in the blockchain protocol, often described as on-chain governance. Onchain governance includes, for example, a consensus mechanism (cf. box B 3-3). Offchain governance, on the other hand, comprises decision-making rules for amendments to the blockchain's protocol or criteria by which to select people who validate transactions (in the case of restricted groups of validators). In contrast to elements of onchain governance, elements of offchain governance are not compiled and codified but instead arise as a result of lived experience. In the case of public blockchains, for example, an opinion leadership of prominent persons of the blockchain developer community is often established.

The design of governance systems can play an important role in realizing the potential benefits of blockchain technologies. For instance, the use of blockchain technologies is often aimed at reducing dependence on an intermediary or a central authority. However, the use of blockchain technologies does not necessarily guarantee the avoidance of central authorities. This recentralization of blockchain technologies can result from the governance of the blockchain if prominent persons have been able to establish opinion leadership or if a closed group of actors is responsible for validating transactions in private blockchains.

In addition, less strict onchain and offchain governance and blockchain security often have conflicting objectives. At the very least, ensuring the blockchain's security requires either strict on-chain governance or strict off-chain governance. Public blockchains – in which anyone can validate transactions (as participants usually remain anonymous) therefore usually use proof-of-work as a consensus mechanism in order to ensure adherence to the blockchain's regulations (cf. box B 3-3). On the other hand, private blockchains in which transactions can only be confirmed by participants whose identities are known can be based on other consensus mechanisms as adherence to the regulations can also be enforced outside the blockchain. This makes it possible to avoid the drawbacks of proof-of-work systems, such as the high energy requirements. Public blockchains in which anyone can validate transactions are referred to as public unpermissioned blockchains. By contrast, public blockchains in which only certain participants can validate transactions are known as public permissioned blockchains.

Public permissioned blockchains can also be made open to all validating participants (or organizations) who fulfil specific criteria. These criteria might relate to having business operations in a particular sector of the economy, as applied by the Energy Web Foundation,[377] or require participants to be not-for-profit organizations, as is the case for the Interplanetary Database (IPD).[378] Selecting participants in this way can help to create transparent governance structures without recentralizing the blockchain to a closed group of validating participants.

Box B 3-5

The use of blockchain technology in the asylum process

Blockchain technology has already been used in Germany as part of a proof-of-concept for the reliable and expedient exchange of information in asylum processes.[379] In this case, it supported the exchange of information between reception centres, the Federal Office for Migration and Refugees (BAMF) and the immigration authorities. The evaluation identified "significant benefits in terms of process reliability, transparency and efficiency".[380]

In the asylum process, asylum seekers are registered at an initial reception centre before being allocated to a reception centre. If an application is lawfully submitted, the BAMF holds a hearing to examine the case. If the BAMF decides to approve the asylum application, the immigration authorities then issue a residence permit. To ensure that this process proceeds both quickly and reliably, the various authorities must at all times observe and apply the regulations governing the asylum procedure and must have access to up-to-date information on each case. Blockchain technology improves on the current situation in both regards.

Decentralized data storage (cf. box B 3-3) means that the relevant authorities can always check the current status of an asylum case. As a result, data from the various systems in different departments – such as the workflow and document management system at the BAMF or the personalization infrastructure components at the initial reception centres – can be integrated and made available to all participating authorities. Furthermore, by using smart contracts stored in the blockchain (cf. box B 3-3), processes can be automated, making it possible to avoid deviations from established processes or document them in full as and when they occur. This minimizes waiting times between the authorities' work steps and renders the entire process markedly more reliable.[381]

The blockchain architecture for the asylum process, analysed using proof-of-concept development, was implemented in 2018 as part of a pilot project overseen by the BAMF, the immigration authorities and the Dresden AnkER Centre.

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transparent smart contracts, insurance cases are processed automatically as soon as flight delays occur.[382] In addition to insurance policies, blockchain technologies are used for various other applications relating to financial transactions, such as payment infrastructure between banks.[383]

Several European countries[384] are currently piloting blockchain-based land registers. This would automate processes such as requesting a land register excerpt or creating a land register entry. The services of intermediaries such as notaries and banks would no longer be required to the same extent for such tasks, while the administrative costs of maintaining a land register could also be reduced. In countries without a functioning land register, this would make it possible to establish a reliable register for real estate, even where public trust in state authorities has been damaged.[385]

Blockchain technologies can also be used to create digital keys that should not be copied – such as keys to apartments, houses and cars. In the case of locks, the property owner can use a smart contract on the blockchain to define the conditions for opening the lock. These conditions might include paying a deposit or paying rent in advance. The tenant can then use their smartphone to confirm their identity and will be given access to the apartment if confirmation that these conditions have been fulfilled is entered in the blockchain.[386]

Such applications are evidence that many actors are currently developing, testing and introducing blockchain technologies to create marketable products. Yet these still represent just a small subsection of the areas in which blockchain technologies are used. The blockchain's potential extends far beyond these applications; indeed, blockchain technologies can lead to radical changes in existing industries. In the energy industry, for example, blockchain technologies can be used to provide transparent information about the costs of operating a power network, thereby allowing network charges to be levied efficiently and fairly based on consumers' actual usage. Box B 2-7 describes potential applications of blockchain technologies for the energy sector.

On an even more fundamental level, however, blockchain technologies are transforming the way in which we store data. Blockchain technologies allow data to be stored securely and in a decentralized manner. On this basis, individuals have the ability to retain control of their own data rather than having to cede this control to central institutions such as major internet companies. This gives hope that citizens and companies could make their data more accessible and allow it to be used under controlled conditions.[387]

Decentralized data storage is ultimately also associated with hopes of easing the market concentration in data-driven industries and dismantling barriers to entry in such markets. Blockchain technologies therefore have the potential to engender significant changes in market structures and induce radical transformations.

Yet despite the range of highly promising applications and the potential of such technologies to disrupt existing structures, it remains to be seen whether blockchain technologies will be able to become a cross-cutting technology in future. Whether the expectations placed upon it will actually prove feasible depends to a large degree on blockchain governance (cf. box B 3-4).

B 3-4 Germany as a blockchain location

Germany is home to an active community of developers working on blockchain technologies. Almost half of all German blockchain start-ups are based in Berlin.[388] Domain experts believe that this concentration of development activity makes Germany – and Berlin in particular – a key international location for blockchain technologies.[389] Berlin has a high concentration of developers who work to develop blockchain infrastructure. Prominent organizations in this regard include: the Web3 Foundation, which promotes the development of a decentralized internet; the Energy Web Foundation, which works to create open blockchain technology for energy markets, and the IOTA Foundation, which develops blockchain technology for IoT applications. The Ethereum Foundation plays a particularly important role,[391] as Ethereum is currently a quasi-standard in the blockchain community.[392]

However, it is difficult to conduct a precise assessment of Germany's performance in an international comparison. There are various reasons for this. For one, blockchain development activities and their objectives are heterogeneous. Developments relating to the fundamental infrastructure of blockchains, such as the work conducted by the Ethereum Foundation, is often the result of a group of developers working on open source software. These developers collaborate internationally, which makes it difficult to pinpoint a single location. At the same time, working on open source software makes it impossible to compare development activities by analysing patent figures because open source software is, by its nature, not patented. Another approach is to attempt to compare the number of blockchain start-ups in different countries.[393] However, such lists (and in particular those which make international comparisons) are often incomplete and can therefore produce a distorted image of the international distribution of blockchain start-ups.

Nevertheless, it is clear that Germany finds itself in a dynamic, competitive market in which other countries are becoming increasingly attractive locations. The world's largest initial coin offerings (ICOs), a financing instrument used by blockchain-related start-ups, took place outside Germany.[394] Of the 20 largest ICOs to date only one took place in a European country: Switzerland. One of these start-ups, Tezos, is working to develop a blockchain technology in which all users have a right to co-determine the future development direction of the technology.

B 3-5 Barriers to the diffusion of blockchain technologies

There are still various barriers making it hard to develop blockchain technologies further and thereby realize their potential in commercial and societal applications. These barriers primarily relate to technological development, regulation and legislative as well as political and societal acceptance.

As a result, technological solutions that deliver higher scalability of public blockchains are still yet to be launched. Moreover, popular blockchains such as Bitcoin and Ethereum have so far used energy-intensive PoW consensus mechanisms which create serious negative climate externalities (cf. box B 3-3).[395]

In terms of the legal and regulatory framework conditions for the use of blockchain technologies, Germany has for the most part adopted a cautious, watchful approach.[396] At present, there is a lot of uncertainty around the application of the General Data Protection Regulation in the context of blockchain technologies, the classification of ICOs, the taxation of cryptocurrencies, and the use of blockchain technologies in regulated markets such as the energy sector.[397] To reduce this uncertainty, qualified people must be appointed in ministries and public authorities. Barriers to communication between the political, administrative sphere on the one hand and the blockchain community on the other need to be dismantled.[398] There are also barriers with respect to the potential users of blockchain technologies. For instance, the wider public lacks a broad understanding of the potential uses and benefits of blockchain technologies, due in part to the overly abstract and technical descriptions of blockchain technology, with too little connection to practical applications available today.

B 3-6 Recommendations

The Commission of Experts considers blockchain technology to have significant potential to benefit companies, citizens and administrative bodies. To realize this potential, the Commission of Experts recommends that the Federal Government enact the following measures:

– The Federal Government's planned Blockchain Strategy should contain an analysis of Germany's strengths and weaknesses as a location for blockchain technology. This would include analysis of current legal and regulatory framework conditions which inhibit innovation.
– The strategy should include proposals for Regulatory Test Beds, which would allow the identified barriers to innovation to be tested and legal amendments prepared.
– The Blockchain Strategy should specify interfaces with other strategies formulated by the Federal Government in relation to digital policy, such as the AI Strategy and the implementation strategy for digitalization. Synergies generated by these strategies should also be identified and exploited.
– Companies' legal uncertainty has to be reduced by developing skills and domain expertise of relevant people in ministries and authorities. These enhanced competencies should also be used to analyse application concepts for blockchain technologies and, where prudent, to initiate pilot projects.
– Finally, citizens and companies should be better informed of the benefits and drawbacks of blockchain technologies; this would equip them with the skills and knowledge required to handle blockchain applications with confidence.

B 4 Digitalization of tertiary education institutions

Download data

German tertiary education institutions – according to their own statements – attach great importance to digitalization. However, this is not reflected equally well in the levels of digitalization achieved in research, teaching and administration. Significant development potential therefore exists for the continuing digitalization of German tertiary education institutions, above all in teaching and in administration.

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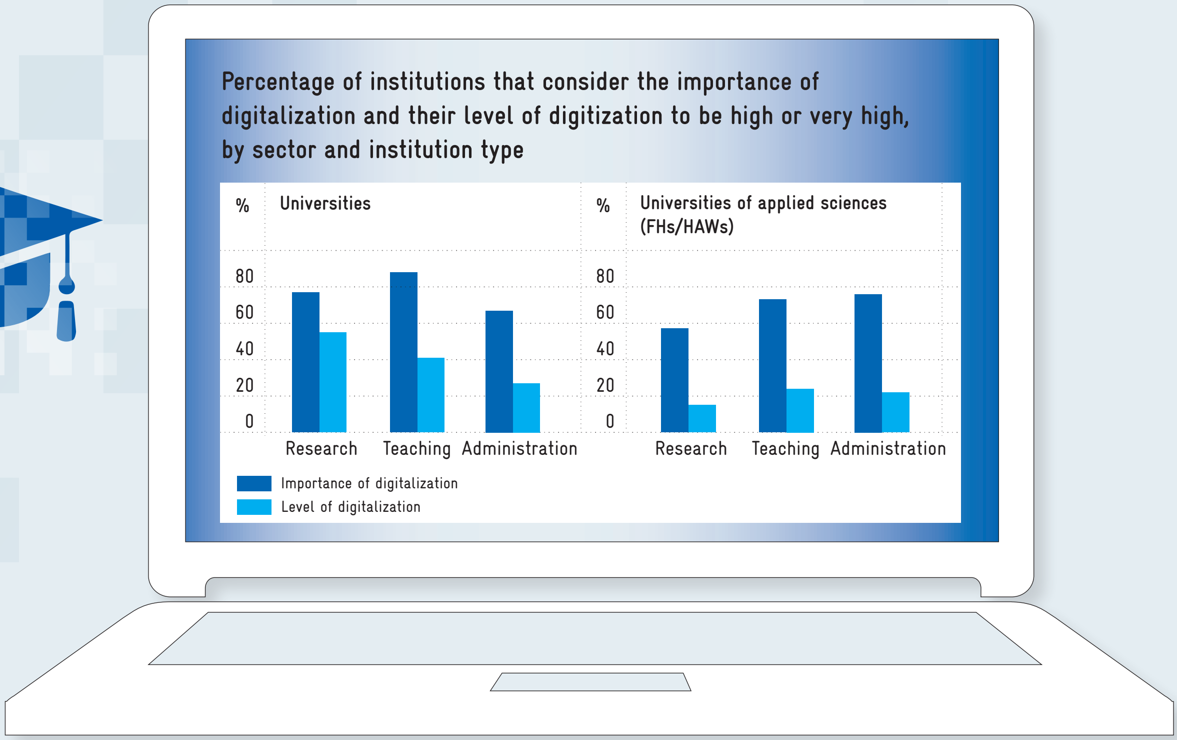
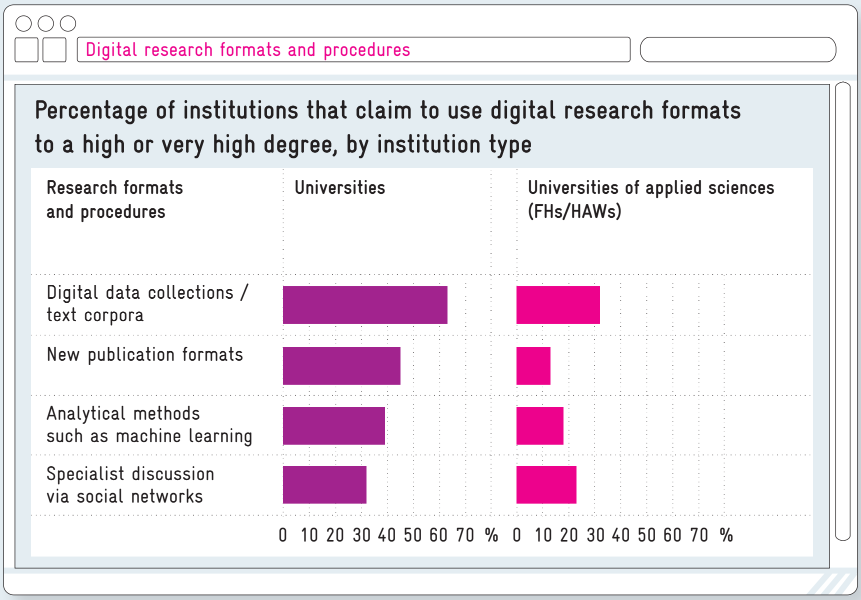
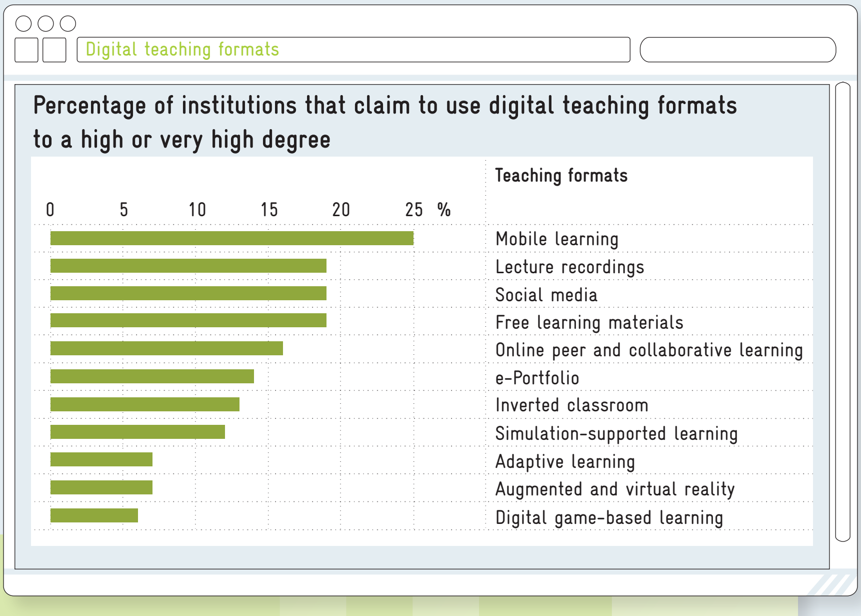




In terms of research, digitalization relates to the increasing application of computer-assisted procedures and the systematic use of digital resources.

Source: The information provided in the glossary and the figures refer to Gilch et al. (2019).

The digitalization of teaching denotes the permeation of digital components and learning tools through teaching and learning processes.



Glossary of teaching terms

Mobile learning
Mobile learning denotes all learning processes that use mobile, portable devices.

Open educational resources, OER
Open educational resources are teaching and learning materials not subject to a term of protection or provided under a free licence.

Online peer learning / collaborative learning
The terms online peer learning and collaborative learning denote forms of study in which at least two students share their knowledge and experiences online and solve problems together.

e-Portfolio
e-Portfolios are digital collections of learning process documentation and learning products. They help to map and visualize the learning process, and thereby evaluate it.

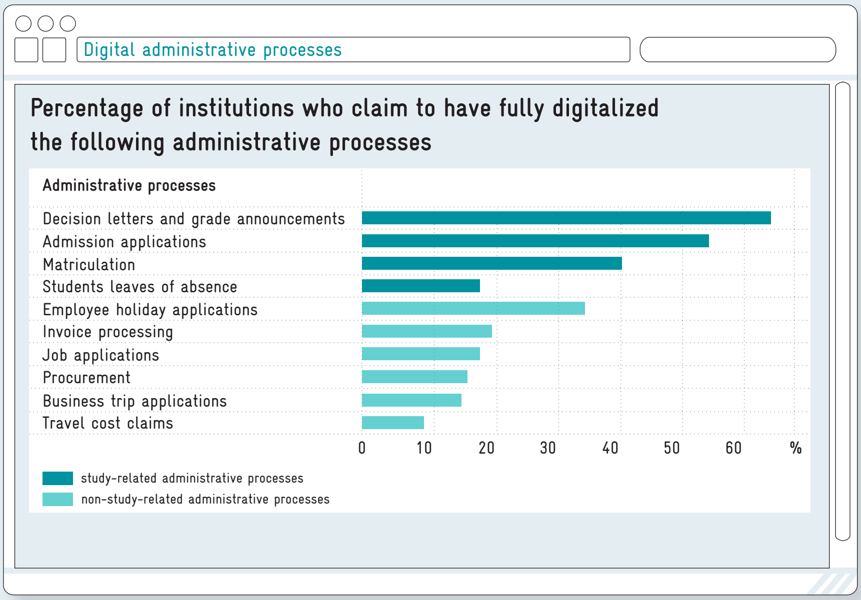
Inverted classroom
In the inverted classroom technique, dissemination of knowledge is transferred in self-study, usually through online tools and resources. Intermediary phases of attendance classes seize on specific aspects that posed problems for students during self-study and explore them in detail.

Simulation-supported learning
Simulations are interactive visualizations that use a simplified model to analyze an issue or situation, thereby making it possible to illustrate interrelated causes and effects.

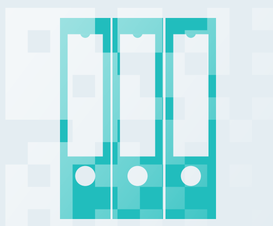
Adaptive learning
Adaptive learning is a teaching method that uses learning environments which tailor content to students' individual requirements and unlock certain content only when defined criteria have been met.

Augmented and virtual reality
Augmented reality is an experience in which perceptual information supplements objects in the real world. Virtual reality, on the other hand, involves complete immersion into a virtual environment.

Digital game-based learning
Digital game-based learning is a digital variant of educational games. The structure and content of these games are shaped by pedagogical considerations; the objective is to achieve predefined learning outcomes.



The digitalization of administration involves reshaping administrative workflows to create a digitally networked process.



B 4 Digitalization of tertiary education institutions

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The digitalization of tertiary education (TE) institutions is of central importance for research and innovation activities in Germany. In their dual role as educational and research institutions, TE institutions are responsible for training academic professionals for an increasingly digitalized world as well as exploiting the potential of digitalization for internationally compatible research and innovation activities. Following on from the Commission of Experts' 2018 report, which examined the issue of digital education,[399] this chapter assesses the extent to which TE institutions implement digital processes in their research, teaching and administrative work, as well as the challenges they face.

B 4-1 State of digitalization at German TE institutions

According to a survey conducted on behalf of the Commission of Experts, German TE institutions consider digitalization of their processes to be highly important. Indeed, 83 percent of TE institutions who responded stated that digitalization was a high or very high priority for them.[400] This is, however, not reflected in the level of digitalization of research, teaching and administration achieved to date (cf. infographic). There is therefore considerable scope to further digitalize German TE institutions.

Digitalization as a challenge for governance in TE institutions

The digitalization of research, teaching and administration is a major challenge for TE institutions. In contrast to commercial organizations, there are certain aspects specific to TE institutions that retard the digitalization process. According to the Imboden Commission, the governance of many German universities is characterised by a lack of efficiency orientation.[401] In addition, TE institutions have been suffering for years from structural underfunding, which makes it difficult to invest in digitalisation processes.

Alongside these internal problems, TE institutions face numerous external requirements – such as rising student numbers, a growing dependence on third-party funding, and the Excellence Initiative – which have rendered the governance of TE institutions' increasingly complex.[402]

One key method by which TE institutions can respond to the challenges of digitalization is to develop a strategy based on the university's profile, its target groups and its development objectives. However, in the survey conducted on behalf of the Commission of Experts, just 14 percent of TE institutions that responded confirmed that they have a digitalization strategy in place.[403] A further 41 percent said they were working to develop a digitalization strategy, while 31 percent have plans to do so.[404] The most commonly stated objectives pursued through a digitalization strategy include improving the quality and efficiency of administration and enhancing the quality of teaching.

The Commission of Experts believes it is a positive signal that a majority of German TE institutions either have or are working to develop a digitalization strategy. It recommends defining clear responsibilities for digitalization processes as part of these strategies.

Digitalization of research: German tertiary education institutions are well placed

In terms of research, digitalization relates to the increasing application of computer-assisted procedures and the systematic use of digital resources.[405]

The state of digitalization in research (cf. infographic) varies considerably between universities (Universitäten) and universities of applied sciences (Fachhochschulen, FHs / Hochschulen für angewandte Wissenschaften, HAWs). This can predominantly be ascribed to the differing structural orientations of the two TE institution types.[406]

Research information systems[407] have been fully or partially implemented at almost half of universities. In addition, around 30 percent of universities have implemented research data management systems[408] either in part or in full. Researchers' use of digital data collections is considered to be high or very high by 63 percent of universities. In addition, 45 percent of universities stated that they use new publication formats often or very often, while 39 percent use digital analysis methods to a high or very high degree.[409]

At universities of applied sciences (FHs/HAWs), less than 20 percent of institutions have implemented research-related IT systems (such as research information and research data management systems). One-third of researchers at FHs/HAWs use digital collections often or very often. Meanwhile, 18 percent of FHs/HAWs claim to use new publication formats often or very often. Only 13 percent of FHs/HAWs consider the level of use of digital analysis methods at their institution to be high or very high.[410]

Regardless of the type of TE institution, the level of digitalization in research depends to a large extent on the engagement of individual researchers and research groups.[411] Researchers at TE institutions use an array of digital tools to simulate, model, visualize, collect and evaluate data, as well as to publish research results – and do so of their own accord, without having to be supported centrally by their respective institutions.[412]

Nevertheless, this gives rise to wide-ranging requirements for training, consultancy and other services, for which TE institutions should develop and provide suitable solutions (cf. box B 4-1 for an example).[413] This is particularly pertinent as consultancy requirements will continue to grow as artificial intelligence and data science become increasingly important.[414]

Positive recent developments

The digitalization of research is currently being shaped by developments in several areas that are also of major significance for TE institutions. These areas include supercomputers, research data infrastructure and open access.

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Box B 4-1

Example of good practice in research: the eResearch Alliance

Since its foundation in 2014, the eResearch Alliance has pooled the capacities of central infrastructural facilities at the University of Göttingen, the Gesellschaft für wissenschaftliche Datenverarbeitung mbH Göttingen and the Göttingen State and University Library.[415]

The eResearch Alliance provides a central infrastructure for researchers, faculties and research associations in Göttingen and beyond. Its aim is to provide researchers with IT services to enable them to make existing research methods more efficient and to facilitate the use of new research methods.[416]

To achieve this, the eResearch Alliance offers a variety of information, consultancy and training services relating to innovative information and communication technologies. Such services include research data management, research infrastructure to facilitate collaborative working with digital methods and tools, visualization options for research data and publication strategies. Furthermore, the eResearch Alliance offers individual IT consultancy and services for researchers.[417]

Supercomputers

Supercomputers are of growing importance for the field of research. For example, more and more powerful computers are needed to simulate neuronal networks and new medications, as well as to calculate climate models. While supercomputer capacities are steadily increasing, the pace just barely keeps up with demand for computing capacity.[418] As a result, German and European researchers rely on supercomputers beyond European shores, which can lead to issues in terms of data security, data protection, securing property rights and ensuring confidentiality.[419] The expansion of German supercomputer capacities will alleviate these issues to a degree. In September 2018 and January 2019, new supercomputers were commissioned at the Forschungszentrum Jülich and the Leibniz Supercomputing Centre in Garching near Munich, thereby supplementing high-performance computing infrastructure under the auspices of the Gauss Centre for Supercomputing (GCS).[420] The GCS is also working to develop an exascale supercomputer.[421]

In addition, the Federal Government and the Länder have agreed to create a national network called National High Performance Computing (Nationales Hoch- und Höchstleistungsrechnen), in which the strengths of the German high-performance computing centres are to be further developed. It aims to allow researchers at TE institutions to access the computing capacity they require when and where they need to, across Germany.[422] The Commission of Experts welcomes this commitment from the Federal Government and the Länder.

Research data infrastructure

In November 2018, the Joint Science Conference (Gemeinsame Wissenschaftskonferenz, GWK) announced the creation of a National Research Data Infrastructure (Nationale Dateninfrastruktur, NFDI).[423] The NFDI is tasked with creating systematic connections between the many often decentralized, project-bound and temporary data resources in science and research.[424] To achieve this, the NFDI will set data management standards and, as a regionally distributed and cross-disciplinary knowledge repository, secure and make usable research data in the long term.[425] Contact points will also be set up to provide researchers with on-site support in preparing and using the research data.[426]

The NFDI is to be designed by users and providers of research data in cooperation with institutions of the scientific infrastructure, such as archives, libraries, (data) collections and specialized information centres. For this purpose, they will collaborate in consortia eligible for financial support.[427]

The Federal Government and the Länder intend to provide up to 90 million euros annually in the final stage of expansion by 2028 for the establishment and promotion of the NFDI. The Federal Government will bear 90 percent of these costs, with the Länder covering the remaining 10 percent.[428] The NFDI forms the national pillar for the planned European Open Science Cloud. In the future, this Cloud should link research data across Europe and disciplines.[429]

The Commission of Experts expressly welcomes the foundation of a National Research Data Infrastructure (NFDI) as an important step towards overcoming the fragmented research data landscape in Germany.

Open Access

Open access denotes unrestricted, direct access to scientific literature and other materials, usually free of charge and online.[430] As a result, publishers' business models that artificially limit access through paywalls and legal restrictions are being replaced by models in which publishing houses provide their services in return for payment from authors or third parties. The aim is to maximize the dissemination and usability of scientific information. This includes creating the possibility of bringing together all scientific information in the future, analysing it with the help of digital tools and evaluating it across disciplines – including using AI-based methods.[431]

The open access principle has grown increasingly popular in recent years. National and international scientific organizations have committed to implementing open access models in numerous agreements, such as the Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities, issued in 2003.[432]

The secondary publication right[433] for scientific authors, as recommended by the Commission of Experts, was added to the German Copyright Act (UrhG) in 2014.[434] It grants a certain group of state-funded scientists a contractually non-negotiable secondary publication right under defined framework conditions.[435]

To accelerate the transition to open access models, 16 national and international research funding organizations came together with the European Commission and European Research Council to form Coalition S. In their joint strategy, known as Plan S, they demand that researchers publish their research results in Open Access journals or repositories from 2020 onwards if the research work was financed by public funds.[436]

The German Research Foundation (DFG) – Germany's central research funding organization – has not yet joined Coalition S. While the DFG advocates open access models and supports Coalition S with a series of measures, it refuses to obligate researchers to use open access.[437] Above all, the DFG is fearful that the open access obligation demanded by Coalition S will mainly lead to an increase in publication charges. However, the DFG has announced that, in future, it will request that funding recipients publish the results of their research on open access platforms. Until now, the DFG has only recommended they do so.[438]

The Commission of Experts approves of this position. In the medium-term, the aspiration should be to transition to an open access system. However, researchers should retain the option of deciding for themselves where and how they publish the results of their research.

Digitalization of teaching: Digital teaching formats offer potential for development

In terms of teaching, digitalization denotes the permeation of digital components and learning tools through teaching and learning processes. As the survey conducted on behalf of the Commission of Experts shows, TE institutions primarily regard digitalizing teaching as a strategic element by which to improve the quality of teaching. Furthermore, digital learning formats provide a higher degree of flexibility, such as through time-independent and location-independent learning or individualized learning paths (cf. box B 4-2 for an example).[439]

Infrastructure for digital learning formats already exists

A central IT system that supports teaching is known as a learning management system (LMS)[440]. In the survey, 85 percent of responding TE institutions indicated that these systems have already been implemented either partially or in full.[441] However, most TE institutions only use their LMS as a structured document storage system.

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Box B 4-2

Example of good practice in teaching: Hamburg Open Online University (HOOU)

Launched in 2015, the Hamburg Open Online University (HOOU) is a collaborative project between all of Hamburg's public TE institutions,[442] including the University Medical Center Hamburg-Eppendorf (Universitätsklinikum Hamburg Eppendorf). At the HOOU, Hamburg's TE institutions develop innovative teaching and learning formats and materials on a common platform, which are made freely available to students and civil society.[443]

The aim of the HOOU is to enhance classic attendance teaching at Hamburg's TE institutions with the possibilities of digital technologies. In addition, collaborations across institutional boundaries are to be simplified. The original feature of the HOOU lies in the creation of a digital space in which students, teaching staff and civil society can meet to work together on interdisciplinary, cross-institutional projects.[444] The HOOU also makes it possible to pursue individualized learning paths.[445]

To date, the HOOU has offered around 50 learning opportunities. In addition, users have access to a variety of learning materials, such as informatics tutorials and scientific visualizations.[446]

More demanding applications, such as forums, exams and peer grading by course participants, are exceptions to this.[447]

Furthermore, by their own account, almost 90 percent of TE institutions have established service centres (e-learning centres) to support teaching staff in using digital instruments and to develop digital teaching content.[448]

The use of digital teaching and learning formats continues to lag behind the infrastructural framework conditions. The survey shows that mobile learning and social media are used frequently at 25 percent and 19 percent of TE institutions respectively. Only 13 percent of institutions use inverted classroom formats to a high or very high degree. The proportion of responding institutions who said they use adaptive learning, augmented/virtual reality and digital game-based learning on a frequent or very frequent basis in their teaching was between 6 and 7 percent (cf. infographic).[449]

These results are supported by a 2017 survey that examined digital teaching in TE institutions.[450] However, the survey also shows that a majority of teaching staff consider the technical equipment at TE institutions to be good.[451]

Incentives to develop digital teaching formats

In the survey conducted on behalf of the Commission of Experts, 62 percent of responding TE institutions indicated that they have put specific incentives in place to encourage teaching staff to supplement and develop their teaching with digital tools.[452] The incentives mentioned by institutions include the provision of additional personnel capacities in the form of substitute teachers and student staff (64 percent). Other measures include highlighting digital teaching formats as examples of good practice (53 percent), awarding prizes and bonuses to teaching staff (50 percent) and reducing teaching obligations (39 percent).[453]

Creating incentives for digital teaching by giving due consideration to the additional effort in the teaching loads entails further challenges for higher education institutions.[454] The digitalization of teaching is accompanied by significant one-time expenditure for initial set-up, but requires low expenditure for the subsequent use of teaching materials. The effort required to create such materials is only difficult to illustrate in a teaching load distribution system that has been based on attendance teaching to date. It is therefore necessary to develop incentive-compatible concepts.

A fundamental problem with the expansion of digital teaching formats is that teaching is still not the primary quality criterion upon which academic staff at TE institutions are evaluated. Furthermore, many teachers find the support and consultancy services currently offered by institutions' service centres to be insufficient.[455] Furthermore, it is difficult for the TE institutions to provide incentives for digital teaching, as there are uncertainties with regard to the legal requirements for teaching loads.[455]

International trends in digital teaching

German TE institutions have not yet expanded their digital offerings in response to the sharp increase in international demand for degree-level education. While globally oriented education platforms have become established in the USA, Asia and some European countries[457] and are developing new online services on a large scale,[458] German TE institutions primarily use their learning platforms for their own needs or within small-scale partnerships. Digital learning formats for the international market are mostly marketed by established overseas providers.[459] The most notable of these learning formats are open access online courses and massive open online courses (MOOCs), some of which are supervised by tutors and can sometimes lead to formal certification. The range of digital learning courses on offer is growing dynamically: between 70 and 140 new online courses are launched around the world every month. At present, 180 of the 6,800 courses available online are offered by German education institutions.[460]

Internationally, two in three new courses now offer the option of earning a formal certificate known as a micro-degree.[461] In addition, online courses are increasingly designed as MicroMasters programmes. MicroMasters programmes are multi-stage Masters courses with mandatory examinations which award MicroMasters certificates that can, in turn, be put towards a 'full' Masters course at a TE institution.[462] German organizations that offer MicroMasters programmes include openHPI, oncampus and Hamburg Open Online University (HOOU).[463]

In 2017, RWTH Aachen University became one of the first German TE institutions to offer a MicroMasters course via the international online learning platform edX.[464] Another way of using internationally available MOOCs is to integrate them in institutions' own Masters programmes. For instance, students at the Baden-Wuerttemberg Cooperative State University (Duale Hochschule Baden-Württemberg, DHBW) have the option of earning the credits required for their course of study by completing a MicroMasters programme offered by the Massachusetts Institute of Technology (MIT).[465]

Internationally renowned universities such as MIT and the École Polytechnique Fédérale de Lausanne (EPFL) have now implemented digital teaching platforms in order to attract exceptionally talented students who successfully complete online programmes to undertake attendance courses at the institution itself.[466]

In its annual reports, the Commission of Experts has repeatedly called for the growing importance of further education opportunities to be afforded greater attention to ensure that the digital transformation is a success.[467] In the view of the Commission of Experts, online learning programmes such as MOOCs and MicroMasters programmes represent important and useful additions to the existing range of teaching instruments.[468]

The Commission of Experts regrets the reticence of German TE institutions to engage in the systematic development and provision of innovative digital education and further education programmes.

Digitalization of administration: Non-study-related processes have ground to make up

The digitalization of administration involves reshaping administrative workflows into digitally networked processes.

The results of the survey conducted on behalf of the Commission of Experts indicate that study-related IT systems (such as study-focused campus management systems)[469] (cf. box B 4-3) feature a higher degree of implementation than non-study-related IT systems (such as computer-aided facility and enterprise resource planning systems)[470] – a trend discernible across all TE institutions.

Study-related administrative processes include, among others, processing admission applications, generating decision letters and issuing grade announcements, as well as student matriculation. These processes operate with a high degree of digitalization across TE institutions. For instance, 66 percent of responding institutions generate decision letters and grade announcements using fully electronic processes; 56 percent process admission applications in this manner. Furthermore, students can use a fully digital process to matriculate at 42 percent of responding institutions.[471]

By contrast, the degree to which non-study-related administrative processes – such as processing travel cost claims, business travel applications and procurement requests – have been digitalized is assessed as being markedly lower.[472] Less than 20 percent of responding institutions have fully digitalized these processes.[473] The assertion that German TE institutions have ground to make up in terms of the digitalization of administrative processes is confirmed by a comparison with the progress made at Swiss institutions.[474]

The digitalization of administrative processes at TE institutions is covered by the provisions of the Online Access Act (Onlinezugangsgesetz, OZG), which aims to advance the digitalization of public administration and entered into force in August 2017.[475] The OZG stipulates that, by the end of 2022, all administrative services provided by the federal government, the federal states and local authorities must be accessible online for the respective users via an online administration portal. According to the OZG implementation catalogue, TE institutions must make all administrative services that relate to a course of study (e.g. matriculation, applying for a leave of absence, awarding study places and issuing electronic copies of diplomas) available in digital form. The legislation also addresses support for potential applicants and when arranging student finance.[476]

To achieve these targets, the digitalization process and the internal networking of institutions' administrative systems will have to accelerate considerably in the years ahead.

Box B 4-3

Example of good practice in administration: Technical University of Munich – TUMonline

TUMonline is the campus management system operated by the Technical University of Munich (TUM). Since going live in 2010, it has been continuously developed in terms of user-friendliness and process optimization.

TUMonline supports all IT processes connected to the study cycle. This includes overseeing admission processes and student, seminar, module and examination management, as well as handling accreditations, degree administration, evaluation and alumni management.[477]

In terms of studies and examinations, digital applications are available via TUMonline for the following administrative services: degree course and examination administration, producing transcript records and examination decisions, administration of final exams, producing diplomas and confirming accreditations and recognitions. Students can also use TUMonline to create new recognitions, generate advance printouts for proof of successful study and create matriculation certificate.

It is absolutely crucial that the system is user-friendly. From the outset, the aim has been to make the system easy to navigate, to ensure the layout and operability are as user-friendly as possible and to make ongoing improvements to the system.

TUMonline also provides users with a wide range of advice and support. Teaching staff, students and support staff can access instructions and tutorial videos on the functions of TUMonline.[478]

B 4-2 Challenges for the digitalization of tertiary education institutions

Potential of cooperation on digitalization not yet exhausted

Intensifying cooperation between institutions is a commonly used method of exploiting digitalized processes' potential to increase efficiency in tertiary education. According to TE institutions, the field of standardisable, non-profile-related processes are particularly fertile ground for such cooperation.[479] The survey conducted on behalf of the Commission of Experts revealed that TE institutions are engaged in associations and collaborative endeavours in the following focus areas: digitalizing teaching and learning (72 percent), digitalizing infrastructure (67 percent), digitalizing administration (58 percent) and digitalizing research (49 percent).[480]

A large part of the associations and collaborative endeavours are located within a single Bundesland (cf. figure B 4-4).[481] In all areas, the proportion of TE institutions engaged in associations and collaborative endeavours within their respective Bundesland is over 50 percent. International associations and collaborative endeavours are least common. It can be seen that international collaborative endeavours most commonly relate to the digitalization of research.[482]

The high level of cooperation within individual Länder can be explained, among other aspects, by the fact that the Länder governments not only support their TE institutions but also initiate, promote and demand collaboration projects themselves.[483]

Research: Collaborative endeavours in digitalization projects within specialist disciplines are particularly important, as subject specifics have to be considered – not only in research but also, for example, in terms of research data management.[484]

Teaching and study: Collaborative endeavours enable teaching materials to be created and shared and can even make it possible to offer a joint range of courses that a single institution would be unable to provide.[485] Collaborative endeavours to develop the skills of teaching staff play a major role, especially at state level within a Bundesland.[486]

Administration: TE institutions consider collaboration and inter-institutional service offerings on legal and technical issues to be particularly helpful – such as in relation to collaboration agreements, implementing regulations, data protection, IT security, procurement law, the publication of examples of good practice as well as the setup of digital infrastructure.[487]

Further collaboration is needed in relation to IT services. German TE institutions use various IT services (e.g. cloud services, video and media servers) provided by the institutes' own computing centres. These represent alternatives to commercial options offered by private-sector providers. To provide their own cloud services and media servers, institutions are forced to tie up a significant amount of already limited resources – which is why TE institutions work together to develop IT services.[488] One drawback of these alternative services is that they are usually funded at state level, precluding their use in other Länder.[489]

There is also a need for TE institutions to adopt coordinated approach when purchasing software licenses. Acquiring such licences can entail significant costs when institutions act alone. Centralized licence procurement is not generally in place at state level. As a result, it is difficult for TE institutions to negotiate favourable conditions with software providers.

Digitalization demands long-term funding

Digitalization is a resource-intensive, long-term task facing the tertiary education system – a system which has been subject to chronic underfunding for many years and which is characterized to a large extent by programme and project funds that are only temporarily available.[490]

The Federal Government and Länder initiated numerous funding programmes and initiatives in response to institutions' digitalization-related funding requirements. Despite these measures, TE institutions name resource issues as a central challenge. Indeed, some institutions – primarily large universities and universities of applied sciences (FHs/HAWs) – finance the infrastructural requirements for digitalization through basic funds freed up by restructuring their budgets.[491] Most TE institutions, however, rely on third-party funding from Federal Government and Länder to finance their digital infrastructure. Since digitalization is a permanent task for TE institutions, project funds are not sufficient from a TE institutions' perspective to implement digitalization projects in a sustainable and coordinated manner on a broad scale.

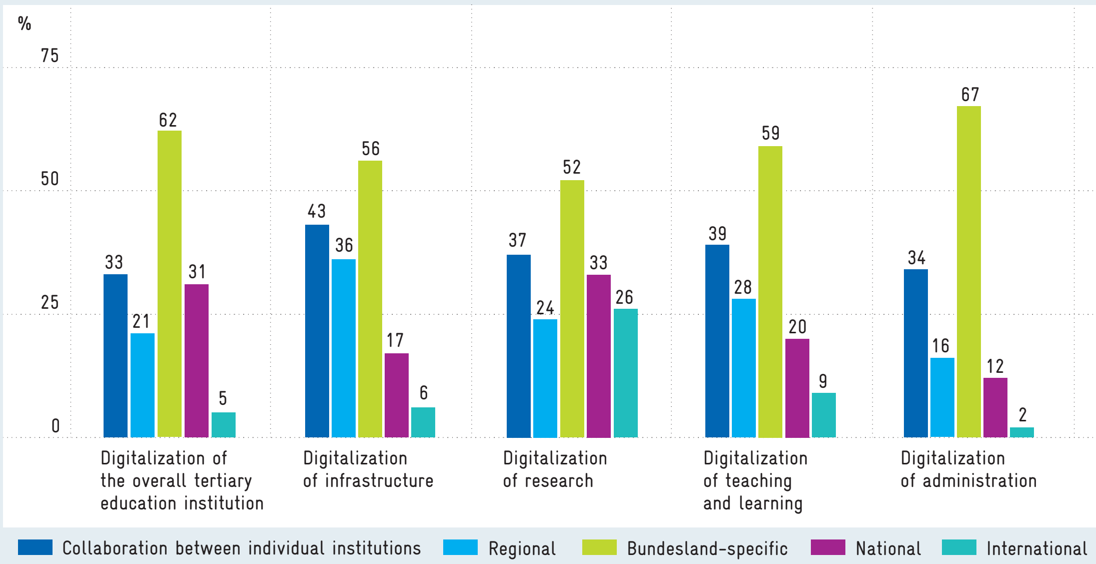
TE institutions' representatives who responded to the survey said that project funding often leads to the creation of parallel structures and isolated applications[492] because IT software and hardware is repeatedly installed 'as new' in funded projects rather than being integrated in the existing IT landscape.

B

Fig. B 4-4

Download data

Scope of associations and collaborative endeavours to digitalize German tertiary education institutions as percentages



Source: Gilch et al. (2019: 130).

The result is growing complexity and fragmentation, which prevents synergies and has a negative impact on the usability of IT systems. Furthermore, the temporary and somewhat unpredictable nature of project funding makes it harder for institutions to set medium-term and long-term strategic goals for digitalization projects.[493]

Measures taken by the Federal Government and the Länder

The Federal Government is playing its part in promoting the digitalization of tertiary education through the programme agreed with the Länder (Quality Pact for Teaching), which aims to improve studying conditions and boost the quality of teaching. As part of the competitively structured Quality Pact for Teaching, the Federal Government will provide around €2 billion for projects in the TE sector between 2011 and 2020. Even though the Quality Pact for Teaching is not explicitly aimed at financing digitalization projects, a large amount of the funding is used for this purpose. According to the BMBF, digitalization and the use of digital technologies are important aspects in about half of the funded projects.[494]

In addition, the BMBF supports research into digital teaching methods in tertiary education and research data management. Funded research projects will examine the effectiveness of proven and innovative approaches and formats in digital tertiary education.[495]

In this context, the BMBF also promotes the German Forum for Higher Education in the Digital Age (Hochschulforum Digitalisierung, HFD), an independent national platform which encourages engagement with digitalization; it also brings together and advises institutions and actors from the fields of politics and business on the challenges the issue poses.[496]

The Federal Government addressed the issue of the digitalization of TE institutions in its coalition agreement.[497] The agreement announced that, in relation to digitalization, institutions would be supported in improving the quality of studying, teaching and research as well as enhancing the quality of administration and academic exchange. TE institutions and TE associations innovative in digitalisation are to be awarded funding via a competitive process. Support has also been announced for concepts to network institutions, such as teaching and learning platforms.[498]

The majority of German Länder have proposed digitalization strategies and concepts in recent years.[499] Most – but not all – of these digitalization concepts feature targets with a specific academic focus or which relate to TE institutions. In concepts that include corresponding targets, it is possible to determine various areas of focus. These are usually the promotion of the digitalization of teaching and learning as well as of research.

Recruitment of IT specialists hampered by inflexible tariff structures

TE institutions have reported serious issues due to a shortage of IT specialists. There are no significant differences with respect to the type and size of tertiary education institution.[500]

According to the institutions themselves, the main challenge in the recruitment of IT specialists lies in the established pay-scale groupings for IT specialists. A study conducted by the IT Planning Council (IT-Planungsrat) supports this assessment: it found that the most common reason given by candidates who withdrew their applications for public-sector IT positions was that the offered wage was too low.[501]

The shortage of skilled workers affects TE institutions in locations with strong, high-growth economies in particular, as they are in direct competition with companies prepared to pay higher wages for IT specialists.[502] TE institutions are also at a disadvantage compared to non-university research institutions (außeruniversitäre Forschungseinrichtungen, AUFs). The majority of AUFs financed by the Federal Government are subject to the Collective Wage Agreement for the Civil Service (Tarifvertrag für Einrichtungen der öffentichen Verwaltung von Bund und Kommunen, TVöD) as opposed to the corresponding wage agreement applied at Länder level (Tarifvertrag der Länder, TVL).[503] Compared to the TVöD, the TV-L lacks flexibility.[504]

Furthermore, the TVöD is subject to a supplementary guideline for employers issued by the Federation of Municipal Employers' Associations (Vereinigung der kommunalen Arbeitgeberverbände) for the recruitment and retention of skilled workers,[505] which will make it possible to classify newly appointed IT specialists in higher groupings in salary tables and to consider allowances.[506]

TE institutions are also less attractive destinations for IT specialists due to the tendering of mainly temporary employment contracts. Many IT positions are temporary due to the prevailing project financing structure applied to digitalization projects in TE institutions (cf. p. 101). The situation at many institutions is further complicated by the aforementioned deficits in TE institutions' governance systems (cf. p. 94): the insufficient professionalization of management structures means that TE institutions are not making sufficient use of the legal options to make employment relationships more flexible.

Significant uncertainty in relation to data protection and copyright law

Data protection poses problems for many TE institutions. There is considerable uncertainty regarding the implementation of data protection regulations in day-to-day operations. In particular, the European Union's General Data Protection Regulation (GDPR) is repeatedly cited as a problem in the digitalization of administration and teaching. Regulations set by the Federal Government and the Länder further complicate matters. TE institutions emphasize that, while data protection may not prevent digitalization projects from being implemented altogether, it does entail a significant degree of extra effort and reviewing work.[507]

Due to reservations and a lack of knowledge about the opportunities permitted by data protection legislation, TE institutions have only used learning analytics software[508] to a very limited extent.[509] Institutions' data protection officers often lack the resources to handle the scope and complexity of the topic.[510] If the issues surrounding data protection were resolved, learning analytics would offer a major opportunity to develop the quality and didactics of teaching and deploy resources more efficiently.[511]

The use of IT services offered by commercial providers by employees of TE institutions is another issue with implications for data protection. For example, Dropbox, Google Docs and Skype are popular and frequently used due to the high level of user-friendliness they offer. However, using such IT services is questionable from a data protection perspective because personal data can be stored on servers which are located outside the European Economic Area and which are not GDPR-compliant.[512] Until the IT services provided by TE institutions offer a similar degree of user-friendliness, user behaviour cannot be expected to change.

Studies have also repeatedly mentioned copyright law as a problem in the digitalization of TE institutions, since the provision and use of digital works (e.g. in key texts and materials, in teaching and in research) was only possible within narrow limits.[513] The Commission of Experts criticized the existing legal framework in its 2015 report and called for the introduction of a general exemption to copyright for scientific and educational purposes.[514] In copyright law, such exemptions limit the exploitation rights of originators in certain situations.[515]

The Federal Government took this criticism on board and, through the Act to Revise Copyright Law to the Requirements of the Knowledge-Based Society (Gesetz zur Angleichung des Urheberrechts an die aktuellen Erfordernisse der Wissensgesellschaft, UrhWissG), introduced such a general exemption to copyright for scientific and educational purposes.[516] Despite the remaining usage restrictions, the reform has, overall, provided more clarity and made it easier for teaching staff and researchers at TE institutions to copy and distribute published works.[517] The reform came into force on 1 March 2018. It is set to be evaluated after four years and is initially in force until the end of February 2023.[518] The Commission of Experts welcomes this development.

Recommendations B 4–3

Recommendations for tertiary education institutions

In the digitalization of the TE institutions, a technically complex task is compounded by inadequately developed governance structures. For digitalization to succeed, the TE institutions must continue to modernize their administration and overcome departmental thinking ("silo mentality").[519]

– In view of this, the Commission of Experts recommends that TE institutions develop a digitalization strategy with clearly defined goals and a suitably coordinated implementation plan. Such a digitalization strategy should go hand in hand with profile-building measures by TE institutions – something the Commission of Experts has repeatedly advocated. The need for extra-occupational training should be taken into account in particular.

- TE institutions should increase their negotiating power by bundling the purchase of licenses on an inter-university basis. As yet, there is no institution or body that negotiates TE institutions' licences for software, platforms, cloud services, etc. The Ministries of Science and Culture of the Länder can provide support for this process.

Recommendations for education and tertiary education policy

- The digitalization of Germany's structurally under-financed tertiary education system is an ongoing task which requires long-term financing. The Commission of Experts recommends that the TE institutions should be supported through the introduction of a lump-sum digitalization payment. TE institutions should receive a specific amount per student with which to develop and maintain their digital infrastructure and applications and expand their digital teaching and learning offerings.
- The support for the digitalization of TE institutions through competitively awarded project funding should continue in order to incentivize innovative TE institutions and motivated individuals.
- If digitalization leads to increased efficiency at TE institutions and thereby creates additional financial leeway, these should be permanently available to TE institutions for qualitative improvements in infrastructure, teaching and research.
- In order to make it easier for TE institutions to recruit IT specialists, the Commission of Experts recommends that the Länder, in their capacity as public service employers, should introduce some flexibility into the existing pay regulations with an orientation towards the Collective Agreement for the Public Service (Tarifvertrag für den öffentlichen Dienst, TVöD).
- Digitalization presents comprehensive technical, organizational and legal challenges for TE institutions. Small institutions in particular find it difficult to make sufficient capacity available. The Commission of Experts therefore suggests that TE institutions should be supported through the creation of IT service centres and by strengthening existing advisory and support institutions.

STRUCTURE AND TRENDS

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Overview

Measuring and reporting Germany's performance as a location for research and innovation is an integral part of the annual reports of the Commission of Experts for Research and Innovation. The process involves compiling a number of indicators which allow conclusions to be drawn on the dynamics and efficiency of Germany's research and innovation system. For the sake of clarity, the indicators are divided into eight thematic sets. Based on these indicator sets, the performance of the German research and innovation system is presented in an intertemporal comparison, and compared with the most important competing countries.386 Furthermore, individual indicators are shown at the Länder level to reveal differences in performance within Germany. Most of the indicators have been drawn from studies on the German innovation system commissioned by the Commission of Experts. In addition to the indicators listed here, these studies also offer comprehensive further material for indicators and analysis. The studies can be accessed and downloaded from the Commission of Experts' website. The same applies to all the charts and tables in the annual report and to the related data sets.

C 1 Education and qualification

Investment in education and a high level of qualification strengthen a country's medium- and long-term innovative capacity and boost its economic growth. The indicators listed in section C 1 provide information on qualification levels, as well as an overview of Germany's strengths and weaknesses as an innovation location. Comparing these figures with those of other industrialized countries facilitates an assessment of Germany's performance at the international level.

C 2 Research and development

Research and development processes are an essential prerequisite for developing new products and services. As a rule, a high level of R&D intensity has positive effects on competitiveness, growth and employment. R&D investments and activities by companies, tertiary education institutions and governments therefore provide an important source of information for assessing a country's technological performance. Section C 2 provides insights into how Germany's R&D activities compare with those of other countries, how much the individual Länder invest, and which sectorsof the economy are especially research-intensive.

C 3 Innovation behaviour in the private sector

Innovation activities by companies aim to create competitive advantages. In the case of a product innovation, a new or improved good is launched onto the market. By definition, this good differs from any other goods previously sold on the market. The launch of a new or improved manufacturing process is referred to as a process innovation. Section C 3 depicts the innovation behaviour of the German economy by showing the innovation intensity of industry and knowledge-intensive services, and the percentage of turnover that is generated with new products, in the context of an international comparison.

C 4 Financing research and innovation

The financing of business and, in particular, R&D activities is a key challenge, above all for young, innovative enterprises. Since these companies initially generate little or no turnover, self-financing is often not an option. Debt financing is also difficult, as it is not easy for investors such as banks to assess the success prospects of innovative business start-ups. Alternative methods of corporate financing include raising equity or venture capital, as well as public funding. Section C 4 describes the availability of venture capital and public R&D funds in Germany and other countries.

C 5 New businesses

New businesses – especially in research-intensive and knowledge-intensive sectors – challenge established businesses with innovative products, processes and business models. The creation of new businesses and the market exit of unsuccessful (or no longer successful) businesses is an expression of innovation competition for the best solutions. The business dynamics described in section C 5 therefore represent an important aspect of structural change. Young businesses can open up new markets and leverage innovative ideas – especially in new fields of technology, when new demand trends emerge, and in the early phase of transferring scientific knowledge to the development of new products and processes.

C 6 Patents

Patents are intellectual property rights for new technical inventions. Thus, they often provide the basis for exploiting innovations on the market, while at the same time supporting coordination and the transfer of knowledge and technology between the stakeholders in the innovation system. Section C 6 presents the patent activities of selected countries, while also examining the extent to which these countries have become specialized in the fields of high-value and cutting-edge technology.

C 7 Scientific publications

The continuous creation of new knowledge greatly depends on the efficiency of the respective research and science system. Using bibliometric data, section C 7 depicts Germany’s performance in this field by international comparison. A country’s performance is determined on the basis of its researchers’ publications in scientific journals. The perception and importance of these publications is measured by the number of citations.

C 8 Production, value added and employment

Levels of work input and value creation in a country’s research-intensive and knowledge-intensive sectors – as percentages of the economy as a whole – reflect the economic importance of these sectors and allow conclusions to be drawn on the country’s technological performance. Section C 8 depicts the development of value added and productivity in research-intensive industries and knowledge-intensive services by international comparison. The section also provides insights into Germany’s global trade position in the fields of research-intensive goods and knowledge-intensive services.

Education and qualification[521] C 1

The proportion of the working population in Germany holding tertiary qualifications (ISCED 5+6 and ISCED 7+8) has again risen slightly. In 2017, this figure was 31.4 percent – 0.2 percentage points higher than in the previous year (C 1-1). The percentage of people with low qualifications (ISCED 0-2) also increased slightly, from 10 to 10.1 percent. The percentage of people with low qualifications in Germany is the second lowest by international comparison; only in Finland is the figure lower.

The number of new tertiary students as a percentage of the relevant age group (C 1-2) in Germany has fallen by 3 percentage points, from 63 to 60 percent. The adjusted figure for German under-25s (i.e. excluding new international tertiary students) also fell by 3 percentage points, from 48 to 45 percent.

In 2017, the rate of qualified school-leavers (C 1-3), i.e. the number of school-leavers qualified for higher education as a percentage of the relevant age group, was 51 percent. The Standing Conference of the Ministers of Education and Cultural Affairs (KMK) expects the rate of qualified school-leavers to continue to increase, reaching around 58 percent by 2030. In 2017, there were 440,826 qualified school-leavers in Germany. The Standing Conference of the Ministers of Education and Cultural Affairs has forecasted that the number of qualified school-leavers will remain broadly constant until 2030.

The number of first-time graduates (C 1-4) fell slightly in 2017 compared to the previous year, from 315,168 to 311,441. The proportion of first-time graduates that graduated from a university also decreased once again, falling to 53.9 percent in 2017. By contrast, the number of graduates from universities of applied sciences rose from 52 to 52.6 percent.

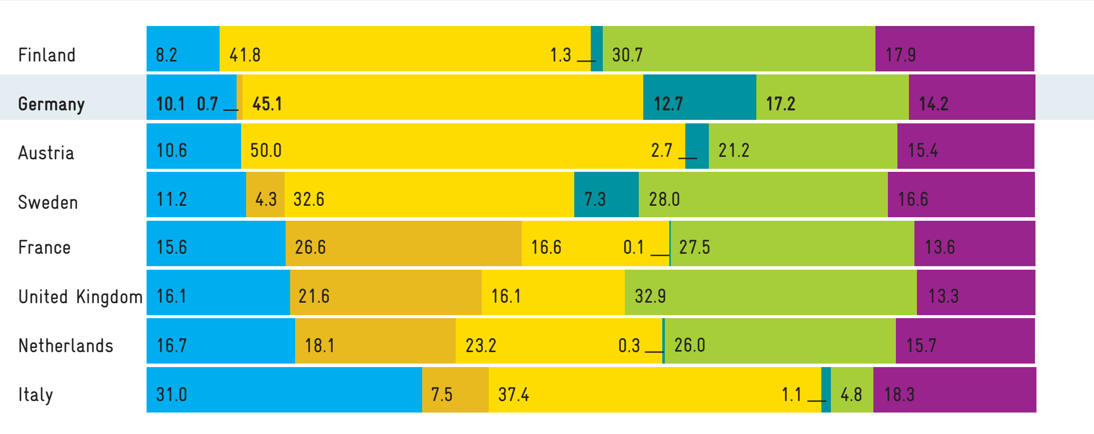
The number of foreign students with university entrance qualifications gained in Germany (Bildungsinländer) has fallen for the first time in a decade, from 93,411 in the winter semester 2016/17 to 92,581 in the winter semester 2017/18. On the other hand, the number of foreign students in Germany with university entrance qualifications gained outside of Germany (Bildungsausländer) rose once again (C 1-5). In the winter semester 2017/18, 282,002 foreign students (Bildungsausländer) were matriculated students of German tertiary education institutions. This figure has almost doubled since the winter semester 2001/02.

The further training rate (C 1-6) fell to 5.0 percent in 2017, compared to 5.2 percent the previous year. There was a particular decline in the further training rate of gainfully employed and highly qualified persons, from 9.7 to 8.9 percent. By contrast, the rate of corporate participation in further training rose from 52.8 percent in 2015 to 53.2 percent in 2016.

Fig. C 1-1

Download data

Qualification levels of gainfully employed persons in selected EU countries in 2017 as percentages



Classification of the ISCED qualification levels[1].

- ISCED 0-2: (Pre)primary and lower secondary education
- ISCED 3*: General and vocational upper secondary education without direct access to tertiary education
- ISCED 3**: General and vocational upper secondary education with direct 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 degree, doctoral degree or equivalent qualification

[1] UNESCO uses the ISCED classification of educational levels as standards for international comparisons of country-specific education systems. They are also used by the OECD.
Source: Eurostat, European Labour Force Survey. Calculation by CWS in Gehrke et al. (2019).

C

Tab. C 1-2

Download data

Share of new tertiary students as a percentage of the relevant age group in selected OECD countries

University entry rate: number of new tertiary students as a percentage of the relevant age group.

OECD countries[1]	2006	2009	2012	2013[2]	2014[2]	2015[2]	2016[2]	2013[3]	2014[3]	2015[3]	2016[3]
Germany	**35**	**40**	**53**	**59**	**64**	**63**	**60**	**45**	**48**	**48**	**45**
Belgium	35	31	34	67	67	69	72	54	57	59	62
Finland	76	69	66	55	53	56	58	41	40	42	42
Italy	56	50	47	42	44	46	48	–	–	41	41
Japan	45	49	52	–	80	80	80	–	–	–	–
Sweden	76	68	60	56	62	62	62	40	42	41	40
Switzerland*	38	41	44	–	–	–	–	–	–	47	47
United Kingdom	57	61	67	58	61	69	64	42	44	50	48
USA	64	70	71	52	52	52	52	47	47	46	50
OECD average	**56**	**59**	**58**	**67**	**68**	**66**	**66**	**50**	**51**	**48**	**49**

1) To date, no figures have been made available for France, South Korea or China since ISCED 2011. These countries are therefore not included in the table. Instead, three European OECD countries were included to supplement the results: Belgium, Finland and Italy.
2) The table shows the university entry rates according to the ISCED classification for levels 5, 6 and 7. Please note: figures from 2013 and later were compiled according to ISCED 2011, figures before 2013 according to ISCED 97; this table is therefore not comparable with previous years. ISCED 2011 used here has nine levels, while ISCED 1997 only had seven. ISCED 2011 distinguishes between four instead of two levels in the field of higher education (ISCED 1997: Levels 5A and 6; ISCED 2011: Levels 5 to 8) and enables a distinction to be made between 'general and vocational upper secondary education without direct access to tertiary education (ISCED 3*) on the one hand and 'general and vocational upper secondary education with direct access to tertiary education (ISCED 3**) on the other.
3) Adjusted rate for under-25s, excluding new international tertiary students.
* The missing figures are not shown due to a data error. For further information on the calculation of the rates for Switzerland, see Gehrke et al. (2019), Chap. 4.1.7.
Sources: OECD (ed.): Education at a glance. OECD indicators, various years in Gehrke et al. (2019).

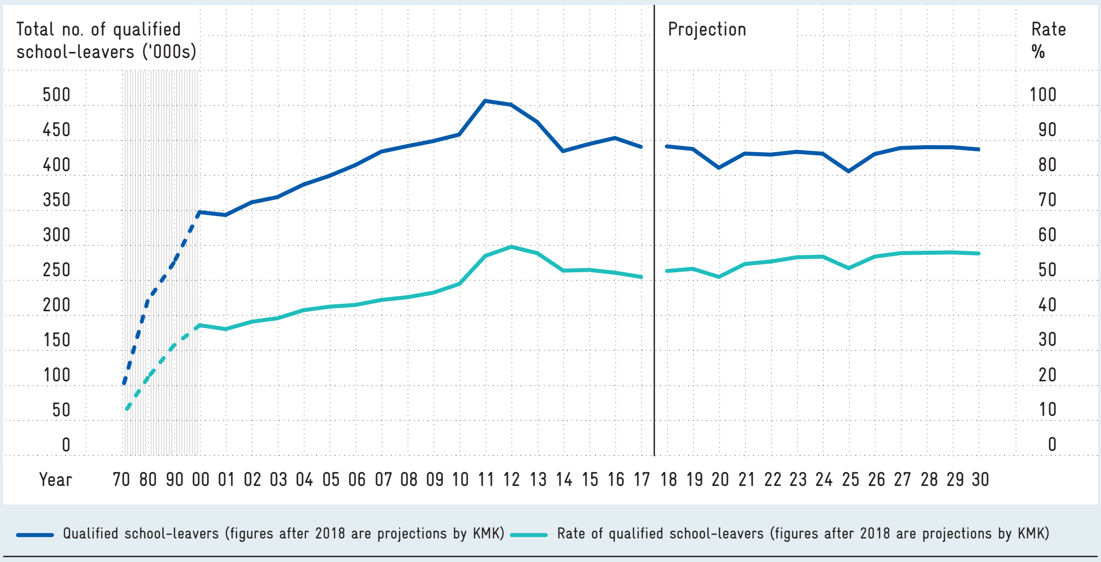
C

Fig. C 1-3

Download data

School-leavers qualified for higher education in Germany 1970–2030 (figures for 2018 and later are projections)

School-leavers qualified for higher education: either with a 'general' or '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.



Since 2013, the actual figures no longer include school leavers who have passed the school part of the 'technical' Abitur but must still do a period of professional practical training according to Länder rules to fully qualify for tertiary education.
Source of actual figures: Federal Statistical Office (BA) in Gehrke et al. (2019).
Quelle Prognosewerte: Statistische Veröffentlichungen der Kultusministerkonferenz in Gehrke et al. (2019).
Source of forecast figures: statistical publications of the Standing Conference of Education Ministers (KMK) in Gehrke et al. (2019).

C

Tab. C 1-4

Download data

Number of first-time graduates and subject-structure rate[1]

First-degree graduates and subject structure rate: the subject structure rate indicates the percentage of first-degree graduates who have completed their studies in a particular subject or group of subjects. First-degree graduates are persons who have successfully completed a first degree.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Total number of graduates[2]	**239,877**	**260,498**	**287,997**	**294,330**	**307,271**	**309,621**	**309,870**	**313,796**	**317,102**	**315,168**	**311,441**
Percentage of women	51.8	52.2	51.7	52.1	51.4	51.3	51.5	51.2	51.1	52.0	52.6
Percentage of graduates from universities	62.4	62.4	62.0	62.0	62.1	61.3	59.9	59.0	56.8	54.7	53.9
Humanities	**30,997**	**36,458**	**38,684**	**38,385**	**39,435**	**38,444**	**38,247**	**38,788**	**37,135**	**34,886**	**32,205**
Percentage of subject group	12.9	14.0	13.4	13.0	12.8	12.4	12.3	12.4	11.7	11.1	10.3
Legal, economics and social sciences	**98,668**	**101,418**	**116,414**	**119,289**	**122,294**	**122,239**	**123,171**	**125,628**	**128,273**	**132,737**	**134,605**
Percentage of subject group	41.1	38.9	40.3	40.5	39.8	39.5	39.7	40.0	40.5	42.1	43.2
Human medicine	**13,358**	**14,345**	**15,142**	**15,222**	**15,686**	**15,856**	**16,534**	**17,331**	**17,935**	**19,521**	**20,308**
Percentage of subject group	5.6	5.5	5.2	5.2	5.1	5.1	5.3	5.5	5.7	6.2	6.5
Agriculture, forestry and food sciences, veterinary medicine	**6,534**	**7,204**	**7,729**	**7,125**	**7,521**	**7,345**	**7,158**	**7,008**	**7,442**	**6,978**	**7,148**
Percentage of subject group	2.7	2.8	2.7	2.4	2.4	2.4	2.3	2.2	2.3	2.2	2.3
Art	**10,399**	**11,185**	**11,544**	**11,820**	**12,525**	**12,866**	**12,542**	**11,913**	**11,514**	**11,268**	**11,119**
Percentage of subject group	4.3	4.3	4.0	4.0	4.1	4.2	4.0	3.8	3.6	3.6	3.6
Mathematics, natural sciences	**22,986**	**27,377**	**30,953**	**32,800**	**34,096**	**32,793**	**31,665**	**31,635**	**30,001**	**28,081**	**26,261**
Percentage of subject group	9.6	10.5	10.7	11.1	11.1	10.6	10.2	10.1	9.5	8.9	8.4
Engineering	**53,496**	**58,514**	**64,004**	**65,621**	**71,128**	**75,697**	**77,049**	**78,018**	**81,300**	**78,552**	**76,133**
Percentage of subject group	22.3	22.5	22.2	22.3	23.1	24.4	24.9	24.9	25.6	24.9	24.4

[1] The Federal Statistical Office's new subject-group classification has been in use since the 2015/16 winter semester. Apart from minor changes, such as the renaming of study subjects or the merger of Veterinary Medicine with Agricultural, Forestry and Food Sciences, there were two major re-classifications. The subject group Legal, Economic and Social Sciences now also includes Psychology, Education and Special Needs Education, which used to be assigned to the subject group Language and Cultural Sciences (now called Humanities). Since the changeover, Computer Science has been counted under Engineering and not, as previously, as part of Mathematics, Natural Sciences. Furthermore, a new area of study called Materials Science was introduced under Engineering. These two subjects had previously been assigned to Mechanical Engineering. All the time series have been retrospectively reclassified to fit the new system of subjects. This avoids breaks in the time series. However, comparisons with the tables from the previous EFI Reports are now only possible to a limited extent.
[2] Graduates with first academic degree.
Source: Federal Statistical Office and research by DZHW-ICE, in Gehrke et al. (2019).

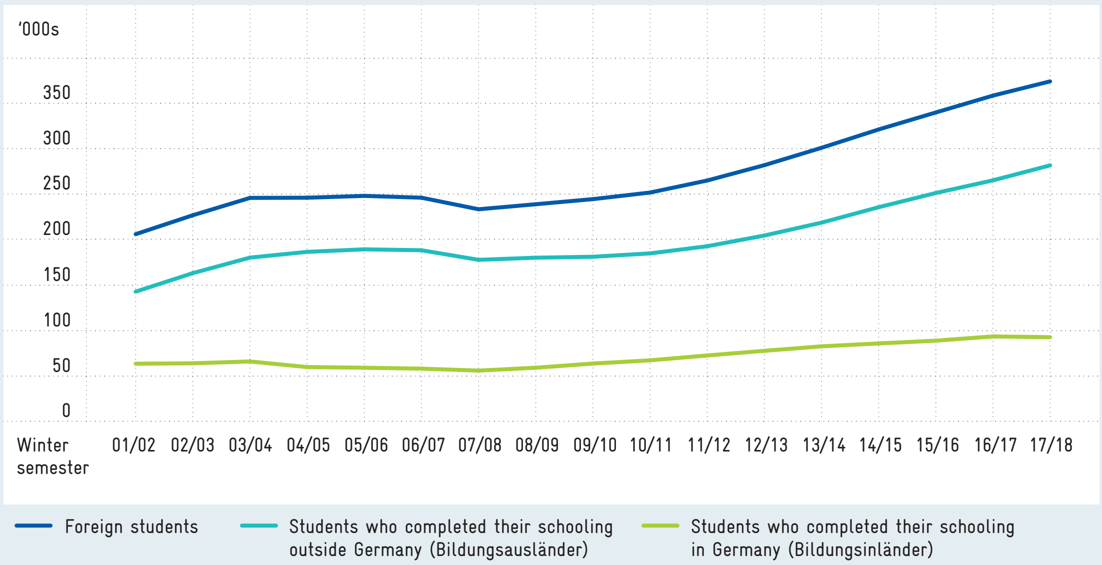
C

Fig. C 1-5

Download data

Foreign students at German tertiary education institutions

Foreign students are defined as persons without German citizenship. They can be divided into students who obtained their higher-education entrance qualification in Germany (Bildungsinlander/innen), and those who obtained this qualification abroad (Bildungsausländer/innen).



Source: Federal Statistical Office and research by DZHW-ICE, in Gehrke et al. (2019).

C

Participation of individuals and companies in further training as percentages

Tab. C 1-6

Download data

Individual further-education rate: percentage of people who had participated in a further-education measure in the last four weeks prior to the time of the survey. Corporate participation in further training: percentage of companies where employees were released for training or whose training costs were paid.*

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
a) Individual further-education rate	4.9	5.5	5.0	4.9	4.9	5.1	4.9	4.8	4.9	5.2	5.0
Gainfully employed persons	**5.9**	**6.4**	**5.8**	**5.6**	**5.6**	**5.9**	**5.6**	**5.5**	**5.5**	**5.8**	**5.4**
low (ISCED 0-2)	1.5	1.7	1.4	1.3	1.0	1.4	1.4	1.3	1.2	1.5	1.5
medium (ISCED 3-4)	4.1	4.4	4.2	3.9	3.9	4.1	3.9	4.2	4.3	4.5	4.2
high (ISCED 5-8)	11.4	12.2	10.6	10.5	10.3	10.6	10.1	9.4	9.3	9.7	8.9
Unemployed persons	**3.1**	**4.9**	**4.3**	**3.9**	**4.6**	**3.8**	**3.6**	**3.7**	**3.7**	**4.2**	**5.3**
low (ISCED 0-2)	2.5	2.4	2.7	3.5	3.6	3.1	2.9	2.8	2.6	3.3	5.1
medium (ISCED 3-4)	2.9	5.3	4.0	3.2	4.0	3.6	3.4	3.3	3.4	3.6	4.3
high (ISCED 5-8)	5.4	8.1	8.4	8.3	10.0	6.6	5.4	6.4	6.3	7.2	8.6
Inactive persons	**1.7**	**2.3**	**1.9**	**2.0**	**1.9**	**1.6**	**1.8**	**1.8**	**2.0**	**2.4**	**3.2**
low (ISCED 0-2)	0.8	1.4	1.8	1.6	1.5	1.4	1.4	1.3	1.7	2.5	4.0
medium (ISCED 3-4)	1.7	1.8	1.5	1.8	1.9	1.4	1.5	1.6	1.6	1.8	2.2
high (ISCED 5-8)	3.5	5.4	3.4	3.6	2.7	2.8	3.5	3.4	3.7	4.4	4.9
b) Corporate participation in further training[1]	**45.5**	**49.0**	**44.6**	**44.1**	**52.6**	**53.1**	**52.1**	**53.6**	**52.8**	**53.2**	**-**
By sector											
Knowledge-intensive manufacturing	65.3	65.1	52.6	55.9	62.9	65.5	66.7	69.9	70.6	64.0	-
Non-knowledge-intensive manufacturing	33.2	37.8	32.5	33.3	41.2	43.2	41.8	43.0	44.5	46.3	-
Knowledge-intensive services	63.2	68.3	58.7	57.1	68.7	67.2	67.4	67.0	67.5	69.2	-
Non-knowledge-intensive services	37.3	39.4	38.0	37.5	44.9	45.3	44.3	46.0	43.8	43.7	-
Non-commercial economy	49.9	53.8	51.9	51.2	59.0	60.3	58.4	61.9	60.1	59.3	-
By company size											
< 50 employees	43.2	46.9	42.5	41.8	50.5	50.9	49.8	51.4	50.5	50.8	-
50 – 249 employees	85.1	86.7	81.3	83.3	90.8	89.7	90.1	90.8	89.3	90.0	-
250 – 499 employees	95.2	95.9	92.0	93.3	95.9	96.5	97.0	96.9	96.8	96.4	-
≥ 500 employees	95.3	97.8	96.0	97.9	98.4	97.8	99.1	99.1	97.1	97.8	-

* Question in the IAB Establishment Panel: "Were employees released to participate in in-house or external training measures and/or were the costs of training measures paid wholly or in part by the establishment?" For ISCED, cf. C 1-1.
Basic unit a) All persons aged 25-64.
Basic unit b): All companies with at least one employee subject to social insurance contributions.
[1] The data for corporate participation in further training was not available by the editorial deadline.
Source a): European Labour Force Survey (special evaluation). Calculations by CWS in Gehrke et al. (2019). Data for 2016 and 2017 relating to unemployed and inactive persons are only comparable with previous years' data to a limited extent due to methodological adjustments and stricter confidentiality regulations.
Source b): IAB Establishment Panel (special evaluation). Calculations by CWS in Gehrke et al. (2019).

C

C 2 Research and development[522]

R&D intensity (C 2-1) in Germany – i.e. R&D expenditure as a percentage of gross domestic product – has risen. While R&D intensity in 2016 was 2.93 percent, it reached a figure of 3.02 percent in 2017. Sweden experienced a similarly marked increase in its R&D intensity, which rose from 3.25 to 3.33 percent in the same period. However, this remains below the levels reached in 2008 and 2009, when Sweden's recorded R&D intensity was 3.5 and 3.45 percent respectively. The level of R&D intensity has decreased in the United Kingdom and France: in the UK, the figure fell from 1.69 in 2016 to 1.67 percent in 2017, while France recorded a fall from 2.25 to 2.19 percent in the same period. Japan also recorded a significant decline, with its R&D intensity falling from 3.28 in 2015 to 3.14 percent in 2016.

The budgetary estimate for civil R&D (C 2-2) – i.e. the financial resources set aside for R&D in the state budget – rose again in Germany in the past year. The 2018 figure was 58 percent above the initial level of 2008. Strong increases in budgetary estimates were also recorded in Sweden, South Korea and Switzerland, while the levels recorded in the USA, the UK and France showed only moderate growth compared to the initial year of 2008. Japan's budgetary estimate saw striking growth recently. After several years of moderate growth, the Japanese budgetary estimate increased markedly from 117 percent in 2017 to 130 percent in 2018.

The distribution of gross domestic expenditure on R&D by performing sector (C 2-3) in Germany shows that the proportion attributable to the private sector fell from 70 percent in 2006 to 68.7 percent in 2016. Tertiary education (TE) institutions have significantly increased their share of expenditure incurred in the implementation of R&D activities. TE institutions' share of R&D expenditure rose from 16.1 to 18 percent between 2006 and 2016. The state's share barely changed, decreasing from 13.9 to 13.8 percent.

At the time of going to print, figures for the Länder were only available up to 2016. The average R&D intensity of the Länder (C 2-4) increased from 2.45 to 2.93 percent between 2006 and 2016. However, the increases in R&D expenditure for the individual Länder vary significantly. While the R&D intensity of Baden-Württemberg increased from 4.04 to 4.92 percent and Lower Saxony recorded a rise from 2.21 to 3.31 percent, Berlin was the only state in which the R&D intensity failed to increase. At 3.49 percent, R&D intensity in Berlin in 2016 remained at the same level as in 2006. The R&D expenditure of the individual Länder can be subject to pronounced fluctuations from one year to the next, as changes in the R&D expenditure of individual industrial firms can heavily influence these indicators.

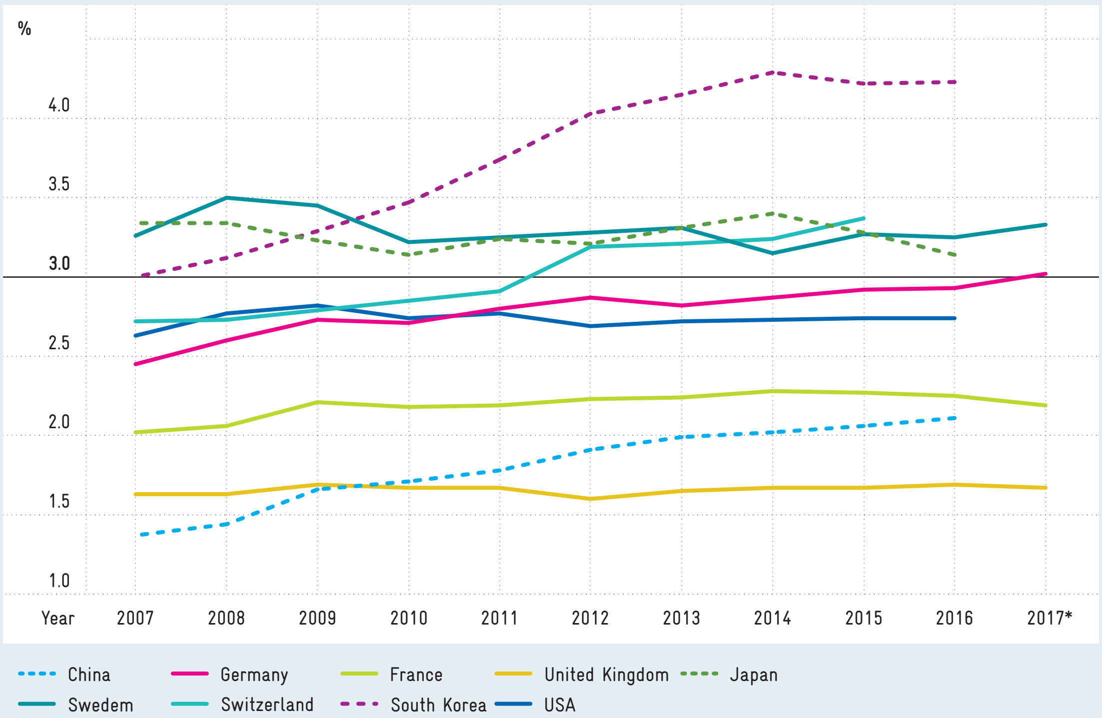
No recent data is available for the indicators 'internal corporate R&D expenditure by origin of funds' and 'internal corporate R&D expenditure as a percentage of turnover from the company's own products'. Table C 2-5 and figure C 2-6 have therefore been taken over from the 2018 report.

Fig. C 2-1

Download data

R&D intensity in selected OECD countries and China 2007–2017 as percentages

R&D intensity: percentage of an economy's gross domestic product (GDP) spent on research and development.



* Data for 2017 is provisional.
Source: OECD, EUROSTAT. Calculations and estimates by CWS in Schasse (2019).

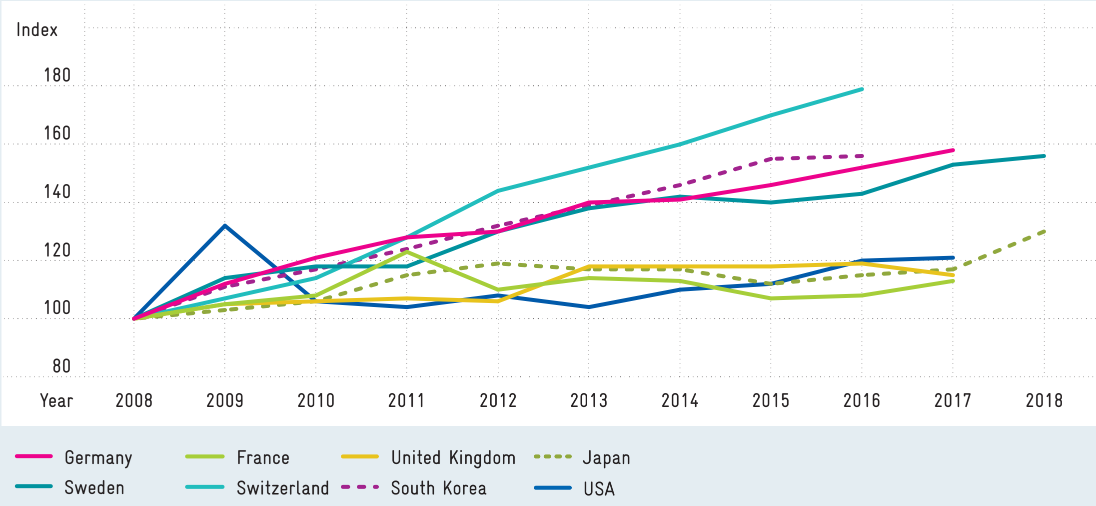
C

Fig. C 2-2

Download data

State budget estimates for civil R&D

R&D budget estimates: the chart shows the amounts set aside in the budget to finance R&D.



Index: 2008 = 100, data partially based on estimates.
Source: OECD, EUROSTAT. Calculations and estimates by CWS in Schasse (2019).

Tab. C 2-3

Download data

Distribution of gross domestic expenditure on R&D (GERD) by performing sector in 2006 and 2016

Gross domestic expenditure on research and development (GERD) in the private sector, the tertiary education sector and the public sector.

	2006					2016				
		of which ... (in %) was performed by					of which ... (in %) was performed by			
Countries	GERD in USD m	Private sector	Tertiary education institutions	Public sector	Private non-profit	GERD in USD m	Private sector	Tertiary educa-tion	Public sector	Private non-profit
Germany	**69,318**	**70.0**	**16.1**	**13.9**	**-**	**118,159**	**68.2**	**18.0**	**13.8**	**-**
France	42,347	63.1	19.2	16.5	1.2	62,163	63.6	22.0	12.9	1.6
Japan	138,565	77.2	12.7	8.3	1.9	168,645	78.8	12.3	7.5	1.4
Sweden	11,900	74.7	20.6	4.5	0.2	15,796	69.6	26.8	3.4	0.2
Switzerland[1)]	8,436	73.7	22.9	1.1	2.3	17,788	71.0	26.7	0.9	1.5
South Korea	35,413	77.3	10.0	11.6	1.2	79,354	77.7	9.1	11.5	1.6
United Kingdom	33,299	61.7	26.1	10.0	2.2	47,245	67.0	24.6	6.3	2.1
USA	353,328	70.1	13.9	12.0	4.1	511,089	71.2	13.2	11.5	4.1
China	105,581	30.4	9.2	19.7	-	451,201	77.5	6.8	15.7	-

Data available as of 12/2018. [1)] 2004 instead of 2006, 2015 instead of 2016.
Germany and China: Private non-profit organizations included under "public sector".
Source: OECD, EUROSTAT. Calculations by CWS in Schasse (2019).

C

Tab. C 2-4

Download data

R&D intensity of Germany's Länder in 2006 and 2016 as percentages

R&D intensity: Lander expenditure on research and development as a percentage of their gross domestic product, broken down by sectors.

	2006				2016			
Länder	Total	Private sector	Public sector	Tertiary education institutions	Total	Private sector	Public sector	Tertiary education institutions
Baden-Württemberg	4.04	3.27	0.38	0.39	4.92	4.01	0.40	0.52
Bavaria	2.95	2.37	0.25	0.33	3.17	2.42	0.31	0.44
Berlin	3.49	1.73	0.98	0.77	3.49	1.44	1.13	0.93
Brandenburg	1.22	0.29	0.66	0.26	1.73	0.61	0.76	0.36
Bremen	2.14	0.91	0.68	0.55	2.85	1.02	1.04	0.78
Hamburg	1.81	1.12	0,35	0.35	2.22	1.25	0.44	0.54
Hesse	2.55	2.06	0.16	0.33	2.88	2.16	0.27	0.45
Lower Saxony	2.21	1.49	0.32	0.40	3.31	2.43	0.36	0.53
Mecklenburg-Western Pomerania	1.45	0.33	0.58	0.55	1.85	0.60	0.64	0.60
North Rhine-Westphalia	1.74	1.09	0.26	0.39	1.98	1.13	0.30	0.54
Rhineland-Palatinate	1.69	1.21	0.16	0.33	2.44	1.80	0.17	0.46
Saarland	0.98	0.32	0.28	0.38	1.56	0.67	0.34	0.54
Saxony	2.29	1.10	0.64	0.55	2.71	1.17	0.77	0.76
Saxony-Anhalt	1.21	0.36	0.44	0.41	1.46	0.37	0.49	0.59
Schleswig-Holstein	1.18	0.54	0.31	0.33	1.49	0.77	0.33	0.39
Thuringia	1.88	1.01	0.39	0.48	2.05	0.98	0.47	0.60
Germany	**2.45**	**1.72**	**0.34**	**0.39**	**2.93**	**2.00**	**0.40**	**0.53**

Source: SV Wissenschaftsstatistik and Statistical Offices of the Federal Government and the Länder in Schasse (2019).

C

Tab. C 2-5

Download data

Internal corporate R&D expenditure by origin of funds, economic sector, company size and technology category in 2015

Internal R&D: research and development that is conducted inside the company, either for the company's own purposes or comissioned by a third party.

	Internal R&D expenditure				
	Total	of which funded by			
		private sector	public sector	other domestic entities	foreign entities
	in €'000	in percent			
All researching companies (without joint research)	60,657.135	90.1	3.1	0.1	6.7
Manufacturing	51,912.569	90.8	2.0	0.1	7.1
Chemical industry	3,786.071	90.1	1.4	0.0	8.4
Pharmaceutical industry	3,956.079	76.4	0.5	0.0	23.1
Plastics, glass and ceramics	1,398.754	92.6	2.7	0.3	4.4
Metal production and processing	1,354.999	80.5	9.3	0.2	9.9
Electrical engineering/electronics	9,790.457	91.1	2.7	0.0	6.2
Mechanical engineering	5,459.450	95.1	2.1	0.1	2.7
Vehical construction	23,473.463	92.4	1.3	0.2	6.0
Other manufacturing industries	2,693.298	93.0	4.3	0.1	2.6
Remaining sectors	8,744.565	86.1	9.5	0.1	4.2
fewer than 100 employees	2,539.754	75.4	17.4	0.2	6.9
100-499 employees	5,247.883	84.6	7.9	0.2	7.2
500-999 employees	3,660.396	87.6	6.2	0.1	6.1
1,000 employees and more	49,209.102	91.6	1.6	0.1	6.6
Technology categories in industry					
Cutting-edge technology (> 9 percent of costs/turnover spent on R&D)	13,463.726	84.9	3.4	0.0	11.7
High-value technology (3-9 percent of costs/turnover spent on R&D)	32,511.084	93.3	1.1	0.2	5.5

Source: SV Wissenschaftsstatistik in Schasse et al. (2018).

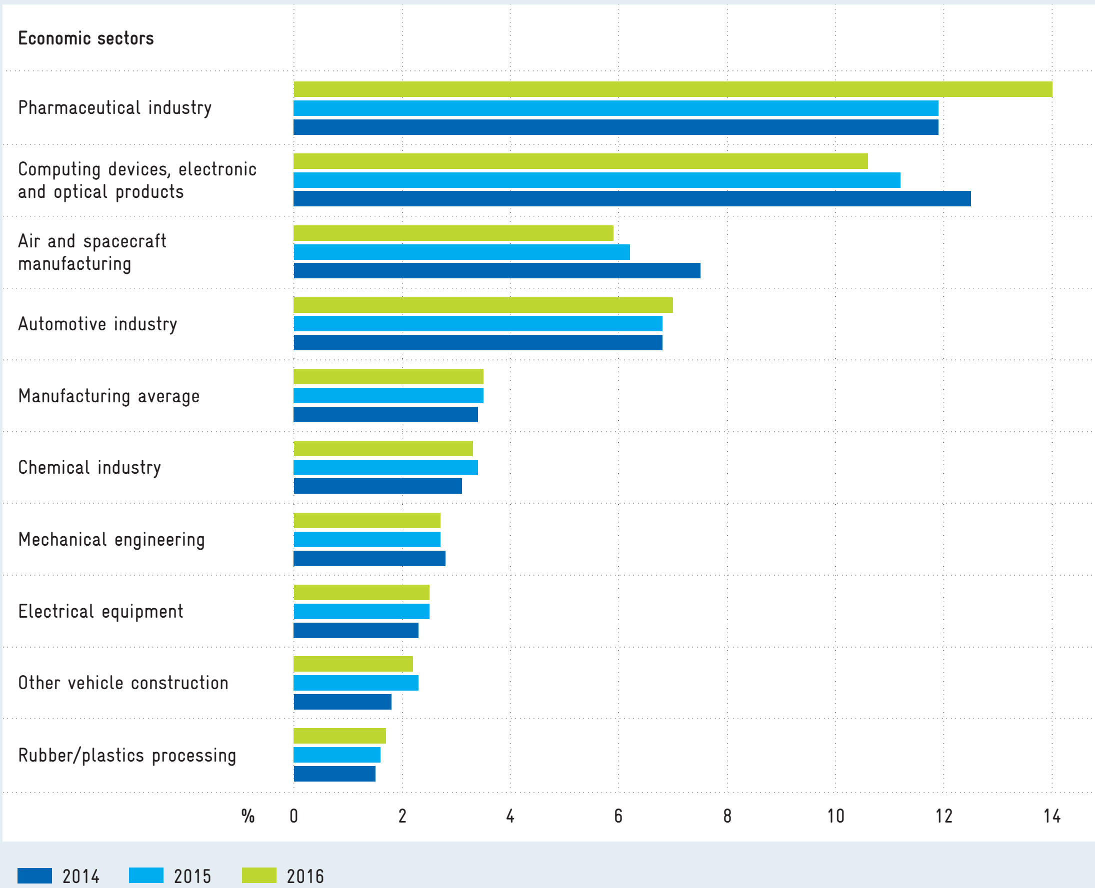
C

Fig. C 2-6

Download data

Internal corporate R&D expenditure as a percentage of turnover from the company's own products 2014, 2015 and 2016

Internal R&D: research and development that is conducted inside the company, either for the company's own purposes or comissined by a third party.



Figures net, without input tax.
Source: SV Wissenschaftsstatistik, Statistisches Bundesamt (Federal Statistical Office), corporate results for Germany.
Calculactions by CWS in Schasse et al. (2018).

C 3 Innovation behaviour in the private sector

The Europe-wide Community Innovation Surveys (CISs) are conducted every two years and provide the underlying data for the international comparison of the private sector's innovation behaviour (C 3-1).[523] Coordinated by Eurostat and based on a harmonized methodology, the CISs are conducted in all EU member states and a number of other European countries. The CISs are based on a largely uniform questionnaire and directed at businesses with ten or more employees in the manufacturing industry and selected services sectors. The current analysis relates to 2016 (CIS 2016). In that year, the innovation intensity of the research-intensive industries in Germany amounted to 7.4 percent. It was therefore higher than the levels in most reference countries. However, Sweden and Denmark recorded considerably higher innovation intensity at 8.2 and 7.8 percent in their respective research-intensive industries.

The data on innovation behaviour in the German private sector, as shown in charts C 3-2 and C 3-3, is based on the Mannheim Innovation Panel (MIP),[524] an annual innovation survey that has been conducted by the Centre for European Economic Research (ZEW) since 1993. Data from the MIP constitutes the German contribution to the CISs. In addition to the data to be reported to Eurostat, the MIP also includes data on businesses with five to nine employees.

In recent years, only minor fluctuations in innovation intensity (C 3-2) have been recorded in all observed sectors of the industry and business-oriented services. The highest rates in the entire study period were in R&D-intensive industry and knowledge-intensive services (excluding financial services). These sectors recorded innovation intensity of 8.7 and 5.3 percent respectively in 2017. At 0.8 and 0.7 percent respectively, the innovation intensities in financial services and other services were significantly lower.

In 2017, the percentage of turnover generated by new products (C 3-3) rose significantly in the fields of knowledge-intensive services (from 11 to 15.4 percent) and other industry (from 6.7 to 8.3 percent) compared to the previous year. Over the same period, R&D-intensive industry recorded a slight increase in this regard (from 34.2 to 34.5 percent), while other services recorded a slight decline (from 6.4 to 6.2 percent).

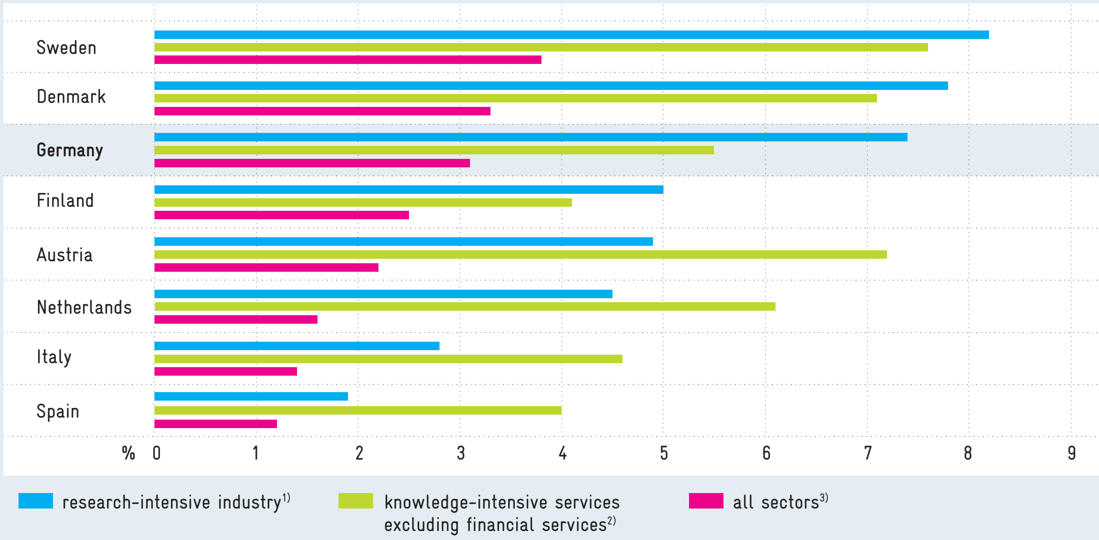
Standardization is an important factor in the commercialization of innovative technologies. At the international level, standards are developed by the committees of the International Organization for Standardization (ISO). By participating in these committees, a country can make a significant impact on global technical infrastructures (C 3-4).[525] In 2018, German companies were involved in the work of the ISO considerably more frequently than representatives of other countries.526 From 2008 to 2018, China, Japan and South Korea significantly increased the number of ISO secretariats run by their representatives

Fig. C 3-1

Download data

Innovation intensity by European comparison in 2016 as percentages

Innovation intensity: innovation expenditure by companies as a percentage of their total turnover.



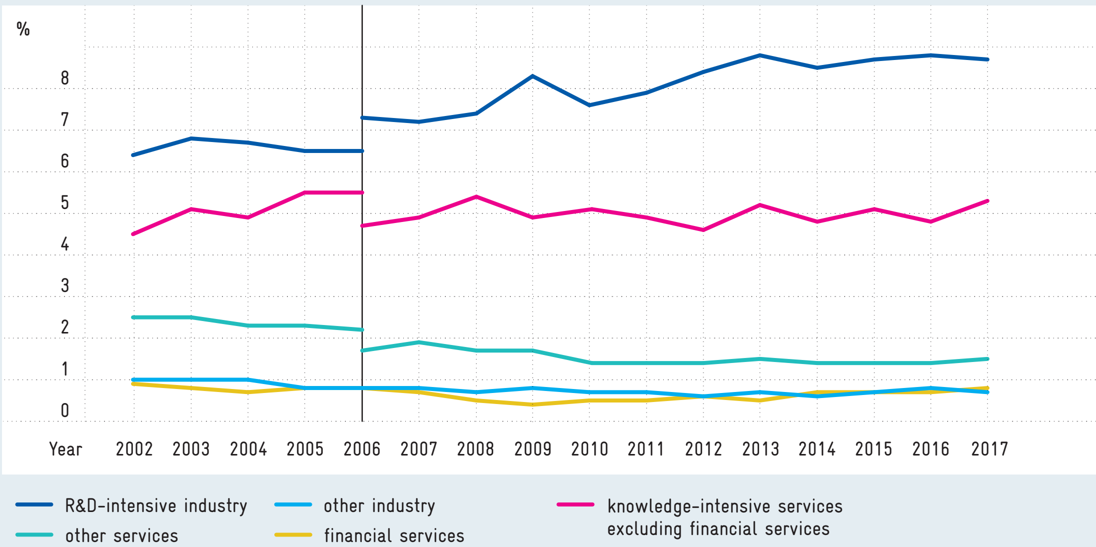
1) Research-intensive industry: divisions 19–22, 25–30 of WZ classification. Since data is not available for all sectors in all countries, the definition of research-intensive industries used in the European comparison differs from the definition normally used by the EFI.
2) Knowledge-intensive services: divisions 58–66, 71–73 of WZ classification. Since data is not available for all sectors in all countries, vthe 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 WZ classification.
Source: Eurostat, Community Innovation Surveys 2016. Calculations by ZEW (Centre for European Economic Research).

Fig. C 3-2

Download data

Innovation intensity in industry and business-oriented services in Germany as percentages

Innovation intensity: innovation expenditure by businesses as a percentage of their total turnover.

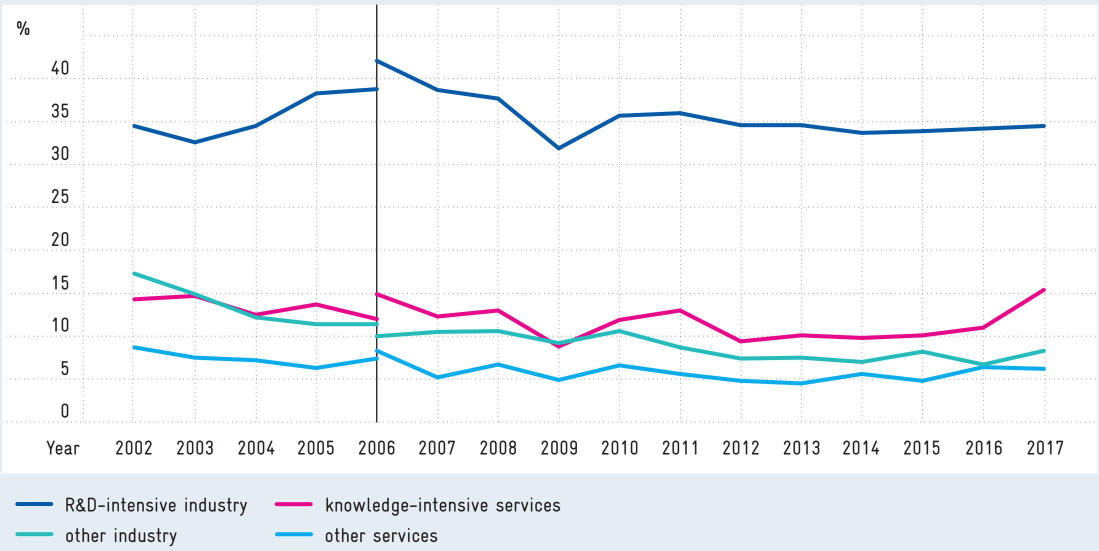


2006: break in time series. Figures for 2017 are provisional.
Source: Mannheim Innovation Panel. Calculations by ZEW (Centre for European Economic Research).

Fig. C 3-3

Download data

Percentage of turnover generated by new products in industry and business-oriented services

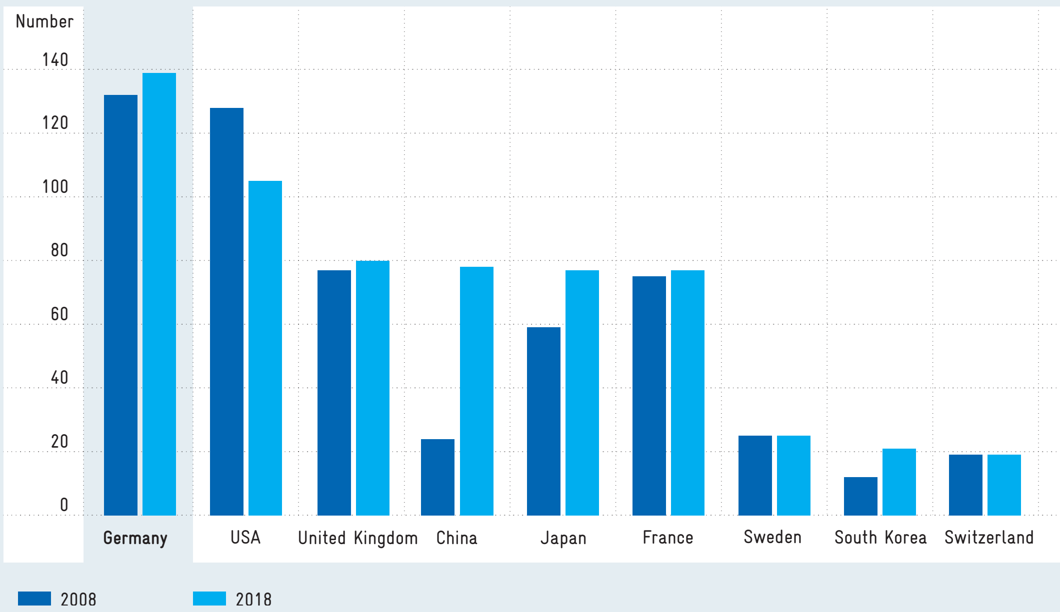


2006: break in time series. Figures for 2017 are provisional.
Source: Mannheim Innovation Panel. Calculations by ZEW (Centre for European Economic Research).

Fig. C 3-4

Download data

Number of secretariats listed by the technical committees and subcommittees of the International Organization for Standardization (ISO)



Source: own diagram based on ISO (2009: 23) and http://www.iso.org/members.html (last accessed on 17 December 2018).

Financing research and innovation[527] C 4

Public financing of research and development (R&D) in the private sector can take place via either direct R&D funding (project funding) or indirect R&D funding (in particular tax-based R&D funding). Figure C 4-1 shows direct and indirect R&D funding as a percentage of gross domestic product (GDP) in selected countries. The instrument of tax incentives for R&D activities is available to businesses in most of the countries listed; however, up to now Germany has not made use of this funding option.

Financing constitutes a major challenge for many innovative companies – not only in the start-up phase, but also during the growth phase.[528] Young, innovative enterprises can often only establish themselves successfully on the market if private investors provide venture capital during the start-up and growth phases.

Figure C 4-2 provides an overview of venture-capital investment as a percentage of national GDP in selected European countries. The data used for the comparison comes from Invest Europe, formerly the European Private Equity and Venture Capital Association (EVCA); they offer good international comparability due to the harmonized collection and processing system used.[529] Germany ranks about mid-table here in the European comparison. The highest levels of venture-capital investment in 2017 relative to GDP were recorded in the United Kingdom and Sweden. In Germany, venture-capital investment as a percentage of GDP only rose very slightly in 2017 compared to the previous year.

Since the Invest Europe data only include venture-capital investment companies that are organized in the association, there is a risk that volumes could be underestimated.[530] Therefore, the analysis of venture-capital investment in Germany draws on data from transactional databases in addition to the Invest Europe data.[531] The advantage of this data is that the individual transaction is the observation unit; this increases the likelihood that co-investments by atypical market participants[532] and non-European investors are also included.

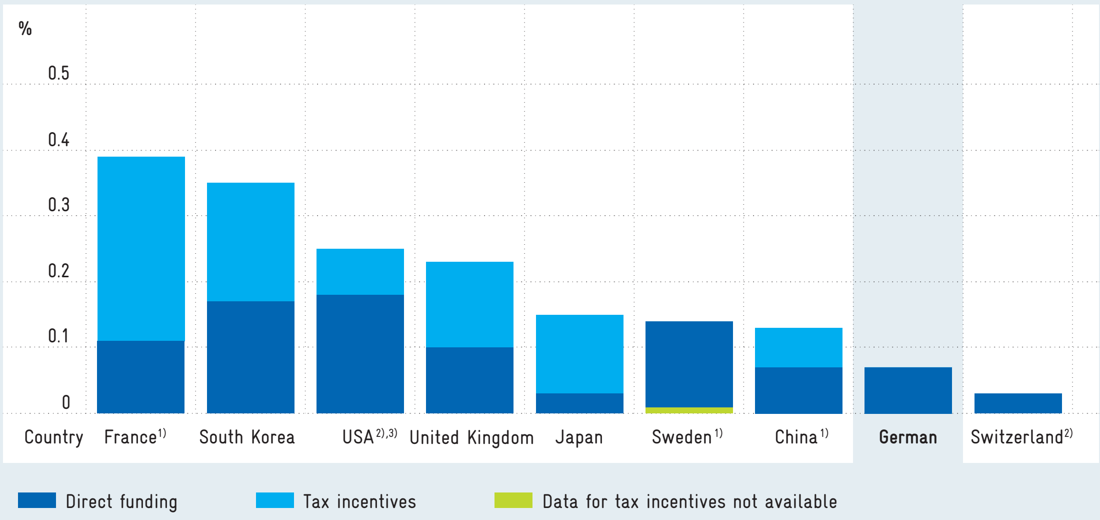
Figure C 4-3 provides an overview of the development of venture-capital investment in Germany. Analysis of the Invest Europe data reveals a slight increase in venture-capital investment in 2017 compared to the previous year. When the transaction data are included in the observation of venture-capital investment, a significant increase can be observed in the period 2008–2017. Using this data leads to a significant change in the structure of venture-capital investment. However, such a change would probably also be found for other countries. The extended data base does not, therefore, allow conclusions to be drawn on whether Germany's weak position by international comparison as regards the availability of venture capital might have improved relative to other countries in the meantime.

Fig. C 4-1

Download data

R&D spending in business sector directly and indirectly funded by the public sector in 2015 as a percentage of national GDP

The public funding of private-sector R&D is divided into direct R&D funding (project funding) and indirect R&D funding (through tax incentives).



[1] 2014. [2] 2013. [3] Data revised.
Source: OECD (2018b).

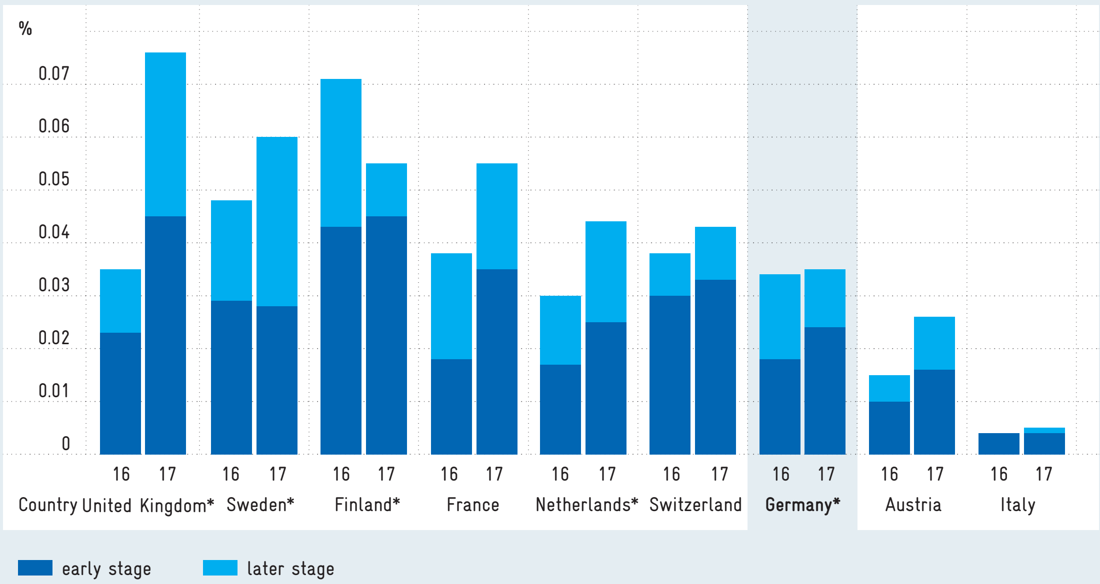
C

Fig. C 4-2

Download data

Venture-capital investment as a percentage of national GDP in 2016 and 2017

Venture capital is defined here as temporary equity investments in young, innovative, non-listed companies.



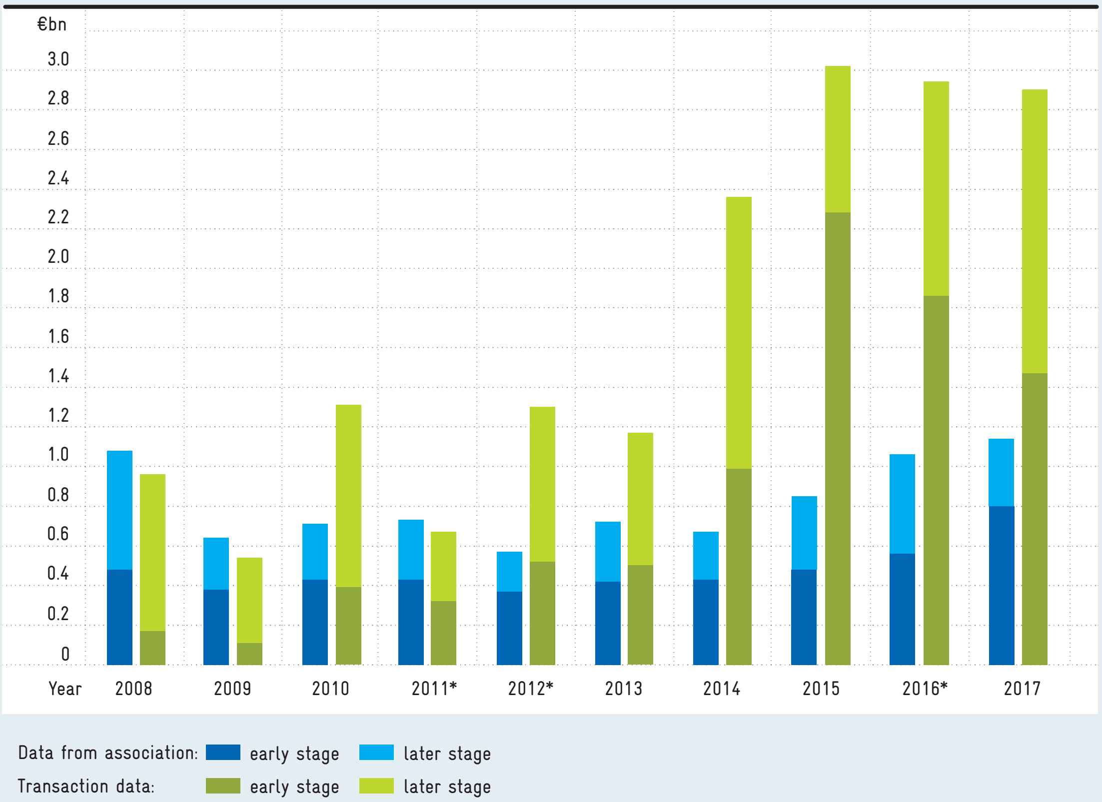
* Data for 2016 partially revised.
Investments are broken down according to the portfolio companies' head offices. Early stage comprises the seed phase and the start-up phase.
Source: Invest Europe and Eurostat. Calculations by ZEW in Bersch and Gottschalk (2019).

Fig. C 4-3

Download data

Development of venture-capital investment in Germany 2008–2017 in €bn

Venture capital is defined here as temporary equity investments in young, innovative, non-listed companies.



* Data from association partially revised.
All transaction data 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 and Gottschalk (2019).
Source of transaction data: Bureau van Dijk, Majunke. Calculations by ZEW in Bersch and Gottschalk (2019).

C

C 5 New businesses

An international comparison of rates of new businesses – i.e. the number of new businesses as a percentage of the total number of businesses – is only possible at the European level.[533] The Business Demography Statistics provided by Eurostat are used for this purpose (cf. C 5-1). They constitute part of the European Union's Structural Business Statistics (SBS), an official database that is based on evaluations of business registers in the individual Member States. The figures for Germany are provided by the Federal Statistical Office's business demography statistics, which are derived from the German business register.[534] In 2016, the rate of new businesses in Germany was 6.7 percent, well below the figures for the UK (15 percent), France (9.7 percent) and the Netherlands (9.6 percent).[535] Germany also failed to reach a top position in the field of knowledge-intensive services, where its start-up rate was 7.9 percent. Germany's rate of new businesses of 3.4 percent in the R&D-intensive industries was the lowest of the countries examined here.

The figures on company dynamics in the knowledge-based economy shown in charts C 5-2 to C 5-4 are taken from an evaluation of the Mannheim Enterprise Panel (MUP) conducted by the Centre for European Economic Research (ZEW). The MUP is a ZEW panel dataset on businesses located in Germany and is compiled in cooperation with Creditreform, the largest credit information bureau in Germany. The definition of 'business' used for the MUP is restricted exclusively to economically active businesses; 'new businesses' are defined as original, newly formed businesses.[536] The rate of new businesses shown in figure C 5-2 is calculated on the basis of different data from that used in the Business Demography Statistics, which means that a direct comparison cannot be drawn here.[537] According to the data provided by the MUP, the rate of new businesses in the knowledge-based economy in 2017 was unchanged from the previous year at 4.5 percent (C 5-2).[538] The rate is therefore markedly lower than during the financial and economic crisis (2008: 6.2 percent; 2009: 6.8 percent).

The closure rate in the knowledge-based economy was lower than those of all other sectors during the entire study period. In 2017, the sector's closure rate was recorded at 3.5 percent, a decline of approximately 0.4 percentage points compared to 2016 (C 5-3).[539] In all the sectors of the knowledge-based economy examined, the current rate was the lowest ever recorded in the study period.

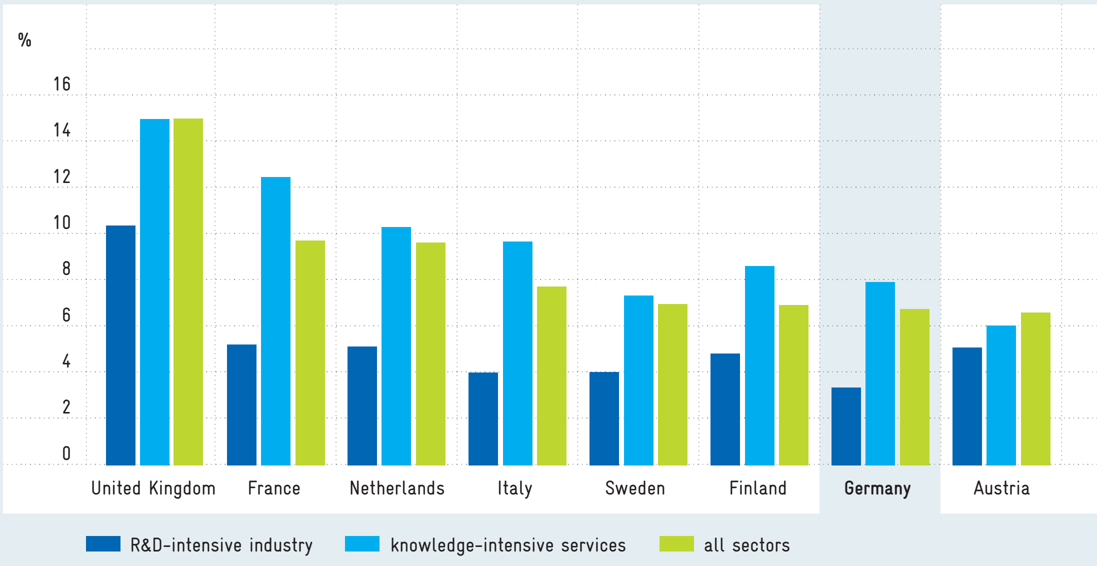
Comparison of the Länder for the period 2015 to 2017 reveals significant differences in rates of new businesses within Germany (C 5-4).[540] Berlin had the highest rates of new businesses of all Länder: across all industries (7.3 percent), in R&D-intensive industries (5.3 percent) and in knowledge-intensive services (7.0 percent). The lowest rates were seen across all industries in the east German Länder. The figure was 3.3 percent in Thuringia, 3.7 percent in Saxony, 3.8 percent in Mecklenburg-Western Pomerania, 4.0 percent in Saxony-Anhalt and 4.1 percent in Brandenburg.

Fig. C 5-1

Download data

Rates of new businesses in 2016 by international comparison as percentages

Rate of new businesses: number of new businesses as a percentage of the total number of businesses.



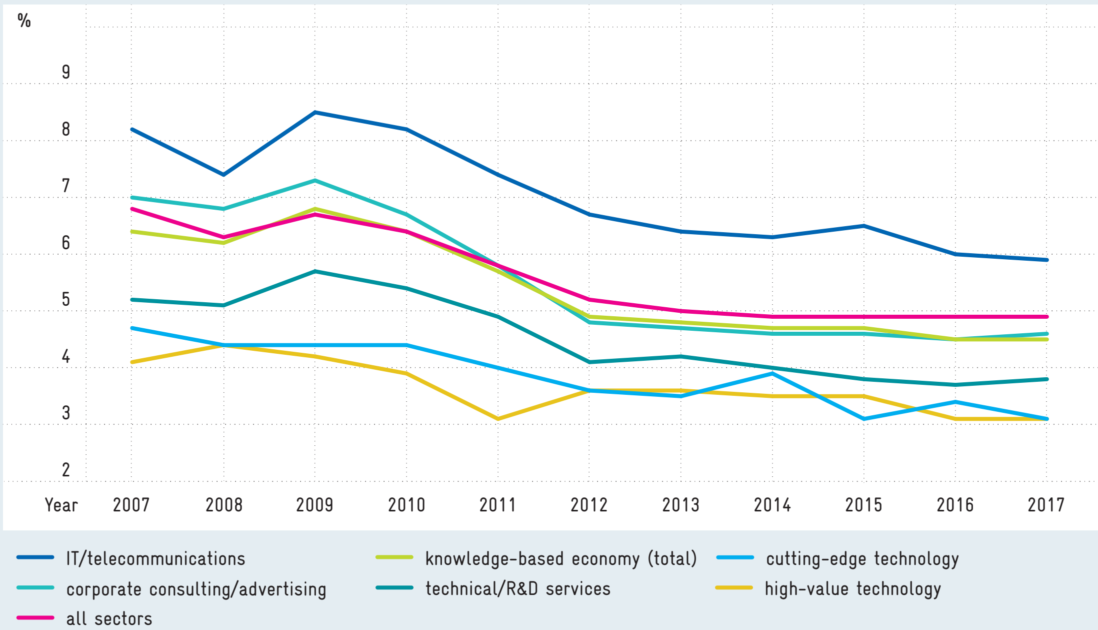
Source: Business Demography Statistics (Eurostat). Calculations by ZEW in Bersch and Gottschalk (2019).

Fig. C 5-2

Download data

Rates of new businesses in Germany's knowledge-based economy 2007–2017 as percentages

Rate of new businesses: number of new businesses as a percentage of the total number of businesses.



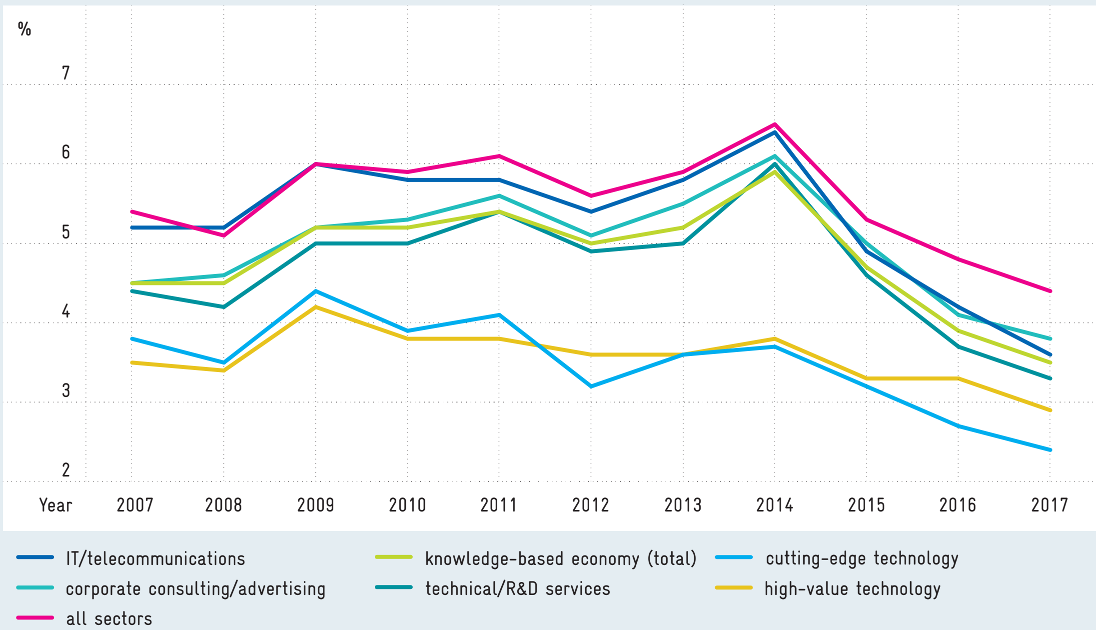
All figures are provisional.
Source: Mannheim Enterprise Panel (ZEW). Calculations by ZEW in Bersch and Gottschalk (2019).

Fig. C 5-3

Download data

Closure rates in Germany's knowledge-based economy 2007–2017 as percentages

Closure rate: number of businesses that close down during a year as a percentage of all businesses.



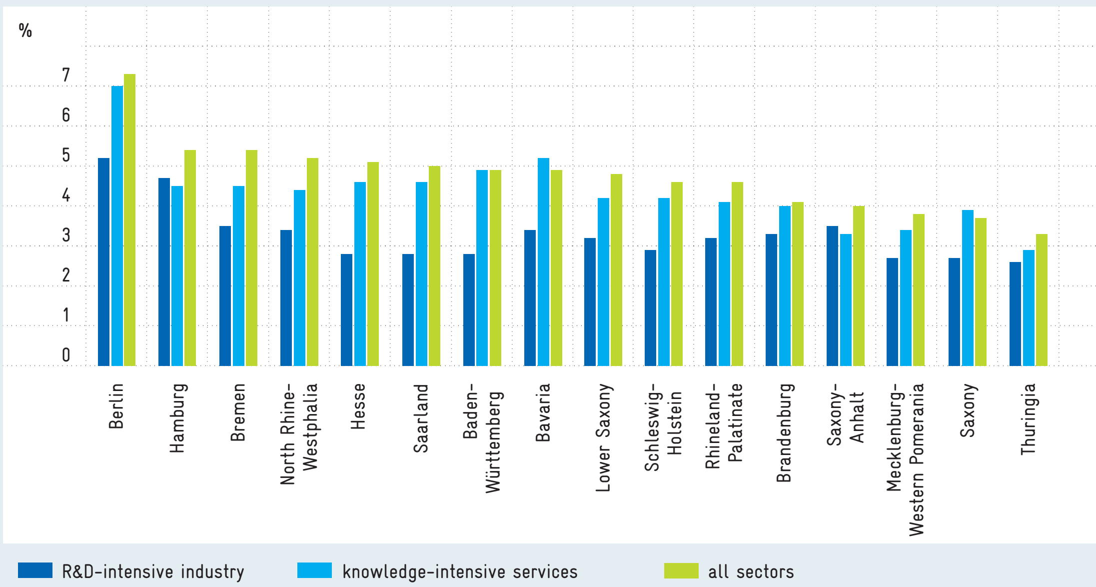
All figures are provisional.
Source: Mannheim Enterprise Panel (ZEW). Calculations by ZEW in Bersch and Gottschalk (2019).

Fig. C 5-4

Download data

Rates of new businesses by Länder 2015–2017 as percentages

Rate of new businesses: number of new businesses as a percentage of the total number of businesses.



All figures are provisional.
Source: Mannheim Enterprise Panel (ZEW). Calculations by ZEW in Bersch and Gottschalk (2019).

Patents[541] C 6

Since the mid-2000s, transnational patent applications have been stagnating both in Germany and in other major European economies such as the UK, Sweden and Switzerland (C 6-1). By contrast, China, South Korea and Japan in particular have recorded high growth rates. China has overtaken Germany and is now one of the leading nations in transnational patent applications together with Germany, the USA and Japan.

While the USA is in the lead in terms of the absolute number of applications in 2016, it is not among the frontrunners with regard to patent intensity (i.e. patent applications per million of the working population (C 6-2)). In this regard, the leaders are Switzerland, Sweden and Japan, followed by Finland, Germany and South Korea. Patents are an important tool for securing market shares in the context of the international technology trade. A high patent intensity therefore reflects both a strong international orientation and a pronounced export focus on the part of the respective economy.

Further conclusions on a country's technological performance can be drawn from patent activities in the field of R&D-intensive technologies. This sector is made up of industries 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 over 9 percent).

International comparisons show that Germany is highly specialized in high-value technology (C 6-3) as a result of its traditional strengths in the automotive, mechanical-engineering and chemical industries. Together with Japan, Germany records the highest figure in this regard among the comparison countries.

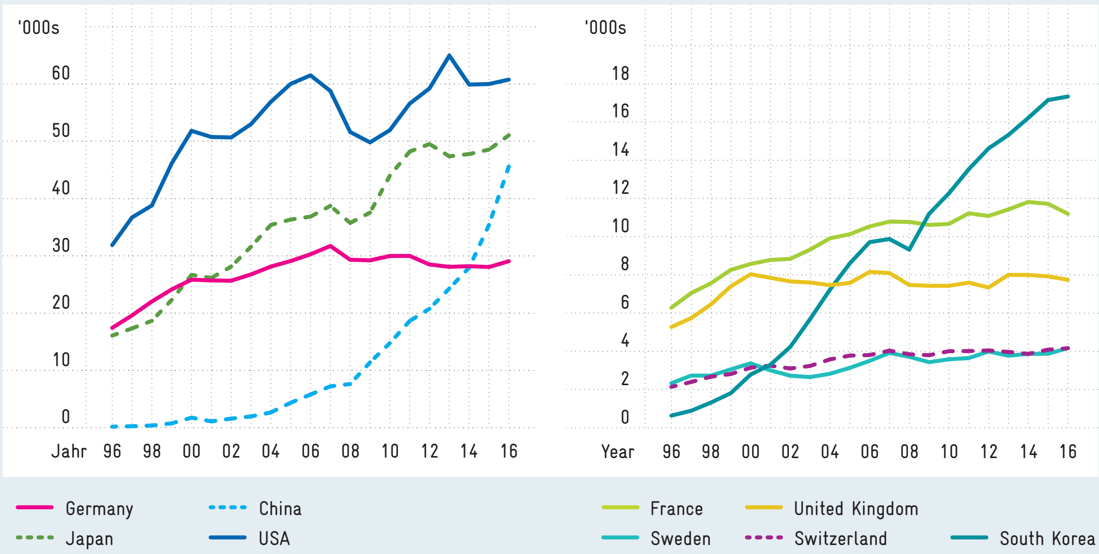
By contrast, China, Sweden, South Korea and the USA are particularly specialized in cutting-edge technology (C 6-4).

Fig. C 6-1

Download data

Development of the number of transnational patent applications in selected countries over time

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. (2019).

Tab. C 6-2

Download data

Absolute number, intensity and growth rates of transnational patent applications in the field of R&D-intensive technology in 2016[1)]

The R&D-intensive technology sector comprises industries that invest more than three percent of their turnover in research and development. Intensity is calculated as the number of patents per million gainfully employed persons.

	absolute[1)]	intensities[1)]	intensities in R&D-intensive technology	growth (2006 = 100)[1)]	growth in R&D-intensive technology (2006 = 100)
Total	**275,011**	**-**	**-**	**132**	**132**
China	45,589	60	42	787	771
Germany	**29,055**	**704**	**405**	**96**	**97**
EU-28	76,374	341	193	102	102
Finland	1,876	766	423	96	79
France	11,196	421	245	106	105
United Kingdom	7,739	245	143	95	94
Italy	5,758	253	121	92	89
Japan	51,030	789	480	138	129
Canada	3,471	192	117	88	79
Netherlands	4,464	530	284	102	98
Sweden	4,165	848	570	119	126
Switzerland	4,158	903	478	109	107
South Korea	17,337	656	422	178	167
USA	60,742	401	265	99	99

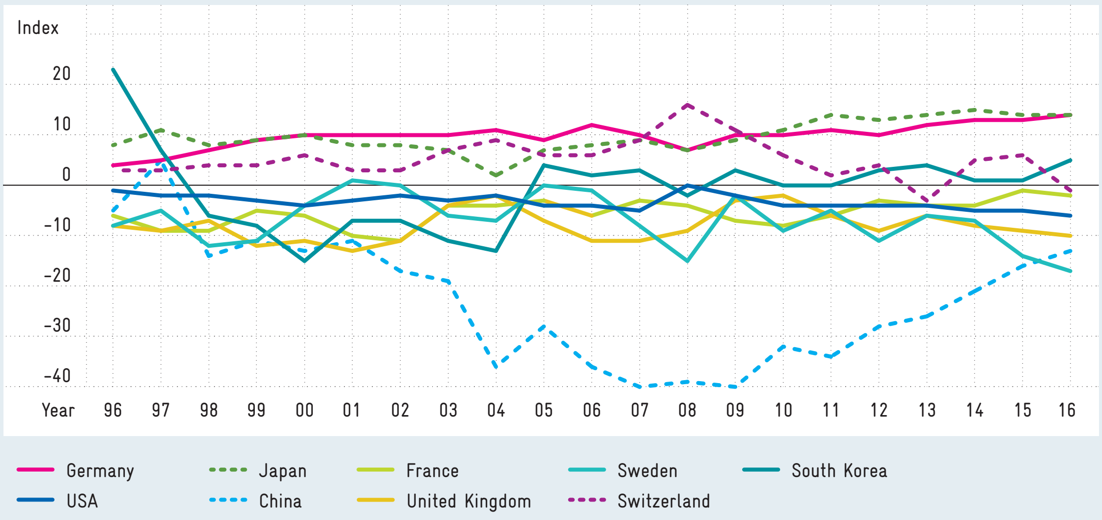
1) Figures refer to all industries.
Source: EPO (PATSTAT), OECD (MSTI), World Bank, calculations by Fraunhofer ISI in Neuhäusler et al. (2019).

Fig. C 6-3

Download data

Development of the specialization index in selected countries over time in the field of high-value technology

The specialization index is calculated on the basis of all transnational patent applications worldwide. Positive or negative values indicate whether the surveyed country's level of activity in a given field is disproportionately high or disproportionately low compared to the global average.



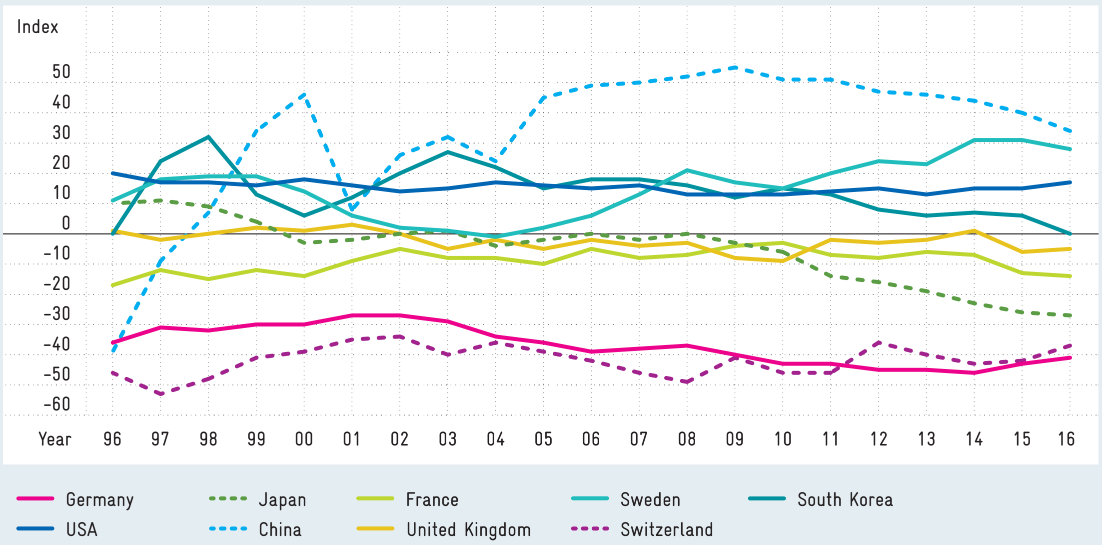
Source: EPO (PATSTAT). Calculations by Fraunhofer ISI in Neuhäusler et al. (2019).

Fig. C 6-4

Download data

Development of the specialization index in selected countries over time in the field of cutting-edge technology

The specialization index is calculated on the basis of all transnational patent applications worldwide. Positive or negative values indicate whether the surveyed country's level of activity in a given field is disproportionately high or disproportionately low compared to the global average.



Source: EPO (PATSTAT). Calculations by Fraunhofer ISI in Neuhäusler et al. (2019).

C

C 7 Scientific publications[542]

A large proportion of new technologies and services are based on developments and results from science. Bibliometric indicators and metrics are regularly used as yardsticks for evaluating scientific achievements to estimate the performance of a research and science system in both quantitative and qualitative terms.

The bibliometric database Web of Science (WoS) covers worldwide publications in scientific journals, as well as citations from these publications. The research affiliation of scientists referenced in the database makes it possible to assign individual publications to a specific country. Fractional counting is employed in cases where several co-authors from different countries contribute to a publication. Indicators on the quantity and quality of scientific publications can be used to assess the performance of a research and science system.

Significant changes can be identified in individual countries' and regions' shares of all publications in Web of Science (C 7-1) when comparing the years 2007 and 2017. Most countries' publication shares have declined, including the major western European nations of Germany, France and the United Kingdom as well as the USA. Germany's share of publications fell from 5.6 to 4.4 percent, the UK's fell from 6.1 to 4.6 percent, France's fell from 4.0 to 2.8 percent and the USA's tumbled from 25.7 to 19.4 percent. In contrast, China achieved enormous growth in its share, which rose from 8.1 to 18.4 percent. Only a handful of European countries have been able to increase their share of publications. Denmark, for instance, increased its share from 0.6 to 0.7 percent from 2007 to 2017, while the Polish share rose from 1.2 to 1.3 percent over the same period.

The international alignment (IA) of selected countries and regions in relation to Web of Science publications (C 7-2) is an indicator of the quality of scientific publications. In this regard, it is clear that the quality of German authors' publications increased between 2007 and 2015. According to this indicator, publications from Switzerland, the USA and the Netherlands are of the highest quality. China has significantly improved the quality of its publications, though this figure remains below average.

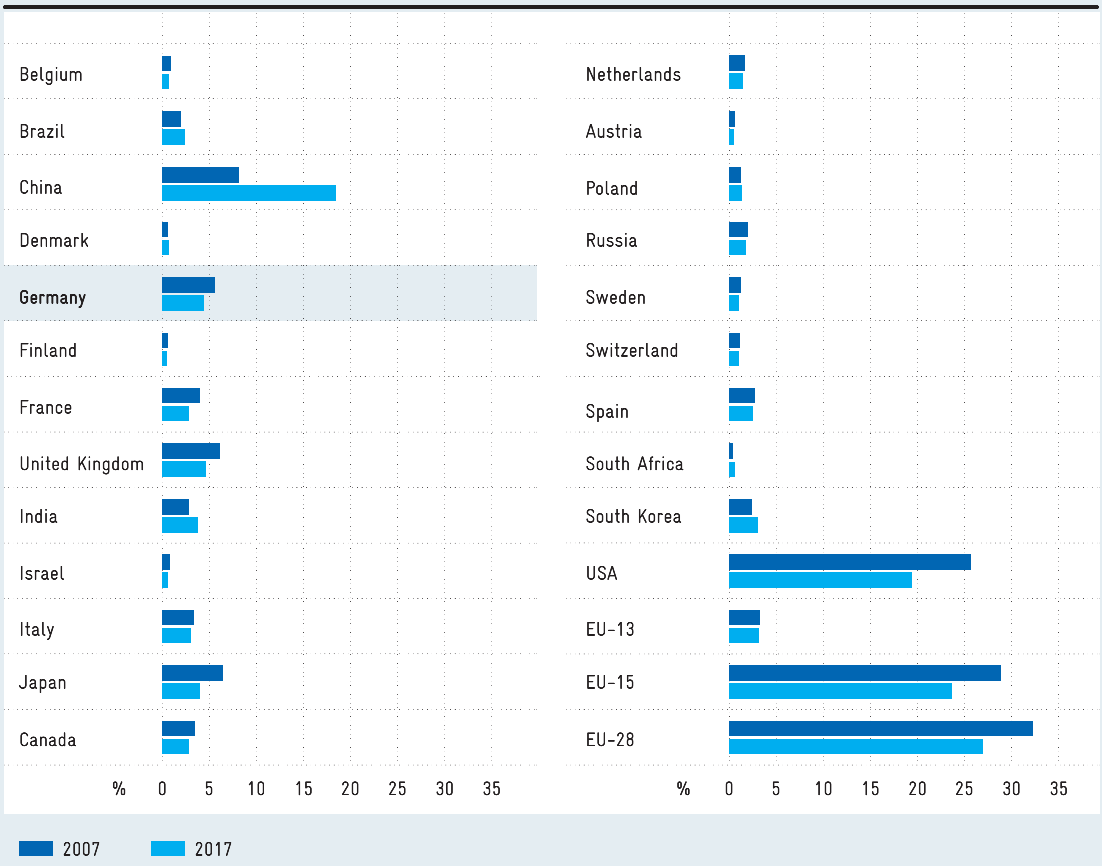
The scientific regard (SR) of specific countries and regions for publications in Web of Science (C 7-3) shows that the index value for articles authored in Germany has fallen from 9 to 4. Nevertheless, articles authored in Germany were cited more often in 2015 than other articles in the same journals. This prominence has, however, reduced in comparison to 2007.

Fig. C 7-1

Download data

Percentages of all publications in the Web of Science from selected countries and regions in 2007 and 2017

The analysis concentrates on countries' shares, rather than on absolute figures, to compensate for changes, especially the ongoing expansion of data collection.



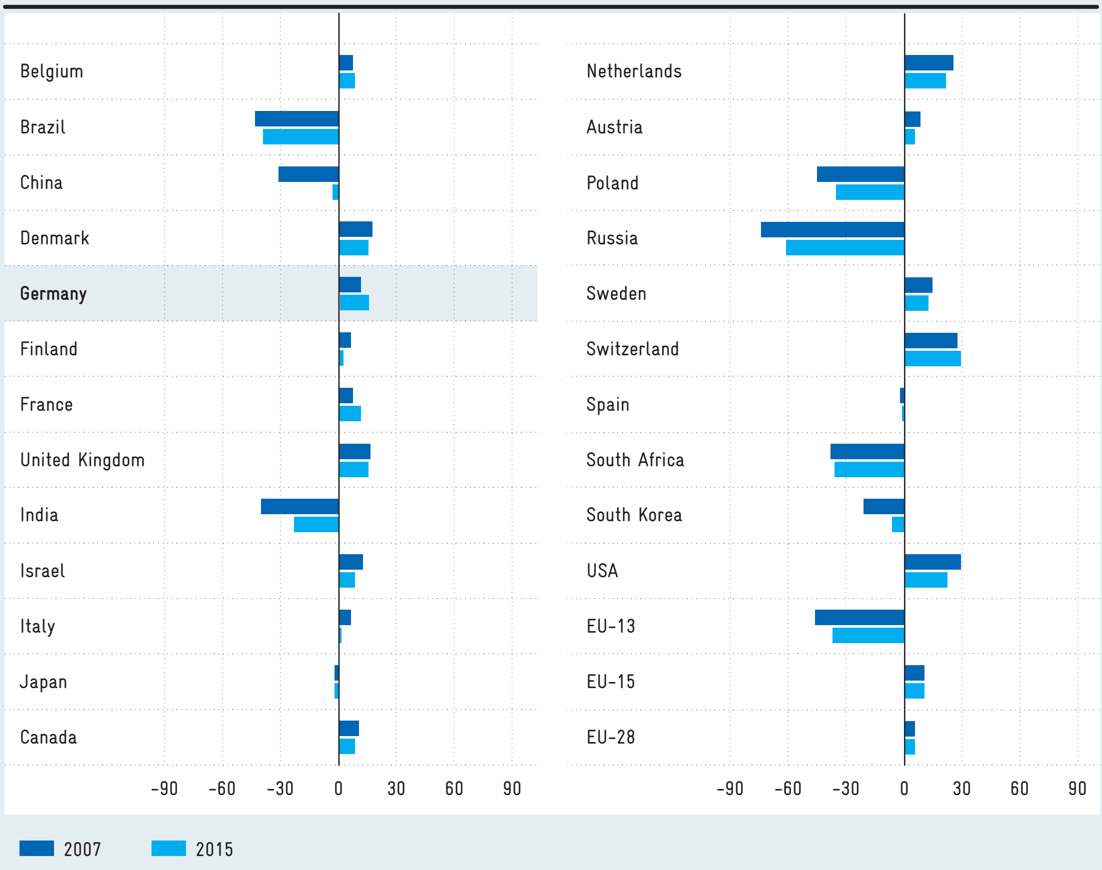
Fractional counting.
Source: Web of Science. Research an calculations by the DZHW in Stahlschmidt et al. (2019).

Fig. C 7-2

Download data

International alignment (IA) of publications in the Web of Science from selected countries and regions in 2007 and 2015 (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 an calculations by the DZHW in Stahlschmidt et al. (2019).

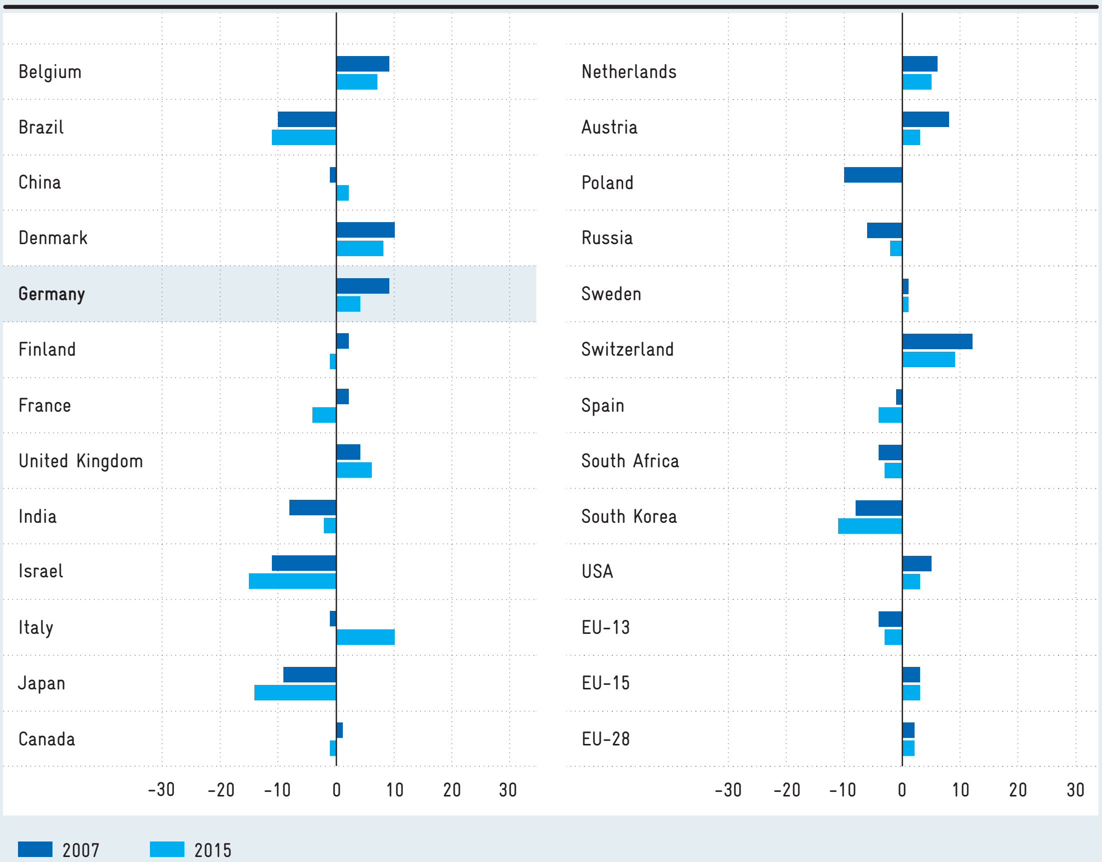
C

Fig. C 7-3

Download data

Scientific regard (SR) of publications in the Web of Science from selected countries and regions in 2007 and 2015 (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 appear. Positive or negative values indicate an above-average or below-average scientific regard. The index is calculated without self-citations.



Fractional counting.
Source: Web of Science. Research and calculations by the DZHW in Stahlschmidt et al. (2019).

C 8 Production, value added and employment[543]

A country’s specialization pattern in foreign trade can be measured using the RCA indicator.[544] It shows a product group's export/import ratio relative to the export/import ratio of processed industrial goods overall. In 2017, as in previous years, Germany again showed a comparative advantage in trade in R&D-intensive goods (C 8-1). R&D-intensive goods are made up of high-value technology goods and cutting-edge technology goods. A more precise analysis of these two groups of goods shows that Germany had a positive comparative advantage only in trade in high-value technology goods; in trade in cutting-edge technology goods, however, it had a negative comparative advantage. France, the United Kingdom, Switzerland, South Korea and the USA recorded positive RCA indicator figures for cutting-edge technology; Japan and China, on the other hand, had a negative RCA indicator throughout the study period. Sweden has recorded negative RCA indicators since 2010.

The contribution of research-intensive and knowledge-intensive industries to a country’s value added allows conclusions to be drawn about the country’s technological performance in international comparison (C 8-2). Relative to the other countries studied, Germany’s share of value added was the highest in the field of high-value technology: in 2016, it accounted for 9.3 percent of total German value added. In the field of cutting-edge technology, Germany’s figure of 3.0 percent was much lower than the frontrunners Switzerland (8.5 percent) and South Korea (7.4 percent). In all the countries examined, knowledge-intensive services contributed much more to national value added than research-intensive industries. However, with a value-added share of 24.7 percent, they played a lesser role in Germany than in other European countries and the USA.

Following the decline in gross value added in several industrial sectors in the crisis year of 2009, value added in Germany has recovered and continuously risen since 2010 (C 8-3). At 2.8 percent, growth in knowledge-intensive services in 2016 was lower than in the previous year (2015: 3.8 percent). A slower increase in value added was also recorded in non-knowledge-intensive services (2.9 percent in 2016 compared to 5.0 percent in 2015). In manufacturing, on the other hand, the increase in value added in 2016 was higher than in 2015. In knowledge-intensive manufacturing, the figure for 2016 was 6.2 percent (2015: 4.0 percent), while the value added increase for non-knowledge-intensive manufacturing was 4.7 percent (2015: 4.0 percent).

The services sector was the main source of the increase in employment subject to social insurance contributions in different industrial sectors of the German economy between 2010 and 2017 (C 8-4). Employment rose by 17.3 percent in non-knowledge-intensive services during this period and by 19.7 percent in knowledge-intensive services. Employment subject to social insurance contributions rose by 7.3 percent in the non-knowledge-intensive manufacturing industry and by 10.7 percent in the knowledge-intensive manufacturing sector.

Tab. C 8-1

Download data

Revealed comparative advantage (RCA) of selected countries in foreign trade in research-intensive goods 2005–2017

Year	China[1]	France	Germany	Japan	Sweden	Switzerland	South Korea	United Kingdom	USA[2]
					R&D-intensive goods				
2005	-29	7	**10**	42	-1	18	17	14	17
2010	-27	6	**12**	33	-6	22	19	11	1
2015	-27	5	**13**	31	-5	28	13	3	2
2017	-30	3	**13**	30	-4	29	9	13	-1
					High-value technology goods				
2005	0	6	**27**	75	-2	24	11	4	-5
2010	-16	-2	**30**	61	-3	21	7	15	-10
2015	-3	-6	**27**	63	1	21	13	1	-14
2017	-3	-5	**25**	64	2	24	0	9	-17
					Cutting-edge technology goods				
2005	-53	8	**-34**	-14	1	4	24	33	55
2010	-35	20	**-35**	-22	-11	25	33	1	22
2015	-46	21	**-23**	-35	-22	41	12	8	27
2017	-50	16	**-21**	-40	-25	40	20	19	24

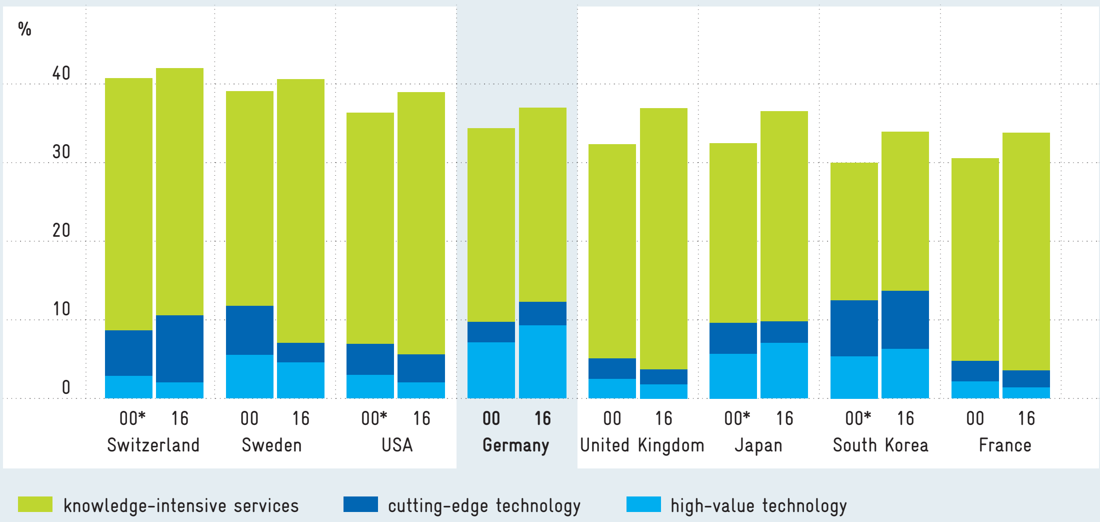
A positive RCA value means that the exp./imp. ratio for this product group is higher than for processed industrial goods as a whole.
[1] Incl. Hong Kong. [2] From 2009, data for the USA were revised on the basis of national sources.
Source: UN COMTRADE database, researched September 2018. Calculations and estimates by CWS in Gehrke and Schiersch (2019).

Fig. C 8-2

Download data

R&D-intensive industries and knowledge-intensive services as a percentage of value added in 2000 and 2016

R&D-intensive industries have an above-average R&D intensity, while knowledge-intensive services are characterized by an above-average proportion of employees with tertiary education qualifications.



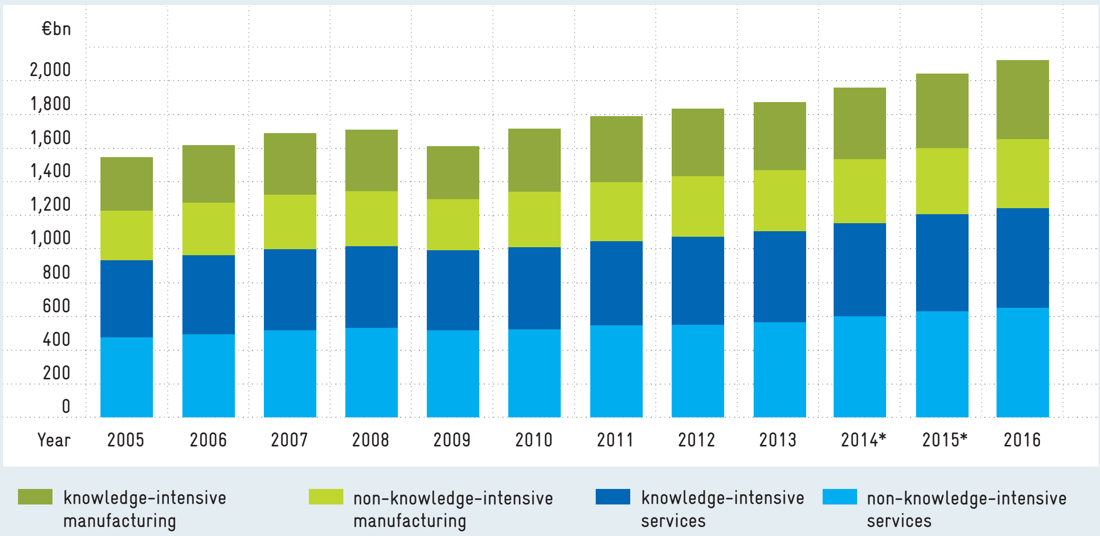
* Data partially revised.
Source: OECD STAN, Eurostat, Eurostat SDBS, EUKLEMS, OECD SBS, Statistics Canada, CBS Israel. Calculations and estimates by DIW Berlin in Gehrke and Schiersch (2019).

Fig. C 8-3

Download data

Development of gross value added in different industrial sectors of the economy in Germany 2005–2016 in €bn

Gross value added is the difference between the total value of all goods and services produced and the intermediate inputs received from other companies 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 partially revised.
Source: Statistisches Bundesamt (Federal Statistical Office), Fachserie 18, Reihe 1.4. Calculations by CWS in Gehrke and Schiersch (2019).

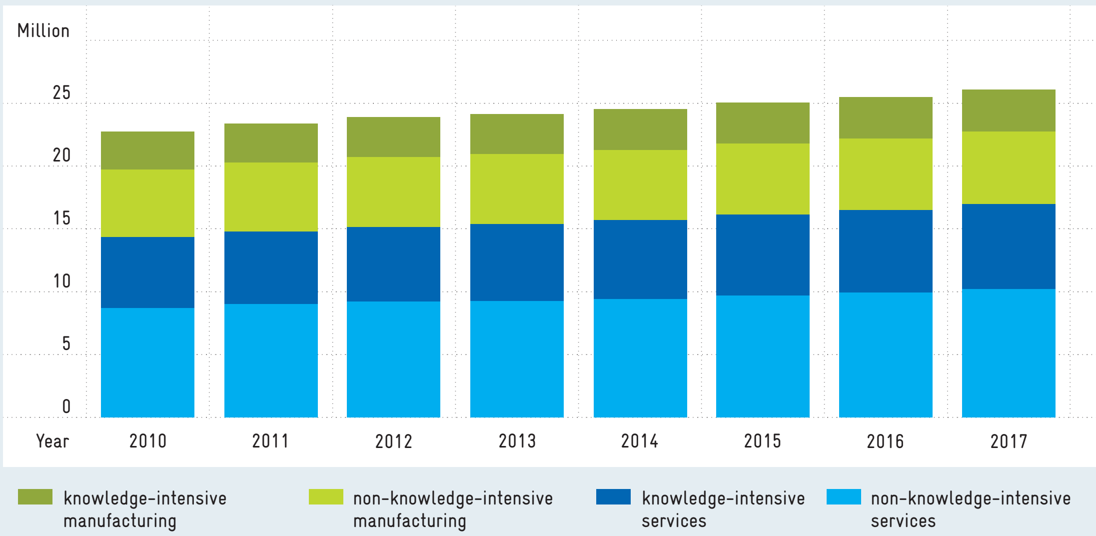
C

Fig. C 8-4

Download data

Development of the number of employees subject to social insurance contributions in different industrial sectors of the economy in Germany 2010–2017

Employees covered by social security insurance comprise all employees who are liable to contribute to health, pension and long-term care insurance, and/or to pay contributions according to German employment-promotion law, or for whom contribution shares must be paid to statutory pension insurance or according to German employment-promotion law.



Source: Federal Employment Agency. Calculations by CWS in Gehrke and Schiersch (2019).

LISTS

D

Contents

List of figures, tables and boxes

D 1

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List of abbreviations D 2

AHRC Arts & Humanities Research Council
AI Artificial intelligence
AnkER-Zentrum Zentrum für Ankunft, Entscheidung, Rückführung (Transit Centre for Arrival, Asylum Decision and Return)
API Application Programming Interface
ARegV Anreizregulierungsverordnung (Incentive Regulation Ordinance)
ARPA Advanced Research Projects Agency
AUF Außeruniversitäre Forschungseinrichtung (non-university research institution)
BaföG Bundesausbildungsförderungsgesetz (Federal Training Assistance Act)
BAMF Bundesamt für Migration und Flüchtlinge (Federal Office for Migration and Refugees)
BAND Business Angels Network Deutschland
BBSRC Biotechnology & Biological Sciences Research Council
BITKOM Bundesverband Informationswirtschaft, Telekommunikation und neue Medien (an association representing companies in Germany's digital economy)
BMAS Bundesministerium für Arbeit und Soziales (Federal Ministry of Labour and Social Affairs)
BMBF Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research)
BMI Bundesministerium des Innern, für Bau und Heimat (Federal Ministry of the Interior, Building and Community)
BMVg Bundesministerium der Verteidigung (Federal Ministry of Defence)
BMWi Bundesministerium für Wirtschaft und Energie (Federal Ministry for Economic Affairs and Energy)
BRICS Brazil, Russia, India, China, South Africa
BVK Bundesverband Deutscher Kapitalbeteiligungsgesellschaften (German Private Equity and Venture Capital Association)
BWA Betriebswirtschaftliche Auswertung (reporting method primarily for SMEs based on turnover and KPIs)
CHP Combined heat and power (also known as cogeneration or cogen)
CI Crown Indicator
CIS Community Innovation Surveys
CO_2 Carbon dioxide
dApp Decentralized Application
DARPA Defense Advanced Research Projects Agency
DAX Deutscher Aktienindex (German stock index)
DFG Deutsche Forschungsgemeinschaft (German Research Foundation)
DFN Deutsches Forschungsnetzwerk (German National Research and Education Network)
DHBW Duale Hochschule Baden-Württemberg (Baden-Württemberg Cooperative State University)
DLT Distributed Ledger Technology
DSM Deutscher Startup Monitor (German Start-up Monitor)
EAF European Angels Fund
EDC European Data Cooperative

EEG .... Erneuerbare-Energien-Gesetz (Renewable Energy Sources Act)
EFI .... Expertenkommission Forschung und Innovation (Commission of Experts for Research and Innovation)
EIB .... European Investment Bank
EIF .... European Investment Fund
EMBL .... European Molecular Biology Laboratory
EPFL .... Ecole Polytechnique Fédérale de Lausanne
EPSRC .... Engineering and Physical Sciences Research Council
ERP .... Enterprise Resource Planning
ERP-SV .... ERP-Sondervermögen (ERP Special Fund)
ESF .... European Social Fund
ESOP .... Employee Stock Ownership Plan
ESRC .... Economic and Social Research Council
ETH .... Eidgenössische Technische Hochschule (Swiss Federal Institute of Technology)
EU .... European Union
EU ETS .... European Union Emissions Trading System
Eurostat .... Statistical office of the European Commission
EVCA .... European Private Equity and Venture Capital Association
FAIR .... Findable, Accessible, Interoperable, Re-usable
FCA .... Financial Conduct Authority
FH .... Fachhochschule (a form of tertiary education institution; a university of applied sciences)
GCS .... Gauss Centre for Supercomputing
GDP .... Gross Domestic Product
GDPR .... General Data Protection Regulation
GERD .... Gross Domestic Expenditure on Research and Development
GESSI .... German Standards Setting Institute
GHG .... Greenhouse gas
GW .... Gigawatt
GWB .... Gesetz gegen Wettbewerbsbeschränkungen (Act against Restraints on Competition)
GWK .... Gemeinsame Wissenschaftskonferenz (Joint Science Conference)
HAW .... Hochschule für angewandte Wissenschaften (University of applied sciences; a form of tertiary education institution)
HERD .... Higher Education Expenditure on R&D
HFD .... Hochschulforum Digitalisierung (an independent German platform that encourages engagement with digitalization in tertiary education)
HOOU .... Hamburg Open Online University
HTGF .... Hightech-Gründerfonds
HTS .... Hightech-Strategie
IA .... International alignment
IAB .... Institut für Arbeitsmarkt- und Berufsforschung der Bundesagentur für Arbeit (Institute for Employment Research, a special office of the Federal Employment Agency, BA)
ICO .... Initial Coin Offering
IE.F .... Internet Economy Foundation
IfM .... Institut für Mittelstandsforschung (a BMWi-funded institute tasked with conducted research into and advising on SME-related policy)
IoT .... Internet of Things
IPDB .... Interplanetary Database
IPO .... Initial Public Offering
ISCED .... International Standard Classification of Education
ISO .... International Organization for Standardization
IT .... Information technology
KPI .... Key Performance Indicator
kVA .... Kilovolt ampere
kWh .... Kilowatt hour

LMS	Learning management system
M&A	Mergers and acquisitions
MBG	Mittelständische Beteiligungsgesellschaft (a privately held investment company with public funding; each of the Länder has its own MBG)
MDD	Mezzanin-Dachfonds für Deutschland (Mezzanine 'Fund of Funds' for Germany)
MiFID	Markets in Financial Instruments Directive
MIP	Mannheimer Innovationspanel (Mannheim Innovation Panel)
MIT	Massachusetts Institute of Technology
MOOC	Massive Open Online Course
MRC	Medical Research Council
MUP	Mannheimer Unternehmenspanel (Mannheim Enterprise Panel)
NERC	Natural Environment Research Council
NFDI	Nationale Forschungsdateninfrastruktur (National Research Data Infrastructure)
NIH	National Institutes of Health
NRW	North Rhine-Westphalia
NSF	National Science Foundation
NWO	Nederlandse Organisatie voor Wetenschappelijk Onderzoek (The Netherlands' Organisation for Scientific Research)
OECD	Organisation for Economic Co-operation and Development
OER	Open Educational Resources
ÖPNV	Öffentlicher Personennahverkehr (local public transport)
OZG	Onlinezugangsgesetz (Online Access Act)
PFI	Pakt für Forschung und Innovation (Pact for Research and Innovation)
PoS	Proof-of-Stake
PoW	Proof-of-Work
PtJ	Projektträger Jülich (Project Management Jülich)
RCA	Revealed Comparative Advantage
RCAP	Research council acknowledging publication
RE	Renewable energy
RfII	Rat für Informationsinfrastrukturen (Council for Scientific Information Infrastructures)
RWTH	Rheinisch-Westfälische Technische Hochschule (Rhine-Westphalian Technical University)
R&D	Research and development
R&I	Research and innovation
SBS	Structural Business Statistics
SHA	Secure Hash Algorithm
SME	Small and medium-sized enterprise
SNF	Swiss National Science Foundation
SR	Scientific regard
STFC	Science & Technology Facilities Council
TCP/IP	Transmission Control Protocol/Internet Protocol
TU	Technische Universität (technical university)
TUM	Technische Universität München (Technical University of Munich)
TV-L	Tarifvertrag für den öffentlichen Dienst der Länder (Collective Wage Agreement of the Civil Service, applicable at Länder-level)
TVöD	Tarifvertrag für den öffentlichen Dienst (Collective Wage Agreement of the Civil Service, applicable at Federal level)
TWh	Terawatt hour
UKRI	UK Research and Innovation
UN	United Nations
US	United States
USA	United States of America
VFH	Virtuelle Fachhochschule (lit.: Virtual University of Applied Sciences, a BMBF-funded project offering accredited Bachelor's and Master's level online courses)

VKA .... Vereinigung kommunaler Arbeitgeberverbände (lit.: Federation of German Employers' Associations, a national body that coordinates on issues of collective bargaining policy)
VSOP .... Virtual Stock Option Plan
WIFO .... Österreichisches Institut für Wirtschaftsforschung (Austrian Institute of Economic Research)
WoS .... Web of Science
WR .... Wissenschaftsrat (German Council of Science and Humanities)
ZEW .... Leibniz-Zentrum für Europäische Wirtschaftsforschung GmbH Mannheim (Leibniz Centre for European Economic Research)

Glossary

D 3

Accelerator
In relation to new enterprises, the term accelerator is used to refer to a fixed-term funding programme that affords young start-ups access to the infrastructure required to establish their business. The main elements of accelerator infrastructure are access to financial resources, a network of clients and consultancy in the sense of mentoring (usually from successful entrepreneurs).

Agenda 2030
The Agenda 2030 for Sustainable Development was adopted at the United Nations' Sustainable Development Summit in September 2015. It contains a catalogue of 17 goals for sustainable development (SDGs).

Anchor investor
An anchor investor is an investor who invests and acquires a large or controlling share in listed companies, start-ups or venture-capital funds. In this way, the financing of the company is visibly secured, making it easier to attract the remaining funds required, since the confidence of interested investors is strengthened.

Autonomous driving
Autonomous driving allows vehicles to drive independently to a set destination in real traffic without the intervention of a human driver.

Big data
The term big data subsumes various technological developments in the field of data storage and processing which make it possible to integrate and process increasingly large volumes of data of various formats in ever shorter times. Big data provides an opportunity to control and, above all, extract value from the exponentially increasing data volumes created by the advancing ubiquity of information technology and communications.

Bildungsinländer, Bildungsausländer
New students with foreign nationality who gained their university entrance qualifications in Germany are known in Germany as "Bildungsinländer" (lit.: domestically educated persons); new students who gained their university entrance qualifications outside of Germany and come to Germany to study are known as "Bildungsausländer" (lit.: foreign-educated persons).

Biomass
Biomass is composed of substances produced through or bound within living beings. In the context of energy technology, biomass denotes the use of animal and plant products that can be used to generate heat energy, electrical energy and which can be used as fuels.

Biomass-derived solid fuel
Biomass-derived solid fuel is the term used to describe all organic substances produced or accumulated by humans, animals or plants (e.g. wood waste and industrial timber).

Biomass-derived liquid gas
Biomass-derived liquid gases are gases gained from organic waste as well as from renewable raw materials.

Building automation technologies
Technologies which serve to reduce the energy requirements of a building, such as by automatically lowering the room temperature in the absence of persons, are known as building automation technologies.

Business angel
Business angels are affluent private individuals who provide innovative start-up founders and young, innovative companies with capital and entrepreneurial expertise. They invest portions of their private assets directly in a company, without the help of an intermediary, and receive shares in the company in return.

Campus management systems (CMS)
Campus management systems are usually modular IT application systems used in tertiary education institutions to provide comprehensive support in business processes in relation to the student lifecycle (e.g. administration of students, courses and examinations).

Carbon capture & storage (CCS)
In geological CO2 storage, gas is trapped in sealed soil formations or by adsorption processes.

Carbon capture & utilization (CCU)
CCU refers to the continued use of CO2 generated by industrial processes, for example in order to produce synthetic methane or synthetic liquid fuels.

Charging infrastructure
In this context infrastructure stands for the charging infrastructure of electric vehicles. The topic includes installing and expanding fast-charging points by motorways with connections to a medium-voltage network as well as EV charging stations and private charging points.

Closure rate
The closure rate is defined as the number of closed-down companies as a percentage of the annual average number of active companies in a country.

Clusters
Economic clusters are agglomerations and collaboration networks made up of economic and scientific stakeholders in the fields of R&D and production, usually brought together by similar focuses and interests or geographical proximity.

Clusters of Excellence
Clusters of Excellence are a funding line created as part of the Excellence Strategy (cf. ibid). They are intended to provide support to specific projects in internationally competitive fields of research at universities and universities consortia.

Collaborative Research Centres
Collaborative Research Centres are long-term DFG-funded research institutions at tertiary education institutions in which researchers work together within a multidisciplinary research project.

Combined heat and power (power-to-heat)
In combined heat and power systems, power and heat are generated simultaneously in the same system. Using the waste heat generated through power production as thermal heat enhances the efficiency of the system as a whole.

Community Innovation Survey (CIS)
Community Innovation Surveys are the European Union's most important statistical instrument to collect data on innovation activities in Europe. The CIS analyze the impact of innovation on the economy on the basis of a survey of a representative sample of companies.

Computer-aided facility management systems
Computer-aided facility management systems are IT systems which support the planning, management and documentation of facility management processes, such as the administration and management of buildings and their technical facilities.

Concentrated solar power
Concentrated solar power designates steam generation using mirrors which intensify the sun's rays; cf. also solarthermics.

Curricular standard value
The curricular standard value (German: Curricular-normwert) numbers the teaching hours (in weekly hours per semester) for a specific course of study required for a student within standard periods of study. Curricular standard values are set down in the Capacity Regulations (Kapazitätsverordnungen, KapVO) of the Länder.

Cutting-edge technology
When an annual average of more than 9 percent of turnover is spent on research and development in the manufacture of an R&D-intensive product, the latter is referred to as a product of cutting-edge technology.

Data aggregation and sharing
Data aggregation is the collection and summarization of data and information in databanks. Data sharing is the process of exchanging data.

Decarbonization
Decarbonization describes the energy system's transition from carbon-containing fossil fuels to renewable energy sources.

Decentralized storage systems
An example of a decentralized storage system is the battery in an electric car.

Deutsche Börse Venture Network
The Deutsche Börse Venture Network is a network that aims to connect investors and young, qualified high-growth companies. It was launched in 2015.

DFG Research Centres
DFG Research Centres are internationally visible innovative research facilities at tertiary education institutions that are funded by the DFG.

Disruptive innovations
Disruptive innovations are innovations with the capacity to effect significant transformations of markets, organizations and societies and which harbour major value-creation potential.

District storage solutions
District storage solutions provide local electricity storage solutions (usually for electricity from PV systems) in order to reduce the burden on the transmission grid.

E-government
E-government (electronic government) means using information and communication technologies via electronic media to run governmental and administrative processes. In e-government, public services and administrative matters are digitized and made available online.

Electric vehicles
Electric vehicles are vehicles which exclusively use an electric motor and draw their energy from a battery within the vehicle that is charged via the power grid.

Energy efficiency
Energy efficiency is a measure of energy required for a defined use. Energy efficiency increases as the energy losses involved in providing a product or service decrease.

Energy-efficient construction and renovation
Energy-efficient construction and renovation comprises the designing, planning and creating of energy-saving and resource-conserving buildings.

Energy recovery systems
Energy recovery systems are systems which enable expended energy to be used again, e.g. by converting vehicles' kinetic energy into electricity when braking, or by collecting and using the waste heat from industrial processes.

Enterprise resource planning systems
Enterprise resource planning systems support business processes, including the management and administration of business resources such as capital, personnel and production resources.

Equity capital
Equity capital is the capital provided by an external shareholder for a company's self-financing. Equity financing is highly dependent on the company's legal form.

Euronext
Euronext is a multinational European stock exchange.

Excellence Initiative
The Excellence Initiative was a three-phase funding programme from 2005 to 2017 operated by the Federal Government and the Länder. Funding was provided through three funding lines: Graduate Schools, Clusters of Excellence and Institutional Strategies. The aim of the Excellence Initiative was to strengthen Germany's long-term position as a location for science, to enhance its international competitiveness and boost the visibility of cutting-edge research at German universities. It was implemented by the German Research Foundation (DFG) and the German Council of Science and Humanities (WR). Its successor programme is the Excellence Strategy (cf. ibid).

Excellence Strategy
The Excellence Strategy is the indefinite successor programme to the Excellence Initiative (cf. ibid), which ended in 2017, and comprises two funding lines. Firstly, the Clusters of Excellence aim to provide support to specific projects in internationally competitive fields of research at universities and in consortia of universities. The Universities of Excellence funding line serves to sustainably strengthen universities and university consortia as institutions and consolidate their position as international research leaders on the basis of successful Clusters of Excellence.

Exit channel
Exit channel is the name given to back out of an investment. Exit channels for holdings in start-ups include selling to a strategic investor, floatation, selling to another investment company or selling the shares back to the company's founder.

Externalities
Externalities are defined as the effects of economic activities on third parties who do not receive compensation as a result. Knowledge externalities are one such example.

Fleet management systems
Fleet management systems enable the administration, planning, management and monitoring of vehicle fleets.

Fuel cells
Fuel cells convert the energy from the chemical reaction of, for instance, hydrogen and oxygen, into electrical energy.

Fund of funds
A fund of funds, also known as an umbrella fund, is an investment strategy where investors fund other funds.

Gross domestic product (GDP)
GDP is the total value of all goods produced and services provided in a country's economy within a year. It is not relevant in this context whether domestic or foreign actors are involved in the production of GDP; the only important factor is where the value is added. GDP is an indicator of the economic performance of an economy by international comparison.

Gründungsradar
The Gründungsradar, an instrument of the Stifterverband für die Deutsche Wissenschaft and the Heinz Nixdorf Foundation, compares German tertiary education institutions' efforts to promote start-ups.

Heat pump systems
Heat pump systems generate thermal energy from a reservoir at a lower temperature (e.g. ambient air, groundwater) via impulse energy such as electricity (electrical heat pump) or gas (gas heat pump) and discharge this thermal energy as useful heat in a system that is to be heated to a higher temperature.

Heat recovery technologies
cf. Energy recovery systems.

High-Tech Strategy (HTS)
The High-Tech Strategy is the approach pursued by the Federal Government in efforts to integrate the promotion of innovation across all federal ministries. The current edition, the HTS 2025, was adopted by the Federal Cabinet in September 2018.

High-value technology
High-value technology refers to R&D-intensive goods (cf. ibid) in the production of which, on an annual average, more than 3 percent, but not more than 9 percent, of turnover is spent on research and development.

Higher Education Pact
The Higher Education Pact (Hochschulpakt) is an agreement between the Federal Government and the Länder, first implemented in 2007 and currently set to run until 2020. It aims, on the one hand, to provide a range of study courses that is in line with demand and, on the other, to intensify competition for research funding by financing the DFG programme allowance.

Hybrid vehicles
Hybrid vehicles feature both an electric motor and a combustion engine, thereby combining electrical and conventional drive and energy systems.

Hydrogen-powered vehicles
Sometimes referred to collectively as hydrogen mobility, the use of vehicles that are powered by hydrogen and that do not emit any greenhouse gases.

IAB/ZEW Start-up Panel
The IAB/ZEW Start-up Panel is a representative sample of German start-ups that provides information about start-ups and young enterprises in Germany.

Incubator
An incubator offers services to the founders of start-ups that are still in a very early phase. These services include networking opportunities and passing on business skills and knowledge as well as coaching and mentoring services.

Industry 4.0
In industrial production, machines, plants and products are connected to form an IT network of embedded systems to allow flexibility and efficiency. The term Industry 4.0, which was coined in Germany within the framework of the 2011 Hannover Messe (Hanover Trade Fair), thereby focuses on the use of the 'Internet of Things' in an industrial context.

Innovation intensity
The term innovation intensity denotes innovation expenditure in relation to turnover.

Innovative heat and cold storage
Innovative heat and cold storage refers to storage systems that make it possible to (partially) uncouple the production of heat or cold from consumption levels, e.g. by using the chemical properties of salts.

Innovative transmission grid technologies
Innovative transmission grid technologies are technologies applicable in transmission grids

for maximum voltage, including direct current, alternating current and overhead line monitoring. Superconductors are one example of innovative transmission grid technologies: they make it possible to transport power in the high voltage range. Superconductors are materials whose electrical resistance falls down to zero when the temperature drops below a certain level, known as the critical temperature. As a result, these materials transport power with almost zero losses.

Knowledge-intensive services
Knowledge-intensive services are primarily characterized by a workforce with an above-average percentage of employees who have tertiary education qualifications.

Landlord-to-tenant electricity
In landlord-to-tenant electricity models, electricity produced locally (and usually from renewable energy sources) is used by tenants or local commercial users.

Learning management systems (LMS)
Learning management systems are systems that serve to provide learning content and organize learning processes.

Low-temperature heating systems
Low-temperature heating systems provide heating more efficiently using a lower supply temperature. However, large surfaces (such as a wall or floor) are required to dissipate this heat.

Massive open online course (MOOC)
MOOCs are online courses open to interested users around the world that usually feature high numbers of participants.

Mezzanine funds
Mezzanine funds are funds which invest mezzanine capital, i.e. capital that is part debt and part equity.

Mid-cap funds
Mid-cap funds are funds which primarily invest their resources in medium-sized listed enterprises.

Mobility aggregators
Business models that consolidate various modes of transport, e.g. by providing an app that enables users to travel using various modes, are known as mobility aggregators.

Offshore wind
Offshore wind denotes wind turbines that generate electricity at sea.

Onshore wind
Land-based wind turbines that generate electricity are known as onshore wind.

Pact for Research and Innovation
The Pact regulates the funding increases afforded to five non-university science and research organizations by the Federal Government and the Länder. In return, the science and research organizations are obligated to improve the quality, efficiency and performance of their respective research and development activities.

Peer-to-peer power trading
Peer-to-peer power trading denotes the direct sale of generated power to end clients, without the involvement of intermediaries (e.g. blockchain-based systems).

Photovoltaics (PV)
Photovoltaic technologies generate power directly by converting solar energy into electrical energy.

Power-to-chemicals
The process of producing chemical raw materials using electricity is referred to as power-to-chemicals.

Power-to-gas
Power-to-gas describes processes which use electricity to produce synthetic gases (e.g. synthetic hydrogen, synthetic methane) that can later act as a source of power.

Power-to-heat/cold/steam
Power-to-heat/cold/steam denotes the conversion of electrical energy into heat, cold or steam.

Power-to-liquids
In power-to-liquids processes, synthetic liquid fuels are produced from hydrogen and carbon through methanol synthesis or Fischer-Tropsch synthesis.

Priority Programmes
A particular feature of the DFG's Priority Programmes is the nationwide collaboration between the researchers participating in them.

Private equity
Private equity describes the off-exchange provision of equity capital to a company that initially requires

investors' capital in order to share its economic success with its funders at a later point in time.

Public-private partnership (PPP)
PPPs are collaboration forms between public authorities and private enterprises in which the state performs its duties in collaboration with private enterprises or delegates its duties to private companies in full. In such cases, companies benefit from the contacts and experiences gained by working with public administrations as well as the contract awarded to them and the opportunity for investment. Public authorities, on the other hand, sometimes require the financial support of private companies to implement specific projects.

Pumped-storage power station
A pumped-storage power station is a storage power station that stores energy by pumping water to a higher elevation.

Quality Pact for Teaching
In June 2010, the Federal Government and the Länder initiated the "Programme to Improve Study Conditions and the Quality of Teaching" (Qualitätspakt Lehre), set to run until 2020. This complemented the Higher Education Pact 2020 (cf. ibid). The funding provided by this Pact is not intended to improve the mentoring available to students or the quality of teaching across the entire tertiary education sector. Instead, the programme's objective is to improve tertiary education institutions' staffing levels for teaching, mentoring and consultancy activities and to further qualify existing personnel.

R&D intensity
The term R&D intensity denotes the proportion of a company or sector's expenditure (or a country's gross domestic product) spent on research and development (R&D).

R&D-intensive goods
R&D-intensive goods comprise the cutting-edge technology goods (cf. ibid) and high-value technology goods (cf. ibid).

Reducing process emissions
Reducing process emissions lowers the waste products and emissions produced by various production and manufacturing processes.

Repositories
Repositories are document servers operated at tertiary education or research institutions and are used to archive scientific materials and make them available for use.

Research data management systems
Research data management systems are systems which prepare, store, archive and publish research data.

Research information systems
Research information systems are combined database and reporting systems that make it possible to comprehensively document, evaluate and further develop research activities.

Research Training Groups
Research Training Groups are DFG-funded and are established to facilitate the qualification of doctoral researchers within the framework of a thematically focused research programme and a structured training strategy.

Research Units
Research Units are closely coordinated working alliances of excellent researchers, funded by the DFG.

Scale
Scale is the SME segment on the German stock exchange, set up in 2017.

Silent participation
In a silent participation, an investor acquires a holding in a company but does not act as a shareholder externally. While the investor shares in the company's profits, they do not have a decision-making right or the right to co-determination.

Small-cap funds
Small-cap funds are funds which primarily invest their resources in smaller listed enterprises.

Small wind power systems
Small wind power systems are power-generating wind power systems less than 50 metres tall and with an output below 50 kW.

Smart grid technologies
Smart grid technologies facilitate improved grid management through more precise real-time measurements and the abilities to intervene more

precisely in (decentralized) power generation and consumption systems.

Smart meters
Smart meters are electronic electricity meters that use a communication unit to record and make consumption and generation data available (for end users and network operators), typically doing so in real time.

Solarthermics
Solarthermics is the name given to the direct use of radiant heat from the sun, e.g. hot water generation using solar collectors.

Start-ups
A start-up is a young, newly founded company with innovative business ideas and high potential for growth.

Start-up rate
The start-up rate is the number of start-ups in relation to the total number of companies.

Tenure track
Tenure track is the term given to academic career pathways in which young researchers who successfully pass an evaluation have their position converted into a tenured (unlimited) professorship.

Track records
A capital-investment company's history of success and experience is known as its track record.

Transaction throughput
The number of transactions completed per unit of time is referred to as transaction throughput.

Transnational patent applications
Transnational patent applications are applications in the form of patent families which 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. Such patents are particularly important for the export-based German economy, since they secure the protection of inventions beyond the domestic market.

Venture capital
Venture capital, also known as risk capital, refers to initial capital for start-up entrepreneurs and young enterprises. It also includes funding used to strengthen the equity-capital bases of small and medium-sized enterprises, enabling them to expand and to implement innovative, sometimes very risky projects. Venture-capital investments are also associated with a high risk for the capital investors. This is why venture capital is also referred to as risk capital. Venture capital is often provided by special venture-capital companies (capital-investment companies).

Venture capital funds
Venture capital funds are funds which invest venture capital (cf. ibid).

Venture debt
Venture debt is a form of debt financing used by start-ups. It usually takes the form of an unsecured, maturity (bullet) loan. In exchange for the relatively high-risk nature of their investment, the provider of debt capital receives a relatively high rate of interest and, depending on the specific details, may have the option to convert the loan into shares.

Virtual power stations
A virtual power station connects numerous small-scale power-generation systems, such as photovoltaic systems, wind turbines and cogeneration units, thereby creating a network with the aim of providing a flexible supply of electricity.

Wallet
In the context of the blockchain, a wallet is a software application in which a blockchain address is stored. The wallet makes it possible to access cryptocurrencies associated with the blockchain address and to initiate transactions.

D 4 Economic sectors in R&D-intensive industries and knowledge-intensive industrial services[545]

R&D-intensive industrial sectors within the Classication of Economic Activities, 2008 edition (WZ 2008) (4-digit classes)

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 instruments 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 Manufacture 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 machine tools
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 industries services 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 entities
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 works

Emphasis 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

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 of 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 Specialised design activities
743 Translation and interpreting activities
823 Organisation 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) in the series 'Studien zum deutschen Innovationssystem' ('Studies on the German innovation system'). The findings are integrated into the report of the Commission of Experts.

1-2019
Gehrke, B.; Kerst, C.; Wieck, M.; Trommer, M.; Weilage, I. (2019): Bildung und Qualifikation als Grundlage der technologischen Leistungsfähigkeit Deutschlands 2019. Studien zum deutschen Innovationssystem. Berlin: EFI.

2-2019
Schasse, U. (2019): Forschung und Entwicklung in Staat und Wirtschaft 2019. Studien zum deutschen Innovationssystem. Berlin: EFI.

3-2019
Bersch, J.; Gottschalk, S. (2019): Unternehmensdynamik in der Wissenswirtschaft in Deutschland 2017, 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.

4-2019
Neuhäusler, P.; Rothengatter, O.; Frietsch, R. (2019): Patent Applications – Structures, Trends and Recent Developments 2018. Studien zum deutschen Innovationssystem. Berlin: EFI.

5-2019
Stahlschmidt, S.; Stephen, D.; Hinze, S. (2019): Performance and Structures of the German Science System. Studien zum deutschen Innovationssystem. Berlin: EFI.

6-2019
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D 7 Endnotes

A 1

1 Cf. BMBF (2018b).
2 Cf. https://www.hightech-strategie.de/de/leitfaden-fuer-die-zukunft-1781.html (last accessed on 18 January 2019).
3 For the first phase of the HTS, cf. BMBF (2006) and EFI (2008: chapter C 5); for the second phase of the HTS, cf. BMBF (2010) and EFI (2011: chapter A 5); for the third phase of the HTS, cf. BMBF (2014) and EFI (2015: chapter A 3).
4 Cf. BMBF (2018b: 9 and 11).
5 BMBF (2018b: 11), own translation.
6 The third phase of the HTS specified six priority challenges: "the digital economy and society", "sustainable economy and energy", "innovative world of work", "healthy living", "intelligent mobility" and "civil security". For the third phase of the HTS, cf. more detailed EFI (2015: 25ff.).
7 BMBF (2018b: 26), own translation.
8 Cf. BMBF (2018b: 34).
9 Cf. BMBF (2018b: 4 and 34).
10 Cf. EFI (2012: 60ff.).
11 Cf. EFI (2014: 27).
12 Cf. EFI (2017: 27).
13 Cf. BMBF (2018b: 46).
14 Cf. BMBF (2018b: 46ff.).
15 Cf. BMBF (2018b: 47).
16 Cf. https://www.bmi.bund.de/SharedDocs/kurzmeldungen/DE/2018/08/cyberagentur.html and https://www.bmvg.de/de/aktuelles/bundeskabinett-beschliesst-cyber-agentur-27392 (each last accessed on 18 January 2019).
17 Cf. also EFI (2017: 27 und 93ff.).
18 Cf. also EFI (2017: 27 and 93ff.).
19 Cf. also EFI (2017: 91 and 104).
20 Cf. also EFI (2017: 29 and 105ff.).
21 Cf. EFI (2017: 51ff.).
22 Cf. BMBF (2018b: 52).
23 For example, cf. EFI (2008: 32ff.) and EFI (2017: chapter B 7).
24 Cf. EFI (2017: chapter B 7).
25 The Commission of Experts considers the term "mission" to be misleading in this context as it suggests a classic mission-oriented approach to R&I policy. In a classic mission-oriented approach to R&I policy, the targets – and the technological developments with which the targets are to be achieved – are defined in advance. cf. EFI (2017: 88).
26 Cf. BMBF (2018b: 16).
27 Cf. EFI (2015: 25).
28 Cf. BMBF (2018b: 60).
29 In the first two phases of the HTS, this body was the Industry-Science Research Alliance (Forschungsunion); in the third phase of the HTS, it is the High-Tech Forum.
30 In this regard and in the following, cf. BMBF (2018b: 61).
31 Cf. EFI (2015: 27f.).
32 Cf. BMBF (2018b: 62).
33 Cf. BMBF (2018b: 61).
34 Cf. EFI (2017: chapter B 5-3) and EFI (2014: chapter A 2).
35 Cf. https://www.stifterverband.org/pressemitteilungen/2018_11_12_forschung_und_entwicklung (last accessed on 18 January 2019).
36 Cf. EFI (2013: 21).
37 Cf. CDU, CSU, SPD (2018: 67).
38 The Commission of Experts' rough calculations are based on the assumption that R&D expenditure will rise by the same amount until 2025 and that the Federal Government's share of R&D expenditure will remain constant. Data for 2017 was taken as the basis, namely: gross domestic product, R&D expenditure and the R&D expenditure of the Federal Government at 2017 prices. Data source for gross domestic product in 2017: Federal Statistical Office (Statistisches Bundesamt). Data sources for R&D expenditure in 2017: Eurostat Database and Schasse (2019). Data for R&D expenditure of the Federal Government in 2017: BMBF.
39 Cf. o.V. (2018: 1).
40 Cf. o.V. (2018: 2).
41 Cf. o.V. (2018: 2f.).
42 As the sole shareholder, the Federal Government is also the only shareholder in the meeting of partners. By contrast, however, the Federal Government's representatives do not hold a majority on the Supervisory Board. Cf. o.V. (2018: 3) and information issued by the BMBF on 18 October 2018.
43 Cf. o.V. (2018: 2).
44 Cf. o.V. (2018: 3f.).
45 In this regard and in the following, cf. o.V. (2018: 5).
46 By way of comparison: the DARPA budget for 2018 and 2019 is USD 3.2 and 3.4 billion respectively. Cf. https://www.darpa.mil/about-us/budget (last accessed on 18 January 2019). Cf. also Harhoff et al. (2018: 12).
47 In this regard and in the following, cf. https://www.bmi.bund.de/SharedDocs/kurzmeldungen/DE/2018/08/cyberagentur.html and https://www.bmvg.de/de/aktuelles/bundeskabinett-beschliesst-cyberagentur-27392 (each last accessed on 18 January 2019).
48 In this regard and in the following, cf. DFG and WR (2018).
49 Cf. GWK (2016).
50 In this regard and in the following, cf. Azoulay et al. (2018).
51 In this regard and in the following, cf. Berger and Rumpe (2008) and http://archive.darpa.mil/grandchallenge/overview.html (last accessed on 18 January 2019).
52 Cf. https://www.darpa.mil/news-events/2014-03-13 (last accessed on 18 January 2019).
53 Cf. http://robots.stanford.edu/personal.html (last accessed on 18 January 2019).
54 Cf. https://velodynelidar.com/newsroom/it-began-with-a-race/ (last accessed on 18 January 2019).

55 Cf. https://www.darpa.mil/about-us/timeline/arpanet (last accessed on 18 January 2019).

56 Cf. GWK (2018b). The same applies to the Teaching Quality Pact.

57 In this regard and in the following, cf. EFI (2018: 21).

58 Cf. CDU, CSU, SPD (2018: 32).

59 Cf. EFI (2018: 21). In its position paper, "Hochschulbildung im Anschluss an den Hochschulpakt 2020", the German Council of Science and Humanities (WR) discusses the advantages and drawbacks of various capacity-related and quality-related indicators. Cf. WR (2018: chapter C.III.2).

60 In this regard and in the following, cf. EFI (2017), EFI (2016: 28 and 30) and EFI (2017: 19 and 40). In this regard, cf. also WR (2018: 43).

61 Cf. EFI (2017: chapter B 7).

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62 The European Union's High Level Group recently expanded on the definition of AI used by the European Commission to date: "Artificial intelligence (AI) refers to systems designed by humans that, given a complex goal, act in the physical or digital world by perceiving their environment, interpreting the collected structured or unstructured data, reasoning on the knowledge derived from this data and deciding the best action(s) to take (according to pre-defined parameters) to achieve the given goal. AI systems can also be designed to learn to adapt their behaviour by analysing how the environment is affected by their previous actions. As a scientific discipline, AI includes several approaches and techniques, such as machine learning (of which deep learning and reinforcement learning are specific examples), machine reasoning (which includes planning, scheduling, knowledge representation and reasoning, search, and optimization), and robotics (which includes control, perception, sensors and actuators, as well as the integration of all other techniques into cyber-physical systems)." Cf. High Level Group (2018: 7). In order to avoid exaggerations in the societal discourse relating to AI, a recent study by Agrawal et al. (2018) proposed using the term 'prediction machines', because even particularly powerful systems are predominantly based on classification or prediction algorithms. What makes modern systems special is the speed and precision with which they perform this task. An underlying aim of the Federal Government's AI strategy is the promotion of so-called weak AI (also known as narrow AI). Weak AI comprises processes that solve specific problems. This is in contrast to approaches which use so-called strong AI (also known as full AI or artificial general intelligence), which represent attempts to develop machine intelligence with intellectual abilities equal or superior to those of humans.

63 Two examples from the field of human medicine are the classification of skin cancer with the help of deep machine learning and the evaluation of cardiovascular risk factors using computer vision. Cf. Esteva et al. (2017) and https://ai.googleblog.com/2018/02/assessing-cardiovascular-risk-factors.html (last accessed on 18 January 2019).

64 Cf. EFI (2008: 66ff.).

65 Symbolic AI is based on the concept of developing rules that make it possible to draw conclusions from input values. By contrast, in the case of neural AI, these rules are the result of a reconciliation of input values and conclusions. Symbolic AI is therefore a deductive system, while neural AI is an inductive system. Cf. Cardon et al. (2018). In the case of visual recognition, the input values are photos and the conclusions are the identified contents of the images (e.g. a cat in a photo of a cat). In this context, rules can be a combination of colours and geometric forms that describe the appearance of a cat. To develop a symbolic AI so that it can identify images of cats, these rules need to be described as precisely as possible. A neuronal AI intended to recognise images of cats, however, would have to match numerous photos with corresponding image contents in order to be able to derive rules defining these image contents.

66 Cf. Krizhevsky et al. (2012).

67 Cf. https://www.bmbf.de/foerderungen/bekanntmachung-1367.html (last accessed on 18 January 2019).

68 Vgl. https://www.softwaresysteme.pt-dlr.de/de/ml-kompetenzzentren.php (last accessed on 18 January 2019).

69 Cf. Bughin et al. (2017).

70 PricewaterhouseCoopers, for instance, has forecasted a potential cumulative increase in GDP of 26 percent by 2030 if AI is applied in practice. Cf. Rao and Verweij (n.y.). Accenture has predicted that the growth rates of 16 industries will increase by 1.7 percentage points per year until 2035. Cf. Purdy and Daugherty (n.y.). A study by McKinsey & Company has identified additional (global) value creation potential of USD 13 trillion by 2030 or (to covert this figure) a cumulative 16 percent increase in GDP compared to 2018. Annual GDP growth would increase by an average of 1.2 percentage points. Cf. Bughin et al. (2018).

71 Initial studies had confirmed that there is considerable potential to replace human labour with digital technologies. For example, cf. Frey and Osborne (2017). Wider public discourse erroneously interpreted this as evidence supporting the notion of imminent mass unemployment. More recent studies which also take into account the complementarities between technology and human labour as well as the effects on employees' income have come to the conclusion that the use of AI will likely see the demand for human labour rise in Germany. In this regard, cf. Manyika et al. (2017), Chui et al. (2016) and WEF (2018). In addition, cf. Autor and Salomons (2017) and Dauth et al. (2017). Studies of past technological developments also show that employees in Germany with a moderate level of qualifications were well prepared for technological changes – unlike those in other countries. The reasons for this included good quality, broad vocational training with regularly updated curricula as well as systematic efforts to provide further training and education to older employees. Cf. EFI (2016: 55ff.).

72 Cf. Barocas and Hardt (2017) and https://fairmlbook. org/ (last accessed on 18 January 2019).

73 Cf. https://www.faz.net/aktuell/feuilleton/debatten/wie-man-algorithmen-transparent-machen-kann-15652267.html (last accessed on 18 January 2019). The Federal

Government's coalition agreement demands that "algorithm-based and AI-based decisions, services and products" be rendered verifiable.

74 Cf. EOP (2016).

75 Cf. Heumann and Zahn (2018).

76 Cf. CDU, CSU, SPD (2018).

77 These include: i) strengthening research in Germany and Europe; ii) holding innovation competitions and creating European innovation clusters; iii) boosting the transfer of scientific results in business and the Mittelstand; iv) stimulating start-up dynamism; v) actively shaping structural transformation and reacting to potential labour market distortions; vi) reinforcing education and training and supporting the recruitment of skilled workers; vii) using AI in administrative procedures; viii) applying measures to provide data and make it available; ix) amending the regulatory framework; x) supporting standardization measures, and xi) facilitating societal dialogue and developing policy frameworks. Cf. Bundesregierung (2018).

78 In the Mittelstand 4.0 competence centres, AI trainers aim to establish at least 1,000 corporate contacts per year.

79 Investment in China and the USA are both markedly higher. Cf. Heumann and Zahn (2018: 10 and 13).

80 Cf. Heumann and Zahn (2018). This piece discusses KPIs (key performance indicators) with which to evaluate national AI strategies.

81 Cf. Harhoff and Heumann (2018).

82 Intergovernmental cooperation offers the collaborating countries greater flexibility and, in an ideal scenario, also reduces bureaucratic costs. On the other hand, cooperation in the context of EU programmes facilitates the integration of institutions from all EU member states.

83 Cf. https://www.embl.de/aboutus/general_information/ (last accessed on 18 January 2019). The EMBL has six locations (Heidelberg, Hinxton, Grenoble, Hamburg, Rome and Barcelona).

84 Cf. Bundesregierung (2018: 33f.).

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85 For a more detailed description of the research funding organizations, cf. Janger et al. (2019). The UKRI is the umbrella organization comprising the following seven research funding organizations: AHRC, BBSRC, EPSRC, ESRC, MRC, NERC and STFC.

86 DFG (2014: §1).

87 Cf. http://www.dfg.de/dfg_profil/aufgaben/index.html (last accessed on 18 January 2019) and DFG (2014: §1). Terms in quotation marks in this section and in the following correspond to the wording of the Statutes of the DFG.

88 This does not include scientists and researchers who work at either a non-profit institution or an institution which does not permit the immediate publication of research results. Cf. http://www.dfg.de/foerderung/antrag_gutachter_gremien/antragstellende/index.html (last accessed on 18 January 2019).

89 Cf. BMBF (2018a: 90).

90 Far smaller shares of funding were given to Leibniz Association institutes (2 percent), the Max Planck Society and the Helmholtz Association (each receiving 1.2 percent), universities of applied sciences (0.4 percent), the Fraunhofer-Gesellschaft and tertiary education institutions of education, theology and the arts (0.1 percent); the remaining 3.7 percent of funding was awarded to other groups of recipients. The very low shares of funding awarded to the Max Planck Society, the Helmholtz Association and the Fraunhofer-Gesellschaft have fallen slightly, while the (also very low) share awarded to universities of applied sciences has risen slightly since 2008. Cf. Kroll (2019: 7f. and 22). The figures reflect the contact address provided by applicants in their applications. The actual allocation of funding may deviate from this, including due to multiple allocations, for instance in the case of professorships jointly appointed by tertiary education institutions and AUFs.

91 Funding for the programme allowance is provided to the DFG by the Federal Government and the Länder in the context of the second column of the Higher Education Pact as special financing in addition to institutional funding. Cf. o. V. (2014: article 2).

92 Cf. BMBF (2018a: 81 and 83) as well as https://www.fraunhofer.de/de/ueber-fraunhofer/profil-struktur.html (last accessed on 18 January 2019).

93 Cf. BMBF (2018a: 75).

94 The AUFs in this case include the Max Planck Society, the Fraunhofer-Gesellschaft, the Helmholtz Association, Leibniz Association institutes (insofar as they do not pay a lump sum to the DFG), German locations of internationally supported research institutions as well as research institutions which are associated with these organizations and which draw their basic financing from public funds. Cf. DFG (2018c).

95 The duty to cooperate is considered to be fulfilled when the researcher submits the funding application together with a member of academic staff at a German tertiary education institution, and when the German tertiary education institution's staff member is either clearly the lead applicant in the joint application or is set to receive at least 50 percent of the requested funding. Scientists and researchers on fixed-term contracts are exempt from the duty to cooperate, as are applications for support from certain funding lines. These include applications submitted in the context of a Research Unit or a Priority Programme, in the funding area of Scientific Library Services and Information Systems, for the promotion of an international conference, as well as applications in relation to a Workshop for Early Career Investigators, a Project Academy or a Reinhart Koselleck Project. Cf. DFG (2018c).

96 This financing formula relates to funding made available to the DFG, not including the Excellence Initiative. Cf. o. V. (2015: §3). When the Excellence Initiative is included, the ratio is 67.9 percent from the Federal Government and 31.2 percent from the Länder. Around 1.0 percent of funding is provided by other parties. Cf. DFG (2017: 232). The portion provided by the Länder is calculated on the basis of the Königstein formula. The Königstein formula,

which is determined by the GWK, aims to ensure that two-thirds of the share due from the Länder is determined by tax revenues while one-third is determined by the relative populations of the Länder. Cf. o. V. (2015: §4).

97 Cf. o. V. (2015: §3).

98 In conjunction with the four AUFs and the DFG, in 2005 the Federal Government and the Länder agreed the Pact for Research and Innovation (PFI) for 2006 to 2010 with the aim of enhancing the German science system's international competitiveness. The PFI was extended in 2009 for the period from 2011 to 2015 and in 2014 for the period from 2016 to 2020. Cf. GWK (2014).

99 Cf. GWK (2014), GWK (2009a) and GWK (2005b).

100 In 2006, €190 million was provided; from 2007 to 2010, the figure was €380 million per year. In 2011, the amount provided returned to €190 million. Cf. GWK (2005a: §2).

101 The amounts provided are as follows: €27.1 million in 2011; €215.1 million in 2012; €483.9 million in 2013; €502.6 million in 2014, €530 million in 2015; €525 million in 2016, and €440 million in 2017. Cf. GWK (2009b: §2).

102 The funding awarded is a statistically averaged amount of award decisions made by the DFG. All of the following analyses are based on award decisions. The analyses are therefore not based on funding actually called up or paid out. Cf. DFG (2018a: 30ff.). There are two views of awarded funding: on the one hand there are awards for newly established projects, while on the other there is funding calculated as being allocated to projects already approved for one year. The Fraunhofer ISI report is based on evaluations of ongoing projects.

103 The total funding volume for Individual Grant Programmes, for example, increased from €684.5 million in 2008 to €1,095.2 million in 2017. The volume of funding for Collaborative Research Centres rose from €537.5 million to €716.9 million over the same period. There were also relative increases in funding for Research Units, Priority Programmes and Research Training Groups – though these were relatively small. Cf. Kroll (2019: 20).

104 From 2008 to 2010, there was significant annual growth of almost 9 percent in the total funding amounts. This growth can be traced, among other aspects, to the introduction of the programme allowance in 2007. Between 2010 and 2013, this growth slowed markedly and, in some years, the funding amounts even decreased. From 2014, the funding volume increased year-on-year by between 4 and 6 percent; this can be traced in particular to significant additional fund allocations as part of the Excellence Initiative, though it is currently falling again (cf. endnotes 100 and 101). Cf. Kroll (2019: 3, 17 and 20).

105 Cf. Kroll (2019: 17f.).

106 The instruments of Individual Grant Programmes serve to finance thematically focused, fixed-term research projects. Cf. http://www.dfg.de/foerderung/programme/index.html (last accessed on 18 January 2019). The category of Individual Grant Programmes comprises a wide range of funding programmes, e.g. Research Grants, Research Fellowships, programmes for junior researchers such as the Emmy Noether Programme and the Heisenberg Programme, Reinhart Koselleck Projects and other, smaller programmes. The largest share of funds in this context is awarded in the form of Research Grants. Cf. DFG (2018a: 32).

107 The most important Coordinated Programmes include: Collaborative Research Centres, i.e. long-term tertiary education institution-based research institutions in which researchers work together within a multidisciplinary research programme; DFG Research Centres, i.e. internationally visible and innovative research institutions at tertiary education institutions; Research Units, i.e. close-knit teams of excellent researchers; Research Training Groups, i.e. facilities established by tertiary education institutions to promote early career researchers, and Priority Programmes, which promote nationwide collaboration between researchers. Cf. http://www.dfg.de/foerderung/programme/koordinierte_programme/index.html (last accessed on 18 January 2019).

108 The Excellence Initiative is intended to promote both cutting-edge research and the qualitative improvement in Germany as a location for tertiary education and science with a wide-ranging approach. In 2016, the Federal Government and the Länder adopted the Excellence Strategy as an extension of the Excellence Initiative. Projects awarded funding through the Excellence Strategy will be funded from 2019 onwards. Cf. DFG (2018a: 32ff.).

109 For a detailed overview and description of all DFG funding instruments, cf. http://www.dfg.de/foerderung/programme/index.html (last accessed on 18 January 2019).

110 Cf. Kroll (2019: 3 and 20).

111 Cf. http://www.dfg.de/foerderung/programme/koordinierte_programme/index.html (last accessed on 18 January 2019).

112 http://www.dfg.de/foerderung/programme/koordinierte_programme/index.html (last accessed on 18 January 2019).

113 Cf. Kroll (2019: 3 and 20).

114 By way of example, the average funding amount awarded across all Collaborative Research Centres in 2017 stood at €10.9 million. The average funding amount per sub-project conducted as part of a Collaborative Research Centre was €500,000. The average funding amount awarded to Research Training Groups was €4.3 million. However, when submitting applications for funding, Research Training Groups do not have to structure their application into sub-projects, so that the volume corresponds to the total funding amount for a new proposal of a Research Training Group. As the structure of funded projects can vary considerably, it is not possible to carry out a systematic comparison of the average funding amounts of the programmes. Since 2008, the average funding volumes for all funding lines (with the exception of Research Training Groups) have remained relatively constant; Research Training Groups' funding has increased by 38.7 percent. Cf. Kroll (2019: 11).

115 In this case, the approval rate relates to newly approved projects. Cf. Kroll (2019: 13f.). The noticeable fall in the approval rate for Individual Grant Programmes from 2009 to 2013 can be traced back to a sharp increase in the number of new applications received for funding from the Individual Grant Programmes category. Cf. DFG (2015: 3).

116 Cf. Kroll (2019: 13). Due to the fact that the Individual Grant Programmes category comprises very different funding lines, the actual duration of projects funded through the Individual Grant Programmes category are spread over a broad spectrum. According to information provided by the DFG, the standard funding duration for new applications for Research Fellowships, for instance, is around a year; for the Emmy Noether Programme, it is currently around five years. The standard funding term for new applications for Research Grants is three years. Once an initial application has been approved, applications for extensions can usually be submitted. According to the WIFO study conducted on behalf of the Commission of Experts, the share of extension applications is 14 percent. Cf. Janger et al. (2019: 174). According to the DFG, the vast majority of such cases are approved and extend the actual duration of a project. In the case of Research Grants, there is no limit to the number of extension applications that can be submitted, so that long-term projects can reach funding durations of ten years and more. Cf. http://www.dfg.de/foerderung/programme/einzelfoerderung/sachbeihilfe/ (last accessed on 18 January 2019).

117 Cf. http://www.dfg.de/foerderung/programme/koordinierte_programme/sfb/index.jsp and http://www.dfg.de/foerderung/programme/koordinierte_programme/graduiertenkollegs/index.html (both of which were last accessed on 18 January 2019). As Collaborative Research Centres are subject to a funding period of four years and extension applications are not shown in the data, the statistical total duration is not known.

118 The WIFO report is based on new funding awards.

119 Research funding in tertiary education is measured in this case on the basis of the OECD's HERD indicator (in the national currency). This includes all R&D expenditure in the tertiary education sector. In 2016, the proportion of the DFG (18 percent) was comparable to that of the Netherlands (18 percent) and Switzerland (15 percent). It was, however, markedly lower than the figure in the United Kingdom (31 percent) and the USA (47 percent). Cf. Janger et al. (2019: 164).

120 In 2016, the funding amount provided by the DFG per researcher in the tertiary education sector (in full-time equivalents) was €27,372; only in the United Kingdom was the funding amount per researcher in the tertiary education sector (in full-time equivalents) lower at €18,035; the figure was highest in Switzerland at €38,462. Cf. written information issued by the WIFO on 11 December 2018. In addition to universities, in Germany, the Max Planck Society's institutes also conduct basic research. The level of joint funding provided by the Federal Government and the Länder for research by the Max Planck Society corresponds to around 80 percent of funding for the DFG by volume. Cf. BMBF (2018a: 75). The ratio of competitive to basic financing in the field of basic research therefore shifts more heavily towards basic financing when research at Max Planck institutes are taken into account. In an international comparison, Germany has a relatively large sector of AUFs, though some of the comparison countries also feature similar institutions. For example, cf. van Dalen et al. (2014).

121 The figures are lower for the USA and the United Kingdom at 3.4 and 4.6 percent respectively; Switzerland leads the way on at 11.1 percent. Cf. written information issued by the WIFO on 11 December 2018.

122 The DFG does not currently have any funding lines in categories for which no examples are named.

123 In the WIFO classification, the Excellence Initiative is regarded as one funding line and is therefore not divided into three separate instruments of Graduate Schools, Clusters of Excellence and Institutional Strategies. If the three had been considered separate funding lines, Graduate Schools could have been allocated to the Education and Training category. However, as it is counted as special funding under the Excellence Initiative, it has been allocated to this category. That being said, the international findings would not be systematically changed if Graduate Schools were allocated to the Education and Training category.

124 Cf. Janger et al. (2019: 23f.). In the first part of the chapter, the original classification of the DFG was used to adequately describe the structure of the DFG for Germany. In contrast, the classification introduced for the international comparison in the second part had to fairly represent the various structures and models of all examined countries, while simultaneously summarizing to a greater degree. In this respect, the classification used in the detailed description for Germany is therefore not completely identical to the classification used in the international comparison; nevertheless, large sections of the two are congruent. For a complete classification of DFG instruments and for the allocation of other countries' funding programmes to internationally comparable categories, cf. Janger et al. (2019).

125 The percentage of funding for Structural Priority Area programmes at the DFG has risen significantly in recent years (from 1997 to 2017), while the figures for the BBSRC, ESRC and SNF have fallen or increased only slightly; the figures for the MRC and NERC have also risen significantly. Cf. Janger et al. (2019: 167).

126 In an international context, Breschi and Malerba (2011), for example, have identified a positive effect of EU-funded collaborative projects in the information sciences, which, however, shows decreasing marginal returns as the number of researchers involved increases; Ida and Fukuzawa (2013) have identified different effects in different fields of research with regard to the quantity and quality of research results in excellence centres in Japan; Rogers et al. (2012) have identified positive effects on the quality of research results in the field of nanotechnology due to research centres in the USA.

127 Result according to the classification drawn up by the WIFO to allow international comparison. In the WIFO classification, the disciplines of biology, agricultural sciences, forestry and veterinary medicine are classified as natural sciences; meanwhile, the DFG classifies them as life sciences. According to the DFG classification, the greatest share of DFG funding awards was for projects allocated to the life sciences. Cf. Janger et al. (2019: 26 and 169) and DFG (2017: 179).

128 Cf. Janger et al. (2019: 169).

129 Cf. Janger et al. (2019: 170). Nevertheless, it must be considered that projects newly approved for funding in Germany, the United Kingdom (EPSRC), the USA and, by way of exception, in Switzerland can be prolonged by means of extension applications (for funding through the NSF in the USA, only one extension application is permitted). Extension applications, however, are not always identifiable in the data available. The percentage of extension applications is highest for the NIH and DFG (at 27 percent and 14 percent respectively) and the approval rate for extension applications is higher than the approval rate for new applications. The proportion of extension applications to the SNF is 1.7 percent. There is no corresponding data for the NSF or the UKRI. Cf. Janger et al. (2019: 174).

130 A comparison of two US funding organizations (the Howard Hughes Medical Institute and the NIH) in the field of life sciences indicates that a longer funding duration, in particular, has a positive impact on the quality of the research results. Cf. Azoulay et al. (2011). Heinze et al. (2009) and Carayol and Lanoë (2017) have both arrived at similar findings. Similar effects can also be identified for a form of individual funding in Germany, the Gottfried Wilhelm Leibniz Prize. Wilhelm (2018) shows that increasing the funding duration (and the funding amount) leads to an increase in quality, i.e. an increase in the number of publications in high-ranking academic journals and a simultaneous fall in the total number of publications. Cf. Wilhelm (2018). This means that a longer funding duration increases quality rather than quantity.

131 While Aghion et al. (2010), Payne and Siow (2003) and Whalley and Hicks (2014) have found that increasing the amount of funding has a positive impact on the quantity of research outcomes, Fortin and Currie (2013) found that funding more smaller-scale projects generates greater returns than funding fewer larger projects. In terms of the effect that increasing funding amounts has on the quality of research outcomes, Payne and Siow (2003) and Whalley and Hicks (2014) both identify no effect. A variety of factors can influence the direction of the effects. Such factors include, for instance, the extent to which additional funding is provided for a specific purpose or whether the recipients have the discretion to dispose of the funds freely. Greater freedom in the use of funding can have a positive effect on research results. Cf. Aghion et al. (2010) and Azoulay et al. (2011). From a theoretical perspective, negative effects could appear if an increase in funding amounts were accompanied by a reduction in the acceptance rate and if that led researchers with higher-risk projects to decide not to submit an application and therefore also miss out on funding. Cf. Lazear (1997). In addition, the effects could also be discipline-specific, e.g. Fortin and Currie (2013) concentrate on projects in natural sciences and engineering.

132 In the following, cf. Kroll et al. (2019). Research council acknowledging publications (RCAPs) are the English-language equivalent of German Publikationen mit Förderverweis (PFöV). In relation to the United Kingdom, the term RCAPs relates to all publications funded by at least one of the seven British research funding organizations included in this study (AHRC, BBSRC, EPSRC, ESRC, MRC, NERC, STFC). For the USA, RCAPs are all publications which received funding from at least the NIH or the NSF.

133 While differences in terms of publications in different disciplines and journals exist, these do not tend to be country-specific. Cf. Kroll et al. (2019: 2).

134 The CI is defined as the discipline-specific number of citations for all of a country's publications divided by the expected discipline-specific number of citations for all of a country's publications. The expected discipline-specific number of citations for a publication is the average number of citations for all publications around the world of the same document type, in the same discipline and published in the same year. Cf. Waltman et al. (2011).

135 Cf. Janger et al. (2019: 175f.).

136 For all countries, the proportion of RCAPs is highest in natural sciences and engineering and is lowest in the humanities and social sciences. Cf. Kroll et al. (2019: 5ff.). This indicates internationally comparable subject-specific funding and publication structures.

137 RCAPs' relative share of all publications in the respective countries remained broadly constant over the study period. Cf. Kroll et al. (2019: 5f.).

138 Over the same period, RCAPs in Switzerland increased by 70 percent; RCAPs rose by 59 percent in the Netherlands and by 53 percent in the United Kingdom. Only in the USA, where RCAPs increased by 23 percent from 2010 to 2017, was the relative growth recorded lower than in Germany. Cf. Kroll et al. (2019: 5).

139 Exceptions to this are the USA, over the entire study period from 2010 to 2017, as well as the United Kingdom from 2010 to 2013. In Germany, the share of RCAPs and the share of all publications written in co-authorship remained almost identical from 2010 to 2012. The differences since 2013 have been very minor. Cf. Kroll et al. (2019: 12f.).

140 The only exceptions to this have been in the Netherlands where, in certain years (2014, 2016 and 2017), RCAPs were written by Dutch co-authors with the same frequency as all publications in the country; in some years (2010 to 2013), RCAPs were actually written less frequently by Dutch co-authors than was the case for all publications. Cf. Kroll et al. (2019: 15f.).

141 The only exceptions to this have once again been recorded in the Netherlands where, in some years (2010 to 2012), international co-authors were more common for RCAPs than for non-funded projects and national co-authors were less common for RCAPs. Cf. Kroll et al. (2019: 13f.).

142 Cf. Kroll et al. (2019: 14). It is possible that international collaborative projects rather receive funding from international funding organizations.

143 In the following, cf. Kroll et al. (2019: 16ff.).

144 The values for 2010 to 2014 are similar.

145 According to the OECD, the excellence rate for 2015 was somewhat lower for all of the countries examined here, though the rankings were broadly the same (except that, in the OECD comparison of countries, the USA was above the UK). The OECD excellence rate for all publications in Germany in 2015 was 12.1 percent. This placed Germany in 11th position in the OECD comparison

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of countries. According to the OECD, Switzerland had the highest excellence rate in 2015 at 15.3 percent, followed by the Netherlands on 14.8 percent. The USA and the United Kingdom ranked in 5th and 6th place in the OECD comparison of countries with excellence rates of 13.9 percent and 13.6 percent respectively. Cf. OECD (2017: 122).

146 The total number of publications relative to the number of researchers in the tertiary education sector (in full-time equivalents) in 2015 was 1.87 for the Netherlands, 1.45 for Switzerland and 1.07 for Germany; at 0.75, the number of publications per researcher in the tertiary education sector (in full-time equivalents) was lowest in the United Kingdom. Data on the number of researchers in the tertiary education sector is not available for the USA. Own calculations based on https://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB (last accessed on 18 January 2019) and Kroll et al. (2019: 21).

147 The positive deviation in the excellence rates of RCAPs from the excellence rates of all publications in the respective country remained relatively stable from 2010 to 2014. Since 2014, a slight decrease can be seen in the extent of this deviation. Cf. Kroll et al. (2019: 17).

148 In the following, cf. Schmoch et al. (2016).

149 Möller et al. (2016) found that the Excellence Initiative has positive effects on citation rates, effects which are more pronounced for AUFs than for universities. However, due to the short timescale, these results should not be regarded as conclusive.

150 In the course of time, it is clear that the CI of RCAPs and the CI of publications as a whole are converging, in particular in Germany, the Netherlands and Switzerland. Cf. Kroll et al. (2019: 18f.).

151 Cf. EFI (2013: chapter A 6), EFI (2014: chapter A 2) and EFI (2017: chapter B 5-3).

152 The DFG itself regularly publishes descriptive reports which provide an overview of the various key indicators of funding programmes (e.g. demographic characteristics of funding recipients, funded disciplines, personnel in funded projects), though they explicitly avoid serving as evaluative objectives. There are also occasional evaluation studies based on process-produced DFG data. These independent evaluations are rather descriptive in part; in other parts, though, they apply a differentiated mix of methods in order to identify cause-and-effect relationships, e.g. Möller (2016) and Sirtes (2013). In doing so, the effects of funding are considered and assigned to various input parameters. In this context, the recently published evaluation of the first funding period in the Excellence Initiative should be mentioned positively; in contrast to previous evaluations, it primarily identified strong announcement effects. That is to say, the positive effects of the Excellence Initiative can be traced back to the announcement of these measures and other related efforts made by universities in order to receive funding. The effects do not result from the actual receipt of funding as they are already adjusted in advance. Cf. Menter et al. (2018).

153 Cf. CDU, CSU, SPD (2018: 32).

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154 In this regard and in the following, cf. EFI (2009: 93) and EFI (2012: 76).

155 Cf. Bersch and Gottschalk (2019: 9 and 11).

156 Cf. Berger et al. (2019: 23ff.).

157 While the number of new businesses in relation to GDP fell by a total of 40 percent between 1988 and 2006, start-up related indicators such as the number of successful initial public offerings (IPOs) by a cohort of new businesses in relation to GDP initially showed a positive trend which then turned negative. Guzman and Stern (2017) developed an indicator which maps the differences in the quality of start-ups between regions and over time.

158 The Deutscher Startup Monitor (DSM) allocates the start-ups recorded during its survey to German Länder and regions. In the DSM 2018, 19 percent of recorded start-ups were headquartered in North Rhine-Westphalia, with 15.8 percent in Berlin, 12.6 percent in Baden-Württemberg and 12.3 percent in Bavaria. The shares headquartered in all other Länder were below 10 percent. In terms of the regional breakdown, the DSM created start-up regions. In total, 15.8 percent of start-ups were recorded in the Berlin start-up region, 11.2 percent in the Rhine-Ruhr metropolitan region, 7.2 percent in Hamburg, 6.1 percent in Stuttgart/Karlsruhe and 5.9 percent in Munich. In relation to the DSM, cf. KPMG AG (2018: 22f.).

159 In the USA, the geographical concentration of venture-capital investments is even greater than in Germany: 80 percent of all investment went to start-ups in the states of California, Massachusetts and New York. Cf. https://nvca.org/blog/8-take-aways-8-graphics-historic-2018-venture-capital/ (last accessed on 18 January 2019). In the United Kingdom, the London region is dominant. Cf. BVCA (2018).

160 The increased innovation in later development phases can be traced back to the pronounced cooperation activities carried out by start-ups. Cf. Lejpras (2014) and Stephan (2014).

161 In total, 77 percent of start-ups from the world of science conduct R&D activities, as do 15 percent of new businesses overall. In the field of high-tech industry, 57 percent of new businesses conduct R&D activities. Some 53 percent of start-ups from the world of science and 12 percent of new businesses overall develop product innovations that are new to the market. In the high-tech industry, the proportion of new businesses developing market innovations stands at 31 percent. Data on start-ups from the world of science relates to the 2013 and 2015 cohorts of start-ups. The figures on new businesses overall and the values for new businesses in the field of high-tech industry relate to the year 2016. Start-ups from the world of science are referred to as ‘spin-off start-ups’ in the ZEW study. Cf. Berger et al. (2019: 7, 10f. and 13f.).

162 Almost one in five European universities and AUFs offer an incubator programme. Cf. Zinke et al. (2018: 135). For tertiary education institutions’ start-up activities, cf. Frank and Schröder (2018). For AUFs’ start-up activities, cf. GWK (2018a).

163 In the results of the ZEW study, an average of 1,270 start-ups from the world of science were founded each year in the period 2013 to 2015. This corresponds to 11 percent of all new businesses in the high-tech sector. Cf. Berger et al. (2019: 6f.). The high-tech sector comprises the fields of cutting-edge technology and high-value technology.
164 Cf. EFI (2017: 20).
165 Cf. GWK (2018a: 64).
166 The number of start-ups each year from the Fraunhofer-Gesellschaft varied between 18 and 24 between 2007 and 2015; at the ETH Zürich, the number varied between 21 and 25, at Stanford University between 11 and 25, and from the Helmholtz Association between 13 and 21. Cf. Deutscher Bundestag (2018a: 3) and the sources stated therein.
167 The Pact for Research and Innovation III (PFI III) was extended in 2014 for the period from 2016 to 2020. In this regard and in the following, cf. GWK (2014).
168 Cf. GWK (2018a: 111f.).
169 These are licensing, option and transfer agreements for all forms of intellectual property (e.g. patents). The contracts granted and/or transferred rights to third parties in isolation. Utilization agreements for joint inventions are not included. Cf. GWK (2018a: 111).
170 This is due, among other aspects, to the fact that start-ups from AUFs are markedly more technology-driven than start-ups from tertiary education institutions. Cf. GWK (2018a: 15f.).
171 In this context, it must be considered that the surveyed tertiary education institutions do not cover all start-ups and that 191 tertiary education institutions in Germany took part in the Gründungsradar out of the national total of 394. Cf. Frank and Schröder (2018: 2 and 10).
172 Cf. Frank and Schröder (2018: 33).
173 In mapping the development of start-ups recorded over time, information was only used from tertiary education institutions that participated in the survey in both years (72 institutions). Cf. Frank and Schröder (2018: 5).
174 The support for start-ups, in particular regarding how they are embedded in tertiary education institutions in structural and institutional terms, has markedly improved at most institutions since 2012. Tertiary education institutions have also made improvements compared to 2012 in relation to the awareness of start-ups and support for start-up projects. In this regard, EXIST-funded tertiary education institutions lead the way. Cf. Frank and Schröder (2018: 2ff., 13 and 20).
175 The projects from the second competitive round of EXIST IV expired in April 2018. Cf. Kulicke (2015: 6).
176 While almost all large and medium-sized tertiary education institutions responding to the Gründungsradar stated that they promote start-ups, support for start-ups continues to play a subordinate role at smaller institutions. Cf. Frank and Schröder (2018: 9).
177 In principle, a project receives funding of €2 million over a term of up to four years. Cf. Bundesanzeiger (2018).
178 In the following, cf. https://www.exist.de/DE/Programm/Ueber-Exist/inhalt.html (last accessed on 18 January 2019).
179 For more details, cf. https://www.exist.de/DE/Programm/Ueber-Exist/Exist-Rueckblick/inhalt.html (last accessed on 18 January 2019) and Kulicke (2017a: 2).
180 Cf. Kulicke (2018: III), Kulicke (2017b: 64), Kulicke (2017a: 36) and Frank and Schröder (2018: 3).
181 Cf. https://www.land.nrw/de/pressemitteilung/landesregierung-gibt-150-millionen-euro-fuer-foerderprogramm-exzellenz-start (last accessed on 18 January 2019).
182 Cf. Böhm et al. (2019: 68).
183 Cf. Egeln et al. (2002: 62).
184 In this regard and in the following, cf. https://www.unr.edu/enterprise/docs/license, https://research.umbc.edu/office-of-technology-development/licensing-of-umbc-inventions/express-license-2/, https://otm.wustl.edu/for-inventors/quick-start-license/ and https://ctl.cornell.edu/technology/ricochet/ (each last accessed on 18 January 2019).
185 The BMBF already has plans to establish standards for remuneration between transfer organizations and founders. Cf. BMBF (2017: 12).
186 Cf. Böhm et al. (2019: 115).
187 Especially start-ups currently developing their business model are often considered trend scouts. In this regard and in the following, cf. Böhm et al. (2019: 57f.).
188 Cf. Böhm et al. (2019: 61).
189 Cf. https://www.vc-magazin.de/wp-content/uploads/sites/10/_EPAPER_/epaper-Corporate-und-Start-Ups-2018/#0 (last accessed on 18 January 2019).
190 This question was answered by 237 of the 248 companies surveyed. Cf. Löher et al. (2018: 6).
191 Cf. Zinke et al. (2018: 60) and https://www.vc-magazin.de/wp-content/uploads/sites/10/_EPAPER_/epaper-Corporate-und-Start-Ups-2018/#0 (last accessed on 18 January 2019).
192 In this regard and in the following, cf. Böhm et al. (2019: 48ff.). The IfM study comes to similar conclusions: 54 percent of the family-owned companies surveyed intend to tap into new technologies, 51 percent aim to shape the digitization process and 50 percent plan to advance the development of products and services. Almost one company in three aims to gain access to new markets (29.4 percent), and almost one in four hopes to gain access to talented, skilled workers (26.2 percent). Cf. Löher et al. (2018: 10). A survey of collaborative endeavours between start-ups and DAX companies indicates that listed companies are particularly interested in start-ups with innovative business models shaped by digitization. Cf. Kawohl et al. (2018: 4).
193 In the following, cf. Böhm et al. (2019: 50ff.).
194 In this regard and in the following, cf. Böhm et al. (2019: 61), Löher et al. (2018: 14 and 18) as well as Wallisch and Hemeda (2018: 11).
195 Collaborative endeavours between SMEs and start-ups harbour significant potential with regard to innovation and digitization. According to a survey of SMEs, only 38 percent of SMEs have ever collaborated with a start-up. At the same time, 70 percent of the SMEs surveyed said they were interested in collaborating with start-ups. There is increasing interest in collaborating with Mittelstand companies, especially from highly promising

hardware start-ups. Collaborative endeavours offer the benefits of cooperation on equal terms as well as a low risk of interference and incorporation. Cf. Zinke et al. (2018: 132) and Wallisch and Hemeda (2018: 6 and 16). Of the 252 IT start-ups surveyed, 21 percent would welcome support through cooperation with established companies. Cf. BITKOM (2017: 31).

196 Cf. Zinke et al. (2018: 38f.) and BMWi (2018a: 11).

197 In the following, cf. https://finder.startupnationcentral.org/ (last accessed on 18 January 2019) and Zinke et al. (2018:140).

198 The BMWi has a ten-point plan which includes moves to expand the central start-up platform founded by the BMWi and KfW in April 2018. Cf. BMWi (2018a: 5). The purpose of this platform, however, differs from that of the Israeli online platform.

199 Cf. Veugelers and Cassiman (1999) in Bersch et al. (2016).

200 Holding companies represent an exception to this. Cf. Bersch et al. (2016: 51ff.).

201 The probability that a start-up will be acquired increases with the size and diversification of established companies' offerings. The companies purchased tend to be young start-ups. Purchasing young-start-ups entails a greater risk of failure, especially in the case of start-ups pursuing radical innovations. At the same time, however, established companies also have a greater opportunity to influence the start-up's product, service or business model. Cf. Bersch et al. (2016: 51ff.). Of the German family-owned businesses surveyed, 7 percent stated that they had acquired start-ups in 2018. This question was answered by 113 companies. Cf. Löher et al. (2018: 8).

202 Cf. Schweitzer et al. (2018: 122) and Wu (2018: 121ff.). Cunningham et al. (2018) show that, in some cases, established pharmaceutical companies buy out potential competitors in order to minimize future competition. The authors demonstrate in particular that the companies choose to acquire those start-ups that currently have innovative, development-stage products in the pipeline in segments where the established company already offers a profitable medication. This development project is often shut down following the buyout. The authors show that, when the established company already has a product on the respective market, development projects of purchased start-ups are 40 percent less likely to be brought to market than comparable projects that are not purchased. This can curb future competition between the medication in the development stage and the medication already on the market. As the established company's gains from protecting its monopoly are higher than the sum of the potential gains of both companies in a competitive scenario, the purchase price offered to start-ups is often highly attractive for both parties.

203 Cf. Schweitzer et al. (2018: 123f.).

204 Due to their lack of securities, bank financing is not usually an option for early-stage start-ups. Cf. EFI (2012: 85).

205 In this regard and in the following, cf. Böhm et al. (2019: 9f.) and the literature stated therein.

206 Investments by business angel funds are included as business-angel investments. Such investments concern assets managed on behalf of one or more business angels and which are used as direct venture-capital investments. Unlike venture capital funds, business angels who provide funding take an active role in their portfolio companies and offer them support and guidance in addition to their financial commitment. In this regard, cf. Bersch et al. (2018:44).

207 Cf. BAND (n.y.) and BVK (2018).

208 In this regard, cf. also Egeln and Gottschalk (2014).

209 This is associated with the rise of major rounds of financing. An example of the rise of large-scale rounds of financing with the involvement of foreign investors is a company called Delivery Hero. Before its floatation in June 2017, the company had received more than €1 billion from investors. The South African media group Naspers acquired 10 percent of the company's shares for €387 million shortly before its IPO. Cf. Bersch et al. (2018: 44).

210 Cf. Woodward (2019).

211 Cf. Deutscher Bundestag (2018c: 9) and Zinke et al. (2018: 35).

212 In this regard and in the following, cf. EFI (2012: 88) and EFI (2017: chapter B 4-2).

213 In this regard and in the following, cf. Deutscher Bundestag (2018c: 3).

214 This is demonstrated, for instance, by the comparison with the USA. Cf. BAND (n.y.).

215 Cf. EFI (2017: 85 and 87).

216 Cf. https://www.kfw.de/KfW-Konzern/Newsroom/Aktuelles/Pressemitteilungen-Details_490496.html (last accessed on 18 January 2019).

217 In this regard and in the following, cf. https://www.danskvaekstkapital.dk/dvk1/en/ (last accessed on 18 January 2019) and Vækstfonden presentation materials.

218 Cf. Deutscher Bundestag (2018b).

219 The German Private Equity and Venture Capital Association (BVK), the Internet Economy Foundation (IE.F) and Roland Berger GmbH are proponents of establishing what they refer to as a "Zukunftsfonds Deutschland", a future-focused fund for Germany drawing on elements of the Danish model. Cf. BVK; IE.F; Roland Berger GmbH (2018: 33ff.).

220 Cf. https://www.bundesregierung.de/breg-de/aktuelles/verlustverrechnung-neu-geregelt-346602 (last accessed on 18 January 2019), EFI (2017: 85f.).

221 In this regard and in the following, cf. EFI (2017: 86). In relation to whether the administrative services provided by fund managers are subject to turnover tax in various countries, cf. Invest Europe (2018).

222 Other exit channels include the sale of shares to another holding company or the company founders buying back shares.

223 Cf. Deutscher Bundestag (2018c: 9) and Zinke et al. (2018: 35).

224 Cf. EFI (2017: 86).

225 Correct as of December 2018. Cf. http://www.venture-network.com/dbvn-de/ueber-uns (last accessed on 18 January 2019).

226 Cf. http://www.deutsche-boerse-cash-market.com/dbcm-de/primary-market/marktstruktur/segmente/scale?frag=1217334 (last accessed on 18 January 2019).

227 Cf. http://www.faz.net/aktuell/finanzen/finanzmarkt/startups-fit-fuers-parkett-machen-boersenplaetze-buhlen-um-tech-unternehmen-15806386.html (last accessed on 18 January 2019).

228 Cf. https://high-tech-gruenderfonds.de/de/boersendebuet-beim-high-tech-gruenderfonds-nfon-meistert-als-erstes-htgf-portfolio-startup-den-sprung-an-die-boerse-htgf-war-2008-der-erste-investor-des-cloud-telefonie-anbieters-und-haelt-auch-nach/ (last accessed on 18 January 2019) and KfW (2018: 1).

229 The Federal Government's programmes in the field of venture capital are classified as start-up financing (Gründungsfinanzierung) and growth financing (Wachstumsfinanzierung) according to the BMWi (2018e).

230 In this regard and in the following, cf. https://www.bmwi.de/Redaktion/DE/Artikel/Mittelstand/gruendungsfinanzierung-high-tech-gruenderfonds.html (last accessed on 18 January 2019).

231 In addition to the Federal Government (ERP SV) and KfW Capital, six private investors hold participating interests in HTGF I, while 18 hold participating interests in HTGF II. Cf. Deutscher Bundestag (2017: 3 and 79ff.). Until KfW Capital commenced business operations in October 2018, KfW held a participating interest.

232 Cf. https://www.bmwi.de/Redaktion/DE/Artikel/Mittelstand/gruendungsfinanzierung-high-tech-gruenderfonds.html (last accessed on 18 January 2019).

233 Until KfW Capital commenced business operations in October 2018, KfW was among the investors.

234 Cf. https://high-tech-gruenderfonds.de/de/high-tech-gruenderfonds-htgf-iii-gibt-startschuss-fuer-investments/ and https://high-tech-gruenderfonds.de/de/high-tech-gruenderfonds-iii-second-closing-uebertrifft-mit-3165-millionen-euro-alle-erwartungen/ (each last accessed on 18 January 2019).

235 Cf. https://www.bmwi.de/Redaktion/DE/Artikel/Mittelstand/gruendungsfinanzierung-high-tech-gruenderfonds.html sowie http://www.foerderdatenbank.de/Foerder-DB/Navigation/Foerderrecherche/suche.html?get=fec915f01ec81055c2f3bbfae82e4704;views;document&doc=9241 (each last accessed on 18 January 2019).

236 In this regard and in the following, cf. Deutscher Bundestag (2017: 3) and http://www.foerderdatenbank.de/Foerder-DB/Navigation/Foerderrecherche/suche.html?get=0a16e8775474cbaf28ab3c848ac0ede3;views;document&doc=12046 and http://www.bafa.de/DE/Wirtschafts_Mittelstandsfoerderung/Beratung_Finanzierung/Invest/invest_node.html (each last accessed on 18 January 2019).

237 The fund aims to support companies which provide training, were founded as a result of unemployment, or which are led by women or people with a migrant background. In addition, the fund focuses on commercially oriented social enterprises and environmental enterprises. Cf. Deutscher Bundestag (2017: 3) as well as http://www.foerderdatenbank.de/Foerder-DB/Navigation/Foerderrecherche/suche.html?get=0a16e8775474cbaf28ab3c848ac0ede3;views;document&doc=12046, https://www.mikromezzaninfonds-deutschland.de/start.html and https://www.bmwi.de/Redaktion/DE/Artikel/Mittelstand/unternehmensfinanzierung-mikromezzaninfonds.html (each last accessed on 18 January 2019).

238 In this regard and in the following, cf. Deutscher Bundestag (2017:3) as well as http://www.foerderdatenbank.de/Foerder-DB/Navigation/Foerderrecherche/suche.html?get=0a16e8775474cbaf28ab3c848ac0ede3;views;document&doc=12046 (last accessed on 18 January 2019).

239 In this regard and in the following, cf. http://www.foerderdatenbank.de/Foerder-DB/Navigation/Foerderrecherche/suche.html?get=a6fcab7b58c1e583dfb791880cc0e3b0;views;document&doc=12947&typ=KU and https://www.bmwi.de/Redaktion/DE/Artikel/Mittelstand/innovationsfinanzierung-coparion.html (each last accessed on 18 January 2019). Until KfW Capital commenced business operations in October 2018, KfW was involved as an investor.

240 Cf. BMWi (2018g).

241 Cf. https://www.bmwi.de/Redaktion/DE/Pressemitteilungen/2018/20180312-eu-investiert-in-deutschen-venture-capital-markt.html (last accessed on 18 January 2019).

242 On the one hand, the ERP/EIF Fund of Funds is actively engaged in early-phase funds with links to public and private research centres and facilities. On the other, it invests in funds that provide follow-up financing for early-phase and growth-phase technology companies. Cf. BMWi (2017a) and http://www.foerderdatenbank.de/Foerder-DB/Navigation/Foerderrecherche/suche.html?get=d3f9d549c0e1151C30550d2c4d23b973;views;document&doc=8933 and https://www.bmwi.de/Redaktion/DE/Artikel/Mittelstand/innovationsfinanzierung-erp-eif.html (each last accessed on 18 January 2019).

243 Cf. Ausfelder et al. (2017).

244 Cf. https://www.bmwi.de/Redaktion/DE/Artikel/Mittelstand/innovationsfinanzierung-erp-eif.html (last accessed on 18 January 2019).

245 In this regard and in the following, cf. https://www.bmwi.de/Redaktion/DE/Artikel/Mittelstand/innovationsfinanzierung-erp-eif.html (last accessed on 18 January 2019) and Deutscher Bundestag (2017: 4).

246 In this regard and in the following, cf. http://www.foerderdatenbank.de/Foerder-DB/Navigation/Foerderrecherche/suche.html?get=6dbfb491a3ce9404c25474caf3af142a;views;document&doc=13229 (last accessed on 18 January 2019), Deutscher Bundestag (2017: 4). Until KfW Capital commenced business operations in October 2018, KfW oversaw the programme.

247 In this regard and in the following, cf. http://www.foerderdatenbank.de/Foerder-DB/Navigation/Foerderrecherche/suche.html?get=6dbfb491a3ce9404c25474caf3af142a;views;document&doc=13229 (last accessed on 18 January 2019) and Deutscher Bundestag (2017: 4).

248 Cf. https://www.bmwi.de/Redaktion/DE/Artikel/Mittelstand/innovationsfinanzierung-erp-eif.html and http:// www.foerderdatenbank.de/Foerder-DB/Navigation/Foerderrecherche/suche.html?get=4d1ff2385c08cf2070d92bda708812f9;views;document&doc=12948 (each last accessed on 18 January 2019).

249 Cf. https://www.business-angels.de/neue-instrumente-fuer-mehr-risikokapital-gestartet/ (last accessed on 18 January 2019).

250 Cf. http://www.foerderdatenbank.de/Foerder-DB/Navigation/Foerderrecherche/suche.html?get=4d1ff2385c08cf2070d92bda708812f9;views;document&doc=12948 (last accessed on 18 January 2019).

251 Cf. http://www.foerderdatenbank.de/Foerder-DB/Navigation/Foerderrecherche/suche.html?get=views;document&doc=12949 and https://www.bmwi.de/Redaktion/DE/Pressemitteilungen/2016/20161110-mezzanin-dachfonds-stellt-zusaetzlich-400-millionen-euro-fuer-den-deutschen-mittelstand-bereit.html (last accessed on 18 January 2019) and Deutscher Bundestag (2017: 4).

252 Of this, the EIF provided €100 million, the ERP Special Fund provided €68.54 million, the LfA Förderbank Bayern provided €16.67 million and the NRW.BANK provided €14.79 million. Cf. Deutscher Bundestag (2017: 4).

253 Of this, the EIF provided €200 million, the ERP Special Fund contributed €113.32 million and the LfA Förderbank Bayern and NRW.BANK each provided €33.34 million. Cf. Deutscher Bundestag (2017: 4) and https://www.bmwi.de/Redaktion/DE/Pressemitteilungen/2016/20161110-mezzanin-dachfonds-stellt-zusaetzlich-400-millionen-euro-fuer-den-deutschen-mittelstand-bereit.html (last accessed on 18 January 2019).

254 Cf. Deutscher Bundestag (2018c: 19) and BMWi (2018a).

255 R&D activities often create externalities in the form of knowledge-spillovers. This is when competitors are able to access new inventions without having to bear the costs of R&D activities themselves. In this case, the innovation's private returns differ from its societal returns and researchers opt to invest too little – from a societal perspective – in R&D. This provides the justification for public R&D funding.

256 In this regard and in the following, cf. EFI (2017: 82). For instance, the documentation required by the BMWi Federal Aviation Research Programme to demonstrate solvency moving forward is as follows: In the case of a co-payment of more than €100,000, the company must submit their annual financial statements for the last two fiscal years, a current trade register excerpt and details of its house bank. A co-payment of less than €100,000 allows the company to use the "simplified procedure" which, in principle, does not require the submission of documents to demonstrate the company's solvency moving forward. The credit check is carried out by a credit reference agency. Newly founded start-ups must submit a trade register excerpt, details of their house bank, their opening balance sheet, a current Betriebswirtschaftliche Auswertung (BWA – see List of abbreviations), their turnover and liquidity plan for the project term as well as the average number of employees and company planning for the project term. Cf. BMWi (2017b).

257 Information issued by the BMBF on 28 November 2018. According to the BMBF's five-point plan, "Mehr Chancen für Gründungen", BMBF energy research, for example, generally assumes an optimistic future prognosis for companies. Cf. BMBF (2017). The guidelines for the BMBF funding measure "Gründungen: Innovative Start-ups für Mensch-Technik-Interaktion" (New enterprises: innovative start-ups for human-technology interaction) allow for start-ups with an even lower equity base to be reviewed to examine whether funding can be offered for eligible project-related expenses.

258 In the following, cf. EFI (2017: 122).

259 Relevant matters in this respect include issues of fiscal law, voting rights and such programmes' structure depending on period of service.

260 In the following, cf. KPMG AG (2017: 35).

261 The proportion of employees from other EU member states was over 20 percent at all three locations, as was the proportion of employees from third countries.

262 Cf. KPMG AG (2017: 33).

263 In the following, cf. Gabrysch (2017), https://inside-vc.de/mitarbeiterbeteiligungsprogramme-fallstricke-tipps-und-tricks/, https://www.artax.com/de/unternehmen/deutschland/Start-ups/esop-ein-modell-zur-erfolgsbeteiligung-in-einem-startup.html and https://www.gruenderszene.de/allgemein/virtual-stock-option?interstitial (each last accessed on 18 January 2019).

264 In practice, however, there is still uncertainty as to whether payments made in the context of a VSOP will actually be considered as payment of wages by financial authorities.

265 In this regard and in the following, cf. Startup Genome (2018:13ff. and 46ff.). Around the world, some 29 percent of start-ups can be ascribed to the technology areas of digital media, gaming and adtech, though the start-up rates and early stage deals in these areas are in decline. Cf. Startup Genome (2018: 16).

266 This report drew on data concerning rounds of financing, exits and the number of start-ups founded. In the following, cf. Startup Genome (2018: 13ff. and 46ff.).

267 With regard to regulatory issues in the field of AI, cf. KI Bundesverband e.V. (2018: 54ff.). In relation to the protection of personal and company data, cf. https://www.plattform-i40.de/I40/Navigation/DE/Industrie40/Handlungsfelder/Rechtsrahmen/rechtsrahmen.html (last accessed on 18 January 2019).

268 In this regard and in the following, cf. Löher and Schneck (2018).

269 Cf. BMBF (2018b) and Bundesregierung (2018).

270 For example, the ENavi Kopernikus project examines how the transition to renewable energies can be facilitated in technical, economic and legal terms. Four public utility companies and various regions in Mecklenburg-West Pomerania are involved in the project. Cf. written information issued by the BMBF on 5 December 2018 and https://www.kopernikus-projekte.de/projekte/systemintegration (last accessed on 18 January 2019). In relation to Regulatory Test Beds, cf. also EFI (2017); EFI (2016: 20).

271 The BMWi's Regulatory Test Bed (RTB) Strategy comprises three pillars: the first involves increasing the use of experimentation clauses in new legislation and regulations. Secondly, an RTB handbook is to be created and an RTB network set up in order to resolve the current paucity of information and support the exchange between industry, science and administration. Thirdly, the BMWi aims to implement its own projects and conduct RTB

competitions. Cf. https:// www.bmwi.de/Redaktion/DE/Dossier/reallabore-testraeume-fuer-innovation-und-regulierung.html (last accessed on 18 January 2019) and BMWi (2018h). In addition, as part of its 7th Energy Research Programme, the BMWi is introducing a new programme pillar, "Living Labs for the Energy Transition". Cf. BMBF (2018b: 23) and https://www.bmwi.de/Redaktion/DE/Dossier/reallabore-testraeume-fuer-innovation-und-regulierung.html (last accessed on 18 January 2019).

272 Cf. EFI (2017: 20). A grace period is a period of time after an announcement in which a patent application can be submitted for an invention without the announcement being considered prejudicial to the novelty of the patent. Cf. EFI (2009: 43).

273 Business Angels Network Deutschland (BAND; representing business angels) has recently worked with the Bundesverband Deutsche Startups (representing start-ups) to found the German Standards Setting Institute (GESSI), which is tasked with developing such standard contracts. To begin with, a standard for convertibles was presented in 2018. A standard term sheet is to be published in February 2019. Furthermore, the topic of employee participation programmes is on the Institute's to-do list. Cf. https://www.business-angels.de/business-angels-netzwerk-deutschland-und-startup-verband-gruenden-german-standards-setting-institute-und-veroeffentlichen-ersten-standardvertrag/ (last accessed on 18 January 2019).

B 2

274 Greenhouse gases are gases which contribute to the greenhouse effect. Solar radiation penetrates the atmosphere and is converted into thermal radiation when it reaches the earth's surface before being emitted once again into the atmosphere. Greenhouse gases in the upper layers of the atmosphere prevent a proportion of this thermal radiation from escaping back into space. This produces the so-called greenhouse effect. In this context, a distinction is made between the natural greenhouse effect and the man-made (anthropogenic) greenhouse effect. The natural greenhouse effect acts as a protective shield, raising the average global temperature from -18°C to around 15°C. This natural greenhouse effect has been amplified by additional, man-made greenhouse gases since the Industrial Revolution. CO_2 accounts for the major share of anthropogenic greenhouse gases, and is released by the combustion of fossil fuels such as coal, oil and gas.

275 Cf. BMUB (2016).

276 The energy sector includes emissions from public power and heat supplies, including natural gas compressors. Some publications use the term 'electricity sector' rather than 'energy sector'. Such terms are broadly conterminous and are often used as synonyms (though the term 'electricity sector' can also include emissions from industrial power stations that would not be attributable to the term 'energy sector'). The term 'industry' covers emissions from combustion processes and electricity supplies for commercial manufacturing purposes as well as emissions from industrial processes. 'Transport sector' is used to cover GHGs from fuel combustion in road and rail transport as well as transport on waterways and in national aviation. The term 'building sector' includes emissions from combustion processes in private households and in commercial trade and service contexts that are primarily attributable to fuels burned for heating rooms, cooking and to provide hot water.

277 The Federal Government has only substantiated its GHG reduction targets with specific sector targets for 2030. Cf. BMUB (2014) and BMU (2018a).

278 In its 2018 Climate Protection Report, the Federal Government assumes that the reduction of GHG emissions by 2020 (compared to 1990) will only come to around 32 percent. Cf. BMU (2018b). In evaluating the GHG emission reductions achieved to date, the effect of German reunification must also be considered. Due to the de-industrialization of the former East Germany following reunification, GHG emissions had already reduced by around 9 percentage points between 1990 and 2000 despite there being no active climate protection policy. Cf. Eichhammer et al. (2001).

279 Cf. UNEP (2018) for a comparison of the (non-)attainment of emissions targets in an international context and proposals of how to seal any gaps in reduction plans.

280 Cf. BMUB (2016: 27).

281 In the period from 2008 to 2017, €185 billion was invested in REs by means of the German Renewable Energy Source Act (EEG). Cf. Bundesnetzagentur (2018).

282 The percentage of gross power consumption covered by REs grew from approx. 14 percent in 2007 to approx. 36 percent in 2017. Cf. BMU (2018a).

283 The Federal Government aims to increase the proportion of power consumption covered by REs to two-thirds by 2030. Cf. CDU, CSU, SPD (2018).

284 The sectoral classification of GHG emissions also includes the agricultural sector. In Germany, the agricultural industry produces by far the lowest GHG emissions of all sectors and is not explicitly referenced in the chapter's subsequent sectoral analysis.

285 Sector coupling applications relating to transport and heating are a core element of the so-called transport transition and heating transition.

286 Cf. AGEB (2018).

287 Based on RE systems operating for an average of approx. 1,800 hours per year.

288 For a commentary on the EEG, cf. also EFI (2013).

289 Own calculations based on BMWi (2018f).

290 The assessment of the potential to expand wind and solar facilities is based on an expert study, "Energiesysteme der Zukunft" (Energy systems of the future). Cf. Ausfelder et al. (2017).

291 Cf. BMWi (2018f).

292 In this context, the term 'network externalities' is a synonymous for another commonly used term, 'adoption externalities'. Furthermore, in the context of R&D, externalities also occur in the form of knowledge-spillovers. Cf. EFI (2013). These knowledge-spillovers are not specific to R&D in the energy transition and are therefore not explored in further detail here.

293 Cf. EFI (2013: 49).

294 The price of GHG emissions is also often referred to as the CO_2 price. However, GHGs also include gases other than CO_2; these are stated as CO_2 equivalents.
295 Another instrument to determine the price of CO_2 is quantity control, in which an upper limit is set for emissions and which allows emissions permits to be traded. This is the approach adopted by the EU Emissions Trading Systems.
296 Cf. Umweltbundesamt (2018). There is a broad spectrum of estimates of the societal costs of CO_2. Cf. Ricke et al. (2018) and Pindyck (2016).
297 In some cases, users who adopt new technologies at an early stage can provide other actors with valuable information regarding the existence, characteristics and success conditions of such technologies. Positive effects can also occur when further experience with a technology leads to a reduction in (production) costs. If third parties benefit from such effects without paying compensation, this is referred to as (positive) network externalities. Developers, manufacturers and first-time users of a technology are often unable to collect the entire yield of the knowledge they generate. In this case, network externalities result from the interaction between the suppliers of a technology and its users; that is to say, it results from the relation between the development of a technology and market trends created by one actor's investment and from which other actors can benefit without paying compensation.
298 Cf. Gatzen et al. (2019).
299 Cf. Ausfelder et al. (2017).
300 Cf. Ausfelder et al. (2017).
301 The digitalization of the energy industry is not only necessary with regard to power grid operation. It relates to energy generation (e.g. applying automated control systems to decentralized facilities to form a virtual power station), energy transport (e.g. using real-time grid status data and automated control technology), energy consumption (e.g. using automated load management), energy trading (e.g. through virtual marketplaces, high-frequency trading and micro-transactions) and energy marketing and sales (e.g. through variable tariffs based on time of consumption).
302 The Federal Government promotes these technologies as part of the 7th Energy Research Programme. Cf. BMWi (2018b).
303 The Emissions Trading System includes provisions for specific industrial sectors and gases. The specific industrial sectors relate to power and heat generation, operations in energy-intensive sectors such as oil refineries, steelworks and sites that produce iron, aluminium, metals, cement, unslaked lime, glass, ceramics, pulp, paper, cardboard, acids and basic organic chemicals, as well as commercial aviation. The specific gases include carbon dioxide (CO_2), nitrogen oxide (N_2O), created in the production of nitric acid, adipic acid, glyoxylic acid and glyoxal as well as perfluorinated compounds (PFCs), created in the production of aluminium. Since 2012, the EU ETS has included inner-European air traffic.
304 Moreover, since 2019, national measures and the EU ETS have been more closely intermeshed. If the decommissioning or shutdown of activities within a country reduces the local need for emission allowances in the EU ETS, new regulations now allow a member state to delete a corresponding quantity of certificates.
305 Cf. BMWi (2014).
306 Cf. Löschel et al. (2018).
307 Cf. Umweltbundesamt (2018).
308 Cf. Löschel et al. (2013).
309 Cf. digression on batteries in a distribution network in Gatzen and Pietsch (2019: 84).
310 Cf. Deutsche Energie-Agentur GmbH (2017). For further technologies which offer flexibility options, cf. Ecofys and Fraunhofer IWES (2017).
311 Cf. Ausfelder et al. (2017: 22).
312 District heating accounted for approx. 14 percent, while electric heat pumps made up approx. 2 percent. Cf. BDEW (2018).
313 The housing stock in Germany currently totals approx. 42 million housing units. In recent years, fewer than 300,000 new housing units have been built per year. This ratio demonstrates that the impact of GHG minimization measures will be limited if such measures are only applied to new builds. Cf. Gatzen and Pietsch (2019).
314 Cf. Reetz (2019).
315 One indicator in this regard is the number of start-ups in the area of energy and blockchain technology. For an overview of such start-ups, cf. for example https://www.solarplaza.com/channels/future-grid/11751/report-comprehensive-guide-companies-involved-blockchain-energy/ (last accessed on 18 January 2019).
316 Cf. BMWi (2015: 48).
317 Cf. BMWi (2018c).
318 The Federal Government promotes these technologies as part of the 7th Energy Research Programme. Cf. BMWi (2018b).
319 Cf. Henger and Schaefer (2018).
320 In addition, coordination problems can arise in the building sector between tenants and landlords which, in turn, negatively impact on energy efficiency measures. Tenants would like to keep their payments (i.e. the sum of rent and ancillary rental costs) as low as possible, while not being sufficiently well informed of a building's energy efficiency. Landlords, on the other hand, have little incentive to implement energy efficiency measures if they are not immediately able to pass on the costs of investment and the reduction in profit from energy costs, either due to the market situation, for legal reasons or because their tenants are not sufficiently well informed. Cf. EFI (2013: 54).
321 Expanding such incentives and support is imperative due to the reduction in modernization subsidies from 11 percent to 8 percent in 2019, which lessens the financial incentive to renovate buildings to improve their energy efficiency.
322 Regulatory law to reduce GHG emissions primarily relates to new builds; there are no major obligations to renovate existing buildings and non-residential buildings. Regulatory law measures have therefore barely been used to reduce the lock-in effects in existing buildings.
323 Acatech (2017) and BMU (2018a).
324 Cf. BMWi (2018d: 39).
325 Cf. Ausfelder et al. (2017: 37).

326 The figures for national air traffic show the GHG emissions produced by flights between German airports. The GHG emissions produced by cars, goods vehicles and diesel engine trains are calculated based on the fuel quantities sold in Germany – independent of whether some of this fuel is consumed abroad.
327 Cf. BMWi (2018f).
328 Electric cars, hybrid cars, plug-in hybrids.
329 Cf. BMU (2018a: 39).
330 Cf. BMU (2018a: 39); Acatech (2017: 33).
331 The Federal Government promotes these technologies as part of the 7th Energy Research Programme. Cf. BMWi (2018b).
332 This primarily relates to cars, which are responsible for the majority of GHG emissions in the transport sector.
333 Cf. Gatzen and Pietsch (2019: 62). The direct use of electricity (from RE sources) eliminates the conversion losses that occur, for example, in the production of hydrogen for hydrogen-powered transport. Furthermore, electric motors have a higher degree of efficiency than combustion engines. This means that electric motors require less energy to power the same transport services.
334 Fast charging, on-board power supplies, coordinated charging.
335 Cf. Acatech (2017: 29); Ausfelder et al. (2017: 64).
336 Plug-in hybrids can be charged with a plug that connects to the power grid.
337 Cf. Acatech (2017: 28). Electrolysis for hydrogen production alone involves an energy loss of approx. 30 percent. Cf. Gatzen and Pietsch (2019).
338 Cf. Gatzen and Pietsch (2019: 63).
339 Cf. Gatzen and Pietsch (2019: 63).
340 Depending on their delivery rate, connecting charging stations to the power grid may require installers to either notify or obtain approval from the grid operator (delivery rate of over 4.5 kVA or 12 kVA). Cf. Gatzen and Pietsch (2019: 98).
341 For a detailed analysis of how lock-in effects occur in the German energy system and how to combat them, taking the transport sector as an example, cf. also Fischedick and Grunwald (2017).
342 Cf. https://www.sueddeutsche.de/wirtschaft/co-werte-umweltministerium-knickt-bei-klimazielen-fuer-autos-ein-1.4145921 (last accessed on 18 January 2019). The fleet target for 2030 involves a 37.5 percent reduction in CO_2 emissions between 2021 and 2030.
343 Cf. Ausfelder et al. (2017).
344 Due to its mechanical stability, coke is used in blast furnaces to ensure stable layering. Coke therefore cannot be replaced by REs without the entire process of steel production having to be revised. Cf. Ausfelder et al. (2017).
345 In cement production, limestone is converted into calcium oxide and CO_2. Cf. Ausfelder et al. (2017).
346 Such technologies are known as carbon capture and storage (CCS) or carbon capture and utilization (CCU).
347 For an outline of power-to-X technologies to produce methylene or ammonia, cf. dena (2018). For an outline of how hydrogen can be used in the production of steel, cf. Hölling et al. (2017) and https://www.deutschlandfunk.de/stahlindustrie-wasserstoff-statt-koks-und-kohle.697.de.html?dram:article_ id=429977 (last accessed on 18 January 2019).
348 The Federal Government promotes these technologies as part of the 7th Energy Research Programme. Cf. BMWi (2018b).
349 Plastic strips known as biopolymers can be used to recover energy from waste heat. These strips exhibit extreme bending when heated. This movement can be used to generate power in a thermal engine. Cf. Gatzen and Pietsch (2019: 47).
350 Cf. Viebahn et al. (2018).
351 Among others, cf. https://www.bmbf.de/de/energiewende-565.html (last accessed on 18 January 2019).
352 Cf. BMWi (2018b).
353 For a list of all of the Federal Government's active and planned measures relating to the societal challenge of sustainability, energy and the climate in the HTS 2025, cf. https://www.hightech-strategie.de/de/massnahmen-1697.php (last accessed on 18 January 2019).
354 For instance, by supporting a Kopernikus Project on system integration, the Federal Government is promoting research into the integration of electricity in the building and transport sectors. Cf. https://www.kopernikus-projekte.de/projekte/systemintegration (last accessed on 18 January 2019). Furthermore, expanding project support from matters of individual technologies to systemic and cross-system issues in the energy transition is one of the basic principles of current energy research policy. Cf. BMWi (2018b: 6).

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355 Blockchain was first described as a technology in a 2008 whitepaper. Cf. Nakamoto (2018). The original idea was to create a system which enabled payments to be processed digitally and which could overcome the issue of digital copies and so-called 'double spending'. The development of blockchain technologies therefore created a method to generate non-copyable, unique values in digital form. Since then, as well as cryptocurrencies – which stemmed from this idea – a range of other applications have been created based on blockchain technologies.
356 For example, Vitalik Buterin, the founder of the Ethereum blockchain, announced that he would take a back-seat role at Ethereum in order to allow the growing developer community greater scope to act. Cf. https://www.technologyreview.com/s/612372/ethereums-founder-vitalik-buterin-says-his-creation-cant-succeed-unless-he-takes-a-step/ (last accessed on 18 January 2019).
357 Cf. IBM Maersk (2018a).
358 Cf. IBM Maersk (2018a). In addition, many steps in the documentation of this supply chain have not yet been digitized. Indeed, 60 percent of transactions between companies are conducted on the basis of paper invoices. Cf. Schütte et al. (2017).
359 Alternatively, the data can be stored in different (conventional) databases; however, the data must then be

aggregated along the entire supply chain. This could result in another information advantage for the organization aggregating the data.

360 Cf. IBM Maersk (2018b).

361 Cf. IBM Maersk (2018b).

362 For example, not everyone who uses the Bitcoin blockchain also receives a complete copy of the Bitcoin blockchain. Users are divided into either 'full nodes', which possess a complete copy, and 'lightweight nodes', which do not. Only full nodes can verify transactions and generate new blocks. Cf. Meinel et al. (2018).

363 Blockchain technologies are one example of more general distributed ledger technologies (DLTs). DLTs are technologies which hold and update a distributed data register; that is to say, they do not use a central administrator to do so. DLTs which do not compile transactions in blocks – and which are therefore not blockchains – include IOTA's Tangle or the Hedera Hashgraph. Cf. Reetz (2019).

364 For example, transactions in the Ethereum blockchain can be viewed at https://etherscan.io/. Transactions in the Bitcoin blockchain can be viewed at https://block-explorer.com/ (each last accessed on 18 January 2019).

365 Cf. Meinel et al. (2018).

366 The energy consumed by the Bitcoin blockchain can be estimated based on the number of calculations made in mining and using assumptions relating to the computing power and power consumption of mining hardware. Cf. Vries (2018).

367 The classic payment system Visa carries out around 56,000 transactions per second. Proof-of-work blockchains in particular have a markedly lower throughput. For instance, Bitcoin currently carries out around three transactions per second. Cf. https://www.blockchain. com/de/charts/transactions-per-second? (last accessed on 18 January 2019).

368 The term 'smart contracts' is somewhat misleading as these contracts are neither smart nor intelligent, nor are they contracts in the legal sense of the word.

369 Cf. https://www.cnbc.com/2018/06/07/1-point-1b-in-cryptocurrency-was-stolen-this-year-and-it-was-easy-to-do.html (last accessed on 18 January 2019).

370 Among the largest thefts from crypto-exchanges in 2018 were the thefts on Coincheck (approx. €473 million), Bitgrail (approx. €151 million), Coinrail (approx. €35 million), Bithumb (approx. €27 million) and Bancor (approx. €20 million).

371 In such attacks, the attacker commands greater computing power than the rest of the miners combined and is therefore able to generate new blocks faster than the rest of the network. This therefore makes it possible to abstract (i.e. steal) an amount of cryptocurrency. Examples of successful 51 percent attacks have concerned the cryptocurrencies Verge, Litecoin Cash, ZenCash, Bitcoin Gold and MonaCoin.

372 Cf. https://www.fca.org.uk/firms/regtech/our-work-programme, http://blockchain.cs.ucl.ac.uk/barac-project/ and https://www.r3.com/research/paying-for-mistakes-how-blockchain-technology-can-reduce-regulatory-penalties-and-compliance-costs/ (each last accessed on 18 January 2019). In order to observe regulatory requirements, such as those set down in MiFID II (Markets in Financial Instruments Directive II), a variety of information on completed transactions must be reported. In some circumstances, this information may be distributed across different organizations. Collating the necessary information in a safe and coherent manner therefore entails considerable administrative effort. Blockchain technologies can help to collate the necessary information from across different organizations in a manner that prevents manipulation.

373 In this regard, the FCA explains: "In particular, we believe that using DLT for regulatory reporting purposes could reduce costs to both firms and regulators and significantly improve our access to data. This would, in turn, allow us to identify areas of emerging risk more efficiently and improve the speed and accuracy of our response." FCA – Financial Conduct Authority (2017: 20).

374 Cf. Aste (2018).

375 Cf. https://www.uledger.co/blockchain-works-data-integrity/ and https://www.ericsson.com/en/security/data-centric-security/blockchain-data-integrity (each last accessed on 18 January 2019).Vgl. https://cryptowerk.com/blockchains-iot-clinical-trial-data/ (last accessed on 18 January 2019).

376 Cf. https://cryptowerk.com/blockchains-iot-clinical-trial-data/ (last accessed on 18 January 2019).

377 Cf. https://energyweb.org/ (last accessed on 18 January 2019).

378 Cf. https://ipdb.io/ (last accessed on 18 January 2019).In the case of the IPDB, at least half of the organizations that validate blocks must be not-for-profit organizations.

379 Cf. http://www.bamf.de/DE/DasBAMF/BAMFdigital/Blockchain/blockchain.html (last accessed on 18 January 2019) and Fridgen et al. (2018).

380 Cf. Fridgen et al. (2018).

381 Cf. http://www.bamf.de/DE/DasBAMF/BAMFdigital/Blockchain/blockchain.html (last accessed on 18 January 2019).

382 The program code of the flight delay insurance provider fizzy can be viewed at https://etherscan.io/address/0xe083515d1541f2a9fd0ca03f189f5d321c73b872#code (last accessed on 18 January 2019). In contrast to conventional software, which could automatically work to process flight delays for insurance companies, a smart contract can be viewed at all times because it is stored in a public blockchain.

383 For example, cf. https://ripple.com/use-cases/banks/ (last accessed on 18 January 2019).

384 For the United Kingdom, cf. HM Land Registry (2018). For Sweden, cf. Lantmäteriet (2018).

385 Approaches using blockchain-based land registers are being pursued in countries such as Ghana and Kenya Cf. https://www.reuters.com/article/us-africa-landrights-blockchain/african-startups-bet-on-blockchain-to-tackle-land-fraud-idUSKCN1G00YK (last accessed on 18 January 2019).

386 One example of the use of blockchain technology with regard to motor vehicles is the collaboration between Porsche and XAIN. Cf. https://medium.com/@XAIN/part-1-technical-overview-of-the-porsche-xain-vehicle-

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network-f70bb117be16 or https://newsroom.porsche.com/en/porsche-digital/porsche-blockchain-panamera-xain-technology-app-bitcoin-ethereum-data-smart-contracts-porsche-innovation-contest-14906.html (each last accessed on 18 January 2019).

387 On this basis, blockchain start-ups are working to develop business models which not only make data securely available, but simultaneously also render intellectual property claims transparent and make the use of this data billable. Cf. https://blog.oceanprotocol.com/how-ocean-can-benefit-data-scientists-7e502e5f1a5f (last accessed on 18 January 2019).

388 Of the 150 German blockchain start-ups recorded, 70 are headquartered in Berlin, 22 in Munich, 13 in Frankfurt, 5 in Hamburg and 4 each in Cologne and Mainz. Cf. chain.de (last accessed on 18 January 2019).

389 Cf. Reetz (2019).

390 Cf. Bonset (2018).

391 Cf. Bonset (2018).

392 The activity of developers on the Ethereum blockchain exceeds activities on other blockchain platforms many times over. Taking the number of questions answered on GitHub as a measure, Ethereum appears 330 percent more often than its closest competitor. Taking forks as a measure, Ethereum is some 657 percent ahead of its closest competitor. Cf. EY (2018).

393 VCf. Hileman and Rauchs (2017) or https://outlierventures.io/startup-tracker/#ecosystem (last accessed on 18 January 2019).Vgl. Acatech (2018).

394 Cf. Acatech (2018).

395 It is estimated that the energy consumption of the Bitcoin blockchain in 2018 roughly corresponds to the energy consumption of Austria. Cf. Vries (2018).

396 Cf. the wait-and-see strategy in Finck (2018: 675).

397 Cf. Reetz (2019).

398 The development community is very international, meaning that language barriers in matters of policy and administration not only concern specialist terminology, but also concern the overall language selection (German or English). Cf. Reetz (2019).

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399 Cf. EFI (2018: chapter A 4).

400 Cf. Gilch et al. (2019: 30).

401 The difficulties are due in part to the specific nature of tertiary education (TE) institutions' governance systems, which differ from the governance systems of private companies. For example, the Imboden Commission states that, in addition to legislation concerning TE institutions (Hochschulgesetze) and other regulations, distinct de facto constitutions exist which, in many cases, lead to the leaderships of TE institutions failing to fully utilize the powers formally accorded to them. According to the Commission, cultures of collegial decision-making curb the dynamism of reform processes and prevent the transition of TE institutions from a public authority to an institution that adopts an entrepreneurial approach in its thoughts and actions. Cf. Internationale Expertenkommission Exzellenzinitative (2016).

402 The Imboden Commission states that "Excellence Clusters in particular tend to develop into special units within the university which confronts the leadership of a university with centrifugal forces. The Commission therefore concludes that considerable untapped potential still remains with regard to the governance of German universities and that there is much work to do in this respect." Cf. Internationale Expertenkommission Exzellenz-initative (2016: 35) as well as Reichert et al. (2012: 78ff.).

403 Cf. Gilch et al. (2019: 65).

404 Only 15 percent of participating TE institutions stated that they neither have nor are planning to implement a digitalization strategy. Cf. Gilch et al. (2019: 65f.).

405 Cf. Gilch et al. (2019: 43).

406 Cf. Gilch et al. (2019: 26).

407 Research information systems are combined database and reporting systems that make it possible to comprehensively document, evaluate and further develop research activities. Cf. Riechert et al. (2015).

408 Research data management systems are systems which prepare, store, archive and publish research data. Cf. Simukovic et al. (2013).

409 Own evaluation of survey data in Gilch et al. (2019).

410 Own evaluation of survey data in Gilch et al. (2019).

411 Cf. Gilch et al. (2019: 36).

412 The processes are shaped not only by the TE institutions, but are also influenced to a large degree by the researchers themselves, as well as research communities and parties who support research. Cf. Gilch et al. (2019: 36).

413 Cf. Gilch et al. (2019: 36).

414 Cf. Pongratz (2017: 18).

415 Cf. http://www.eresearch.uni-goettingen.de/de/content/%C3%BCber-uns (last accessed on 18 January2019).

416 Cf. http://www.eresearch.uni-goettingen.de/de/content/%C3%BCber-uns (last accessed on 18 January 2019).

417 The eResearch Alliance advises on topics such as data storage, data exchange and data retention as well as data formats, metadata and potential methods of publishing data. Furthermore, it provides information on open access issues, in relation to the tools and services available on the Göttingen Campus and concerning funding applications for IT hardware and research equipment. Cf. http://www.eresearch.uni-goettingen.de (last accessed on 18 January 2019).

418 Cf. https://www.bmbf.de/de/hoechstleistungsrechnen-staerkt-den-forschungsstandort-deutschland-852.html (last accessed on 18 January 2019).

419 Cf. European Commission (2018) and https://www.faz.net/aktuell/wirtschaft/kuenstliche-intelligenz/wirtschaftliche-aufholjagd-deutschland-sucht-anschluss-an-amerika-und-china-15660967.html (last accessed on 18 January 2019).

420 The Juwels supercomputer in Jülich currently has theoretical peak output of up to 12 petaflops (twelve billion computing operations per second). There are plans to significantly increase its computing power in 2019. Cf. Forschungszentrum Jülich (2018). The supercomputer in Garching, Super-MUC Next Generation, is currently the fastest computer in Germany at 26.9 petaflops, which makes it the eighth-fastest globally. Cf. https://www.lrz.de/services/compute/supermuc/supermuc-ng

and https://www.heise.de/newsticker/meldung/Super MUC-NG-Bayern-in-der-Champions-League-der-Supercomputer-4171864.html (each last accessed on 18 January 2019). The Federal Government and the Länder provide funding for supercomputers in Germany. As well as the further, incremental expansion of the infrastructure, this funding is also addressing the development of computing structures and software technologies. The Federal Government has supported this project with over €225 million in funding. The Länder have contributed the same amount. Cf. https://www.bmbf.de/de/hoechstleistungsrechnen-staerkt-den-forschungsstandort-deutschland-852.html (last accessed on 18 January 2019).

421 The computing speed of the planned Exascale computer is set to exceed the computing speed of current petascale computers by a factor of thousands. In Germany, however, the focus is not to be placed exclusively on Exascale hardware: consideration will also be given to smart scaling, a method that connects numerous computers together. The Federal Government and the Länder plan to support the project with almost €500 million by the end of 2025. Cf. http://www.gauss-centre.eu/SharedDocs/Pressemitteilungen/GAUSS-CENTRE/EN/2017-06a_GCS_smart_exascale_german.html (last accessed on 18 January 2019).

422 The Federal Government and the Länder together provide €62.5 million per year in funding. Cf. GWK (2018c). By setting up this body, the Federal Government and the Länder are reacting to the recommendations on the financing of national supercomputing put forward by the German Council of Science and Humanities (Wissenschaftsrat, WR) in 2015. In its recommendations, the WR criticized the lack of coordination between level 2 computing centres (Hochleistungsrechenzentren); it identified the cause of this to be the competition for funding from the programme for “joint funding for the construction of research facilities, including large scientific installations” pursuant to Art. 91b of the German Constitution (Grundgesetz, GG).

423 Cf. GWK (2018d).

424 In order to use this data for new scientific inventions and innovations, systematic and permanent access to digititalized databases is crucial. The data, collected from various sources and in various ways, must be prepared in such a way that third parties can easily search through the organized data to find the data they require; it must also be possible to connect and analyze this data beyond the boundaries of individual databases, disciplines and countries. To achieve this, a standardized data management approach is required. In accordance with the so-called FAIR principles, research data should be findable, accessible, interoperable and reusable. To date, these requirements have not been met. Cf. RfII (2018).

425 Cf. GWK (2018d).

426 Some contact points already exist, such as those in Thuringia, North Rhine-Westphalia and Baden-Württemberg.

427 The science-based procedure to assess funding applications from consortia is carried out by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG); decisions regarding funding are taken by the Joint Science Conference (Gemeinsame Wissenschaftskonferenz, GWK) on the basis of the DFG’s assessment. Cf. GWK (2018d).

428 The programme started in 2019. Cf. GWK (2018d).

429 To enable research data centres to be virtually networked throughout Europe, Germany, France and the Netherlands together started the GO FAIR initiative. The objective of GO FAIR is to create framework conditions that make it possible to collate research data that currently exists across scientific institutions, in all research disciplines and across national boundaries. In the set-up phases, support and coordination offices were funded by the German, French and Dutch research ministries. These offices will establish implementation networks and promote scientific and e-infrastructure projects to provide data and services according to FAIR principles (i.e. that data should be findable, accessible, interoperable and reusable). Cf. https://www.bildung-forschung.digital/de/mit-go-fair-auf-dem-weg-zur-europaeischen-wissenschaftscloud-2173.html (last accessed on 18 January 2019).

430 At present, there are no standardized statistics regarding the spread of open access. Depending on the distinctions made (i.e. green or golden way), the share of all publications published through open access ways varies between 15 and 45 percent. Cf. Deinzer (2018), Wohlgemuth et al. (2017) and Piwowar et al. (2018). To identify this development and the quantitative status of open access in Germany, the BMBF announced the creation of an Open Access Monitor in its Open Access Strategy published in 2016. Cf. BMBF (2016).

431 Information issued by the Max Planck Digital Library on 12 January 2019. Cf. also https://www.nature.com/articles/d41586-019-00135-8 (last accessed on 18 January 2019).

432 Cf. o.V. (2003); BMBF (2016); CDU, CSU & SPD (2018) as well as European Commission (2017). German scientific organizations, organized together in the Alliance of Science Organisations in Germany, have been pursuing the transformational process to open access since 2015 as part of the global Open Access 2020 Initiative. The Open Access 2020 Initiative is focused on ensuring that the funds raised through the current subscription model are used to support Open Access-based business models. Expert committees are tasked with considering specific publication preferences. The initiative aims to engage all actors involved in the publication process – and especially universities, research institutions, funding providers, libraries and publishers – in order to facilitate a swift and efficient migration to Open Access. Cf. https://oa2020.org/be-informed (last accessed on 18 January 2019). In Germany, the Open Access 2020 Initiative operates in conjunction with the DEAL project. The Alliance of Science Organisations in Germany initiated the DEAL project in 2016 in order to negotiate with major scientific publishing companies on country-wide licensing agreements and a national Open Access solution. The DEAL negotiations are led by the German Rectors’ Conference (Hochschulrektorenkonferenz, HRK). Cf. https://www.projekt-deal.de (last accessed on 18 January 2019). An agreement was reached with

the publishing company Wiley in January 2019. The three-year agreement includes a provision that enables all institutions participating in the DEAL project to access scientific journals published by Wiley dating back to 1997 in return for an annual fee. Researchers at DEAL institutions can publish articles as Open Access articles in Wiley journals. Cf. https://www.hrk.de/presse/pressemitteilungen/pressemitteilung/meldung/wiley-und-projekt-deal-unterzeichnen-einigung-4493 (last accessed on 18 January 2019).

433 Cf. EFI (2013: chapter A 2) as well as https://open-access.net/informationen-zu-open-access/positionen (last accessed on 18 January 2019).

434 Cf. Section 38 para. 4 of the Act on Copyright and Related Rights (UrhG). Cf. https://www.gesetze-im-inter net.de/urhg/_38.html (last accessed on 18 January 2019).

435 Cf. Bruch and Pflüger (2014).

436 Cf. Science Europe (2018) and https://www.coalition-s.org (last accessed on 18 January 2019).

437 Cf. DFG (2018b) and http://www.dfg.de/foerderung/info_wissenschaft/2018/info_wissenschaft_18_56/index.html (last accessed on 18 January 2019).

438 Cf. DFG (2018b) and http://www.dfg.de/foerderung/faq/open_access_faq/index.html (last accessed on 18 January 2019).

439 Cf. Gilch et al. (2019: 37).

440 Learning management systems are systems that serve to provide learning content and organize learning processes. Cf. Baumgartner et al. (2002).

441 Cf. Gilch et al. (2019: 47).

442 These include the University of Hamburg, the University Medical Center Hamburg-Eppendorf, the Hamburg University of Applied Sciences (HAW Hamburg), the Hamburg University of Technology (TUHH), HafenCity University Hamburg (HCU), the University of Fine Arts of Hamburg (HFBK Hamburg) and Hamburg University of Music and Threatre (HfMT).

443 Cf. https://www.mmkh.de/elearning/hamburg-open-online-university-hoou.html (last accessed on 18 January 2019).

444 Cf. https://wissenschaft.hamburg.de/hoou (last accessed on 18 January 2019).

445 Cf. https://www.uni-hamburg.de/newsroom/campus/20170926-hoou.html (last accessed on 18 January 2019).

446 Cf. https://www.hoou.de (last accessed on 18 January 2019).

447 Cf. Schmid et al. (2017: 14ff.) and https://www.e-teaching.org/news/eteaching_blog/themenspecial-lernmanagement-systeme-ein-resuemee (last accessed on 18 January 2019).

448 Own evaluation of survey data in Gilch et al. (2019).

449 Cf. Gilch et al. (2019: 49).

450 This survey shows that more than half of teaching staff regularly use learning management systems and simple digital instruments to support teaching, such as whiteboards, videos and presentation software. By contrast, other instruments and formats, such as digital game-based learning, social networks (social media) and inverted classrooms, are used only rarely. Cf. Schmid et al. (2017).

451 Almost 60 percent of teaching staff consider the media technology equipment at their TE institution to be good or very good. When the responses for ‘satisfactory’ are also included, over 80 percent of teaching staff in TE are generally satisfied with the technical equipment available at their institution. Cf. Schmid et al. (2017: 14).

452 Cf. Gilch et al. (2019: 53).

453 Cf. Gilch et al. (2019: 54).

454 Cf. Gilch et al. (2019: 139) and HFD (2016: 28).

455 Cf. Schmid et al. (2017: 25ff.) and Sailer et al. (2018: 48ff.).

456 Cf. Gilch et al. (2019: 139) and Sailer et al. (2018: 80). The scope available to TE institutions to offer incentives for digital teaching vary due to the uneven regulations concerning teaching commitment (Lehrverpflichtungsverordnungen) in force in different Länder. Cf. HFD (2016: 167) and Gilch et al. (2019: 181). In some Länder, such as North Rhine-Westphalia, the amount of time spent on the creation and maintenance of digital courses is limited to a maximum of 25 percent of the teaching load. Cf. Ministerium des Innern des Landes Nordrhein-Westfalen (2016). In other Länder, such as Lower Saxony, there are no such limits. Cf. Niedersächsisches Ministerium für Wissenschaft und Kultur (2018).

457 In most cases, the platforms are operated by individual TE institutions and institutes, or sometimes by consortia or associations of TE institutions also as part of an entrepreneurial initiative or partnership. To date, German TE institutions have been less active in this sector of academic education. Cf. HFD (2018: 10).

458 Web-based educational services, video lectures, massive open online courses (MOOCs), small mobile learning units and larger, more comprehensive online courses – with or without certification – are now offered on various international platforms. In competition with classic educational institutions, providers such as Udacity can train their customers to become machine learning engineers or data analysts within a short period of time. Such further education and training formats do not ultimately confer Bachelor’s or Master’s degrees and instead offer so-called Nanodegrees. Cf. HFD (2018: 10).

459 Example of MOOCs at the Technical University of Munich (TUM).

460 Cf. HFD (2018: 41).

461 Cf. HFD (2018: 35).

462 Cf. http://www.rwth-aachen.de/cms/root/Die-RWTH/Aktuell/Pressemitteilungen/Maerz-2017/~ngeb/Die-RWTH-Aachen-bietet-den-MicroMaster-a (last accessed on 18 January 2019).

463 Cf. HFD (2018: 40).

464 Course title: Managing Technology & Innovation: How to deal with disruptive change. Cf. http://www.rwth-aachen.de/cms/root/Die-RWTH/Aktuell/Pressemitteilungen/Maerz-2017/~ngeb/Die-RWTH-Aachen-bietet-den-MicroMaster-a (last accessed on 18 January 2019). The terms MicroMasters and Nanodegree are, in some cases, used interchangeably. Cf. https://www.edx.org/micromasters and https://eu.udacity.com/nano degree (last accessed on 18 January 2019).

465 The DHBW is one of MIT's 16 Credit Pathway Schools around the world. Cf. https://micromasters.mit.edu/scm/pathways-masters (last accessed on 18 January 2019). According to information provided by MIT, in December 2018, 7,804 students on its MicroMaster's courses were from Germany. (In addition to MicroMaster's courses, MIT also offers other online learning formats.) Almost 1,000 of these students have already received a course certificate. In total, more than 600,000 people from 196 countries are enrolled in MIT's MicroMaster's courses. These students are, on average, 32 years old and have six years' work experience. Of the students, 37 percent hold a Bachelor's degree and 35 percent hold a Master's degree.

466 Cf. https://micromasters.mit.edu/scm/pathways-masters (last accessed on 18 January 2019).

467 Cf. EFI (2018: 37) and EFI (2015: chapter B 2).

468 Cf. EFI (2015: 56).

469 Campus management systems are usually modular IT application systems used in TE institutions to provide comprehensive support in business processes in the area of student lifecycle (e.g. administration of students, courses and examinations). Cf. Auth and Künstler (2016).

470 Campus management systems have been fully implemented at 48 percent of TE institutions. Some 26 percent of TE institutions report that they have implemented resource management systems in full at their institution. Computer-aided facility management systems have been fully implemented at just 8 percent of TE institutions. Cf. Gilch et al. (2019: 47 and 56). Computer-aided facility management systems are IT systems which support the planning, management and documentation of facility management processes, such as the administration and management of buildings and their technical facilities. Resource management systems (also referred to as enterprise resource planning (ERP) systems) support business processes. Such processes include the management and administration of operating resources, such as capital, personnel and production goods.

471 Cf. Gilch et al. (2019: 57).

472 Other internal administrative processes include invoice processing, applicant management and the processing of staff holiday applications.

473 Cf. Gilch et al. (2019: 57).

474 In a 2017 study conducted by the Swiss consultancy Berinfor, German and Swiss TE institutions were surveyed on the topic of digitalization. While over 60 percent of German and Swiss TE institutions stated that they were taking opportunities to digitize study-related administrative processes to a high or very high degree, the evaluation of non-study-related administrative processes revealed a clear difference between German and Swiss TE institutions. For instance, 46 percent of Swiss TE institutions stated that they were taking opportunities to digitize non-study-related administrative processes to a high or very high degree; by contrast, only 30 percent of German TE institutions stated that they were doing so. Cf. own evaluation on the basis of Berinfor data taken from Licka and Gautschi (2017).

475 TE institutions' internal administrative processes are not covered by the Online Access Act (Onlinezugangsgesetz, OZG).

476 Cf. Stocksmeier and Hunnius (2018: 42f.).

477 Cf. Pongratz (2017: 24).

478 As part of the TUMonline basics video, staff members are given instruction in how to use TUMonline. The video addresses issues including the structure and various functions of TUMonline. It also explains how to apply for a staff card and set up a university email account.

479 These include IT processes in TE institutions' administrations as well as IT infrastructure projects in the field of teaching and, to a lesser extent, in research.

480 41 percent of TE institutions are engaged in collaborative endeavours relating to the digitalization of the institution as a whole. Cf. Gilch et al. (2019: 128).

481 For an overview of the associations and collaborations, cf. Gilch et al. (2019: 240ff.).

482 Cf. Gilch et al. (2019: 130).

483 For example, the Hessian state government promoted the establishment of e-learning competence centres at the state's TE institutions and later supported the creation of the Kompetenznetz E-Learning Hessen, a state-wide e-learning skills network, as a joint initiative of TE institutions in Hesse. Cf. Gilch et al. (2019: 240ff.) and https://wissenschaft.hessen.de/wissenschaft/it-neue-medien/kompetenznetz-e- learning-hessen (last accessed on 18 January 2019). In addition to this example of a domain-specific collaboration (in the field of teaching), overarching forms of collaboration also exist – such as the Digitale Hochschule NRW, a collaborative association of 42 TE institutions and the Ministry of Culture and Science of the State of North Rhine-Westphalia. The overriding aim of the Digitale Hochschule NRW is to coordinate and promote the digitalization of TE institutions in North Rhine-Westphalia in the actions fields of teaching, research, infrastructure and management Cf. Gilch et al. (2019: 241) as well as https://www.dh-nrw.de (last accessed on 18 January 2019).

484 An example of a collaborative endeavour in the field of research is the German National Research and Education Network (DFN), cf. https://www.dfn.de (last accessed on 18 January 2019). The DFN brings together more than 300 TE institutions and research institutions from across Germany and has created a computer-aided information and communication system. A central result of this collaboration is the establishment and further development of a shared cloud for science (the DFN Cloud). Furthermore, developing new and improved cloud services together with its members is a stated aim of the Network. Cf. https://www.dfn.de/dfn-cloud (last accessed on 18 January 2019).

485 Cf. HFD (2016: 30). An example of such a cooperation network is the Virtuelle Hochschule Bayern (vhb) – an institution made up of 31 Bavarian TE institutions that offers network-supported teaching content to students matriculated at a Bavarian TE institution. Cf. https://www.vhb.org/startseite (last accessed on 18 January 2019).

486 Examples of this include: the ILIAS learning platform of the Federal University of Applied Administrative Sciences, cf. https://www.hsbund.de/DE/02_Studium/50_ILIAS/ILIAS-node.html; the ProfiLehrePlus network of Bavarian TE institutions, cf. https://www.profilehreplus.de,

and the Hochschulforum Digitalisierung, cf. https://hochschulforumdigitalisierung.de. An example of an offering spanning Länder boundaries is the Virtuelle Fachhochschule (VFH), cf. https://www.vfh.de (each last accessed on 18 January 2019).

487 Cf. Gilch et al. (2019: 132). An example of this is the Hochschulservicezentrum Baden-Württemberg, which supports administrative departments of non-university TE institutions in introducing and using digital student administration, resource management and data processing. Cf. https://www.hsz-bw.de (last accessed on 18 January 2019).

488 Examples of IT services developed as part of associations and consortia of TE institutions include community clouds, such as the DFN Cloud and Sciebo, and media servers such as Videocampus Sachsen. Cf. HFD (2016: 163) and https://blogs.hrz.tu-freiberg.de/videocampus (last accessed on 18 January 2019).

489 Examples of such services include Sciebo, the cloud storage service from North Rhine-Westphalia, and Videocampus Sachsen. Cf. https://www.sciebo.de and https://blogs.hrz.tu-freiberg.de/videocampus (last accessed on 18 January 2019).

490 Digitalization is an ongoing, long-term task for TE institutions. Due to the short innovation cycles, new investment is repeatedly required in hardware and software as well as in staff qualification measures. In addition, the demand for supercomputers continues to grow, as do the complexity and security requirements of digital systems. Cf. Henke and Pasternack (2017: 81).

491 Cf. Gilch et al. (2019: 126).

492 Cf. Gilch et al. (2019: 126).

493 Cf. HFD (2016: 33).

494 The programme's aims are to obtain better staffing at TE institutions, to support them in qualifying and further training – as well as to secure and further develop high-quality teaching in TE. The basis of the funding programme is the Administrative Agreement (Verwaltungsvereinbarung) between the Federal Government and the Länder pursuant to Article 91b § 1 no. 2 of the German Constitution (Grundgesetz, GG) regarding a joint programme to secure better conditions of study and more quality in teaching, passed on 30 September 2010. The Federal Government supports TE institutions in implementing innovative measures, while the Länder in which TE institutions reside provide overall financing through basic equipment. Cf. https://www.bmbf.de/de/qualitaetspakt-lehre-524.html (last accessed on 18 January 2019) and information issued by the BMBF on 26 May 2018.

495 "Digital university education", a field of research established by the BMBF as part of its funding priority "scientific and university research", is dedicated to creating innovative digital learning and teaching formats as well as researching the structural conditions of their organization and success at different levels of TE. The aim is to generate scientifically substantiated knowledge on functioning digital formats, their framework conditions and any barriers to innovation in order to enable political actors and those in the sector to take action. Duration: 2017 to 2026; funding volume: €38.7 million. Cf. https://www.wihoforschung.de/forschung-zur-digitalen-hochschulbildung-27.php (last accessed on 18 January 2019).

496 The Hochschulforum Digitalisierung (HFD) was founded in 2014. It is a joint initiative of the Stifterverband für die Deutsche Wissenschaft, the CHE Centre for Higher Education and the German Rectors' Conference. The HFD pursues three targets: implementing TE strategies, developing competencies to use digital teaching and learning formats as well as generating new ideas and developing future scenarios. Cf. https://hochschulforumdigitalisierung.de/de/wir/hochschulforum (last accessed on 18 January 2019).

497 Cf. CDU, CSU, SPD (2018: 37ff.).

498 It stated that: "With the 'Open University Network', we want to offer distance-learning TE institutions a platform upon which to coordinate." Cf. CDU, CSU, SPD (2018: 33f.).

499 These concepts, which are often interdepartmental in nature, usually outline a general framework for the Länder governments' deliberations with regard to pushing digitalization forward in various topic areas and are underpinned with various specific measures and financial support, though the funding is frequently subject to budget approval. It is clear that digitalization strategies have been introduced and implemented to differing degrees in the individual Länder. Cf. Gilch et al. (2019: 181).

500 Own assessment of survey data. Cf. Gilch et al. (2019).

501 Cf. IT-Planungsrat (2016).

502 Cf. Gilch et al. (2019: 157).

503 Non-university research institutions that receive the majority of their funding from the Federal Government are not subject to the TV-L. Instead, they are subject to the Collective Wage Agreement for the Civil Service (TVöD) for institutions that receive public funds from the Federal Government (TVöD-Bund) or from municipal authorities (TVöD-VKA). Cf. Gilch et al. (2019: 116).

504 For instance, in the TV-L, IT specialists are allocated to salary groups on the basis of qualification requirements, job characteristics and job profiles in a markedly more stringently regulation system that in the TVöD, which therefore reduces TE institutions' scope to make individual personnel decisions. A further difference between the TVöD and TV-L is the fact that the TVöD allows personnel holding Bachelor's degrees in informatics to be allocated to salary group 13, whereas the TV-L only allows personnel with (postgraduate) diplomas or Master's degrees to be allocated to this group. Cf. Gilch et al. (2019: 117).

505 Differences between the TV-L and TVöD in relation to classification cannot be identified in the wage agreements themselves; instead, differences can be seen in the measures enacted by the Vereinigung der kommunalen Arbeitgeberverbände (VKA) and, independently, in the measures enacted by the Federal Ministry of the Interior (BMI) for the Federal Government as an employer. The general meeting of the VKA passed an "Employers' guideline (Arbeitgeberrichtlinie) for the attraction and retention of skilled workers, in particular in the area of information technology and concerning engineers", which

can be applied by member associations for the scope of jurisdiction of the TVöD-VKA and TV-L until 31 December 2020. The Länder, in their role as employers, are yet to pass a comparable guideline for their scope of jurisdiction. Cf. Gilch et al. (2019: 119) and Vereinigung Kommunaler Arbeitgeberverbände (2018).

506 It is possible to allocate newly recruited skilled workers without professional experience to levels 2 or 3 in the salary table in justified, isolated cases. If necessary in order to prevent individual employees from leaving for positions elsewhere, it is possible to allocate them to level 4. Cf. Gilch et al. (2019: 119). This employers' guideline also includes the option to grant skilled workers a bonus of up to €1,000 per month. The TV-L does not include comparable options. Cf. Gilch et al. (2019: 115) and Vereinigung Kommunaler Arbeitgeberverbände (2018).

507 However, the picture remains somewhat unclear, as other TE institutions have reported that the lengthy period between publication of the GDPR and its coming into force in Germany was sufficient time to prepare for its implementation. Cf. Gilch et al. (2019: 139).

508 The term 'learning analytics' denotes the interpretation of a wide array of data "produced by or collected for students in order to measure their learning progress, predict their future achievements and highlight potential problem areas." Cf. Johnson et al. (2012: 26).

509 Cf. HFD (2016: 52).

510 Cf. HFD (2016: 28).

511 Cf. HFD (2016: 23 and 28).

512 Cf. https://www.forschung-und-lehre.de/was-hochschulen-beim-datenschutz-beachten-muessen-772 and https://www.gew.de/tipps-zum-datenschutz (each last accessed on 18 January 2019).

513 Cf. Gilch et al. (2019: 128ff.) and HFD (2016: 35 and 169f.).

514 Cf. EFI (2015: 60ff.).

515 By introducing an exemption for scientific and educational purposes, the legislator, for example, afforded the users of copyright-protected works the freedom to make private copies for their own, personal use. In general, statutory exemptions can be combined with claims for payment by the copyright holder. Cf. EFI (2015: 60).

516 In accordance with the German Copyright Act (Urheberrechtsgesetz, UrhG), up to 15 percent of a published work may be copied and made available in order to illustrate content in teaching and classroom contexts at educational institutions. However, such content may only be made available to the respective event's teaching staff and participants along with other teaching staff and examiners at the same educational institution. A similar regulation applies to non-commercial scientific research. Up to 15 percent of a published work may be copied, distributed and made available; however, it may only be available to a limited group of people for the purposes of their own scientific research and to third parties in the event that it serves to review the quality of the scientific research. If it serves the purpose of a person's own research, copies can be made of up to 75 percent of a work. A new exemption has been introduced concerning text and data mining (Section 60d UrhG) in order to enable automatic analyses of source texts for non-commercial purposes. Cf. Kreutzer and Hirche (2017) and https://www.bmjv.de/SharedDocs/Gesetzgebungsverfahren/DE/UrhWissG.html (last accessed on 18 January 2019).

517 Cf. Kreutzer and Hirche (2017) and https://www.forschung-und-lehre.de/recht/hochschulrelevante-aenderungen-durch-das-geplante-urhwissg-195 (last accessed on 18 January 2019).

518 Cf. https://www.bmjv.de/SharedDocs/Gesetzgebungsverfahren/DE/UrhWissG.html (last accessed on 18 January 2019).

519 Cf. EFI (2012: 58).

520 Cf. EFI (2012: 58) and EFI (2015: 57).

C 1

521 Cf. Gehrke et al. (2019).

C 2

522 Cf. Schasse (2019).

C 3

523 In this regard and in the following, cf. Rammer and Hünermund (2013).

524 In this regard, cf. also Rammer et al. (2019).

525 Cf. Blind (2002).

526 Cf. ISO (2009) and https://www.iso.org/members.html (last accessed on 18 January 2019).

C 4

527 This section and the figures that follow are based on Bersch and Gottschalk (2019).

528 Internal financing is rarely an option, as these companies initially generate little or no turnover with which to fund investment and pay for current expenditure. Borrowing outside capital in the form of bank loans is also difficult, as it is not easy for banks to assess the companies' success prospects.

529 Invest Europe is the European Association of Private Equity & Venture Capital Investors. Together with the European Data Cooperative (EDC), it runs a platform that collects data on private equity and venture capital. Invest Europe regularly supplies updated data on venture-capital investment based on the information in the EDC database and data from Eurostat and the International Monetary Fund. The data supplied is based on information from the national venture-capital associations, which receive their information from member surveys. The harmonized acquisition and processing of data ensures good international comparability.

530 This is the case when investing market participants are not registered as members of Invest Europe, or if an investor comes from outside Europe.

531 The Zephyr M&A database contains information on mergers and acquisitions (M&A), categorized according to private-equity, venture-capital and business-angel investments. The information includes the investment

sum, the company being invested in (portfolio company), and the investor. Since the Zephyr M&A database primarily contains major investments, information from this database is complemented by information from the Majunke transaction database. It is made available by Majunke Consulting and covers venture-capital investment in Germany, Austria and the German-speaking part of Switzerland. It also contains information on the investment sum, the portfolio company and the investor, and also includes small investments. Since both databases also contain many other investments in companies in addition to venture-capital investments, each transaction is checked to determine with reasonable likelihood whether it is indeed a venture-capital investment. For this purpose, information from regarding the (natural and legal) persons participating in a company is drawn from the Mannheim Enterprise Panel (MUP).

532 Atypical investors are all those market participants who enter into direct venture-capital holdings, but whose core business is another. They may include, for example, asset managers, funds of funds, banks and insurers, as well as established companies.

C 5

533 However, the individual countries' data is not fully comparable. For further details, cf. Müller et al. (2014).

534 In this regard and on individual points, cf. Müller et al. (2013).

535 In this regard and in the following, cf. Bersch and Gottschalk (2019: 29).

536 An original, newly formed company is created when a business activity not exercised before is begun and provides at least one person with their main source of income. A company closure is when a company no longer exercises any business activity and no longer offers products on the market.

537 The MUP has a much narrower definition of economically active companies, market entries and market exits, so that relatively small entrepreneurial activities are not covered in the MUP.

538 In this regard and in the following, cf. Bersch and Gottschalk (2019: 12).

539 In this regard and in the following, cf. Bersch and Gottschalk (2019: 17).

540 In the following, cf. Bersch and Gottschalk (2019: 24).

C 6

541 Cf. Neuhäusler et al. (2019).

C 7

542 Cf. Stahlschmidt et al. (2019).

C 8

543 This section and the figures that follow are based on Gehrke and Schiersch (2019).

544 For a methodological explanation of the RCA indicator,cf. Schiersch and Gehrke (2014: 74f.).

D 4

545 Cf. Gehrke et al. (2013).

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