

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

Research Report

Report on research, innovation and technological performance in Germany 2024

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REPORT ON RESEARCH,
INNOVATION AND TECHNOLOGICAL
PERFORMANCE IN GERMANY

COMMISSION OF EXPERTS
FOR RESEARCH
AND INNOVATION



REPORT

2024 2025 2026

2027 2028 2029

2030 2031 2032

REPORT ON RESEARCH,
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FOR RESEARCH
AND INNOVATION



REPORT 2024

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Foreword

The Commission of Experts for Research and Innovation presents its 2024 Annual Report to the German Federal Government in particularly challenging political times. Issues such as the wars in Ukraine, Israel and the Gaza Strip, the energy crisis and the economic downturn are dominating the political discourse. They all demand the attention of the Federal Government and require its immediate action. But at the same time, and this is the particular challenge for the politics of our time, the focus on these acute problems must not lead to neglecting the necessary transformation of the economy and society towards sustainability based on technological and social innovation. Postponing transformation efforts would not only have dangerous ecological consequences but would also jeopardize the basis of our medium- and long-term prosperity and social stability.

The 2024 Annual Report of the Commission of Experts for Research and Innovation should be read against the background of this tension between multiple current crises on the one hand and long-term transformation requirements on the other. In addition to statements on how transformation-oriented research and innovation policy should be designed in this situation, the Annual Report contains, as in previous years, commentaries on current research and innovation policy as well as analyses of key topics and problem areas in the German research and innovation system. The much-discussed topic of artificial intelligence certainly features prominently here. However, the Annual Report is also dedicated to less widely discussed topics that should be given more attention in the future. These include agriculture and its transformation potential, the international mobility of researchers and the associated question of Germany's attractiveness as a location for science and innovation, as well as social innovations and their role in transformative change.

Berlin, 28 February 2024



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EXECUTIVE SUMMARY

Executive Summary

A Current Developments and Challenges

A0 Transformative R&I Policy

The current coalition government has taken over a project of superlatives from its predecessor: the transformation of the economy and society.

The energy transition, the mobility transition, the digitalization of the economy and society and the creation of sustainable agriculture are just some of the transformations that the Federal Government has placed at the centre of its Future Strategy for Research and Innovation. These transformations require a multitude of technological and social innovations. A complex mission concept consisting of strategies, reforms and measures must be developed and implemented for each one.

The Commission of Experts recognizes the progress that the Federal Government has achieved within the framework of its transformation-oriented policy. However, it fears that due to increasing geopolitical constraints and emerging domestic political unrest, resulting in part from the implementation of transformation-oriented measures, the long-term transformation orientation could give way to a more short-term crisis management policy.

The Commission of Experts therefore recommends that the Federal Government regularly incorporate the following five fundamental considerations into the design and implementation of transformation-oriented policy measures.

- Considering long-term and structural objectives in short-term measures.
- Incorporating social compensation into measures for transformative change from the outset.
- Not supporting structural change exclusively in financial terms.
- Leaving the search for innovative solutions to the economy and allowing society to participate.
- Securing human capital in the long term.

A 1 Commentary on Current R&I Policy

Implementing Future Strategy, Vigorously Pursuing Missions

The Commission of Experts deems the mission team format to be fundamentally suitable for implementing the numerous tasks subsumed within the missions.

The Commission of Experts considers it important to continue the involvement of the state secretary level in the development of the mission teams and to provide continuous strategic support for the operational work of the mission teams. It also considers it important that the mission teams are provided with their own budgets.

In addition, the fundamental question of the time frame of the Future Strategy arises. Given that the missions formulated by the Federal Government are ultra long-term projects, the realization of which requires complex institutional arrangements, achievement of the defined objectives within the current legislative period is illusory. Nevertheless, the Federal Government should continue to vigorously pursue the implementation of its missions and not sacrifice them to day-to-day short-term political considerations. A government that takes mission-oriented policy seriously must realize that a significant part of the successes of its own policy will not be achieved in the current legislative period.

Introducing Regulatory Sandboxes Law Promptly

Regulatory sandboxes create the opportunity to reduce technological and economic uncertainties in the innovation process in a protected space, to test regulatory measures and framework conditions and to involve potential users in development at an early stage. This can significantly shorten the often long path to commercialization of innovations.

The Commission of Experts therefore expressly welcomes the Federal Government's initiative to create a regulatory sandboxes law and urges that the drafting process be brought to a swift conclusion.

Regulatory sandboxes are generally based on experimentation clauses that allow the competent authorities to authorize controlled exemptions from legal requirements and restrictions in order to test an innovation. It is important that the experimentation clauses in the respective laws are as broad as possible and not specifically defined for particular projects. The narrower an experimentation clause is defined, the greater the likelihood that it will no longer be applicable after a relatively short time.

SPRIND Freedom Only Partially Implemented

The Commission of Experts considers the SPRIND Freedom Act, which came into force at the end of 2023, to be an overdue step in the desired direction. However, it criticizes the lack of courage in some points of detail to complete the liberation of the Federal Agency for Disruptive Innovation (SPRIND) and to give it the required independence from politics and the deadlines of the Federal Budget Code.

For example, the demand for the complete abolition of functional supervision by the federal ministries was only partially met in the SPRIND Freedom Act. Even if the functional supervision is to concentrate solely on ensuring the economic fulfilment of tasks and is to be carried out by the Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF) alone instead of three ministries, the Commission of Experts sees the risk of dual control. After all, the BMBF is already represented on the supervisory board alongside the Federal Ministry of Finance (Bundesfinanzministerium, BMF), the Federal Ministry for Economic Affairs and Climate Action (Bundesministerium für Wirtschaft und Klimaschutz, BMWK) and two members of the Bundestag. The scope for political influence is therefore considerable.

All in all, the Commission of Experts hopes that the steps taken with the Freedom Act to unleash SPRIND will also herald a change of direction in research and innovation policy (R&I policy) – away from risk aversion and tight control towards entrepreneurial thinking and agility.

Making DATI Open

A key innovation policy project of the Federal Government is finally taking shape with the convening of a founding commission for the German Agency for Transfer and Innovation (Deutsche Agentur für Transfer und Innovation, DATI) and the decision to establish the agency's headquarters in Erfurt. The so-called DATIpilot has also been launched as the first round for the selection of transfer projects. The two funding formats Innovation Sprints and Innovation Communities initiated as part of the DATIpilot have met with a great response. The Commission of Experts considers the high level of participation in the two funding formats to be a positive sign in terms of awareness and acceptance of the nascent DATI.

The Commission of Experts also attributes the large number of submitted project proposals to the fact that the conditions for participation in the DATIpilot were defined very openly. This openness contrasts positively with the original key issues paper, which was presented in April 2022 and criticized by the Commission of Experts for having too narrow a funding focus.

The Commission of Experts expects that this openness will also be reflected in the DATI concept that is yet to be developed.

Making the Research Allowance More SME-friendly

Despite increasing application numbers, many companies are still unaware of the research allowance introduced in 2020. Smaller businesses in particular are often unaware of the existence of this new funding format. Moreover, three quarters of companies active in research and development (R&D) state that they have not yet applied for a research allowance. Similar to the level of awareness, small and medium-sized enterprises (SMEs) also lag far behind large companies when it comes to submitting applications. In addition to targeted public relations work to improve awareness of the research allowance, initial survey-based studies point above all to the need to reduce the administrative effort involved in applying for the research allowance.

The extent to which the research allowance has succeeded in motivating companies to increase their R&D expenditure cannot be deduced from the studies to date. The same applies to the question of whether companies not previously engaged in R&D have now been motivated to start doing so. Given the declining innovator rate, these issues are of key importance and represent a particular desideratum for the evaluation of the research allowance.

Facilitating IP Transfer for Spin-offs

Germany is struggling to generate research-based spin-offs from scientific institutions such as tertiary education institutions and non-university research institutions. One of the main reasons for this is the difficulty of transferring intellectual property (IP), in the form of patent sales or licence agreements, from the scientific institution to the company being founded.

The IP-Transfer 3.0 initiative was launched to facilitate a more straightforward and start-up-friendly transfer of IP to research-based spin-offs. Among other things, it adopts a model that provides for so-called virtual shares in the spin-offs in return for the transfer of IP. In contrast to conventional shares, the IP donors waive their voting rights in virtual shares.

To mitigate the structural conflicts of interest between scientific institutions and entrepreneurs in IP transfer negotiations, the Commission of Experts recommends modifying the incentive systems. For example, the transfer success of scientific institutions should not be measured based on income from patent sales and licence income, but rather in terms of the sustained success of the spin-offs they support.

Removing the Strict Separation Between Military and Civilian R&D

The relationship between military and civilian research and development (R&D) can be divided into two categories: spillovers and dual use. In many countries, spillovers and dual use are deliberately promoted as they lead to increases in performance and efficiency in both the military and civilian sectors.

Prominent examples include the DARPA (Defense Advanced Research Projects Agency) in the USA and the military unit 8200 in Israel. Germany has so far largely foregone these positive effects due to its strict separation of military and civilian research.

In view of increasing global threats, the Commission of Experts recommends re-evaluating the options for managing military R&D. Studies show that military R&D can have positive effects on civilian R&D via spillovers and thereby also positively impact productivity and employment in the civilian sector in addition to increasing performance in the military sector. To achieve this efficiently, synergies between military and civilian research should be made possible. The strict separation that has been customary in Germany for decades needs to be fundamentally reconsidered and abolished where appropriate.

Facilitating the Utilization of Standard Essential Patents

The Commission of Experts welcomes the EU's initiative to make the market for standard essential patents (SEPs) more transparent and thus reduce the

existing information asymmetry between patent holders and licensees. It deems the planned drafting of voluntary guidelines for SEP licensing and the introduction of a conciliation process prior to the initiation of a legal dispute to be fundamentally sensible. The Commission of Experts is also in favour of setting up an SEP register and introducing an assessment procedure in the form of an essentiality check. However, it is sceptical as to whether an essentiality check can be carried out for the entire SEP portfolio.

The Commission of Experts is equally critical of the establishment of a procedure for determining an aggregate royalty for SEP.

Since the value of SEP licences cannot be defined objectively, but is determined by supply and demand, setting a value that is not based on the market is highly unlikely to lead to an acceptable result for licensors and licensees.

The Commission of Experts is moreover sceptical as to whether the European Union Intellectual Property Office (EUIPO), which is only responsible for the registration of EU trade marks and designs but not for patents, can fulfil the tasks assigned to it within a narrow time frame.

Finally Harnessing the Potential of Data

In its reports, the Commission of Experts has repeatedly emphasized the huge importance of data for the research and innovation system (R&I system). It therefore welcomes the fact that the Health Data Utilization Act has now been passed, paving the way for the use of health data to improve diagnosis and treatment for patients.

However, more measures still need to be taken and implemented, such as the establishment of an agricultural data space and the passing of the Research Data Act.

There are already numerous proposals for improving the infrastructure and access to publicly funded data and for linking individual datasets. These involve, among other things, necessary adjustments to existing legislation and its inconsistent interpretation in the Länder (including the General Data Protection Regulation – GDPR, the Federal Statistics Act and the Tax Statistics Act).

The Commission of Experts reiterates that significant progress in the provision and use of data is essential in order to achieve progress also in the areas of data application and to achieve the digital transformation.

A2 Determining the Causal Effects of Interventions

Many of the evaluation studies on measures of research and innovation policy (R&I policy) carried out on behalf of the Federal Government do not allow any conclusions to be drawn as to whether the developments observed can actually be attributed to the policy measures analysed. The main reason for this is that evaluation studies often do not fulfil the methodological requirements for a causal analysis, not least because the prerequisites for the appropriate use of suitable methods are not always met. The lack of knowledge about the impact of measures impedes evidence-based policy learning. The Federal Government

is therefore called upon to integrate causal analyses of the effects of measures systematically and comprehensively into R&I policy and thus create the conditions for the proper and professional implementation of these analyses and their usability for policy learning.

To this end, it is necessary to include causal analyses in the specifications when tendering for evaluation studies, to improve the availability of data for the evaluating organizations and to publish all commissioned evaluation studies.

B Core Topics 2024

B 1 New Technologies for Sustainable Agriculture

Global population growth, climate change, the decline in arable land and the negative impact on the environment caused by agriculture itself, such as biodiversity loss and groundwater pollution, constitute major challenges for agriculture.

Agriculture must by tendency produce larger quantities of food with fewer environmentally harmful inputs such as pesticides and fertilisers, while at the same time arable land is decreasing and climate conditions are changing. The use of digital and smart technologies as well as green genetic engineering offer agriculture numerous opportunities to increase productivity, make farming practices more sustainable and improve resilience to climate change.

Although digital and smart technologies can significantly reduce negative environmental impacts, farms currently have little incentive to use such technologies as they are still comparatively expensive. There is also a lack of digital infrastructure and interoperability between hardware and digital applications. The opportunities offered by green genetic engineering cannot be fully utilized due to restrictive legislation and a lack of acceptance and information among the public and politicians. The Commission of Experts therefore recommends the following measures, among others, to the Federal Government and in particular to the Federal Ministry of Food and Agriculture (Bundesministerium für Ernährung und Landwirtschaft, BMEL), the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz, BMUV) and the Federal Ministry for Digital and Transport (Bundesministerium für Digitales und Verkehr, BMDV):

- The use of pesticides and fertilisers should be subject to a levy based on the Danish model.
- The digital infrastructure in rural regions must be expanded.

- The Federal Government should create a standardized data room for agriculture across the Länder and adopt clear regulations on data protection and data sovereignty.
- The Federal Government should expand and financially support vocational and continuing education and training measures regarding the use of digital and smart technologies.
- With regard to green genetic engineering, the Federal Government needs a scientifically sound and coordinated communication strategy that is also reflected in political action.
- The Federal Government should vote in favour of the EU Commission's proposal for differentiated regulation of genome-edited plants in the European Council.
- In the long term, the Federal Government should lobby the EU in favour of regulating green genetic engineering independently of the genetic engineering method.

B2 International Mobility in the Science and Innovation System

A competitive science and innovation location is dependent on competent personnel for its universities, research institutions and businesses. In the global competition for scientists and employees in research and development, Germany has only been moderately successful in the past.

According to a study for the Commission of Experts' 2014 Annual Report, more scientists left Germany between 1996 and 2011 than immigrated to the country. It was particularly difficult to attract top scientists to work in Germany at that time.

A similarly negative picture emerged with regard to the international mobility of R&D employees. In line with the analyses in the 2014 Annual Report, developments in the international mobility of scientists and R&D employees are mapped based on evaluations of scientific publications and patent applications. The analyses show that the situation has changed significantly since the 2014 Annual Report.

Germany has become a net receiving country for publishing scientists. Many highly-published authors return to Germany after spending time abroad. A reducing net outward flow can be observed among patent-active inventors. Overall, Germany is therefore on a favourable trajectory. However, the German science and innovation system continues to lose human capital across the board, and demographic ageing will likely lead to staff shortages here too.

The Commission of Experts therefore recommends the following measures, among others:

- The administrative processes associated with international mobility should be integrated into an overall process and accelerated with the help of a digital system that links all parties involved in the process (diplomatic

missions abroad, registration offices, research institutions or businesses and those wishing to immigrate).

- To ensure that visa applications are processed promptly, the German missions abroad should be strengthened in terms of organization and, if necessary, staffing.
- The Federal Government should advocate international harmonization of social security regulations relevant to the immigration of skilled workers.
- Programmes to promote excellence in the science system should be expanded. The Federal Government and Länder programme (Bund-Länder-Programm) for the creation of tenure-track professorships should be continued with a clear focus on international careers in science.

B 3 Social Innovation – A Key Element To Address Societal Challenges

The grand societal challenges such as climate change, demographic ageing, and digitalization will not be overcome by technological changes alone. Rather, social innovations are needed that lead to changes in individual and collective behaviour. Policymakers have recognized the importance of social innovations and consider social entrepreneurs to be important drivers of these innovations. However, evidence-based research and innovation policy (R&I policy) in this regard lacks reliable and representative data on the emergence, dissemination and impact of social innovations. Policy justifications have so far been based on conceptual considerations. For example, it can be deduced that social innovations are not developed to the optimum extent for society as a whole. In addition, the funding options for social enterprises are made more difficult in principle by the fact that the involvement of profit-oriented investors could jeopardize the enterprises' orientation towards the common good. The Commission of Experts therefore recommends the following measures, among others:

- The Federal Government should emphatically support the development of standardized indicators for social innovation, both nationally and internationally, and the creation of an internationally representative database. Care must be taken to ensure that the success of policy measures to promote social innovation and social enterprises can be accurately measured and analysed.
- The Federal Government should open up existing innovation funding programmes even further for social innovations. This allows for improved consideration of complementarities between social and technological innovations.
- Existing funding programmes should be supplemented with specific advisory services such as legal form advice for social enterprises and region-specific consulting services.
- The Federal Government should support a trade fair for social innovations, to promote both networking among various stakeholder groups and the generalization of successful social innovations.

- The measures planned by the Federal Government to promote alternative forms of financing should be implemented swiftly to meet the special needs of social enterprises.

B 4 Artificial Intelligence

As a key enabling technology, artificial intelligence (AI) is characterized by highly dynamic development, has a wide range of applications and unlocks a wealth of potential for innovation and growth. AI therefore has enormous transformative potential that can lead to fundamental structural change in the economy and society. In the recent past, generative AI in particular has developed rapidly. China and the USA are leading the way in technological development in the field of AI. Germany and Europe are lagging far behind and are at risk of falling even further behind. There is a danger that Germany and Europe will become unilaterally dependent and thus lose technological sovereignty. Technological sovereignty is also an important prerequisite for ensuring that European values are upheld in the development and use of AI. The Commission of Experts makes the following recommendations, among others:

- To allow Germany to successfully position itself in the international innovation competition for new technology variants or generations, the Federal Government should continue to firmly support basic AI research.
- Powerful computing capacities must be created to enable the secure development of next-generation foundation models.
- The Federal Government should vigorously drive forward the measures it has initiated to improve the data infrastructure and accelerate the provision of its own data.
- An AI ecosystem is dependent on well-qualified specialists. The Federal Government should work towards ensuring that appropriate programmes are provided in school, academic and vocational education.
- Initiatives to promote open source AI should be supported. Programmes to improve the security architecture of open source models should be launched. Research projects to better understand how open source AI contributes to the AI ecosystem should be set up and measures to promote open source AI should be evaluated.
- The EU's Artificial Intelligence Act (AI Act) should be adapted over time based on the knowledge and experience gained in regulatory practice. In terms of governance, care must be taken to ensure that the bureaucratic burden for the stakeholders subject to the AI Act remains within reasonable limits. The regulatory sandboxes provided for in the AI Act should be used as an instrument for regulatory learning as quickly as possible.

A

CURRENT DEVELOPMENTS AND CHALLENGES



A0 Transformative R&I Policy

The current coalition government has taken over a project of superlatives from its predecessor: the transformation of the economy and society. The energy transition, the mobility transition, the digitalization of the economy and society and the creation of sustainable agriculture are just some of the transformations that the Federal Government has placed at the centre of its Future Strategy for Research and Innovation.¹

A Herculean Task

Transformations of this kind go far beyond the scope and reach, especially in terms of financial requirements, of what constitutes economic and innovation policy in ‘normal’ times. It is a Herculean task for which there exist as yet no precedents and no tried and tested masterplan.

These transformations require a multitude of technological and social innovations. Regardless of the specific nature of an individual transformation, these are not incremental changes by means of marginal interventions and with merely localized effects, but rather a fundamental change that will presumably leave no area of the economy and society untouched. Transformation-oriented change will alter the development of and use of technologies as well as production, consumption and individual behaviour towards nature and society. A complex mission concept consisting of strategies, reforms and measures must be developed and implemented for each one of the above-mentioned transformations.

Budget Competition Increases

Tackling and further developing the necessary transformations will not be easy for the Federal

Government. The increased foreign and domestic political tensions because of the wars in Ukraine, Israel and the Gaza Strip, the energy crisis and the disintegration of the global economy as well as the recessionary after-effects of the COVID-19 crisis all pose further urgent challenges. These compete with the transformations for social and political attention and, above all, for financial budgets – whether private or public. The €100 billion special assets for the Bundeswehr, support for strategically important industrial settlements and the measures required to support the economy document the pressure of current events on political decision-makers and public finances and push the necessary but long-term transformations into the background.

The decision by the Federal Constitutional Court to declare the second supplementary budget for 2021 null and void has further intensified budgetary competition. Over a period of four years, there will be a funding deficit of €60 billion, which will primarily affect the Climate and Transformation Fund (Klima- und Transformationsfonds, KTF),² but will also lead to increased budget competition in other areas, for example for funding important digitalization projects.

The measures to overcome the above-mentioned crises are more short-term in nature compared to the transformations. There is a real danger that the political focus on the current pressing problems will mean that the necessary economic, social and ecological decisions for a long-term transformation will be neglected. After all, the transformation efforts require enormous investments, which ultimately must be borne by the population and demand of it extensive willingness to change whilst imposing a high degree of uncertainty. It is therefore not surprising that many citizens are sceptical about the transformation efforts and in some cases are mobilizing in large numbers against the upcoming changes.

Transformation-oriented Policy Still Lacking Consistency

A substantive policy concept for managing the transformations was already presented by the Commission of Experts in 2021 with the catalytic, market-oriented mission orientation of research and innovation policy (R&I policy). The Commission of Experts submitted a proposal for a political governance structure to match this policy concept in its 2023 report.³

The current Federal Government has embraced these proposals. It has made initial functional changes to the existing governance structures by establishing transformation teams to implement the Sustainable Development Strategy⁴ adopted by the previous government and mission teams as part of the Future Strategy for Research and Innovation. These new structures may appear small-scale considering the major transformation requirements. However, they document an important qualitative step, as they are intended to overcome the departmental principle and the associated silo mentality. In addition, the Federal Agency for Disruptive Innovation (SPRIND) has been freed from administrative and political shackles, new (experimental) policy approaches have been adopted in the DATI-pilot of the German Agency for Transfer and Innovation (DATI), there are the processes of technological redirection in the former coal mining regions and, most recently, the end of funding for technologies that are harmful to the climate and the environment.

These developments show that the Federal Government is thinking in new directions and is fundamentally taking the right steps to tackle the upcoming transformations. However, the approach chosen so far cannot be described as a resolute and coordinated redirection, but rather as a lurching course that manifests itself in measures that are not well coordinated in terms of timing or content. This lack of consistency could prove detrimental to further development. Germany was still in a better economic position in the early stages of the legislative period to drive forward its transformation policy with vigour. Now the transformations must be mastered in the face of economic stagnation and in the context of major geopolitical and military challenges.

The Commission of Experts recognizes the progress that the Federal Government has achieved within the framework of its transformation-oriented policy. However, it fears that due to increasing geopolitical constraints and emerging domestic political unrest, resulting in part from the implementation of transformation-oriented measures, the long-term transformation orientation could give way to a more short-term crisis management policy. This would make the success of the transformations a distant prospect.

The Commission of Experts therefore recommends that the Federal Government regularly incorporates the following five fundamental considerations into the design and implementation of transformation-oriented policy measures:

- Considering long-term and structural objectives in short-term measures

Measures to increase military security, support the establishment of industry and bolster the economy must be designed in such a way that they do not ignore the transformative structural change, but rather accompany it. In its 2023 Annual Report, the Commission of Experts pointed out with regard to the establishment of the Bundeswehr special assets that the funds should also be used for research in the field of cybersecurity and artificial intelligence (AI). The overlap between military and civilian research is comparatively high here, and the link to the digital transformation is direct. The situation is different when it comes to political support for investments as a means of securing technological sovereignty, such as the 'Intel investment' in Magdeburg. Irrespective of the individual assessment of this type of industrial policy, it should always be designed, as the EFI stated in its 2023 report, in such a way "that self-sustaining structures are created which can continue to operate even if the investor withdraws from Germany. To this end, public funding should be invested primarily in infrastructures and in the development of competencies on site, for example in the establishment of R&D capacities, start-up centres and networking activities."⁵

- Incorporating social compensation into measures for transformative change from the outset

Particular problems of transformative change are the socially fair distribution of transformation costs and how to deal with the losers of structural change. Numerous old business models will lose their basis and not all current occupations will still be in demand after the transformation. In addition, climate-friendly technologies and CO₂ pricing will place a relatively greater burden on low-income households than high-income population groups.

At the same time, the structural change associated with transformation opens up a wide range of options for new business models and forms of employment. However, these are in competition with existing structures and can therefore contribute to the emergence or consolidation of social tensions, which further complicate the successful implementation of transformation.

It is therefore important to design political measures in such a way that they address the social problems of transformative change from the outset, thereby ensuring social balance. One example of how things should not be done is the Building Energy Act (Gebäudeenergiegesetz). Apart from the fact that this legislation represents an inefficient double regulation in the context of rising CO₂ prices, it shows how quickly the ignoring of social aspects can severely damage society's willingness to transform. A robust assessment of the payment options available to private households in combination with socially staggered compensation could have mitigated social tensions and defensive attitudes. The Commission of Experts expects the Federal Government to use the experience gained with the Building Energy Act to prepare the long-awaited social compensation for the CO₂ price accordingly.

Socio-politically motivated measures should also be considered in the context of comprehensive economic structural change, such as in the coal-mining regions. These include timely retraining and advanced education measures, as well as measures to support incomes. Prudent political support for structural change is aimed at preserving incomes for a transitional period, but not existing jobs.⁶

- Not supporting structural change exclusively in financial terms

Increased budget competition and the judgement of the Federal Constitutional Court make it necessary to rethink the widespread funding philosophy of 'the more, the better'. Measures to promote outdated or less sustainable technologies and structures (e.g. fossil-fuelled drive technologies and electricity generation) should be consistently scaled back so that their deployment and use become more expensive. This will change relative prices, incentivizing the development and use of climate-friendly innovations. In addition, this transformation process should be supported by deregulation (e.g. regarding approvals in medical-pharmaceutical research⁷) and de-bureaucratization (e.g. for business start-ups⁸) as well as fundamental improvements to the overall conditions (such as clear rules on data use⁹) across the board in order to activate private sector investment.

- Leaving the search for innovative solutions to the economy and allowing society to participate

The intensified budget competition makes it even more necessary to weigh up public funding and private sector investment against each other – also in the context of transformations. In its 2021 Annual Report, the Commission of Experts spoke out in favour of a catalytic, market-oriented mission orientation in R&I policy. This approach implies that solutions to transformation problems should primarily be developed and identified in a market context. However, there may be a need for a push away from the old, no longer desirable technologies towards a technology-open development of new solutions. In this case, politics can catalyse radical changes in direction. It then leaves it to the market players to find the solutions. The advantage of such a policy is not only that market-driven innovation and search activities are stimulated, but also that the motivational aspect of participating in problem-solving is addressed. It therefore stands in contrast to a 'traditional' command-and-control policy that requires the implementation of politically prescribed solutions.

Radically new technological solutions often struggle to penetrate the market and win over potential customers. Successful integration of citizens in the development of innovative technologies at an early stage results in greater acceptance and subsequently wider utilization. The systematic involvement of citizens can be promoted by a range of measures, such as participation in regulatory sandboxes, which can achieve high impact with low public budgets.

— Securing human capital in the long term

The large-scale transformations require newly developed skills and occupations, be it data scientists with knowledge of AI, environmental experts with extensive knowledge in the natural sciences or transformation managers with knowledge of transformation processes based in the social sciences and humanities. A high level of education and training among the population is an important prerequisite for developing an understanding of the necessities of transformation, being involved in problem-solving and being able to utilize innovative and economic opportunities in the transformation.

Unfortunately, Germany is no longer well positioned internationally in terms of educational content and the corresponding structures of education provision. The most recent study by the Programme for International Student Assessment, the so-called PISA study, gave the German school system an even worse grade than previous studies. In a European comparison, Germany has fallen below average. This allows a forecast for Germany's future viability and performance in around two decades: subpar. For an economy that aspires to be an international leader in innovation, technological change and transformation, the outlook is bleak.

The Commission of Experts can only recommend that the Federal Government initiate a fundamental reform of the school system, despite all the difficulties that such a reform entails in a federal system.

However, reform ideas and plans must not stop at schools, but must also cover the areas of vocational and continuing education and training.¹⁰ The degree of digitalization, the structures of education provision, the curriculum and the types of final qualifications must be put to the test, as must the material and financial resources of schools.

And tertiary education institutions cannot be exempt from this either, despite all the freedom in research and teaching. Modern study programmes and courses, more interdisciplinary interlinking of content and a broad-based area of interaction with society and the economy must go hand in hand with adequate basic funding and highly qualified academic staff.

Seeing Transformation as an Opportunity

The many transformation-related problems should not make us forget the many and varied opportunities that go hand in hand with comprehensive structural changes. An economy that manages to successfully master the upcoming transformations with innovative technologies and social innovations will be followed by many others. This will unlock extensive economic potential for those economies that position themselves as successful models for the transformation tasks, as they will accumulate valuable expertise and have innovative products and business models that are in global demand. Investments in transformation will therefore not only pay off in terms of sustainability, but also economically.

At present, Germany is still some way from positioning itself as a model of success for the upcoming transformations. The Federal Government has only just begun to take steps in the desired direction. It therefore needs to communicate even more intensively and transparently where the journey is heading. This will remove uncertainties from the markets and create options – both basic prerequisites for private sector investment and innovation decisions. Politicians must no longer hesitate here.

A 1 Commentary on Current R&I Policy

Implementing Future Strategy, Vigorously Pursuing Missions

Just over a year ago, the Federal Government published its Future Strategy for Research and Innovation.¹¹ At the heart of the Future Strategy are six missions aimed at tackling urgent challenges, ranging from climate, resource and species protection to global health issues and dependencies in technology, energy and raw materials. In its assessment of the implementation status of the Future Strategy,¹² the Commission of Experts comes to a cautiously positive overall conclusion.

The Commission of Experts deems the mission team format, interdepartmental, working independently and supported by an advisory board,¹³ to be fundamentally suitable for implementing the numerous tasks subsumed within the missions. It also makes sense to provide the mission teams and the advisory body with centralized process support and a project office for operational and technical support.¹⁴

The Commission of Experts considers it important to continue the involvement of the state secretary level in the development of the mission teams and to provide continuous strategic support for the operational work of the mission teams. As it already explained in its 2021 Annual Report, interdepartmental mission teams at the operational level alone are only able to coordinate the various innovation and transformation-related goals and strategies of the Federal Government to a limited extent. Although the strategy level is explicitly mentioned in the Future Strategy, there are no precise statements on its implementation within the projected structures.¹⁵

In this context, the Commission of Experts refers to the governance structures for implementing the Sustainable Development Strategy. Here, the State Secretaries' Committee for Sustainable Development, under the leadership of the Chancellery, was created as a committee that meets regularly at strat-

egy level, which in turn sets up seven interdepartmental transformation teams at operational level.¹⁶ Interdepartmental coordination for the implementation of this transformation strategy thus takes place at strategic and operational level.¹⁷

The Commission of Experts fears that the Future Strategy will not be implemented with the same consistency as the Sustainable Development Strategy due to its weakness at the strategy level. As the Future Strategy and the Sustainable Development Strategy cover in part very similar topics,¹⁸ there is also a risk that measures implemented as part of the respective strategy will overlap.

Empower the Mission Teams

Another weakness of the mission teams is that they do not have their own budgets and cannot make any binding financial commitments regarding the decisions they make. This decision-making authority continues to lie solely with the ministries involved, which limits the organizational options and flexibility of the mission teams accordingly.¹⁹

The Commission of Experts therefore recommends that the Federal Government strengthens the position of the mission teams. This can be achieved, for example, by giving them their own financial resources or competences for binding financial commitments. To this end, the departments involved in the mission teams would have to be provided with corresponding budgets. The Commission of Experts is therefore in favour of including the implementation of the missions in the mid-term financial planning in a budget-neutral manner and setting corresponding targets and implementation measures for which the ministries are jointly responsible. The decision on such a multi-year funding horizon requires the support of the ministry management, i. e. at ministerial or state secretary level. As a rule, the mission teams also require support from the strategy level in order to develop enforcement power.

Insufficient Time to Implement Missions and Strategies

In addition to the question of suitable governance, there is also the fundamental question of the time frame for the Future Strategy. Given that the missions formulated by the Federal Government are ultralong-term projects, the realization of which requires complex institutional arrangements,²⁰ achievement of the defined objectives within the current legislative period is illusory. Nevertheless, the Federal Government should continue to vigorously pursue the implementation of its missions and not sacrifice them to short-term political considerations. A government that takes mission-oriented policy seriously must realize that a significant part of the successes of its own policy will not be achieved in the current legislative period.

The Commission of Experts also sees problems like those with the Future Strategy in the implementation of other R&I policy-relevant strategies of the Federal Government, such as the Start-up Strategy and the Digital Strategy. Since developing strategies, roadmaps and implementation reports is time-consuming and labour-intensive, there is often little time available for implementation within a legislative period. For strategic reasons, it can therefore be helpful to formulate achievable short-term objectives in order to achieve quick wins and generate positive momentum.

In general, the Commission of Experts recommends starting with pilot projects for longer-term strategies and projects – as has already happened, for example, with the establishment of the Federal Agency for Disruptive Innovation (SPRIND) and the German Agency for Transfer and Innovation (DATI).²¹ This allows the period until the final realization of the project or until a strategy is fully implemented to be used to gain valuable experience.

Given the high dynamics of change in the domestic and global R&I system, the Commission of Experts expressly welcomes the fact that the Federal Government has designed the Future Strategy as a learning strategy. With its announcement that it will continuously monitor progress in implementation, take experience into account and adjust objectives where necessary, it has at least conceptually taken up the Commission of Experts' call for more agility in R&I policy.²²

Introducing Regulatory Sandboxes Law Promptly

Regulatory sandboxes create the opportunity to reduce technological and economic uncertainties in the innovation process in a protected space, to test regulatory measures and framework conditions and to involve potential users in development at an early stage. This can significantly shorten the often long path to commercialization of innovations.

Define Experimentation Clauses Broadly

Regulatory sandboxes are generally based on experimentation clauses that allow the competent authorities to authorize controlled exceptions to legal requirements and prohibitions for the testing of an innovation.²³ The regulatory sandboxes law will therefore contain corresponding provisions to equip certain laws with subject-specific experimentation clauses in future (the so-called experimentation clause check). It is important that the experimentation clauses in the respective laws are as broad as possible and not specifically defined for particular projects. The narrower an experimentation clause is defined, the greater the likelihood that it will no longer be applicable after a relatively short time.

Moreover, the key importance of systematic evaluations of regulatory sandboxes (cf. chapter A2), i. e. the validation of their respective impact and the necessary regulatory adjustments, should be reflected in the planned law. Evaluations not only create the basis for necessary policy learning, but also prospects for how companies can transfer and scale their innovative products and services to regular operations after successful testing in regulatory sandboxes.

Swiftly Launch Regulatory Sandboxes Law

Binding standards are important for the establishment and operation of regulatory sandboxes.²⁴ The regulatory sandboxes law will define overarching standards for the authorization, implementation and evaluation of regulatory sandboxes. These standards must not be too specific to give the implementing authorities sufficient room for manoeuvre when setting up regulatory sandboxes. This includes, for example, freedom in the temporal and spatial design of regulatory sandboxes, in the involvement of different stakeholder groups and in

the selection and combination of different technologies and behaviours to be tested.

The Commission of Experts takes a positive view of the planned establishment of a one-stop shop as a central competence centre at federal level. It should serve as an advice centre for innovators and implementing authorities. In addition, it should act as a link to the legislator for reporting back any need for regulatory adjustments.²⁵ It is also being considered that innovators can submit initiative proposals to the one-stop shop and have them reviewed.

The Commission of Experts expressly welcomes the Federal Government's initiative to create a regulatory sandboxes law and urges that the drafting process be brought to a swift conclusion.²⁶

SPRIND Freedom Only Partially Implemented

With the SPRIND Freedom Act,²⁷ which came into force at the end of 2023, the Federal Government has granted the Federal Agency for Disruptive Innovation (SPRIND) some of the freedoms that it has urgently needed since it was established in 2019.

Above all, this includes granting SPRIND sovereign tasks (German: *Beleihung*), such as identifying and funding disruptive innovation projects. As a result of being thus authorized, SPRIND can now decide independently on the selection of projects and has a largely free hand in the choice of funding instruments and conditions. Unlike before, it can now commission entrepreneurs directly and invest in existing start-ups instead of having to spin off subsidized projects into its own subsidiaries.

Continued Political Influence

The demand for the complete abolition of functional supervision by the federal ministries was only partially met in the SPRIND Freedom Act. Even if the functional supervision is to concentrate solely on ensuring the economic fulfilment of tasks and is to be carried out by the Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF) alone instead of three ministries, the Commission of Experts sees the risk of dual control. After all, the BMBF is already represented on the supervisory board alongside the Federal Ministry of Finance (Bundesfinanzministerium, BMF), the Federal Ministry for Economic Affairs and Climate Action (Bundesministerium für Wirtschaft

und Klimaschutz, BMWK) and two members of the Bundestag. The scope for political influence is therefore considerable. There is also a risk that conflicting political positions on the supervisory board and administrative restrictions imposed by the technical supervision could have a negative impact on the professional decisions of SPRIND management. In this context, the Commission of Experts recalls the independence of the US Defense Advanced Research Projects Agency (DARPA), which served as a model for the establishment of SPRIND.²⁸ DARPA is not subordinate to any ministry or supervisory board, so formal political influence is largely limited to the appointment of management positions (Program Directors).²⁹

The SPRIND Freedom Act provides a significant degree of flexibility regarding the so-called ban on better pay (German: *Besserstellungsverbot*). This prohibition of better pay stipulates that recipients of government grants must not remunerate their employees better than comparable Federal Government employees. To compete with salaries in the private sector, SPRIND can now exempt its employees from this regulation if there are compelling reasons to do so. Moreover, employees in companies supported by SPRIND can be exempted from the ban on better pay for a maximum period of five years.³⁰ However, the Commission of Experts wonders how this regulation will be applied in practice, as 'downgrading' employees after five years seems unrealistic. There is therefore a risk that employees will have to be withdrawn from the projects or that the projects will have to be terminated.

The Commission of Experts considers the regulations on the self-management of funds and the use of self-generated income to be inflexible. SPRIND's income, for example from the sale of shares in its own start-ups and investments, may not be fully retained and reinvested by SPRIND, but 50 percent must be returned to the Federal Government. Instead of standing on its own two feet financially, SPRIND thus remains dependent on state funding. The Commission of Experts also finds it incomprehensible why the self-management funds remain limited to 30 percent. SPRIND's financial room for manoeuvre could have been expanded unbureaucratically and without additional costs. The Commission of Experts considers the SPRIND Freedom Act to be an overdue step in the desired direction. However, it criticizes the fact that there was a lack of courage in some details to complete SPRIND's

liberation and give it the necessary independence from politics and the deadlines of the Federal Budget Code. It welcomes the fact that the Freedom Act explicitly provides for an evaluation of SPRIND and its funding strategies by 2025.³¹ This will enable an evidence-based readjustment of the statutory regulations and the implemented strategies (cf. chapter A 2).

Overall, the Commission of Experts hopes that the steps initiated with the Freedom Act to unleash SPRIND also herald a change of direction in R&I policy – away from risk aversion and tight control towards entrepreneurial thinking and agility.³²

SPRIND Freedom Act No Blueprint for Project Executing Agencies

The Commission of Experts takes, however, a differentiated view of the demand for comparable degrees of freedom for the project executing agencies that arose in the course of the discussion regarding the SPRIND Freedom Act.³³ After all, the mission of SPRIND differs fundamentally from the portfolio of tasks of the project executing agencies, which, as service providers for the federal ministries, are primarily tasked with supporting and administering support programmes. The Commission of Experts therefore does not consider it appropriate to transfer decision-making authority over the strategic planning and orientation of state support measures to the project executing agencies. This key R&I policy control function is an essential task of the government and its ministries. The situation is different when it comes to the management of funds. More flexibility and autonomy are possible here. To facilitate agile funding management, the previous strict management of project executing agencies by the responsible ministries should be replaced by results-based management of the use of funding. This would not only allow the project executing agencies to react more flexibly to the need to adapt existing R&I projects but would also give them additional room for manoeuvre to experiment with new funding approaches.³⁴

Making DATI Open

A key innovation policy project of the Federal Government is finally taking shape with the convening of a founding commission for the German Agency

for Transfer and Innovation (Deutsche Agentur für Transfer und Innovation, DATI) and the decision to establish the agency's headquarters in Erfurt. The so-called DATIpilot has also been launched as the first round for the selection of transfer projects.

DATIpilot Heavily Oversubscribed

The two funding formats Innovation Sprints and Innovation Communities initiated as part of the DATIpilot have met with a great response. Nearly 3,000 ideas were submitted for the Innovation Sprints. As part of the 18-month innovation sprints, scientists are to be funded with a maximum of one application partner. According to the BMBF, the starting point is existing research results or promising concepts with a sound database that are considered to have high innovation potential.³⁵ Of the ideas submitted, 600 were fundamentally deemed eligible for funding in accordance with the funding criteria. Due to the high level of participation, the BMBF decided to fund 300 projects instead of 100 as originally planned.³⁶ Around 300 concept proposals were received for the four-year Innovation Communities.³⁷ The aim of this funding format is to establish long-term partnerships between scientific institutions (universities of applied sciences, universities and non-university research institutions) and stakeholders from industry, society and administration on a self-chosen topic.³⁸ Similar to the innovation sprints, the demand for funding exceeds the allocated funds. However, the discrepancy here is even greater, as the BMBF has pledged funding for only ten Innovation Communities.³⁹

The Commission of Experts considers the high level of participation in the two funding formats to be a positive sign in terms of awareness and acceptance of the nascent DATI.

Openness Instead of Narrow Funding Focus

The Commission of Experts also attributes the large number of submitted project proposals to the fact that the conditions for participation in the DATIpilot were defined very openly. This openness contrasts positively with the original key issues paper, which was presented in April 2022 and criticized by the Commission of Experts for having too narrow a funding focus.⁴⁰ The Commission of Experts expects this openness to be reflected in the final DATI concept.

Making the Research Allowance More SME-friendly

The Federal Government has drafted the so-called Growth Opportunities Act⁴¹ “to strengthen growth opportunities, investment and innovation, while at the same time simplifying the tax system and making it fairer”.⁴² An important component of the Act is a reform of the research allowance introduced in January 2020.

One of the key points of the reform is the planned tripling of the assessment basis. Instead of the previous maximum of €4 million in eligible expenditure for research and development (R&D expenditure) per year, expenses of up to €12 million will now be tax deductible. Furthermore, in future not only personnel costs but also material expenses will be eligible for funding.⁴³ In addition, SMEs with fewer than 250 employees⁴⁴ will be able to apply for an increase in the previous uniform funding rate of 25 percent of the assessment base to 35 percent.⁴⁵ Contract research is also to benefit from the reform. The current share of eligible costs for a research contract is to be increased from 60 percent to 70 percent.⁴⁶

Research Allowance Increasingly in Demand

The Commission of Experts sees the increase in the research allowance as a positive sign. However, it again questions whether the measures described above are a suitable means of motivating those parties conducting R&D to increase their research activities that were originally the focus of the research allowance: small and medium-sized enterprises (SMEs).⁴⁷

Although an official evaluation of the Research Allowance Act is not yet available,⁴⁸ initial assessments of its utilization and existing problems can be derived from several survey-based studies.⁴⁹

The available studies unanimously conclude that the research allowance is increasingly being claimed, as evidenced by the rising number of applications submitted each year.⁵⁰

The Commission of Experts assesses this development as positive, along with the high proportion of approved or partially approved applications. With an approval rate of 75 to 80 percent, the research allowance clearly stands out from direct R&D proj-

ect funding and is even higher than the average approval rate of 65 percent for the Central Innovation Programme for SMEs (Zentrales Innovationsprogramm Mittelstand, ZIM).⁵¹ The research allowance is therefore highly predictable. Moreover, every second business that claims the research allowance has not previously received any direct R&D project funding. This emphasizes the complementary nature of tax-incentivized research funding to direct project funding.⁵²

SME Participation Still Low

Although the number of applications is increasing, not all businesses are aware of the research allowance. Smaller businesses in particular are often unaware of the existence of this new funding format.⁵³

The situation is similar regarding applications. According to the study, around three quarters of R&D-active businesses state that they have not yet applied for a research allowance. The participation of SMEs in the application process is significantly lower than that of large companies. While around one in two large companies state that they have already applied, only one in four SMEs have done so.⁵⁴

The Commission of Experts points out that the planned expansion of the assessment base, the increase in the funding rate for SMEs and the inclusion of material costs will increase the incentive to submit applications. However, whether an increase in applications will also lead to an increase in R&D expenditure on the part of businesses and not just to deadweight effects can only be clarified as part of an evaluation.

Reduce Administrative Effort

In addition to the need for targeted public relations work to improve awareness of the research allowance, the survey results point above all to the need to reduce the administrative effort involved in applying for the research allowance. The bureaucratic burden is also given as the main reason for not applying. In particular, the two-stage application procedure is perceived as bureaucratic by the companies surveyed, which could explain the reluctance of SMEs in particular.⁵⁵ With this in mind, the Commission of Experts recommends using the reform of the research allowance to simplify the application procedure.⁵⁶

A first step towards reducing bureaucratic costs would be to abolish the two-stage application procedure in favour of a one-stage procedure.⁵⁷ The Federal Government's decision to have the assessment of R&D projects eligible for research allowances under Section 2 of the Research Allowance Act reviewed by a Certification Body outside the tax authorities should not result in additional administrative work for businesses. The planned inclusion of material expenses in the allowance will also only provide a real impetus for more R&D activities if it is possible to minimize the documentation effort for businesses.

Check Research Allowance for Activation Potential

The extent to which the research allowance has succeeded in motivating companies to increase their R&D expenditure cannot be deduced from the studies to date. The same applies to the question of whether companies not previously conducting R&D have now been motivated to start doing so.

Nor is it possible to say whether the research allowance helps to encourage businesses that do conduct R&D to consolidate their research activities. Yet given the declining innovator rate,⁵⁸ these issues are of key importance and represent from the point of view of the Commission of Experts a particular desideratum for the evaluation of the research allowance.

Facilitating IP Transfer for Spin-offs

Germany is struggling to generate research-based spin-offs from scientific institutions such as tertiary education institutions and non-university research institutions. One of the main reasons for this is the difficulty of transferring intellectual property (IP) in the form of patent sales or licence agreements from the scientific institution to the company being founded. These difficulties arise because the value of intellectual property rights is generally difficult to determine, resulting in a high degree of uncertainty. In addition, there are different interests between the start-ups on the one hand and the tertiary education and research institutions on the other. Together, these two factors lead to protracted and potentially unsuccessful negotiations between the two parties.⁵⁹

Tertiary education and research institutions are increasingly focused on exploiting the intellectual property of their employees' economically viable ideas through commercialization. In so doing, they have an interest in stable and highest possible income from IP transfer. This income-orientation is reinforced by the widespread expectation that the costs of their own transfer institutions can be recouped through income from patent sales and licensing, and that permanent surpluses may be achieved. This expectation can hardly be substantiated by empirical findings; with few exceptions, transfer institutions in Germany, but also in other countries, operate at a loss.⁶⁰

Concerns About Violation of State Aid Rules Complicate IP Transfer

IP transfer negotiations are further complicated by uncertainty about EU State Aid rules. Tertiary education and research institutions are bound by State Aid rules when dealing with their spin-offs, as their ideas are based on publicly funded research activities. Accordingly, the granting of licences by a state-funded tertiary education or research institution to an entrepreneur can be considered illegal state aid if the tertiary education or research institution, as the IP donor, undervalues the relevant IP. State Aid rules do not stipulate any specific conditions, but do require IP providers, i. e. tertiary education and research institutions, to assess the value of IP.⁶¹ Although European State Aid rules were amended in March 2023 to facilitate the transfer of IP to spin-offs, there is still a high degree of uncertainty on the part of tertiary education and research institutions.⁶² To avoid any risk of a legal infringement, they tend to set the value of the patent rather high and make this the basis of the licence agreement.

As most founders only have limited financial resources at the time of the spin-off, high prices for patents and high licence payments are detrimental to the further development and scaling of a start-up. As a result, the spin-offs lose financial resources and become less attractive to potential investors.⁶³ Agreements that oblige the spin-offs to make non-performance-related payments to the tertiary education or research institutions, such as patent sales or licence agreements with advance payments or term-related payments, are particularly problematic. The legitimate interest of tertiary

education and research institutions in generating stable income can thus reduce the prospects of success of a spin-off in the long term.⁶⁴

Initiative to Facilitate IP Transfer Launched

The Federal Agency for Disruptive Innovation (SPRIND) has launched the IP Transfer 3.0 initiative in partnership with the Stifterverband and Fraunhofer ISI and with the support of startup.niedersachsen to facilitate a more straightforward and start-up-friendly transfer of IP to research-based spin-offs. Among other things, it adopts a model already practised at TU Darmstadt, which provides for so-called virtual shares in the spin-offs in return for the transfer of IP.⁶⁵ It also proposes limiting the maximum share in a spin-off to 10 percent. In contrast to conventional shares, the IP donors waive their voting rights in virtual shares. The initiators of the model are hoping for two things: firstly, they relieve the tertiary education and research institutions of the administrative obligations associated with conventional investments. Secondly, the entrepreneurs benefit because the liquidity of their start-up is not burdened by high prices when acquiring patents or by high ongoing licence payments. In addition, the spin-offs become more attractive for investors, since in the case of virtual shares, the investors no longer need to coordinate business decisions with the administrative bodies of tertiary education and research institutions.⁶⁶

Moreover, a toolbox was created as part of the project, including the development of model contracts for different IP transfer scenarios,⁶⁷ question-guided decision-making tools to assess the IP situation and the appropriate exploitation models (IP-Wahl-O-Meter) as well as a catalogue of criteria for the standard market valuation of IP (IP-Scorecard),⁶⁸ which should reduce uncertainty in the valuation of IP in accordance with State Aid rules and greatly speed up licensing negotiations.⁶⁹

Since November 2022, 17 tertiary education institutions, research institutions and research alliances have been testing the above procedure. The Commission of Experts expressly welcomes the pilot project. It hopes that it will not only explore new ways of IP transfer, but above all initiate an information and learning process in the transfer community.

Transfer Effects More Important Than Licence Income

To mitigate the structural conflicts of interest between scientific institutions and entrepreneurs in IP transfer negotiations, the Commission of Experts recommends modifying the incentive systems. For example, the transfer success of scientific institutions should not be measured based on income from patent sales and licence income, but rather in terms of the sustained success of the spin-offs they support. The Commission of Experts points out that the commercialization of IP is not a suitable means of improving the financial situation of research and tertiary education institutions, but that it does make an important contribution to overall economic development.

Removing the Strict Separation Between Military and Civilian R&D

The interaction between military and civilian R&D has led to several globally significant innovations. GPS, internet and rocket technology are prominent examples of how originally military developments were taken up by civilian actors, further developed and commercialized for civilian use.

The relationship between military and civilian R&D can be divided into two categories: spillovers and dual use. The term spillovers is used when military R&D contracts with companies trigger further private-sector R&D expenditure or when knowledge and findings from the military sector are adopted by the civilian sector.

Dual use is when technologies can be used for both civilian and military purposes. The importance of dual use has risen sharply in recent years, partly due to the wide range of applications for digital technologies. One current example is developments in the field of artificial intelligence.

Spillovers and Dual Use Can Increase Performance

In many countries, spillovers and dual use are deliberately promoted as they lead to increases in performance and efficiency in both the military and civilian sectors. Prominent examples include the DARPA (Defense Advanced Research Projects Agency) in the USA and the military unit 8200 in Israel.

DARPA, founded in 1958 in response to the Sputnik crisis, is tasked with developing new technologies for the US military. With a most recent projected annual budget of US\$4.1 billion,⁷⁰ DARPA commissions research activities for the military. This results in innovative applications that are adopted and commercialized by the civilian sector. As a result, the R&D projects financed by DARPA for the military generate spillovers in the private sector and thus contribute to the innovative power of the US economy.

DARPA uses an ambitious funding approach to promote application-orientated, particularly high-risk and cost-intensive R&D projects that are generally not financed by private sector actors. It deliberately leaves room for novel approaches. As a result, it plays a pioneering role in the international context.⁷¹

The Israeli military Unit 8200 is a unit of the Israeli Defence Forces that is responsible for secret operations, counterintelligence, code decryption, cyber warfare, military reconnaissance and surveillance. The soldiers in Unit 8200 are trained in the use of information and communication technologies, IT and cybersecurity. After completing their service, they are allowed to utilize the knowledge and skills they have acquired in the military sector in the civilian sector. Many former soldiers are recruited by private IT companies or establish their own startups. Unit 8200 is thus a key factor behind Israel's success as one of the world's leading economies in the field of IT and cybersecurity.

Rethinking the Approach to Military R&D

The impact of military R&D can be measured on the one hand in terms of productivity effects and thus on the output side, and on the other hand in terms of changes in R&D activities and thus on the input side.

A long-term study based on OECD country data shows that an increase in publicly financed R&D leads to an increase in private sector R&D in certain industries. This applies in particular to publicly financed military R&D. The study moreover establishes that the increase in private R&D induced by military R&D also leads to productivity gains, i. e. has not only input-side but also output-side effects.⁷²

A recent long-term study on military R&D expenditure in the USA confirms significant effects on private R&D expenditure. According to the study, one US dollar in publicly funded military R&D stimulates between US\$ 0.57 and US\$ 0.72 in additional private R&D expenditure. There is also evidence of positive effects of defence-related R&D on employment.⁷³

As a result of the strict separation of military and civilian research, Germany has so far largely dispensed with the performance-enhancing effect of spillovers and dual use. The Agency for Innovation in Cybersecurity, established in 2020, is one of the few exceptions here.⁷⁴ The Commission of Experts already pointed out in its last report that, as a result of this separation, scarce resources for research and innovation are not being used efficiently to solve societally important problems, such as securing data networks and critical infrastructure.⁷⁵

In view of increasing global threats, the Commission of Experts recommends re-evaluating the options for managing military R&D. The above-mentioned studies show that military R&D can have positive effects on civilian R&D via spillovers and thereby also positively impact productivity and employment in the civilian sector in addition to increasing performance in the military sector. To achieve this efficiently, synergies between military and civilian research should be made possible. The strict separation that has been customary in Germany for decades needs to be fundamentally reconsidered and abolished where appropriate.⁷⁶

Facilitating the Utilization of Standard Essential Patents

Standards are essential to ensure that products function worldwide and can be linked. Especially in the rapidly developing high-tech sectors, standards play a decisive role in the innovation process. By enabling the interoperability of products, they reduce transaction costs, make market entry easier for new providers and contribute to the spread of innovative technologies.⁷⁷ However, if the technology is protected by patents, businesses wishing to implement the standard must acquire a licence. Patents of this type are known as standard-essential patents (SEPs).⁷⁸ SEPs are particularly important in the telecommunications sector. The 5G mobile communi-

cations standard alone contains tens of thousands of patents.⁷⁹ The right of exclusion granted by SEPs is offset by the obligation of SEP holders to grant licences for these patents on fair, reasonable and non-discriminatory terms (FRAND terms).⁸⁰ This is intended to ensure that access to essential technologies is not blocked and innovation is not impeded.

However, the FRAND system is incapable of satisfactorily solving SEP-related problems.⁸¹ Standard users often have only limited information about who the SEP owners are. In addition, it remains unclear to them whether all patents for which they apply for licences are really necessary or essential in order to implement a standard. Furthermore, it is difficult for standard users with limited resources to assess the appropriateness of the licence fees demanded by SEP holders. The lack of information means that standard users cannot adequately take licensing costs into account when planning – especially for new, innovative products. SEP holders, in turn, complain about protracted negotiations, particularly with the large standard users.⁸² As a result, time-consuming and cost-intensive licensing disputes repeatedly arise over the use of SEPs.⁸³ The growing importance of the Internet of Things (IoT) compared to conventional information and communication technology (ICT) has further increased the existing potential for conflict. This is not only because IoT connectivity is particularly characterized by standards-based technologies, but also because of the large number and heterogeneity of the actors involved in this young technology field compared to the conventional ICT sector.

EU Regulation Aims to Increase Transparency for Patents

The EU has responded to the growing complexity and increasing disputes in licence negotiations and in April 2023 presented a draft regulation on the reform of SEPs.⁸⁴ Other countries are also working on guidelines for SEP licence negotiations.⁸⁵ The aim of the new regulation is to create the basis for both the owners and implementers of SEPs to have an incentive to create and apply innovations in the EU. Furthermore, end users, including SMEs and consumers, should be able to benefit from products based on the latest standardized technologies at reasonable prices.⁸⁶ In future, licensing of SEPs should therefore take place under predictable and transparent conditions and transaction costs should be reduced for both SEP holders and users.⁸⁷

The draft regulation provides for several measures to achieve this goal:

- Development of voluntary guidelines for SEP licensing and establishment of a competence centre at the European Union Intellectual Property Office (EUIPO) to support SMEs, among others;
- Establishment of an SEP register at the EUIPO and introduction of an assessment procedure to check how essential a patent is for a standard (essentiality test);
- Establishment of an expert assessment procedure for reviewing aggregate royalty for SEPs (total maximum price);
- Introduction of an arbitration procedure prior to the initiation of a legal dispute.⁸⁸

Creation of SEP Register and Assessment Procedure Expedient

The Commission of Experts welcomes the EU's initiative to make the market for SEPs more transparent and thus reduce the existing information asymmetry between patent holders and licensees. It deems the planned drafting of voluntary guidelines for SEP licensing and the introduction of a conciliation process prior to the initiation of a legal dispute to be fundamentally sensible. The Commission of Experts is also in favour of setting up an SEP register and introducing an assessment procedure in the form of an essentiality check. However, it is sceptical as to whether an essentiality check can be carried out for the entire SEP portfolio. It argues in favour of focussing essentiality tests on individual, disputed areas on an ad hoc basis. Studies show that there are reliable procedures for determining the essentiality of a patent for a standard with reasonable effort.⁸⁹

The Commission of Experts is equally critical of the establishment of a procedure for determining an aggregate royalty for SEPs. Since the value of SEP licences cannot be defined objectively, but is determined by supply and demand, setting a value that is not based on the market is highly unlikely to lead to an acceptable result for licensors and licensees. This applies in particular to the still young and dynamic IoT market, which has so far offered little guidance for assessing the value of SEPs.

The Commission of Experts is moreover sceptical as to whether EUIPO, which is only responsible for the registration of EU trade marks and designs but not for patents, can fulfil the tasks assigned to it within a narrow time frame. Instead of developing new competences at the EUIPO in the years to come, the Commission of Experts believes that it would be better to use the existing competences at the European Patent Office.

Finally Harnessing the Potential of Data

The Commission of Experts has repeatedly emphasized the importance of data for the R&I system in its reports.⁹⁰ Data is the basis for gaining knowledge and making decisions. It feeds into the development of innovative products and services. Last but not least, it is a key element of the digital transformation. The range of applications for data is broad and extends from controlling digital applications in agriculture (cf. chapter B1) to the development and application of artificial intelligence models (cf. chapter B4) and the evaluation of policy measures to enable the assessment and, if necessary, adaptation of measures on this basis (cf. chapter A2).

The Federal Government has recognized the importance of data and has planned or initiated various measures to improve the provision of and access

to data. The Data Strategy it adopted in August 2023 provides an overview of these measures and the timescales for their planned implementation.⁹¹ Some of the measures have already been implemented. For example, it is very welcome that the Health Data Use Act has now been passed, paving the way for the utilization of health data to improve diagnosis and treatment for patients. More measures still need to be taken and implemented, such as the establishment of an agricultural data space and the passing of the Research Data Act.

Progress in Data Provision and Use Essential

Numerous proposals exist for improving the infrastructure and access to publicly funded data and for linking individual datasets.⁹² These involve, among other things, necessary adjustments to existing legislation and its inconsistent interpretation in the Länder (including the General Data Protection Regulation – GDPR, the Federal Statistics Act and the Tax Statistics Act).

The Commission of Experts reiterates that considerable progress in the provision and use of data is essential in order to achieve progress also in the areas of data application and to achieve the digital transformation. Artificial intelligence as a key enabling technology is just one example, albeit a most important one.

A2 Determining the Causal Effects of Interventions

Many of the evaluation studies on measures of research and innovation policy (R&I policy) carried out on behalf of the Federal Government do not allow any conclusions to be drawn as to whether the developments observed can actually be attributed to the policy measures analyzed. The main reason for this is that evaluation studies often do not fulfil the methodological requirements for a causal analysis, not least because the prerequisites

for the appropriate use of suitable methods are not always met. The lack of knowledge about the impact of measures impedes systematic and evidence-based policy learning. The potential for learning from the evaluation of and experience with implemented measures and adapting future measures where necessary so that their objectives are better achieved remains largely unexploited.

The Federal Government is therefore called upon to systematically and comprehensively integrate causal analyses of the effects of measures into the deployment of R&I policy measures and thus ensure the conditions for the proper and professional implementation of these analyses and their usability in policy learning. To this end, it is necessary to include causal analyses in the specifications when tendering for evaluation studies, to improve the availability of data for the evaluating organizations and to publish all commissioned evaluation studies.

Causal Analyses Required for Research & Innovation Policy Learning

Causal analyses of the effects of policy measures are necessary to evaluate the effectiveness and efficiency of these measures and thus enable policy learning. Policy measures are effective if they achieve the objectives pursued and efficient if there are no more cost-effective ways of achieving the objectives pursued. Policy learning implies that measures are continued unchanged, readjusted or, if necessary, abandoned based on improved knowledge.

The Commission of Experts considers the potential of policy learning in R&I policy to be high for the following reasons:

- R&I policy measures are aimed at a broad range of different R&I activities – from basic research to applied research and application. The various types of R&I activities differ in terms of their starting points and their relevance to policy support. Their results are associated with a varying degree of uncertainty that changes over time.
- The extent to which an R&I policy measure is suitable for supporting certain R&I activities depends heavily on the respective context. The effectiveness of a measure can vary greatly depending on the sector or region.
- R&I policy increasingly aims to steer R&I activities in completely new directions and thus contribute to mastering the grand societal challenges. In doing so, R&I policy often cannot simply fall back on established measures but must adapt them or break completely new ground.

With this in mind, causal analyses of the effects of measures can make a significant contribution to adapting and further developing R&I policy measures and thus improving their impact. Causal analyses are part of ex-post evaluations, which examine and assess measures retrospectively. In addition to such ex-post evaluations, process evaluations are often also required as a means of gaining insights into the feasibility of measures while they are still in place and, if necessary, making adjustments at an early stage. This is particularly true in the context of a mission-oriented and transformative R&I policy, where numerous measures are implemented in parallel or sequentially, the interaction of which can only be incompletely assessed ex ante.

Informative Value of Impact Evaluations Depends on Methodology

The aim of causal analyses of the effects of measures is to determine whether observed changes in predefined target variables are causal, i. e. can be attributed to the policy measure under investigation. The validity of such causal analyses and thus the potential for policy learning depend on the methodology used. This has developed fundamentally in recent decades. Experimental and quasi-experimental methods of causal analysis are now firmly established standards of empirical research in economics and the social sciences.⁹³

The Commission of Experts already pointed out the importance of meaningful evaluation studies in its 2010 Annual Report and since then has repeatedly emphasized the need to carry out causal analyses of the effects of measures.⁹⁴ In addition, in 2013 the Scientific Advisory Board of the then Federal Ministry for Economic Affairs (BMWi) stressed the importance of causal analyses for the evaluation of economic policy measures in one of its reports. The methodological requirements it defined are still relevant – also for R&I policy measures.⁹⁵

The prerequisites for carrying out meaningful causal analyses must already be considered in the design of policy measures and created when the measures are implemented. It is essential to compare the situation arising from the implemented measure with the situation that would have arisen without the measure, the so-called counterfactual state (cf. box A 2-1). This comparison is made using a suitable evaluation design. The main requirements are that

those covered by a measure, the treatment group, are compared with a suitable control group of those not covered (cf. box A 2-1) and that the effectiveness of the measure is tested using suitable experimental or quasi-experimental methods (cf. box A 2-1).

The best possible conditions for a suitable composition of treatment and control groups are provided by genuine randomization of participation in the measure as part of policy experiments (cf. box A 2-1). There are numerous international examples for policy experiments.⁹⁶ In the case of a support measure, for example, true randomization means that the participants are selected at random. If the number of cases is sufficiently large, randomization can ensure that the group of beneficiaries and the control group of non-beneficiaries do not differ statistically in all observable and non-observable characteristics with the exception of the characteristic ‘supported’ or ‘not supported’.⁹⁷ This integrates the counterfactual situation, which is so important for a causal analysis, into the policy measure from the outset.

Randomization can often be combined with a pre-selection according to content-related, funding-relevant criteria associated with the measure.⁹⁸ For example, basic eligibility can be checked first. Randomized selection only takes place within the group of those eligible for funding, and possibly only within a subgroup.⁹⁹

Randomized policy experiments are often not feasible, for example because the necessary number of cases cannot be achieved. If this is foreseeable, then quasi-experimental methods of causal analysis should be considered from the outset (cf. box A 2-1). Their applicability and informative value can be improved by a suitable design of the measure and by collecting the necessary data.

Methodological Potential not Exhausted in Evaluation Practice

In recent years, the Federal Government has commissioned many studies to evaluate R&I policy measures.¹⁰⁰ The Commission of Experts examined the question of how many of these studies claim to demonstrate causal effects of the measures analyzed and to what extent this claim is fulfilled.

To this end, 81 publicly accessible evaluation studies from the areas of responsibility of the Federal Ministry of Education and Research (BMBF) and the Federal Ministry for Economic Affairs and Climate Action (BMWK), published between 2009 and 2023, were analyzed using a standardized analysis scheme.¹⁰¹ The results of this study show that a reliable causal analysis was often not carried out in the past, even in those evaluation studies that make statements on the impact of measures. The results also indicate that the conditions for causal analyses in the evaluation of policy measures need to be improved, for example in terms of data availability.¹⁰²

In 59 of the 81 evaluation studies analyzed, the results were interpreted causally – regardless of the method used (cf. figure A 2-2). Treatment and control groups were compared in 24 of these 59 studies. Only one of these studies conducted randomized policy experiments. Quasi-experimental methods were used in six studies. In seven studies, only matching methods were used (cf. box A 2-1), which have limited suitability for causal analyses. In the remaining ten of the 24 studies, no methods were used that allow a causal analysis of the effects of the measures. This means that only seven of the 81 evaluation studies analyzed were able to draw reliable conclusions as to whether the evaluated measures were effective. In 45 of the 81 evaluation studies, however, developments were interpreted as causal effects of measures, although the methodology used does not allow this conclusion to be drawn.

A total of 40 of the 59 studies with a causal interpretation of results attest to a positive effect of the evaluated R&I policy measures and 19 of the studies attest to at least a partially positive effect. As a result, all the studies analyzed that made an impact statement also found a positive impact. No study concludes that effects of the measures analyzed cannot be shown, or indeed finds negative effects.¹⁰³ This pattern differs significantly from the results of the impact analyses found in the scientific literature. These often conclude that the effectiveness of the measures analyzed cannot be shown.¹⁰⁴

The Commission of Experts notes that most of the evaluation studies analyzed do not meet the requirements for a meaningful causal analysis. Randomized policy experiments have hardly ever been conducted in the past. Methods of quasi-ex-

Box A2-1 Explanation of Basic Terms of Causal Analysis

Causal analysis: Causal analysis refers to statistical methods for determining cause-and-effect relationships between different variables. In policy analysis, causal analysis is used to determine whether and to what extent a certain intervention, such as an R&I policy measure (the independent variable), has a direct effect on the desired result (the dependent variable).

Counterfactual state: The counterfactual state describes the hypothetical situation an entity (e.g. a person, a group, a company, a region) affected by an intervention (the so-called treatment) would be in if it had not been exposed to the intervention.

Randomization: Randomization means that the participants are randomly assigned to two groups:

1. **Treatment group:** This group is subject to the intervention the effect of which is being analyzed.
2. **Control group:** This group is either not subject to any intervention or is subject to a different intervention than the one analyzed. The results of the control group are used to approximate the counterfactual state of the treatment group in order to measure the effect of the intervention or to compare the effect of the different interventions.

Randomization is intended to ensure that there are no systematic differences between the groups before the intervention. This means that all known and unknown variables that could influence the result are evenly distributed across both groups.

Experimental methods: Randomized experiments, often referred to as randomized controlled trials (RCTs), are used in research to test the effectiveness of an intervention under controlled environmental conditions. When appropriately designed and conducted, randomized experiments provide the strongest evidence for causal effects of an intervention.

Quasi-experimental methods: In contrast to experimental methods, quasi-experimental methods are not based on genuine randomization. Instead, constellations are analyzed where participation in an intervention was 'quasi-random' and could hardly be influenced by the participants. For example, in the case of interventions that were limited to individual regions, the possibility of participation is quasi-randomized by belonging to the region. Therefore, comparable units from other regions can be used as a control group. Subject to certain conditions, which differ depending on the method, causal effects of interventions can be estimated in this way.¹⁰⁵

Matching procedures: Matching procedures¹⁰⁶ are statistical techniques whereby, for each unit of observation in the treatment group, one or more units are found in the control group that are similar regarding certain observed variables. Matching procedures can help to reduce distortions caused by non-random participation in measures. In the context of causal analyses, they are used in addition to quasi-experimental methods. Matching alone does not solve the problem that participation in measures can be influenced by non-observable variables.

perimental causal analysis that go beyond mere matching have also only been used in isolated cases although a slightly positive trend can be observed here.¹⁰⁷ This means that policymakers lack the basis to learn from the (non-)effectiveness of previous measures and to increase the effectiveness of future R&I policy measures.

Multiple Reasons for the Lack of Significance of Evaluation Studies

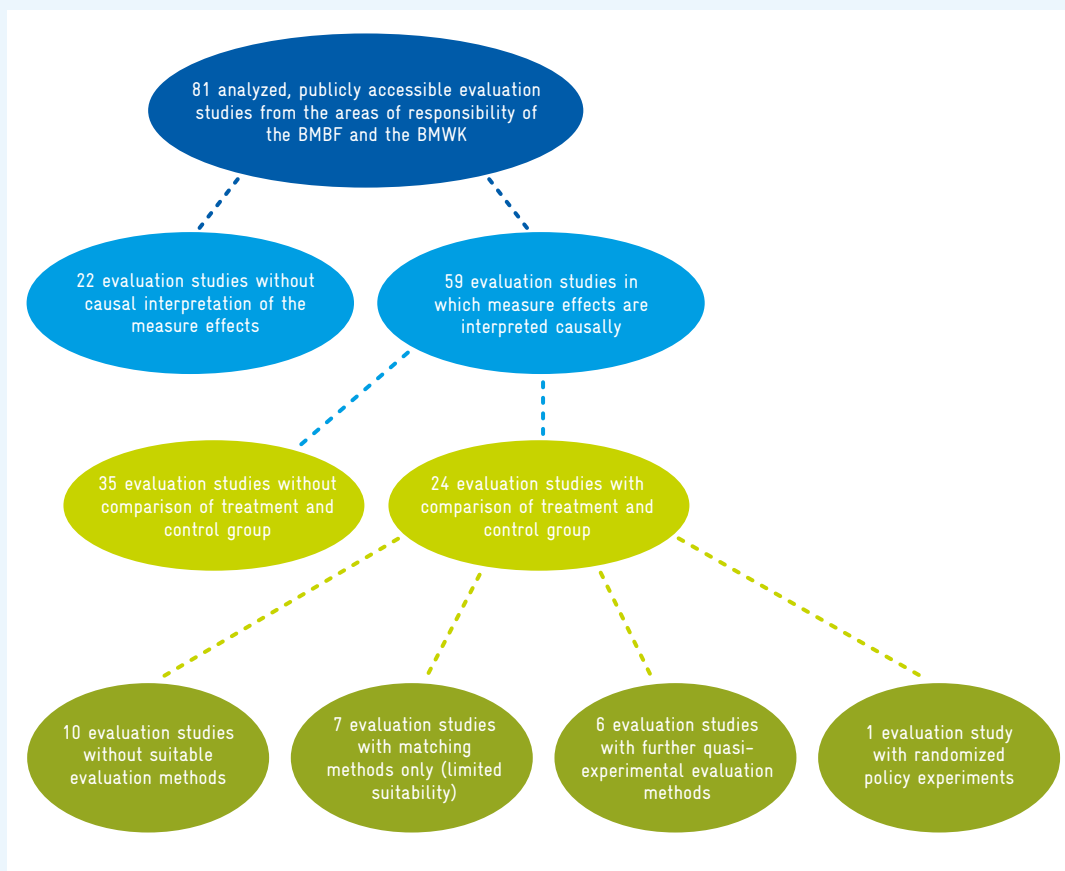
There are several reasons why the research design of an evaluation study may not or not fully meet the requirements for a meaningful impact measurement through causal analysis. Such reasons are cited in 32 of the 81 evaluation studies analyzed by the Commission of Experts. These reasons include:

- Insufficient data availability and quality make it difficult or impossible to identify suitable control groups and conduct meaningful causal analyses. Data that would in principle be available at the start of the measure are not always available for a causal analysis.
- Causal analyses can come up against methodological limitations. For example, a comparison of the treatment and control groups is not meaningful if the number of cases is too small. Moreover, it is not even possible to identify a control group if all potential recipients of a support measure are supported. It is also not possible to identify the effects of measures promptly if the effects of the evaluated policy measure can only be expected in the long term.
- The effectiveness of measures is evaluated based on defined targets. The prerequisite for this is that these targets can be measured or at least approximated. Unintended effects, both positive and negative, cannot always be measured or may be overlooked.
- Evaluating the efficiency of a measure is particularly demanding in terms of data, as this usually requires the effects of different measures to be measured and compared with each other. In many cases, however, at least a cost-benefit estimate can be made based on a causal analysis.

Fig. A2-2 Results on evaluation studies from the areas of responsibility of the BMBF and the BMWK



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Source: Own representation based on Büchele et al. (2024).
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Recommendations for Action

The Federal Government is pursuing ambitious objectives in the field of R&I policy and at the same time is subject to increasing cost-cutting constraints. A meaningful causal analysis of the effects of measures as part of the evaluation of policy measures creates the prerequisites for a learning R&I policy. The Commission of Experts therefore recommends improving the causal analysis of R&I policy measures as the basis for a learning R&I policy, building on the recommendations of previous annual reports.

Systematically Integrate Causal Analyses into R&I Policy Measures

- The conditions for a causal analysis of the effects of measures should already be considered when planning measures and the prerequisites for collecting the necessary data should be established. This means defining precise objectives and, if possible, specifying suitable indicators for examining the achievement of objectives.¹⁰⁸ Internal and external experts with proven expertise in the methodology of causal analyses should be involved already in this phase.
- When tendering for evaluation studies, the terms of reference should include a causal analysis and minimum requirements for the evaluation concept in this regard. A fundamental assessment of the efficiency of the measure, e.g. by means of a cost-benefit analysis, should also be sought. The timing of the evaluation should be chosen so that the relevant effects of the respective measure can be realistically observed.
- When commissioning evaluation studies, particular attention should be paid to the methodological expertise of the providers. Evaluations should not be carried out by organizations that are themselves responsible for the measure to be investigated. Suitable tendering procedures should be used to incentivize new qualified providers.¹⁰⁹

Optimally Align Causal Analyses with the Evaluation Context

- Randomized policy experiments offer ideal conditions for meaningful causal analyses. They should be utilized more often than before in R&I policy. Randomization is particularly suitable when an oversubscription of support measures is to be expected.
 - Regulatory sandboxes represent a special category of R&I policy measures that are intended to facilitate policy learning. When setting up regulatory sandboxes, the subsequent causal analysis should therefore also be considered, e.g. by ensuring that there are meaningful comparison units for the regulatory sandbox to allow its overall impact to be assessed.
 - When analyzing the interaction of different measures in the context of mission-oriented R&I policy, it can be useful to examine the achievement of the mission objectives through the interaction of the measures in aggregated form – possibly also in an international comparison.¹¹⁰
 - Not conducting a causal analysis of the measure effects may be justified in individual cases, not least because the conditions for this cannot be created in every case. However, this must be justified by the particularities of the respective measure context.
 - Where the requirements for robust causal analyses are not met, the use of simpler methods such as matching procedures can provide indications of the effectiveness of measures. However, in such cases, no statements should be made about the effectiveness of measures that are not covered by the methods used.
- ### Expand Expertise and Create Transparency
- The primary prerequisite for policy learning by means of causal analyses of the effects of measures is that they are conducted in an open-ended manner and that both positive and negative results are equally valued as advances in knowledge.¹¹¹

- Irrespective of the results, all analyses of policy effects commissioned by the ministries should be published. The data and programming codes used should also be disclosed or made available to interested researchers on request. This will enable the results to be replicated, possibly using improved methods of analysis developed at a later date.
- The institutional embedding of evaluation practice in the ministries should be further intensified and particular attention should be paid to the further training of staff in the units formulating policy measures.¹¹²

Increase Availability and Quality of Data

- The units or project executing agencies responsible for implementing a measure should systematically provide the evaluation teams with all documents associated with a measure. This includes, for example, draft proposals, information on all applicants and not just those who ultimately receive funding, as well as the preparatory documents and minutes of the selection and funding committees.
- The data laboratories in the ministries should be further developed into research data centres that collect and process data from all R&I policy funding measures and make it available for research.¹¹³ Uniform definitions and, where possible, indicators should be developed and used across ministries in order to ensure the comparability of data across different measures.
- Data that is already collected for administrative purposes is often of great importance for evaluation studies. Access to this data for the purpose of evaluating policy measures should be subject to a light-handed regulation and facilitated comprehensively, i. e. also at lower levels of data aggregation.¹¹⁴

B

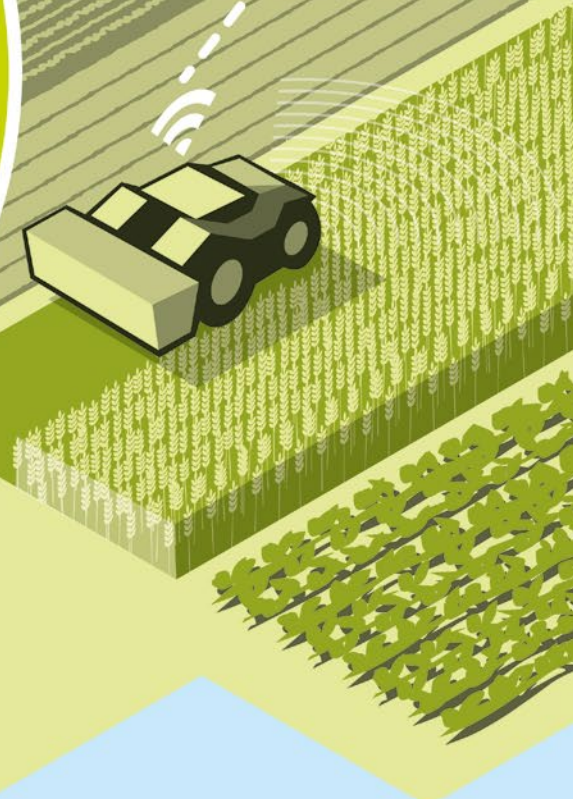
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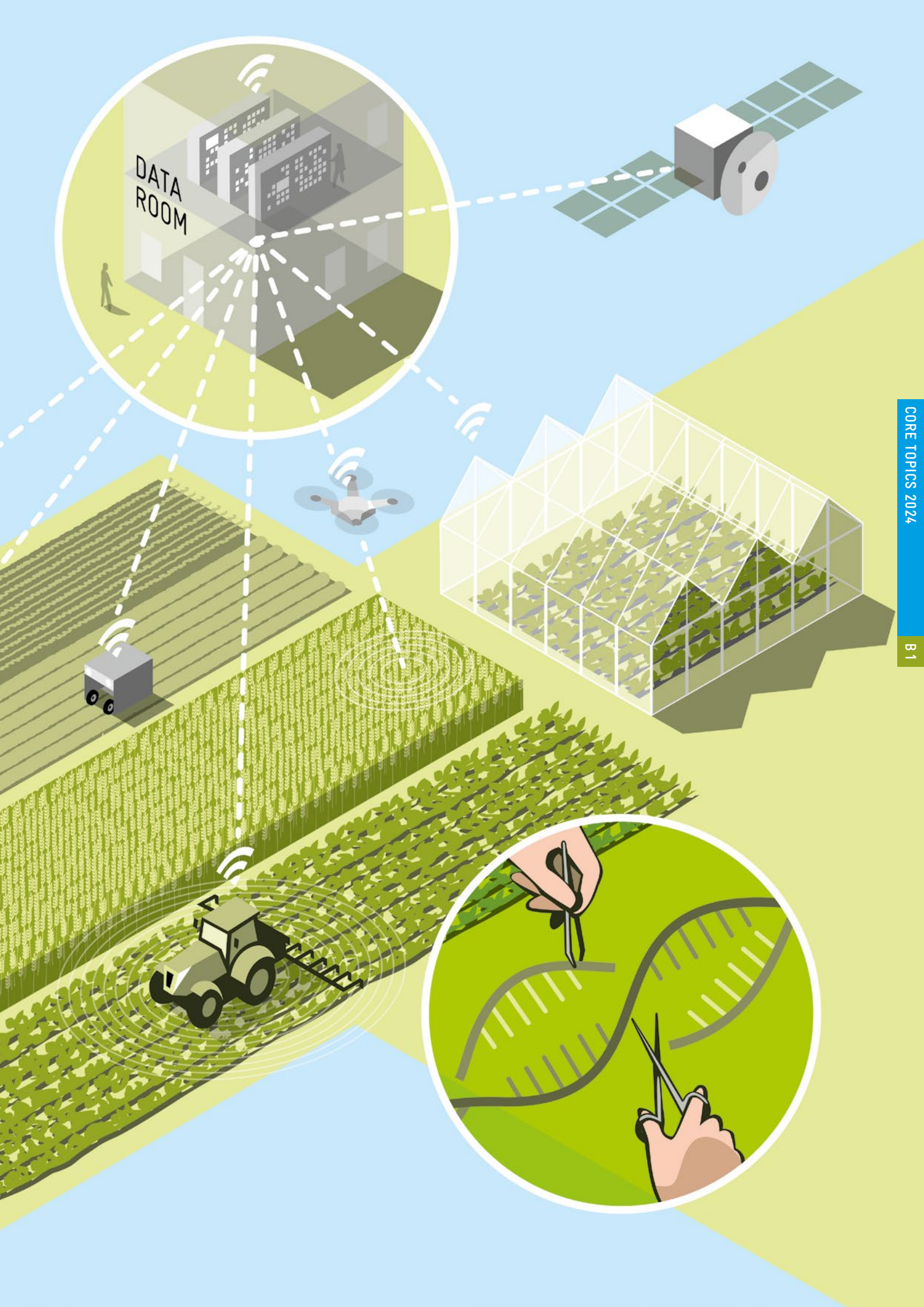


B 1 New Technologies for Sustainable Agriculture



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B 1 New Technologies for Sustainable Agriculture

Agriculture is facing major challenges worldwide. The Sustainable Development Goals (SDGs) formulated as part of the United Nations 2030 Agenda call for the fight against hunger on the one hand and the sustainable use of the natural environment, the preservation of biodiversity and the fight against climate change on the other. Agriculture, which is itself affected by climate change, must by tendency produce larger quantities of food with less environmentally harmful inputs such as pesticides and fertilisers while at the same time arable land is decreasing.¹¹⁵ To master this balancing act, a major transformation of the agricultural system will be necessary – and certainly also a change in dietary habits. A major technological change is likewise required in crop farming, which is the focus of this chapter.¹¹⁶ The use of digital and smart technologies, in particular resource-saving precision technologies, but also green genetic engineering methods that enable the cultivation of plants that are both more climate-resistant and richer in nutrients, offer opportunities here.

However, the use of these innovative technologies is still restricted by many barriers. With regard to digital and smart technologies, digital infrastructure and interoperability between hardware and digital applications are lacking. There are still insufficient incentives for the use of resource-saving precision technologies to reduce environmentally harmful inputs. However, the cultivation of new crops using genetic engineering also faces numerous hurdles in Europe and Germany in terms of the legal framework and acceptance. The Commission of Experts therefore calls on the Federal Government, and in particular the Federal Ministry of Food and Agriculture (Bundesministerium für Ernährung und Landwirtschaft, BMEL), the Federal Ministry for

the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (Bundesministerium für Umwelt, Naturschutz, -nukleare Sicherheit und Verbraucherschutz, BMUV) and the Federal Ministry for Digital and Transport (Bundesministerium für Digitales und Verkehr, BMDV), to provide stronger incentives for the use of digital and smart agricultural technologies and to solve the necessary infrastructure problems, and to actively support the European Commission's proposal to reform the process-based regulations for the use of new genomic techniques. In the long term, method-based regulation should be converted to regulation of the characteristics of the bred plants.

B 1-1 Challenges for Agriculture

Population growth, climate change, the decline in arable land and the negative effects on the environment caused by agriculture itself, such as biodiversity loss and groundwater pollution, constitute major challenges for agriculture.

Food Security as a Challenge for Agriculture

One of the goals formulated by the United Nations in the SDGs is to eradicate all forms of hunger and malnutrition by 2030. This goal is to be achieved by increasing production and productivity in agriculture, adapting to climate change and at the same time making farming methods more sustainable in order to protect natural ecosystems and maintain soil quality.¹¹⁷ The challenge, therefore, is to transform existing intensive agricultural practices into more sustainable forms of farming and at the same time ensure that the demand for food¹¹⁸ is met for a growing world population.¹¹⁹

Climate Change as a Challenge for Agriculture

Extreme weather events have increased significantly in Germany over the past 20 to 30 years.¹²⁰ According to the forecasts of the Intergovernmental Panel on Climate Change (IPCC), this trend is highly likely to continue in Central and Western Europe in the future. The greatest climate-related challenges for agricultural production in Germany are the increase in winter precipitation with an increased risk of erosion and nutrient leaching as well as the increase in dry periods during the main growth season.¹²¹ Climate change affects different crops differently from region to region and across the vegetation periods.¹²² Climate change also influences the habitat conditions of harmful organisms that indirectly affect agricultural production.¹²³ The consequences are losses in the quality and yield of agricultural products.¹²⁴

Agriculture as a Cause of Climate and Environmental Damage

Agriculture is not only affected by climate change, but also contributes significantly to climate change through emissions (especially methane and nitrous oxide) and land-use changes (especially the conversion of forests and peatlands into agricultural land). In addition, agriculture has negative impacts on groundwater and surface water as well as on neighbouring natural ecosystems, particularly their biodiversity, through the use of nutrients and the application of pesticides.¹²⁵ Abundant biodiversity plays a key role in the resilience of agroecosystems and the productivity of soils. It promotes an optimal interplay of processes in nature,¹²⁶ which in turn has a positive effect on agricultural production.¹²⁷

Finally, the withdrawal of groundwater and surface water for irrigation purposes is a major problem in many parts of the world. Even if agriculture in Germany has played a minor role in water withdrawal to date, this may change in the future due to longer periods of drought.¹²⁸ In large parts of Germany, groundwater resources are already in a critical state today.¹²⁹

To meet the challenges of climate change and biodiversity loss and to ensure food security, a major technological change in agriculture is required. Digital and smart technologies, in particular resource-saving precision technologies, as well as green genetic engineering methods for breeding climate-resistant plants with improved pest resistance and improved nutrient uptake offer innovative solutions. However, the extent to which the potential of these technologies can be utilized depends not least on the incentives, skills and overall conditions in the agricultural sector.¹³⁰

B 1-2 Digital and Smart Technologies in Agriculture

The following section looks at digital and smart technologies and their potential for the transformation of agriculture. In addition, obstacles that currently stand in the way of widespread use are identified. Digital and smart technologies include digital hardware and software as well as their connectivity so that data can be received and sent.¹³¹ The various technologies are components of the concepts of precision agriculture and smart farming, which are explained in greater detail below.

Box B 1-1 German Agricultural Sector

The gross domestic product (GDP) of the agricultural sector amounted to around €28.9 billion in 2021, which corresponded to 0.8 percent of Germany's total GDP.¹³² In 2020, 937,900 people were employed in agricultural holdings.¹³³ This corresponded to approximately 2 percent of the labour force in Germany.¹³⁴ Approximately 50.5 percent of the total area in Germany is used for

agriculture, 70.3 percent of which is arable land.¹³⁵ Agriculture was responsible for 7.4 percent of greenhouse gas emissions in 2022.¹³⁶ The public contribution to the funding of agriculture in Germany is essentially made via the Common Agricultural Policy (CAP) of the European Union (EU). The German CAP Strategic Plan 2023–2027 provides, among other things, funds totalling €12.8 billion for basic income support and €8.7 billion for additional direct payments.¹³⁷

B 1-2 a Potential and Challenges of Digital and Smart Technologies

Precise Farming of Specific Areas Possible

Precision farming is the site-specific, targeted and variable application of agricultural inputs such as seeds, plants, fertilisers, pesticides and water. The quantity of inputs used is adapted exactly to the current specific requirements of the respective agricultural sub-area.¹³⁸ Precision farming can reduce the amount of fertiliser and pesticides applied. This allows for savings in operating costs while reducing negative environmental impacts.¹³⁹ Satellite-based navigation technologies, which enable precise positioning, are key to the application of precision farming. The information obtained via sensors can be processed in geographic information systems, so-called field maps.¹⁴⁰ Work processes and the use of resources can be optimized with the help of such field maps and carried out by automated agricultural machinery.¹⁴¹

Better Farm Management Made Possible by Digital and Smart Technologies

Smart farming is looser defined than precision farming and utilizes both the data collected by interconnected devices on the Internet of Things and the processing of this data with other context-specific data to support farmers in making operational decisions or to automate these decisions. The spectrum of tasks ranges from automated data collection and optimization of farm planning to the automation of accounting.¹⁴² In addition to farms, the agriculture 4.0 network also includes manufacturers of inputs, retailers and consumers. The aim is to improve organization and processes along the entire value chain.¹⁴³

Wide Range of Applications for Digital and Smart Agricultural Technologies

Digital (partially) automated agricultural machinery, robots or drones can be used in precision farming. (Partially) automated agricultural machinery includes, for example, tractors with track guidance or part-width section control for the site-specific application of inputs.¹⁴⁴ Robots are autonomously operating machines that are able to register their environment, process information obtained via sensors, make decisions and derive suitable work steps from this.¹⁴⁵ Compared to (partially) automated agricultural machinery, robots are significantly

smaller and gentler on the soil. However, they are still largely at the research and development stage.¹⁴⁶ The currently targeted areas of application range from the determination of plant characteristics and health, soil cultivation, weed control and maintenance work in fruit growing to sowing and harvesting.¹⁴⁷ Drones, as part of remote sensing,¹⁴⁸ are human-controlled or semi-autonomous aircraft that use sensors to monitor plant growth, pest infestation, soil structure, water shortages, erosion and storm damage. Drones can also apply inputs such as pesticides in rough terrain.¹⁴⁹ Thanks to falling costs and simplified operation and control, their use is becoming increasingly widespread in some areas.¹⁵⁰

The functionality of (partially) automated agricultural machinery, robots and drones is largely based on sensors and actuator technology. Sensors record information and convert it into electrical signals that can be digitally recorded and processed. Recording this data makes it possible, for example, to differentiate between crops and weeds.¹⁵¹ Actuators such as motors, section control, robotic arms and display elements convert the processed sensor data into customized agricultural processing.

Farm management and information systems (FMIS) and decision support systems (DSS) assist agricultural holdings through the automated collection and processing of data that enables better planning, monitoring, documentation and optimization of operational processes, e. g. through the automated creation of field maps.¹⁵² Both internal farm data and data from external sources are processed and artificial intelligence (AI) is used.¹⁵³

Widespread Use of Farm Management Systems

In a non-representative survey¹⁵⁴ conducted on behalf of the Commission of Experts between May and June 2023, 40.9 percent of the participating farms and contractors stated that they use FMIS or DSS (cf. figure B 1-2). This is followed at a slight distance by the use of digital technologies for agricultural machinery. Digital information platforms are used by approximately one in three and drones by one in four of the farms surveyed. While detection and sensor technology still play a role for one in five farms, field robots are only used by 4.2 percent of the farms surveyed. However, 12.7 percent of those surveyed stated that they were planning to use field robots.¹⁵⁵

Continued Development in Agricultural Technologies Required

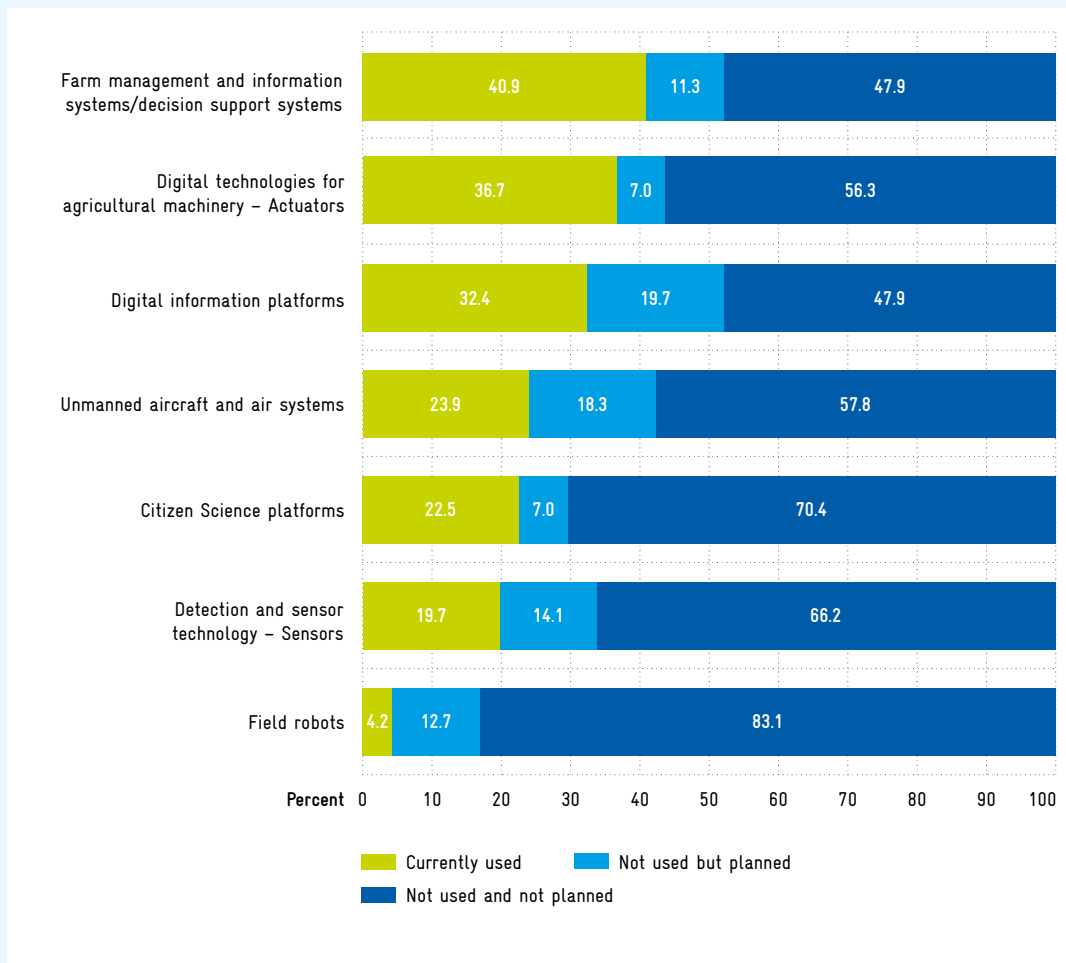
As precision technologies are used in vastly different environments, correct status detection and environment recognition requires the combination of sensors and integrated sensor systems or the linking of data from different sensors. Significant development steps are still needed here, especially for autonomous systems. In addition, the use of advanced applications requires integration into the Internet of Things and, consequently, suitable network structures for fast data transmission, which are still insufficiently established in many rural areas.¹⁵⁶

Analyzing the practical suitability of precision technologies is an important development step. To this end, the BMEL has launched 14 'Digital Experimental Fields'.¹⁵⁷ These are projects within which the funded actors investigate how digital technologies can be optimally used to protect the environment, increase animal welfare and biodiversity and facilitate work.¹⁵⁸ These experimental fields offer interested users the opportunity to learn more about digitalization in agriculture. In addition, cooperation between agriculture and research takes account of practical requirements in the development and testing of new applications to ensure a two-way transfer of knowledge.

Fig. B1-2 Use of digital and smart technologies 2023 in percent



[Download Data](#)



Legend: 40.9 percent of the farms and contractors surveyed stated that they currently use farm management and information systems or decision support systems. 11.3 percent of respondents plan to use them in the future; number of observations: 71; Question text: "Which digital and smart technologies do you use for your activities?" Bars do not always add up to 100 percent due to rounding. Source: Own evaluations based on Geppert et al. (2024). © EFI – Commission of Experts for Research and Innovation 2024.

Incentivizing Use of New Technologies Essential for Sustainability

New digital and smart technologies are often still at a competitive disadvantage compared to powerful conventional agricultural machinery developed for intensive farming. There are three main reasons for this: first, some of these technologies, such as robots, are not yet mature in their development. Second, they are still comparatively expensive due to their limited distribution and therefore small numbers. Third, the negative environmental impacts of conventional agricultural practices are not reflected in the production costs of farms.

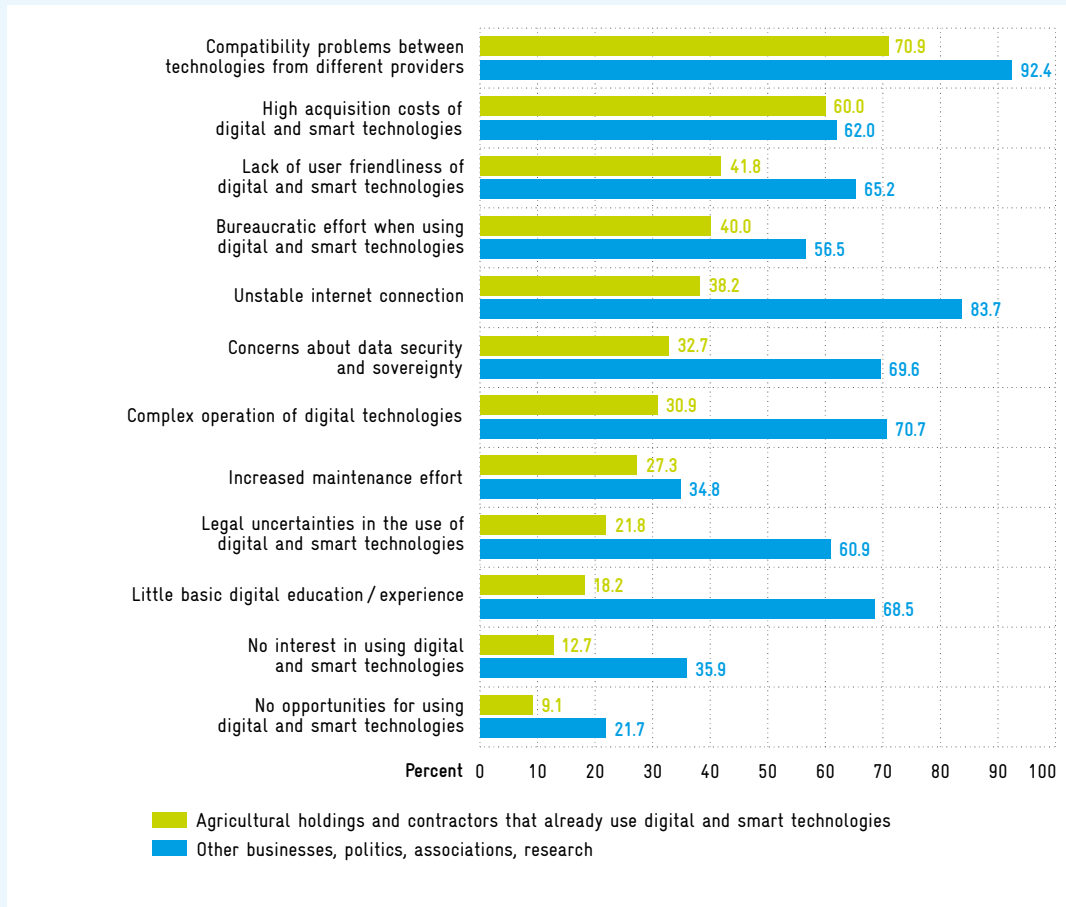
To make robots and drones competitive, for example, their area coverage, duration of use and preci-

sion must be further increased. Switching to cultivation concepts with significantly differentiated and smaller-scale cultivation of land, such as spot farming,¹⁵⁹ would also increase their competitiveness.¹⁶⁰ However, the development costs of robots in particular are very high, so that relatively small numbers of units are likely to result in high acquisition costs for farms.¹⁶¹ In the above-mentioned survey, 60.0 percent of respondents who already use digital and smart technologies cited the high acquisition costs as a (very) major obstacle to their use (cf. figure B 1-3). Due to a lack of experience with the new technologies, the economic benefits for agricultural holdings are also initially uncertain. However, as these new technologies become more widespread and thus larger numbers of units are produced, the acquisition costs are

Fig. B 1-3 Barriers to the use of digital and smart technologies 2023 in percent



[Download Data](#)



Legend: 70.9 percent of the agricultural holdings surveyed that use at least one of the digital and smart technologies surveyed themselves view compatibility problems between technologies from different providers as a major or very major barrier to using digital and smart technologies. Question text: "In your opinion, what factors impede or prevent the use of digital and smart technologies in agriculture?" Possible answers: no barrier, minor barrier, major barrier, very major barrier. The bars show the sum of "major barrier" and "very major barrier". Source: Own evaluations based on Geppert et al. (2024). © EFI – Commission of Experts for Research and Innovation 2024.

likely to fall making the technologies even more attractive.

The survey conducted on behalf of the Commission of Experts also showed that both farmers and representatives from politics, associations, research and industry attribute high potential to digital and smart technologies in the field of sustainability and environmental protection, especially in protecting biodiversity and reducing soil pollution (cf. figure B 1-4). According to a survey of 500 farmers in Germany conducted by Bitkom Research in 2022, 92 percent of respondents believe that digital and smart technologies can save on fertilisers, pesticides and other operating resources.¹⁶²

However, the at times massive environmental impacts caused by the application of fertilisers and pesticides is generally not considered by farms in their cost accounting. The incentives to use new, en-

vironmentally friendly precision technologies are therefore still too low.

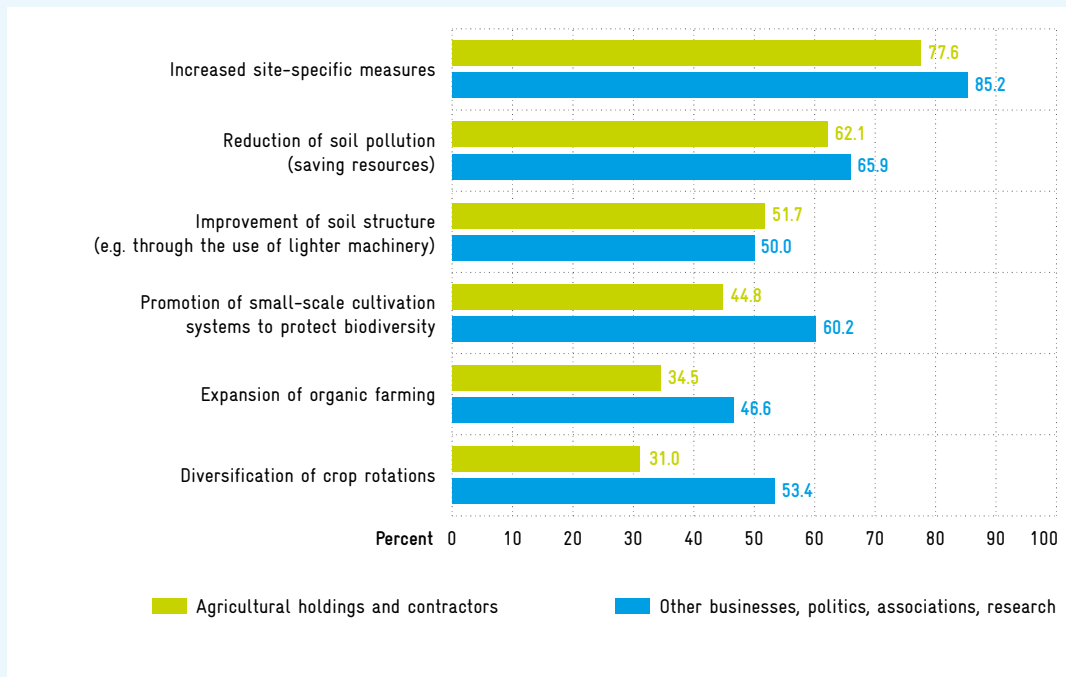
This would change if the use of polluting inputs were subject to a tax or levy. This is already the case in Denmark.¹⁶³ The use of old, unsustainable agricultural technologies would thus become more expensive and newer (precision) technologies would become competitive.

Another alternative would be the introduction of a quota trading system for fertilisers and pesticides like the European emissions trading system for CO₂ certificates (EU ETS). However, a quota trading system for fertilisers and pesticides runs the risk of some agricultural holdings buying up large quantities of quotas. This would concentrate the application of fertilisers and pesticides at certain locations and lead to excessive pollution there. A tax or levy is therefore preferable to quota trading.

Fig. B 1-4 Potential of digital and smart technologies 2023 in percent



[Download Data](#)



Legend: 77.6 percent of the agricultural holdings surveyed consider digital and smart technologies to have a high or very high potential for implementing more site-specific measures. Question text: "How high do you estimate the potential of digital and smart technologies in agriculture for sustainability and environmental protection in the next 10 years?". Possible answers: no potential, low potential, high potential, very high potential. The bars show the sum of "high potential" and "very high potential".
Source: Own evaluations based on Geppert et al. (2024).
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New Skills Needed in the Use of Digital and Smart Technologies

Precision farming and smart farming also require new skills and competences from agricultural workers.¹⁶⁴ Of those surveyed on behalf of the Commission of Experts who use digital and smart technologies, more than 80.0 percent stated that advisory, training and continuing education programmes would facilitate the use of such technologies (cf. figure B 1-5).¹⁶⁵ For example, the use of certain sensors demands the competence to carry out special calibrations, while complex FMIS and DSS require sufficient skills in handling data and software. In the survey, 31.0 percent of farms cited the high complexity of operating digital technologies as a (very) major obstacle to their use (cf. figure B 1-3).

Insufficient Compatibility of Systems

A prerequisite for the combined use of digital and smart technologies is the exchange of data. This requires suitable interfaces and data standards, which are currently only available to a limited ex-

tent. As a result, there are still considerable compatibility problems when exchanging data between products from different manufacturers, such as individual sensors, robots, drones and FMIS, as well as between different FMIS. This increases farmers' lock-in to one provider. In the survey conducted on behalf of the Commission of Experts, 70.9 percent of the farms surveyed that already use digital and smart technologies stated that such compatibility problems are a (very) major obstacle (cf. figure B 1-3). In addition, the lack of availability of agricultural data is often a further obstacle. In the Bitkom Research survey of 500 farmers in Germany in 2022, 56 percent of respondents consider political measures as (very) important for establishing a centralized agricultural platform for farm data management. As many as 95 percent of respondents consider user-friendly and free geodata, farm inputs and weather data to be (very) important.¹⁶⁶

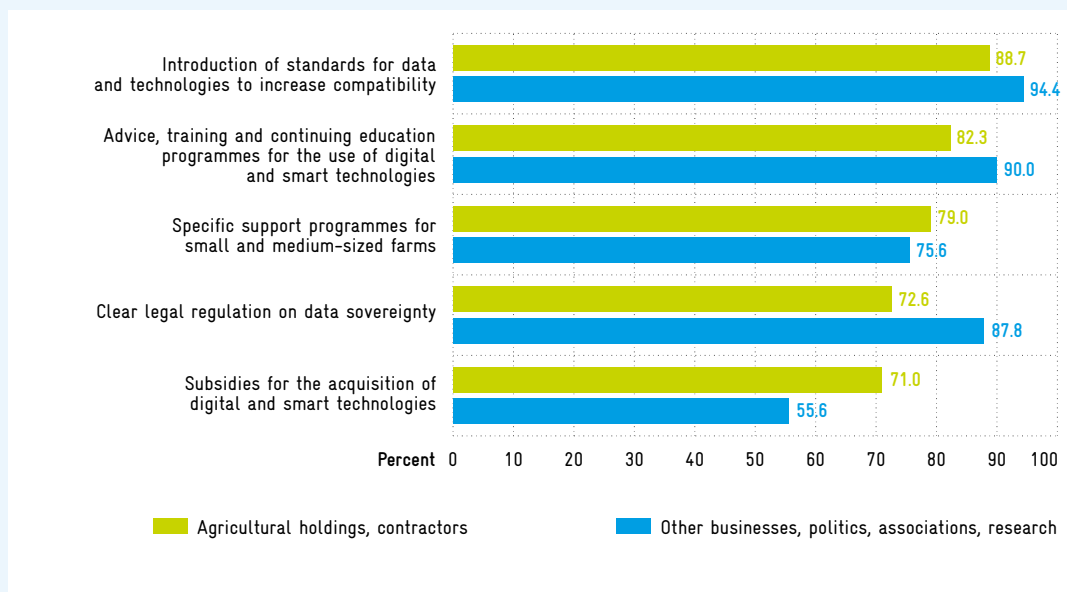
Practical Legal Framework Required

A transparent and widely communicated legal framework¹⁶⁷ for the use of autonomous vehicles

Fig. B 1-5 Measures for facilitating the use of digital and smart technologies 2023 in percent



[Download Data](#)

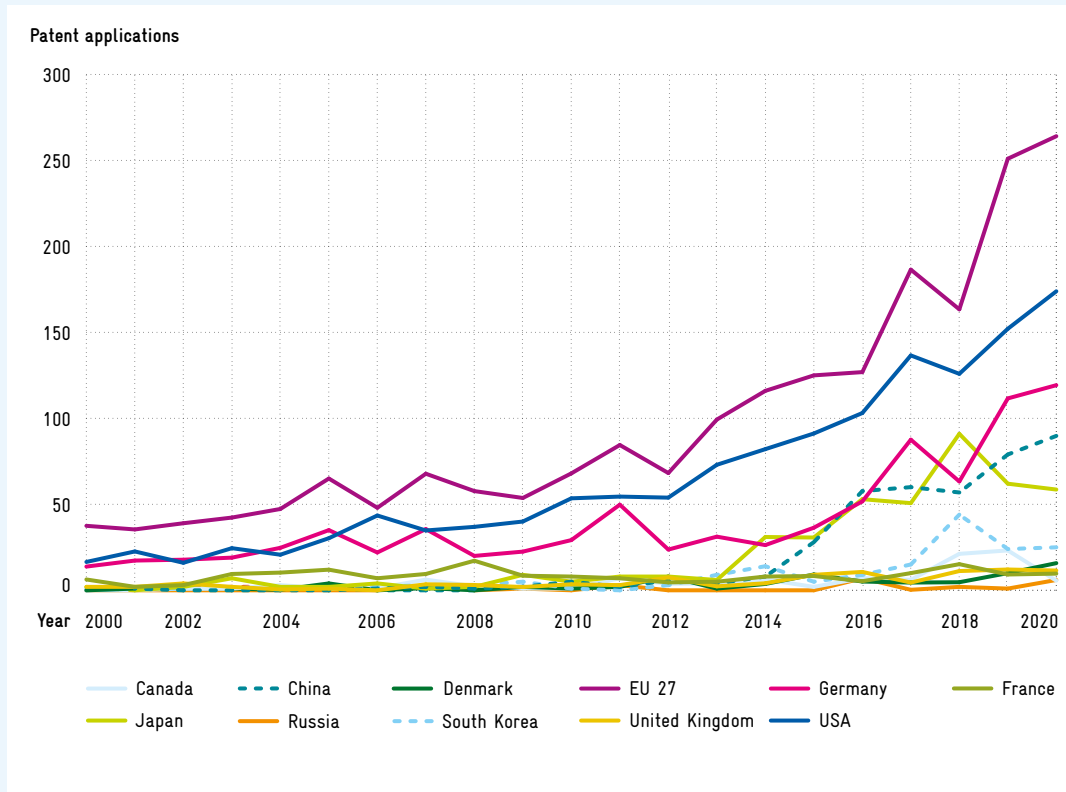


Legend: 88.7 percent of the farms surveyed consider the introduction of standards for data and technologies to increase compatibility to be an important or very important measure to enable the use of digital and smart technologies on farms. Question text: "How important do you consider the following measures to enable the (increased) use of digital and smart technologies on farms?" Possible answers: not important, rather unimportant, rather important, very important. The bars show the sum of "rather important" and "very important". Source: Own evaluations based on Geppert et al. (2024). © EFI – Commission of Experts for Research and Innovation 2024.

Fig. B1-6 Transnational patent applications for digital and smart agricultural technologies in selected countries and regions 2000–2020



[Download Data](#)



Source: PATSTAT. Own calculations.
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such as robots, drones and autonomous agricultural machinery is needed to reduce farmers’ reservations about using them and to create investment security. The Autonomous Driving Act (Gesetz zum autonomen Fahren), which came into force in 2021, is an important first step in this regard. Some drone applications require the use of larger devices,¹⁶⁸ which can drop materials such as pesticides. In addition, large-scale drone operations also require flights beyond visual range. Such operations require complex authorizations from the relevant authorities or the European Aviation Safety Agency.¹⁶⁹

The exchange and processing of a comprehensive database, including internal data, is a prerequisite for the use of precision and smart farming technologies. However, concerns about data security and data sovereignty in internal company processes inhibit the use of FMIS, which is also reflected in the survey results (cf. figure B1-3). One of the aims of

the Data Act (Datenverordnung), which came into force in January 2024, is to address the unresolved legal issues in this area, thereby reducing existing reservations.¹⁷⁰

B1-2 b International Comparison of the Development of Digital and Smart Agricultural Technologies

An increase in the number of transnational patents¹⁷¹ filed in the field of digital and smart agricultural technologies can be observed in the period from 2000 to 2020 (cf. figure B1-6). In the same period, the share of these patents in all agricultural patents also rose continuously – in the EU and Germany from 5.0 percent and 3.5 percent respectively in 2000 to over 15 percent in 2020. This reflects the increasing importance of these technologies in the agricultural sector. Over the entire period, there were more patent applications from the EU than from the USA.

Europe Leading in Actuators, Sensors and Robotics

Patent applications can be broken down into the areas of sensor technology, robotics, actuator technology, drones, AI, decision support and automated systems.¹⁷² Patent applications in the field of sensor technology account for the largest share, and their number has increased significantly more since 2012 than in the years before (cf. figure B 1-7). Although patent applications in the other areas are at a much lower level, they more than doubled worldwide between 2015 and 2020.

In the fields of actuators, robotics and sensors, most patent applications originate from the EU (cf. figure B 1-8). Patent applications from China dominate in the field of drones. Most patent applications in the field of AI come from the USA.

B 1-3 Green Genetic Engineering in Agriculture

In addition to digital and smart technologies, green genetic engineering can also contribute to solving the challenges in agriculture. The following section outlines green genetic engineering methods, their potential and risks, as well as research activities in the field of genome editing.

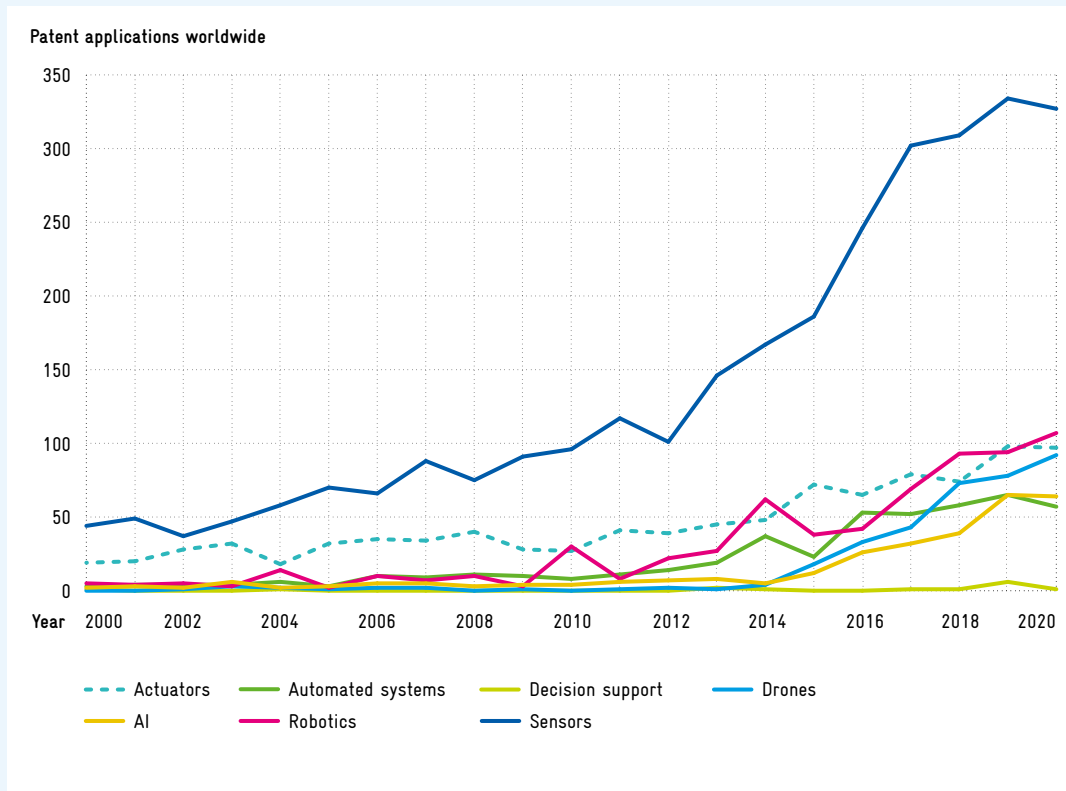
B 1-3 a Methods, Regulation and Application of Green Genetic Engineering

In green genetic engineering, the genetic material of a plant is modified in such a way that new characteristics are created. Possible modifications range from the alteration of individual bases to the incorporation of longer gene sequences into the plant genome. When altering gene sequences, four different

Fig. B 1-7 Transnational patent applications for digital and smart agricultural technologies worldwide by technology area 2000–2020



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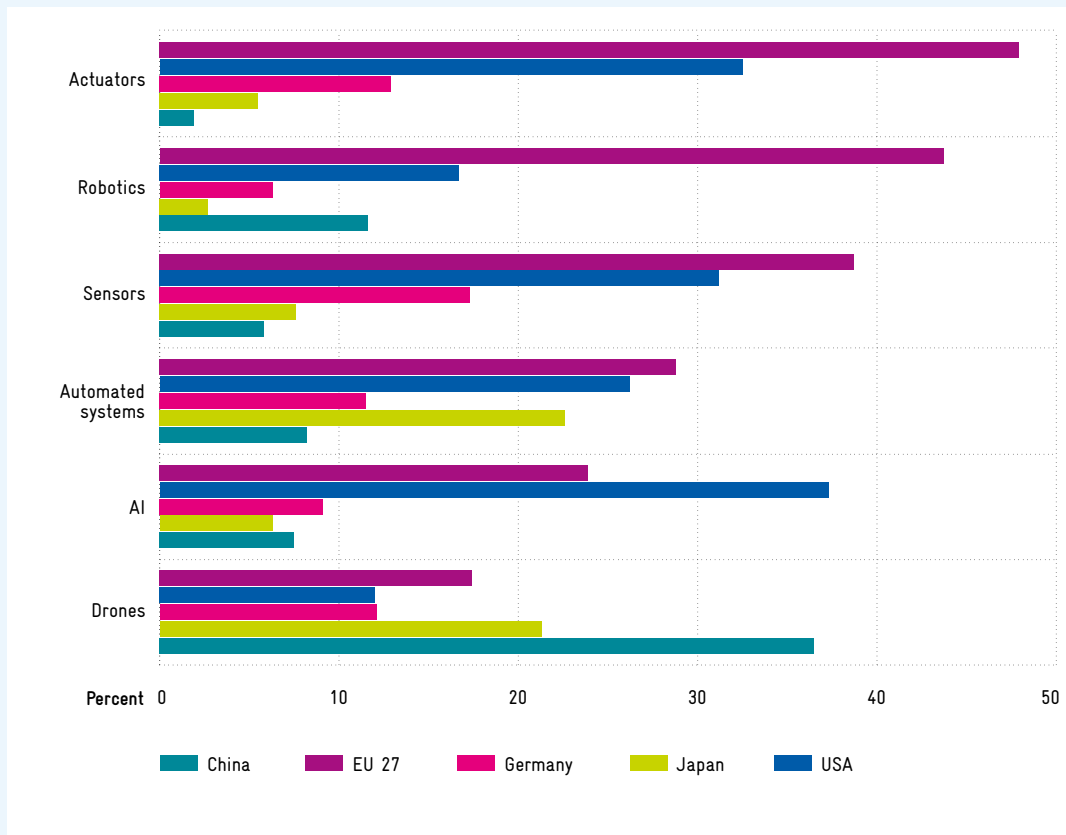


Source: PATSTAT. Own calculations.
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Fig. B 1-8 Percentage of selected countries and regions in transnational patent applications worldwide by technology area 2000–2020



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Source: PATSTAT. Own calculations.
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genetic modifications are distinguished: mutagenesis, cisgenesis, intragenesis and transgenesis (cf. figure B 1-9).¹⁷³ These modifications can be produced by various methods. The three methods discussed below are genome editing,¹⁷⁴ conventional genetic engineering and mutation breeding. In addition, there are other methods of genetic engineering, such as synthetic biology, which shall not be discussed here,¹⁷⁵ as well as methods of conventional plant breeding that do not utilize genetic engineering. In this report, conventional plant breeding primarily refers to techniques such as crossbreeding and selection.¹⁷⁶

Mutagenesis Possible by Several Methods

In mutagenesis, a mutation is created based on the plant's own genetic material without introducing genetic material into the organism. Organisms produced by mutagenesis can therefore also

be the result of conventional plant breeding or by natural means.¹⁷⁷ There are essentially two different methods by which mutagenesis can be carried out: untargeted or random mutation breeding and targeted mutagenesis by means of genome editing. In random mutation breeding, the gene sequence is damaged by chemicals or radioactive radiation, for example. In this method, the location where the plant's DNA¹⁷⁸ is damaged cannot be determined in advance, resulting in plants with many mutations. The plants that have the desired mutation must then be selected in a complex process. In genome editing, the gene sequence is damaged by a targeted (double-strand) break.¹⁷⁹ The so-called CRISPR¹⁸⁰ genetic scissors are the most frequently used genome editing method. In both random mutation breeding and targeted mutagenesis, the damaged gene sequence is repaired by the cell's own system, resulting in mutations.¹⁸¹

Fig. B 1-9 Overview of modifications and methods of green genetic engineering and their current regulation



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Process	Modification	Mutagenesis	Cisgenesis	Intragenesis	Transgenesis
Genome editing		targeted Mutagenesis			
Conventional genetic engineering					
Mutation breeding					

Red means that the plants from this method fall under the strict regulations of the Genetic Engineering Act (Gentechnikgesetz), i.e. they are subject to mandatory labelling as a genetically modified organism (GMO), they are subject to risk assessment and the plants are not permitted in organic farming.

Green means that the plants from this method are not subject to the strict regulations of the Genetic Engineering Act, i.e. there is no labelling requirement as a GMO, the risk assessment does not apply and the plants are permitted in organic farming.

Grey means that this modification cannot technically be carried out using the method.

Source: Own representation.

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Versatile Modifications with Introduced Genetic Material

Whilst in mutagenesis no genetic material is introduced into the organism, in cisgenesis, intragenesis and transgenesis gene sequences of different origins are inserted into the genome of a plant.¹⁸² In cisgenesis, DNA from the plant itself or from closely related, cross-compatible plants is used. The organisms produced in this way could also be obtained by conventional breeding. In intragenesis, fragments of gene sequences from the plant's own species or from a cross-compatible species are recombined and introduced into the plant. These organisms cannot be produced by conventional plant breeding. In transgenesis, gene sequences from foreign organisms are introduced into the plant. These plants are also not produced by conventional plant breeding.¹⁸³

Cisgenic, intragenic or transgenic plants can be produced by two methods: genome editing and conventional genetic engineering. In genome editing, a break is created at a specific location and, in contrast to targeted mutagenesis, a gene sequence is inserted that the cell's own system can use to repair the targeted break. In conventional genetic engineering, gene sequences are inserted into the genetic material of a plant in an untargeted manner, e.g. using transport bacteria or a gene gun. The location and frequency of the insertion cannot be determined.¹⁸⁴

Transgenesis can be used to create new characteristics in plants. Mutagenesis, on the other hand, is limited to the natural diversity of the plant genome.

Cisgenic and intragenic organisms are located between these two extremes.¹⁸⁵

Genome Editing Not a Complete Substitute for Other Methods

The advantage of genome editing methods is that they can shorten the time it takes to develop a modified plant characteristic by years or decades.¹⁸⁶ Since nowadays many genes and their functions have been sequenced, genome editing offers the possibility of implementing changes faster and more precisely than untargeted methods such as conventional genetic engineering and mutation breeding. The prerequisite for realizing the full potential of genome editing is the sequencing of a plant's genome. Reference genomes¹⁸⁷ are available for most of the world's economically important crops.¹⁸⁸ Genome editing allows for precise prediction of genetic modification and potentially results in time and cost savings. It can also be used by small and medium-sized enterprises (SMEs), which are typical of the European seed market, which can have a positive impact on product diversity and competition in the seed market.

By contrast, untargeted mutagenesis produces many mutations at random, which means that a considerable amount of time and money is required to select the few desired plants. However, knowledge of the gene sequences is not a prerequisite here.

Mutation breeding results in a large number of changes in the plant genome, the consequences of which are unknown. In rare cases, genome editing

can also lead to changes in non-target sequences, which are known as off-target effects and are considered undesirable. However, since genome editing is a more precise procedure, such unintended mutations occur much less frequently than with untargeted methods.¹⁸⁹

Genome editing is a valuable tool for expanding the genetic variation of cultivated plants. It is already being used worldwide in plant breeding for various crops. However, only a few genes can be specifically modified at the same time. Yet many characteristics are only formed through the interaction of numerous genes. As not all plant species have been sequenced to date and there are still technical difficulties in using genome editing for transgenesis, the methods of conventional genetic engineering, mutation breeding and conventional breeding will remain indispensable in the future.

Genetic Engineering Strictly Regulated in the EU

Genetically modified organisms (GMOs) are defined in the EU as organisms whose genetic material has been modified in a way that does not occur naturally by crossbreeding or natural recombination. This means that all organisms that have not been created through conventional breeding are considered GMOs.¹⁹⁰

To be approved for cultivation or as food and feed in the EU, GMOs must undergo complex and lengthy approval procedures.¹⁹¹ These procedures include a comprehensive risk assessment and environmental impact assessment. The necessary data must be provided by the developing companies and is reviewed by, among others, the European Food Security Agency (EFSA).¹⁹² Approval as food or feed or for cultivation is granted at EU level and applies to all Member States. In the case of approval for cultivation, the Member States nevertheless have the option of prohibiting cultivation on their territory.¹⁹³ In addition, GMOs are subject to labelling requirements. Products labelled as GMOs must not be used in organic farming.¹⁹⁴

The EU takes a method-based approach to the regulation of genetic engineering.¹⁹⁵ All organisms created using mutation breeding, genome editing or conventional genetic engineering are considered GMOs. However, organisms resulting from mutation breeding are treated differently from organisms resulting from targeted mutagenesis by means of

genome editing. Organisms resulting from mutation breeding do not have to undergo an approval procedure or risk assessment. They are not labelled as GMOs and can therefore also be used in organic farming.¹⁹⁶

GMOs Rarely Cultivated in the EU

The first two GMOs were placed on the market in the EU in 1996. Currently, 140 specific combinations of genetically modified crops and characteristics are approved in the EU. Of these, only one crop, the insect-resistant maize MON810, is approved for cultivation, while the other approvals relate to the use of imported feed or food.¹⁹⁷ Within the EU, MON810 maize is only cultivated in Spain and Portugal, while all other Member States have banned its cultivation despite EU approval.¹⁹⁸ Globally, however, GMOs are grown on about 12.5 percent of arable land – mainly in Argentina, Brazil and the USA.¹⁹⁹ The dominant and commercially successful trait categories of genetically modified plants are herbicide tolerance and insect resistance. These two characteristics are currently being developed primarily using conventional genetic engineering.²⁰⁰ Genome editing does not yet play a significant role in application. To date, only a few plants produced primarily with genome editing are on the market, including a soya bean with an optimized fatty acid composition (cf. box B 1-10).²⁰¹

B 1-3 b Potential of Green Genetic Engineering in Agriculture

Green Genetic Engineering Helps Achieve Food Security

A key objective in plant breeding is to increase yields or maintain them in extreme weather conditions and organic farming, thereby ensuring food security even as agricultural land decreases. This can be achieved through higher yields, but also through resistance to various pests.²⁰² Furthermore, crops can be modified to be more nutritious, thereby helping to improve nutrition.²⁰³ Such characteristics can be created using green genetic engineering methods.²⁰⁴

The development of many plant characteristics is geared towards target markets in industrialized countries. Crop species from developing countries, where food security is a problem, have so far only been genetically modified to a relatively small extent. As cultivation conditions and practices vary greatly between countries, the products of green ge-

Box B 1-10 Case Studies for Green Genetic Engineering Products

Field Pennycress As Catch Crop

The US start-up CoverCress has developed an optimized field pennycress that can be used both as a winter cover crop in a soya-maize rotation and for the production of vegetable oil for biofuels. It is thus adapted to the regional growing conditions. Various methods were used for its development: mutation breeding, selection, conventional genetic engineering and genome editing. Aspects such as soil conservation, soil quality and agrobiodiversity are taken into account with this field pennycress. Since 2013, CoverCress has received US\$ 58 million from private and public investors in several rounds of financing for its development. Bayer AG is now the largest shareholder. It remains to be seen whether this field pennycress will be successful on the market. Extensive field trials are currently underway.²⁰⁵

Soya Bean Optimized for Fatty Acid Composition

The US company Calyxt has used genome editing to develop a soya bean with an optimized fatty acid composition that can be used to produce a

more nutritious and longer-lasting oil. The responsible US authority decided in 2015 that the plant did not need to undergo an approval process, meaning it could be cultivated as early as 2018 and marketed as oil in 2019. The business was discontinued in 2020, as several breeding companies were already offering seeds for such soya oil qualities, both from conventional breeding and conventional genetic engineering, on the market and acceptance among farmers was additionally low because of low yields.²⁰⁶

Drought Tolerant Wheat

The Argentinian company Indear has used conventional genetic engineering to breed a drought and herbicide-tolerant wheat that, depending on the location, yields about 6 percent more under drought stress and is comparable to other varieties under normal growing conditions. The combination of drought stress and herbicide tolerance is aimed primarily at markets in South America and the USA. After more than 15 years of development, approval for cultivation and as food in Argentina was granted in 2020, with both the development using untargeted methods and the approval process taking a long time.²⁰⁷

netic engineering cannot be cultivated everywhere, and developing countries are often excluded from innovative products. Here, genome editing offers developing countries an opportunity to work on the development of plant characteristics themselves.²⁰⁸

Green Genetic Engineering Facilitates Climate Adaptation

Climate change is causing stress in Central Europe through drought, but also through extreme rainfall, a shift in the vegetation period and the influx of harmful organisms. Plant breeding is attempting to counteract these influencing factors by modifying plant characteristics. Genetic engineering in particular can help to adapt plants to climate change by developing drought stress tolerance or resistance to harmful organisms. As complex characteristics for climate adaptation often involve the interaction of several genes and the changes are necessary in a relatively short period of time due to the rapidly changing conditions, the methods of conventional genetic engineering and genome editing offer ad-

vantages over conventional breeding methods. Besides drought stress tolerance and resistance to harmful organisms, initial efforts are underway to prevent seed germination before the harvest to account for the shift in the vegetation period, and to increase the burst resistance of rapeseed pods to protect the harvest from extreme weather conditions such as wind, hail and heavy rain. This provides various options for adapting plants to new climatic conditions. However, comprehensive climate adaptation can only be achieved holistically by combining different breeding methods, cultivation techniques and crop management.²⁰⁹

Green Genetic Engineering Supports Biodiversity and Crop Diversity

Green genetic engineering can improve the pest resistance, nutrient use efficiency and stress tolerance of plants. As a result, green genetic engineering can reduce the input of pesticides and fertilisers into the ecosystem and thus contribute to the biodiversity conservation and other Green Deal objectives. For

example, a meta-analysis found that the amount of pesticides used could be reduced by 42 percent in insect-resistant plants.²¹⁰ To develop corresponding products, incentives for the industry and suitable farming concepts are necessary to enable the cultivation of such products.²¹¹

Moreover, green genetic engineering methods can contribute to increasing crop diversity and thus to biodiversity. As only a few different crop species have been used in genetic engineering to date, the genetic engineering of neglected crop species or the domestication of wild plants²¹² by means of genetic engineering can provide a remedy. This can make agriculture more climate-resistant and less dependent on pesticides and promote agrobiodiversity.²¹³

B1-3 c Risks of Green Genetic Engineering

Two categories of risks can be distinguished: risks associated with the breeding method itself and risks associated with the bred characteristics of the plants.²¹⁴ Since the latter depend on the specific application, it is not possible to compile a general risk profile for genetically modified plants.

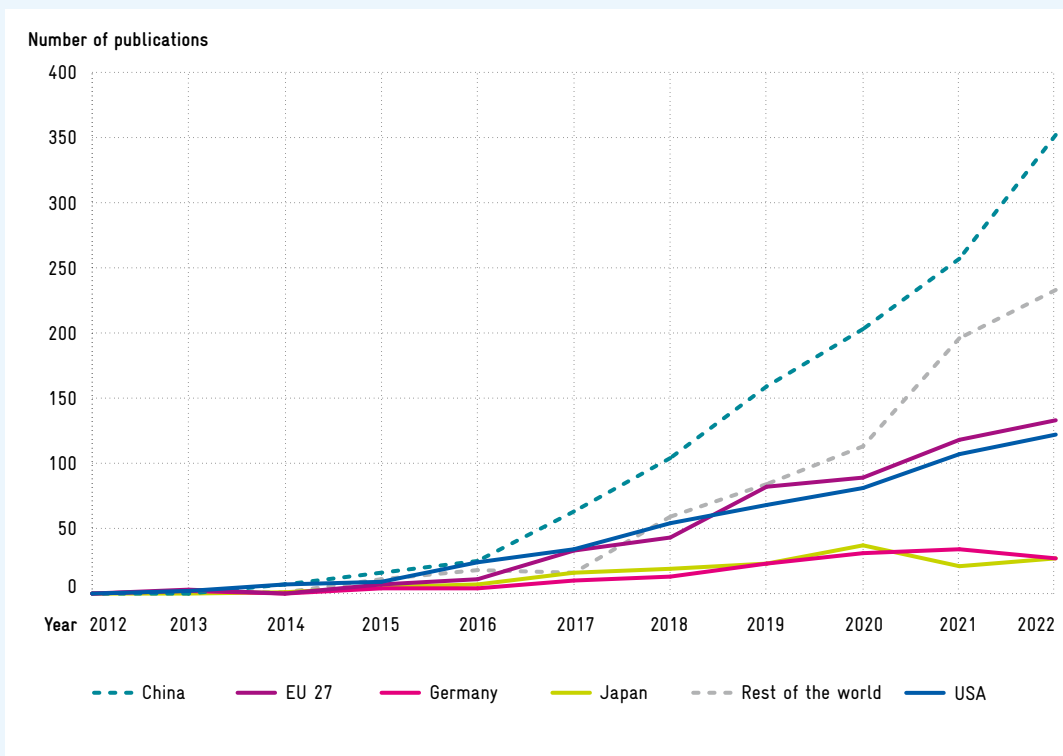
No Method-related Risks Identified in Green Genetic Engineering

In over 30 years of research and application, no method-related risks for humans, animals or the environment have been identified in conventional genetic engineering.²¹⁵ Even though genome editing cannot yet look back on such a long history of safe applications, there are no indications of method-related risks here either. In particular, the EFSA has not identified any new risks for targeted mutagenesis compared to conventional and mutation breeding.²¹⁶ On the contrary: targeted mutagenesis significantly reduces the risk of random mutations. The risks associated with cisgenesis, which involves the introduction of species-specific gene sequences, are also comparable to those of conventional breeding, regardless of the method.²¹⁷ Risks associated with the bred characteristics of the plant can therefore only be assessed on a case-by-case basis and independently of the method.

Fig. B1-11 Number of CRISPR publications in the field of crops for selected countries and regions 2012–2022



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Source: Own representation based on Zyontz (2024).
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Variety of Measures to Minimize Potential Risks

In the EU, as in some non-EU countries, a key element of the approval procedure for GMOs is a risk assessment.²¹⁸ This examines environmental compatibility and safety for humans and animals. The risk assessment analyzes all plant characteristics with potentially undesirable effects and develops strategies for dealing with the risks.²¹⁹ In addition, field trials play an important role not only in the development of a breeding objective, but also in testing the bred plants under different environmental conditions. Based on this data from cultivation, EFSA can issue a recommendation on the risk potential of a plant. Such field trials must be approved and registered in the EU.²²⁰

Specific regulations also apply to the cultivation of genetically modified organisms, which enable the

coexistence of agriculture without and with genetic engineering. These include, for example, the rules of good farming practice for the cultivation of GMOs,²²¹ which are intended to prevent the exchange of genetic material between genetically modified and GMO-free plants. In addition, there is a site register for the cultivation of GMOs in Germany.²²²

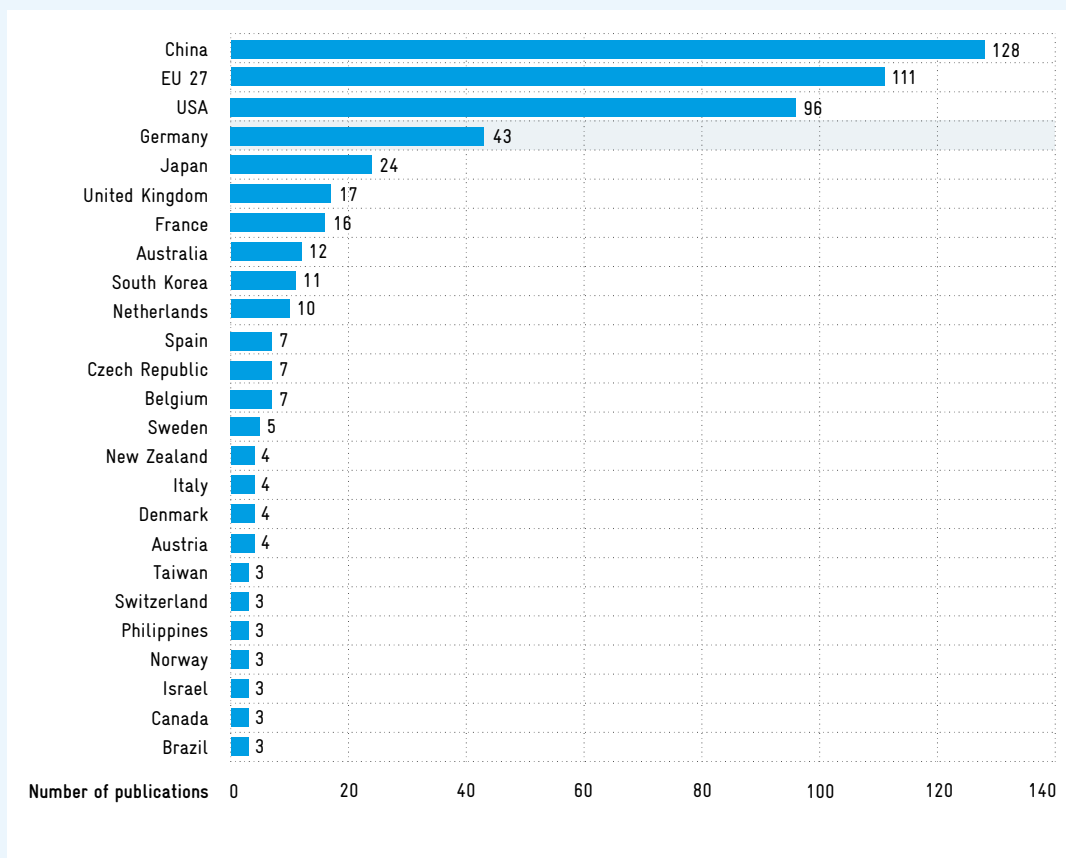
B 1-3 d Research and Innovation Activity on Genome Editing in Crop Plants

The following section uses a publication and patent analysis to examine how research and innovation activities in the field of cultivated crops have developed utilizing CRISPR and where Germany and the EU stand in an international comparison. The focus on CRISPR is appropriate because it is the most widely used genome editing method²²³ and the data availability is particularly good.

Fig. B 1-12 Cumulative number of CRISPR publications in the field of crops in top scientific publications for selected countries and regions 2012–2022



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Legend: China has a total of 128 publications in the top 10 percent of journals in the period 2012–2022.
Source: Own representation based on Zyontz (2024).
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China Leads in Publications and USA in Large Patent Families

A study requested by the Commission of Experts shows a continuous increase in scientific CRISPR publications since 2012 (cf. figure B 1-11).²²⁴ China dominates this development. In terms of cumulative publications in the top journals over time (cf. figure B 1-12), however, China, the EU and the USA rank much closer to each other.

China is also well ahead of the USA and the EU in terms of CRISPR patent applications in the crop sector (cf. figure B 1-13). However, when looking at the applications of the largest patent families, the US is far ahead of China with more than twice as many patent family applications (cf. figure B 1-14), while the EU and, even more so, Germany are clearly lagging behind.

B 1-3 e Barriers to Green Genetic Engineering in Germany

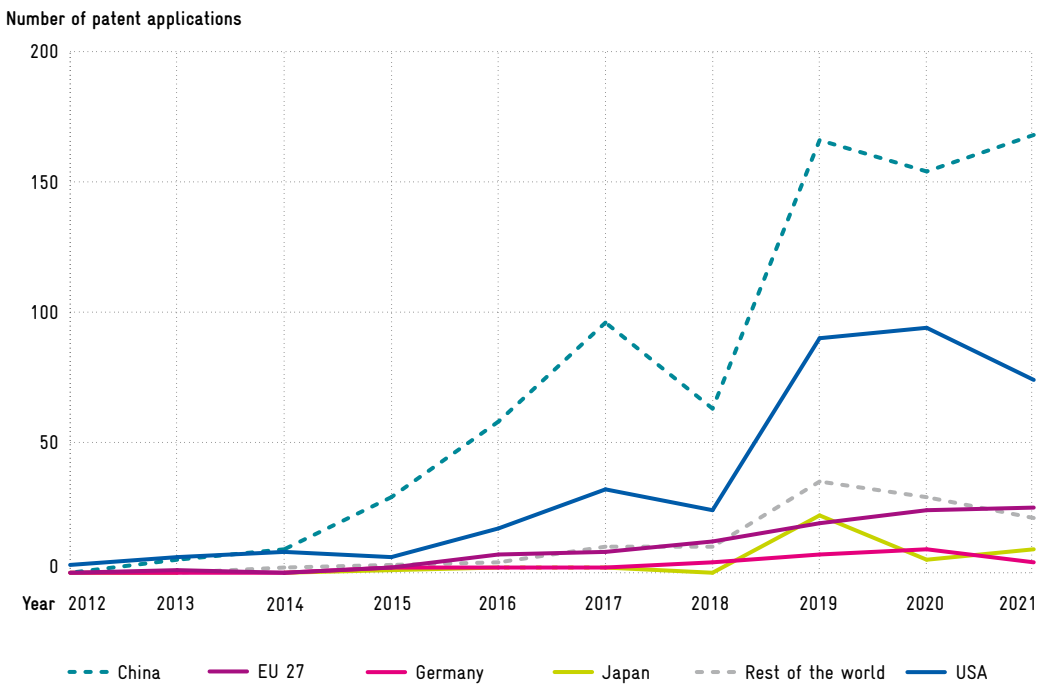
Method-based Regulation Not Up to Date

The current regulation of green genetic engineering does not do justice to the scientific developments of recent decades. Green genetic engineering products are subject to method-based regulation in the EU, even though no method-related risks of green genetic engineering have been identified to date.²²⁵ This method-based regulation focuses on the method and not on the modified plant characteristic that could potentially pose a risk. Since the development of genome editing, there has been a problem of inconsistency in method-based regulation. This is because method-based regulation means that, for example, plants from untargeted mutation breeding and targeted mutagenesis with the same characteristics are regulated differently.²²⁶

Fig. B 1-13 Number of CRISPR patent families in the field of crops for selected countries and regions 2012–2021



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Patent families can have applicants from more than one country. The patent family is counted once for each country represented; therefore some patent families are counted twice.
Source: Own representation based on Zyontz (2024).
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While the plant resulting from mutation breeding does not have to undergo an approval procedure with risk assessment, the same plant from targeted mutagenesis is subject to a strict approval procedure and mandatory labelling as a GMO. In addition, not all plants created through targeted mutagenesis and cisgenesis via genome editing can be distinguished from conventionally bred plants and plants from mutation breeding. This complicates the implementation of regulation.²²⁷ The current regulation leads to considerable uncertainty among plant breeders and may discourage companies, especially SMEs and start-ups, from engaging in research and development.²²⁸ Some countries, including agricultural exporters such as Argentina, Australia, Canada and the USA, have already facilitated the approval of plants developed using new genomic techniques (NGT),²²⁹ including genome editing, through changes to the regulatory framework. This increases the pressure

on the EU to adapt the existing GMO regulation for such NGT plants.²³⁰

Another point of criticism of the current regulation is the lengthy and costly approval procedures. Only larger companies can afford these, which can result in a highly concentrated market structure in the seed and plant breeding market.²³¹ Start-ups and SMEs are thus severely impeded in their innovation activities in these areas.²³² In addition, the current regulation does not recognize whether the bred plants can contribute to the EU's sustainability goals and therefore does not provide any incentives for the development of corresponding plants.²³³

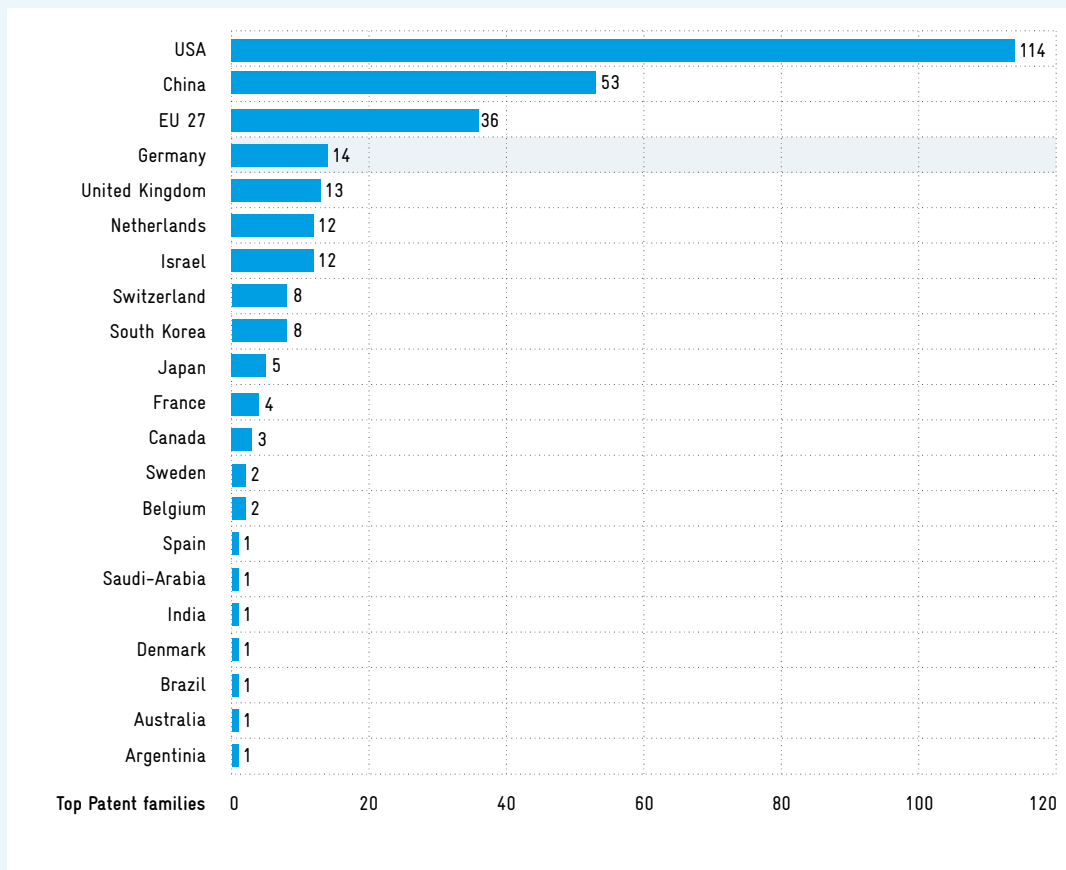
Strict Regulation Limits Research in EU

Research into genetic engineering and new genomic techniques is restricted in the EU by current regula-

Fig. B 1-14 Cumulative number of largest CRISPR patent families in the field of crops for selected countries and regions 2012–2021



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The largest patent families contain three or more applications. Patent families can have applicants from more than one country. The patent family is counted once for each country represented; therefore some patent families are counted twice.
Source: Own representation based on Zyontz (2024).
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tion and the resulting lack of practical relevance.²³⁴ For example, no field trials with GMOs have taken place in Germany since 2013,²³⁵ and there have been no field trials at all with genome-edited plants to date. Research projects at European research institutions are also being abandoned or relocated outside Europe. A career in agricultural biotechnology in the EU has also become less appealing.²³⁶

Proposal for New EU Regulation

The European Commission's proposal for the new regulation of NGT plants created by mutagenesis and cisgenesis could be a partial solution to the aforementioned obstacles.²³⁷ The proposal does not cover NGT plants created by transgenesis and intragenesis. The NGT plants covered by the proposal are divided into two categories, which differ in the extent of the changes made in order to take account of different risk profiles. The first category includes plants that can also arise naturally or through conventional breeding and have been modified in less than 20 base pairs²³⁸ – so-called NGT-1 plants. This also includes plants resulting from targeted mutagenesis. All other plants covered by the proposal fall into the second category (NGT-2). According to this proposal, NGT-1 plants are to be labelled as such, but not as GMOs. NGT-1 plants are moreover exempt from the requirements of the GMO regulation regarding risk assessment and approval. A simple notification to the national authorities is sufficient for field trials.

NGT-2 plants, on the other hand, are still subject to the approval procedures, risk assessments and GMO labelling requirements that also apply to plants from conventional genetic engineering. However, depending on the risk profile, simplified approval and safety procedures may apply. Simplified approval procedures also apply to plants that can contribute to the sustainability goals of the Green Deal.²³⁹ The option for Member States to restrict or prohibit cultivation, such as is possible for GMOs, is to be dropped for NGT-2 plants.²⁴⁰

However, even with this new proposal, the problem remains that regulation is method-based. Nevertheless, the proposal is a pragmatic approach to at least adapt the regulation of plants created by mutagenesis and cisgenesis using new genomic techniques in line with current scientific developments.

An earlier version of the European Commission's proposal contained a so-called free movement clause, which would have expressly prohibited Member States from banning or restricting the release or marketing of NGT-1 plants or related products.²⁴¹ Since this clause has been removed, it cannot be ruled out that individual Member States will still restrict the release and marketing of NGT-1 plants after all and that innovation potential will not be exploited.

GMOs Excluded from Organic Farming

The EU Organic Regulation excludes all plants labelled as GMOs from organic farming.²⁴² However, just like organic farming, GMOs can contribute to the sustainability goals of the Green Deal and the SDGs. Synergies between organic farming and green genetic engineering, such as the reduction of the yield gap in organic farming and the reduction of pesticide use through resistant varieties, remain untapped due to the regulatory incompatibility.²⁴³

Because of the inconsistency of the method-based regulation of green genetic engineering in the EU, plants from mutation breeding do not have to be labelled as GMOs, whereas plants with the same characteristics from targeted mutagenesis are subject to such a labelling requirement. This means that plants from mutation breeding can currently be used in organic farming. In contrast, plants from targeted mutagenesis are not approved for use in organic farming. According to the European Commission's proposal, this ban also applies to NGT-1 plants.

Low Public Acceptance of GMOs

The population in Germany is sceptical about genetic modification of crops.²⁴⁴ When asked about the potential long-term risks of new genetic engineering methods, 79 percent of respondents in a study by the BMUV agree that the long-term consequences cannot be assessed. Similarly high is agreement with the statement that humans have no right to deliberately genetically modify plants and animals.²⁴⁵ However, the study also shows that agreement with these statements fell significantly between 2019 and 2021. Due to the still low level of consumer acceptance, various food retailers are against differentiating between GMOs from conventional genetic engineering and NGT and are in favour of GMO-free production.²⁴⁶

Yet various studies have also shown that the acceptance of genetically modified plants depends on the type and objective of the modification. If a genetic modification is associated with a specific positive benefit for consumers or the environment, acceptance is higher. Acceptance is also greater for minor changes through genome editing than for transgenic plants. Overall, the level of information among the population in Germany about genetic engineering and genome editing as well as the benefits of genetically modified plants for agriculture is low.²⁴⁷

Complex Balancing of Patent Law and Plant Variety Protection

The protection of intellectual property in plants is governed by biopatent law and plant variety protection.²⁴⁸ Plant varieties are excluded from patentability. Their protection is regulated by the Plant Variety Protection Act (Sortenschutzgesetz). According to this law, plant variety protection can be granted if the variety is new, differs from other varieties in decisive characteristics, these characteristics are uniformly expressed during propagation and remain unchanged after each propagation.²⁴⁹

Patents can be granted for technical processes²⁵⁰ for modifying the genome of a plant, so-called process patents, as well as for plants that are bred using such technical processes, so-called product patents. The effect of process and product patents also extends to the offspring of the patented plant obtained by propagation if they too have the characteristics specified in the patent. The effect of a process or product patent therefore also extends to the varieties produced in this way. However, if the technical implementation of an invention is limited to a specific plant variety, the invention is not patentable. Plants that have been created using biological processes or by natural means are not patentable.²⁵¹

The question of whether genetically modified plants should be patentable or whether plant variety protection is sufficient is controversial.²⁵² The argument in favour of plant variety protection, with the comprehensive breeder's privilege it provides, is that small and medium-sized plant breeders can freely use and further develop genetically modified plant varieties for breeding without being burdened by licence fees for patents. The argument in favour of

patent protection is that it can provide the necessary incentives to invest in research and development activities to breed certain desired characteristics using complex genetic engineering methods. A balance must therefore be struck between easy access to genetic material for small and medium-sized breeders and the creation of incentives for costly research. The European Commission has therefore undertaken to evaluate the impact of patenting plants on breeders' access to genetic material, on the availability of seeds for agriculture and on the competitiveness of the EU biotechnology sector by 2026.²⁵³

B 1-4 Recommendations for Action

The use of digital and smart technologies as well as green genetic engineering offer agriculture numerous opportunities to increase productivity, make farming practices more sustainable and improve resilience to climate change. Although digital and smart technologies can significantly reduce negative environmental impacts, farms currently have little incentive to use such technologies as they are still comparatively expensive. The opportunities offered by green genetic engineering cannot be fully utilized due to restrictive legislation and a lack of acceptance and information among the public and politicians.

The Commission of Experts therefore recommends the following measures, to the Federal Government and, in particular, to the Federal Ministry of Food and Agriculture, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection and the Federal Ministry for Digital and Transport:

Introduce a Levy on Pesticides and Fertilisers as an Incentive for the Use of New Technologies

- The use of pesticides and fertilisers should be subject to a levy based on the Danish model. This measure promotes the increased use of digital and smart technologies for sustainable farming. It also creates incentives to breed crops that lead to less use of pesticides and fertilisers. The impact of the levy needs to be evaluated and its implementation design adjusted if necessary.

Expand Digital Infrastructure

A corresponding digital infrastructure is required to accelerate the use of digital and smart technologies. In addition, sufficient compatibility between systems from different vendors is required to avoid dependencies on individual manufacturers.

- The digital infrastructure must also be expanded in rural regions to enable the integration of digital and smart agricultural technologies into the Internet of Things, among other things.
- The Federal Government should create a standardized data space for agriculture across the Länder to share and utilize data for knowledge sharing and enable the use of innovative technologies.
- The Government should lobby both the Deutsches Institut für Normung (German Institute for Standardization, DIN) and the EU to further develop interface standards for digital technologies to ensure the interoperability of the various systems for both hardware and software across manufacturers.

Promote Experimental Fields as well as Education and Training for Digital and Smart Technologies

Because of the reluctance to adopt digital and smart technologies to date, uncertainties exist regarding both economic and ecological benefits.

- More use should be made of experimental fields to test the practical feasibility of new digital and smart agricultural technologies and their effectiveness in specific applications and to make them visible to potential users.
- The Federal Government should expand and financially support training and continuing education measures in the use of digital and smart technologies.²⁵⁴ To this end, corresponding curricula in training centres should be adapted and supplemented.

Clarify the Regulatory Framework

A clear regulatory framework is needed to ensure legal certainty in the development and use of new digital and smart agricultural technologies.

- Clear regulatory conditions and simple procedures for approving the use of fully automated and autonomous agricultural machinery, robots and drones need to be developed. In particular, the dropping ban related to weight restrictions for drones in agriculture should be reformed.
- Clear regulatory conditions in the field of data protection and data sovereignty must be created to enable the legally secure use of digital and smart agricultural technologies and to prevent unauthorized use of data.
- Increased use should also be made of regulatory sandboxes to enable regulatory learning and pave the way for the widespread use of digital and smart agricultural technologies.

Better Educate and Inform the Public on Green Genetic Engineering

The public and politicians have reservations about new genomic techniques and genetic engineering in general, some of which are difficult to justify and are due to a lack of information.

- There is a need for a scientifically sound and coordinated communication strategy on the part of the Federal Government, which is also reflected in political action. It is important to inform the public about the potential contribution of green genetic engineering to achieving sustainability goals and to dispel scientifically unfounded fears.

Agree to EU Proposal, Develop Method-independent Regulatory Framework

The regulatory framework in which green genetic engineering operates in the EU not only inhibits research and development in this field, but also the innovation-based transformation of agriculture.

- In the European Council, the Federal Government should approve the proposal submitted by the European Commission on the differentiated regulation of genome-edited plants. This proposal contains measures for the differentiated labelling of so-called NGT-1 plants and for the simplified approval of plants that can contribute to the EU's sustainability goals.
- The Federal Government should not restrict the release and placing on the market of NGT-1 plants approved in the EU.
- The Federal Government should support the approval of plants labelled as NGT-1 in organic farming, as already envisaged in an earlier draft of the European Commission's proposal.
- In the long term, the Federal Government should lobby the EU to revise the regulation of green genetic engineering so that decisions on the approval of genetically modified plants are primarily based on the properties of a plant rather than the method used.

Evaluate Patent Law and Plant Variety Protection

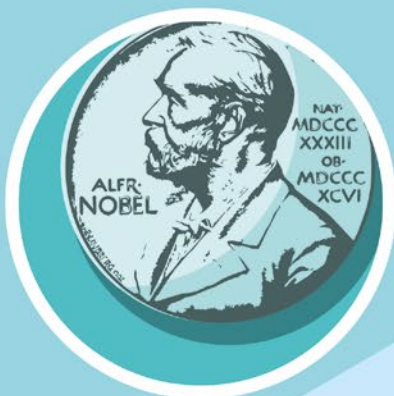
Patent law and plant variety protection strike a balance between free access to breeding material and the protection of investments in the development of new plants through patents. This is a complex issue for which there is not yet sufficient empirical evidence.

- The status quo of patent protection for genetically modified plants should not be changed for the time being. However, the Federal Government should lobby the EU to evaluate the effects of patent law and plant variety protection on the use of genetic engineering methods and on the registration of genetically modified plants and, if necessary, to modify the existing regulations.
- In addition, the market for seeds should be monitored regarding market foreclosure effects in order to introduce measures under competition law if necessary.

B2 International Mobility in the Science and Innovation System



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B2 International Mobility in the Science and Innovation System

A competitive science and innovation location is dependent on competent personnel for its tertiary education institutions, research institutions and businesses. In the global competition for scientists and employees in research and development (R&D employees), Germany has only been moderately successful in the past.

According to a study for the Commission of Experts' 2014 Annual Report, more scientists left Germany between 1996 and 2011 than immigrated to the country. It was particularly difficult to attract top scientists to work in Germany at that time. A similarly negative picture emerged regarding the international mobility of R&D employees. These findings led the Commission of Experts to conclude in 2014 that massive efforts were needed to offer internationally mobile researchers and R&D employees in Germany competitive working and research conditions.

Ten years later, the Commission of Experts is again addressing the international mobility of scientists and R&D employees with this chapter. The aim is to examine whether and how Germany's position in international competition has changed since the analysis in the 2014 Annual Report. This is relevant for two reasons: first, some significant legal reforms have been implemented in Germany since then and programmes to increase the attractiveness of the science and innovation location have been launched or continued, which may have had an impact on mobility in the meantime. Second, it is to be expected that the increased shortage of skilled labour due to demographic ageing will also lead to growing staff shortages in the German science and innovation system. Germany will be increasingly reliant on internationally mobile scientists and R&D employees to counter these bottlenecks.

In line with the analyses in the 2014 Annual Report, developments in the international mobility of scientists and R&D employees are mapped based on examinations of data on scientific publications and patent applications. This data can be used to analyze the mobility of scientific authors and patent-active inventors.²⁵⁵ The analyses show that the situation has changed significantly since the 2014 Annual Report. Germany has become a net receiving country for publishing scientists.²⁵⁶ Many highly-published authors return to Germany after spending time abroad. A decreasing net outward flow can be observed among patent-active inventors. Overall, Germany is therefore on a favourable trajectory. However, the German science and innovation system continues to lose human capital across the board. Additional reforms and packages of measures should therefore further increase Germany's attractiveness as a science and innovation location for international scientists and R&D employees. In addition, the administrative processes associated with the inward flows of skilled workers should be accelerated and digitized and the regulatory framework harmonized internationally. The academic labour market should become more permeable for internationally mobile researchers.

B2-1 Asymmetry of International Migration Flows

A considerable proportion of all scientists and R&D employees change countries at least once in the course of their career (cf. B2-2 and B2-3). Country-specific factors influence which locations these people choose for their work.²⁵⁷

Inward Flows Beneficial for Chosen Locations

International mobility enables researchers and R&D employees to acquire new knowledge and expand their scientific network.²⁵⁸ Surveys show their subjective conviction that international mobility has a positive impact on career prospects.²⁵⁹ Empirical studies also show that mobile authors are on average more productive in generating knowledge than their non-mobile colleagues (cf. B 2-2 and B 2-3) and suggest a positive influence of mobility on the quality of performance.²⁶⁰

From the perspective of the target country, the mobility of researchers and R&D employees can increase research performance and innovation potential both directly through an increase in human capital and indirectly through newly created networks and collaborations.²⁶¹ In addition, international mobility also enables the dissemination of knowledge that has not (yet) been published and is therefore difficult to access by other means.²⁶² From the perspective of the target country, it is desirable to attract internationally mobile researchers and R&D employees. However, in certain cases these incomers may lead to an undesirable transfer of critical knowledge to their country of origin. This is particularly problematic if it impairs the technological sovereignty of the country from which the knowledge drains.

Focus on Brain Gain and Brain Drain Too Narrow

The analyses presented below in B 2-2 and B 2-3 present net balances of incoming and outgoing authors of scientific publications and patent-active inventors in a specific period for individual countries. The countries under analysis differ in terms of whether they were net donor or net recipient countries for these groups of people over the entire period. In the scientific literature and in the public debate on skilled labour mobility, net outward flows are often associated with brain drain (loss of human capital) and net inward flows with brain gain (increase in human capital).

Debates about brain drain and brain gain are generally based on the idea of international skilled labour migration as a zero-sum game between countries. Accordingly, brain drain from the viewpoint of a particular location is directly accompanied by a corresponding brain gain from the viewpoint of other

locations. However, this notion ignores two major advantages of international mobility:

First, international mobility can contribute to increasing research quality and innovation potential globally. At the respective locations, the fit between the individual skills and competences available and those required at the location is improved. The opportunities for international division of labour and specialization are better exploited in the global science and innovation system. Consequently, the supposed zero-sum game of international mobility becomes a positive-sum game.

Second, focussing on current migration balances ignores the fact that international mobility can also have positive medium- and long-term effects on countries that are confronted with outward flows.²⁶³ Outgoing scientists and R&D employees can gain valuable experience abroad, expand their network and then return to their home country more productive than before. Such circular migration movements are known as brain circulation. The home country becomes better integrated into international networks through the outgoers and can benefit from the cross-border exchange of knowledge.²⁶⁴ Finally, the possibility of future emigration itself can motivate young people to invest in education.²⁶⁵

B 2-2 Scientific Publications: International Mobility of Authors

A study conducted on behalf of the Commission of Experts looks at the mobility patterns of authors from a German viewpoint.²⁶⁶ Authors who published at least two scientific publications in the period from 2005 to 2020 and who indicated an organizational affiliation with a research institution in Germany for at least one of these were taken into account. This results in the two groups of non-mobile authors and mobile authors. Authors are classified as mobile if the country of their organizational affiliation changes between two publications.²⁶⁷ Within the group of mobile authors, the study distinguishes between incomers and outgoers. Incomers are further subdivided into immigrants (people who come from abroad and remain in Germany) and returnees (people who return to Germany from abroad). Outgoers are further subdivided into emigrants (people who leave Germany and stay abroad) and visitors (people who come to Germany from abroad and leave again).²⁶⁸

Net Immigration Into the German Science System

In total, 31 percent of all authors who reported a German organizational affiliation in the observation period between 2005 and 2020 were internationally mobile during this period.²⁶⁹ The share of immigrants exceeded that of emigrants, which is reflected in a net immigration of more than 5,400 authors.²⁷⁰ More differentiated insights can be gained from a country-specific analysis of authors immigrating to and emigrating from Germany. Strong bilateral mobility flows exist primarily between Germany on the one hand and the USA, Switzerland and the UK on the other (cf. figure B2-1). Compared to these three countries, Germany has a significant net emigration. The overall net immigration is primarily driven by Germany’s role as a destination country for authors from Italy, Spain, China, Russia and India.

Figure B2-2 uses OECD data to illustrate the development of the annual mobility balances²⁷¹ of incom-

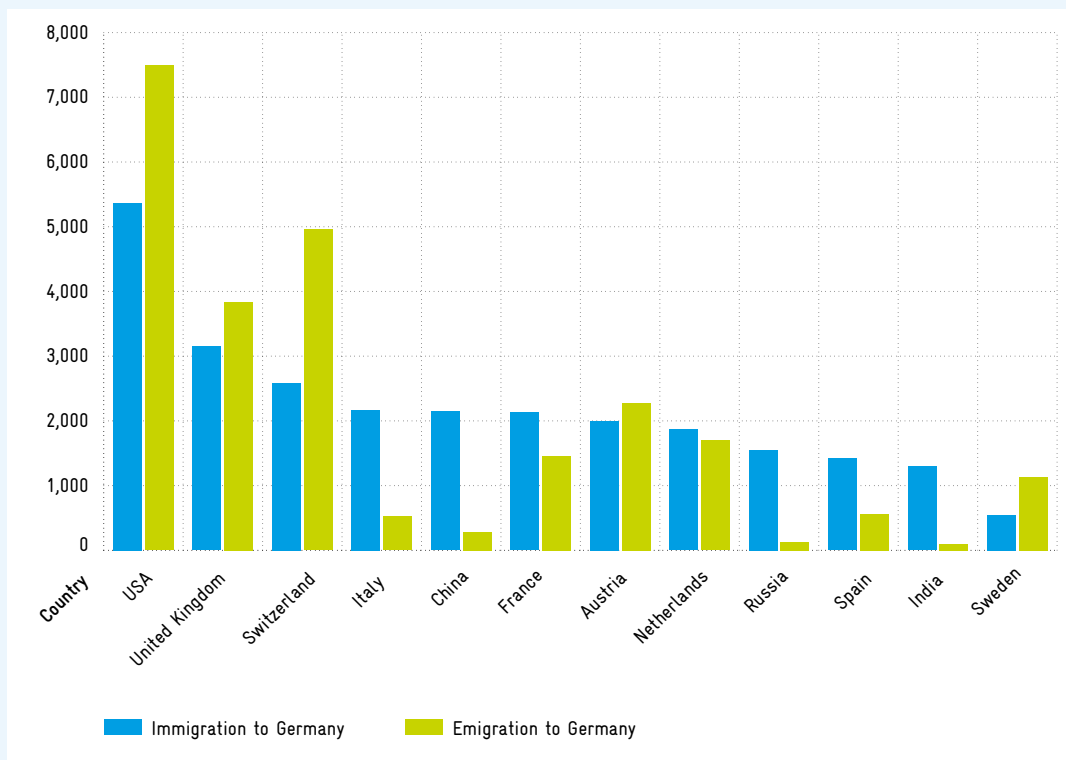
ing and outgoing authors for selected countries.²⁷² The negative mobility balance in Germany at the beginning of the observation period turned positive in 2014 and has continued to show a positive trend since then. Compared to other major European countries, Germany’s net mobility balances show a fairly stable positive trend over the period under review. The UK experienced strong net outward flows of authors after 2016, which is likely due to the effects of Brexit. In a global comparison, the USA has by far the highest net inward flows of authors.²⁷³ China and Canada have recently seen higher net inward flows than Germany. Authors are increasingly leaving the newly industrializing countries of Brazil and India.

Looking at net mobility balances alone does not reveal the share of returnees and visitors in international mobility, which is of significant importance for the empirical relevance of brain circulation. From Germany’s viewpoint, all outgoers are also potential returnees in the medium term, while incomers may only be in the country temporarily.

Fig. B2-1 Bilateral immigration and emigration of authors (relating to Germany) 2005–2020



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Legend: In the period between 2005 and 2020, 7,491 authors moved from Germany to the USA and 5,364 came to Germany from the USA. Source: Own representation based on Coda-Zabetta et al. (2024). © EFI – Commission of Experts for Research and Innovation 2024.

The ratio of returnees to all outgoers (return ratio) and the ratio of immigrants to all incomers (stay ratio) are therefore insightful. During the observation period, there were 44 returnees for every 100 authors who left Germany during this period. This corresponds to a return ratio of 0.44.²⁷⁴ In addition, the observed stay ratio of 0.45 shows that of 100 authors who came to Germany during the observation period, 45 have not yet left Germany again.

Female Scientists Less Mobile

Overall, the share of women among all authors in Germany between 2005 and 2020 is around 36 percent.²⁷⁵ At 73 percent, the share of non-mobile women is 7 percentage points higher than that of men (66 percent).²⁷⁶ It is also apparent that female scientists are particularly mobile in the early stages of their careers and that they often only change location once. Female authors who emigrate from Germany are less likely to return than male authors.²⁷⁷ At the same time, female authors who immigrate to Germany are more likely to stay in Germany than male authors.²⁷⁸

Emigration Linked to Loss of Research Quality

For Germany's research performance and innovation potential, it is not only of great importance how many people move in and out, but also what inflow and outflow of scientific performance is associated with this. Indications of scientific performance can be found in the quality of publications by authors moving in and out of Germany. In the study conducted for the Commission of Experts, the quality of publications is approximated by the average number of citations of the scientific journal in which they were published.²⁷⁹ This quality indicator records the average influence that publications in the respective scientific journal have on further research.²⁸⁰ The publications assessed in this way are considered separately for the incoming and outgoing authors.

Figure B 2-3 provides an overview of the average value of the quality indicator for publications by non-mobile authors and the different types of mobile authors. Overall, the average quality of publications by emigrating authors is higher than that of publications by immigrating authors. Publications by non-mobile authors in Germany are of the lowest quality on average. These differences are particularly pronounced in the life sciences.²⁸¹ A further distinction by country of origin and country of destina-

tion shows that the publications of researchers who come to Germany from the newly industrializing countries of Brazil and China are of higher quality on average than those of authors who leave Germany for these countries. The opposite is true for most of the industrialized countries examined, such as the USA, France and the UK.²⁸²

A comparison of the values of the quality indicator between cohorts, i. e. authors who moved to or from Germany in different years, shows different developments depending on the type of mobility.²⁸³ As shown in figure B 2-4, the quality of publications by immigrants and returnees has increased in later cohorts, with the gap between the two types of mobility becoming noticeably smaller at the end of the observation period. At the same time, when comparing the cohorts of emigrants, it can be observed that the quality of their publications initially decreased over time and has hardly changed since 2011.

Mobility Important for International Collaborations and Research Quality

International mobility of scientists is a driving factor in the initiation of scientific collaborations.²⁸⁴ Co-authorships generate higher quality publications than single authorships.²⁸⁵ International mobility can therefore indirectly lead to an increase in research performance by creating a basis for international collaboration.

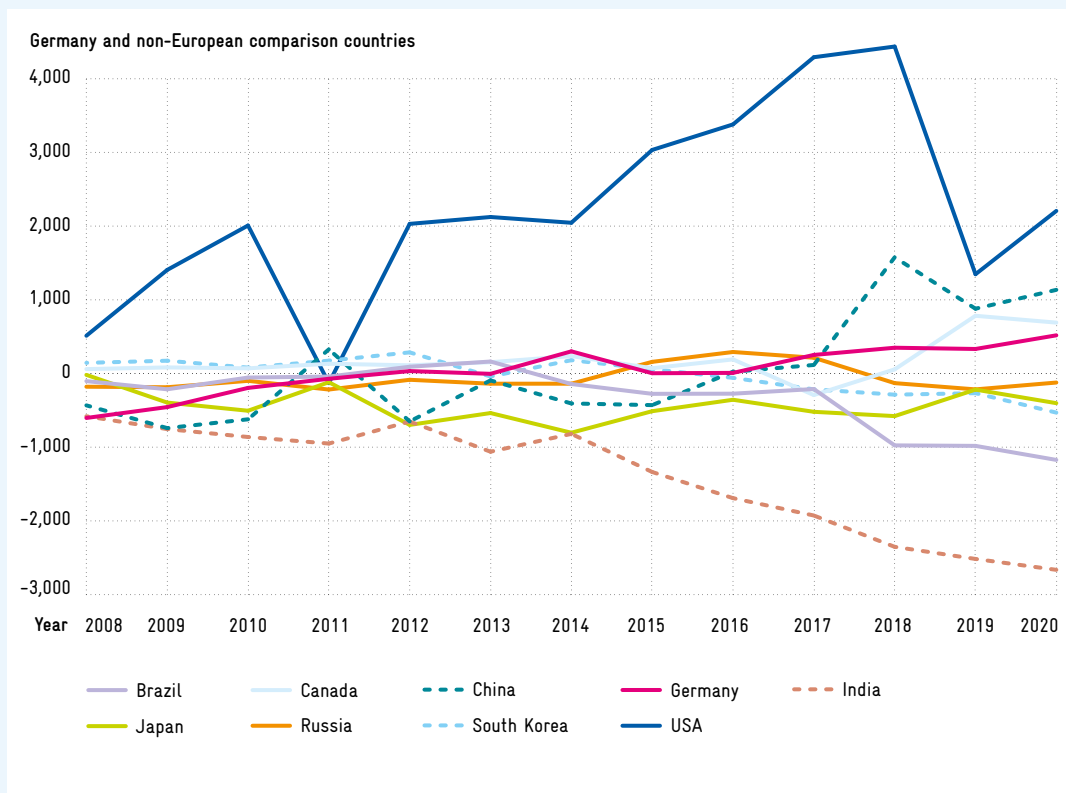
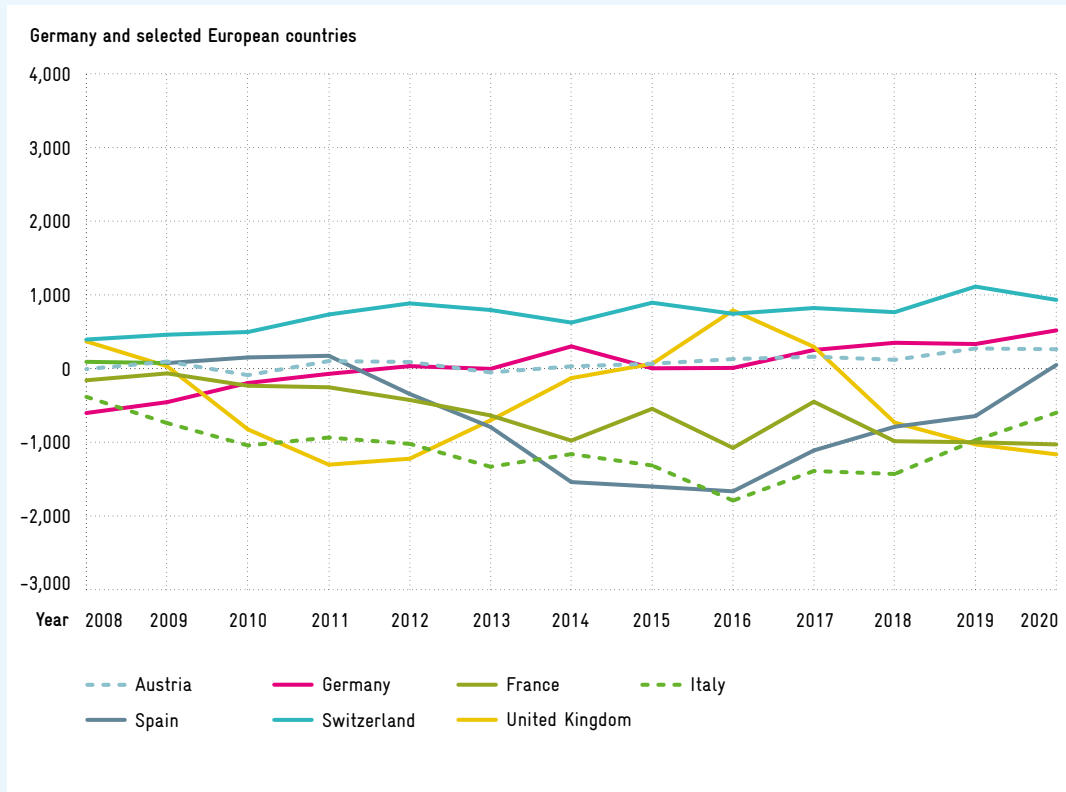
International collaborations are increasing in importance in the German science system.²⁸⁶ Since 2005, the percentage of publications resulting from international collaboration has steadily increased. This development is particularly positive in view of the quality of the publications. As figure B 2-5 shows, publications with international co-authorship are on average of a significantly higher quality than publications with single authorship or those with exclusively national co-authorship.

In terms of the number of co-authorships, the USA and the UK have consistently been the most important partner countries for authors working in Germany since 2005. France and Switzerland are also important partner countries but have been overtaken by China. The importance of China for collaboration with authors affiliated with German organizations has increased immensely in recent years (cf. figure B 2-6), which can be viewed criti-



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Fig. B2-2 Annual mobility balances of incoming and outgoing authors 2008–2020

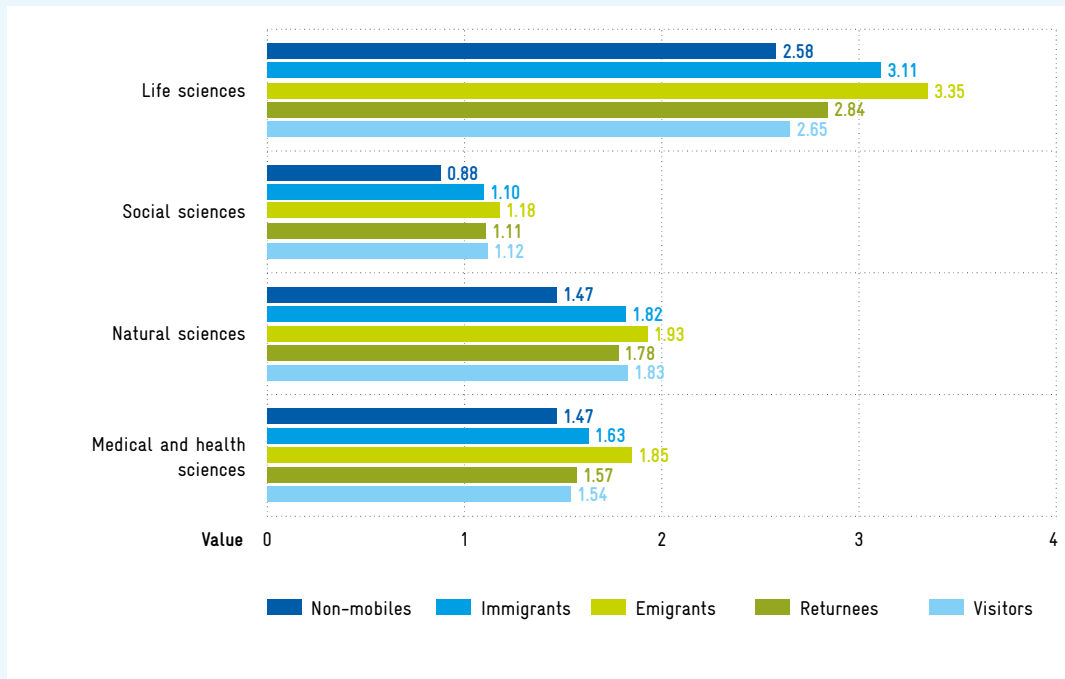


Legend: In 2019, the mobility balance of incomers and outgoers in Germany was +330. This means that more authors came to Germany that year than left the country.
Source: <https://www.oecd.org/sti/scoreboard.htm> (last accessed on 5 November 2023) and OECD (2017). Own representation.
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Fig. B2-3 Average value of the quality indicator for publications by authors of different mobility types (relating to Germany), differentiated by scientific discipline 2005–2020



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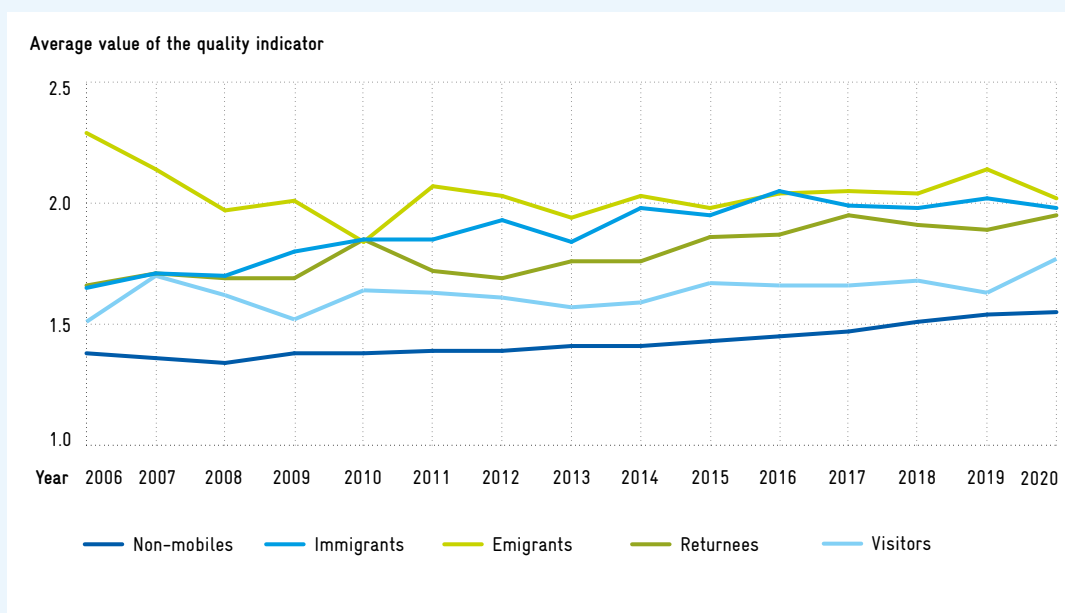


Legend: In the life sciences, publications by emigrants have the highest value of the quality indicator with an average of 3.35. Publications by immigrants have the second-highest value of the quality indicator with an average of 3.11, followed by returnees with 2.84 and visitors with 2.65. Publications by non-mobile authors have the lowest value of the quality indicator with an average of 2.58. Source: Own representation based on Coda-Zabetta et al. (2024). © EFI – Commission of Experts for Research and Innovation 2024.

Fig. B2-4 Average value of the quality indicator for publications by authors of different mobility types (relating to Germany) 2006–2020



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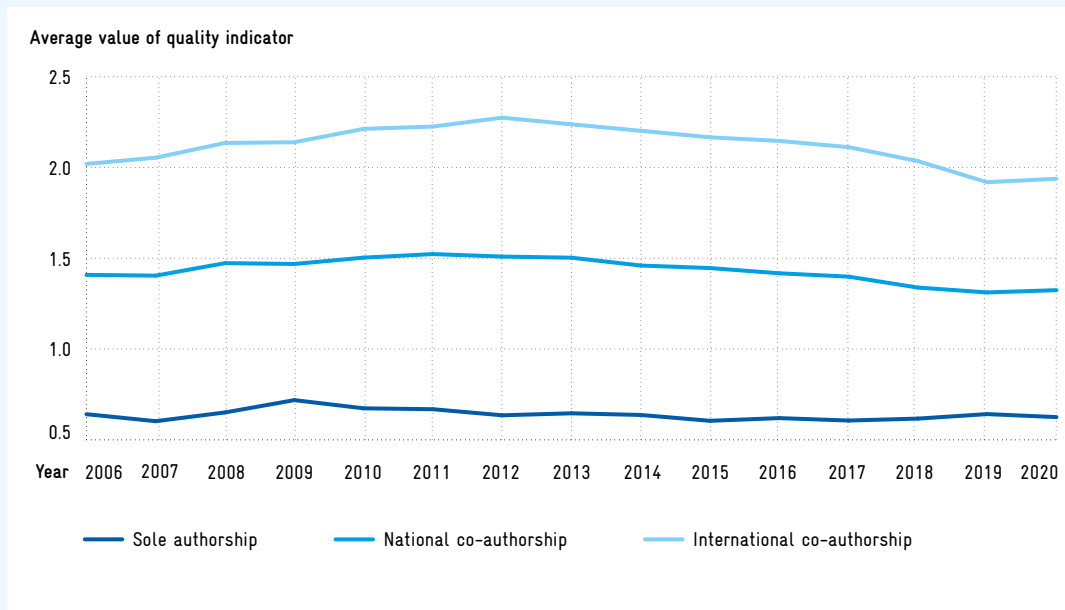


Legend: In 2019, the value of the quality indicator for publications by emigrants with German organizational affiliation was 2.13 on average. The value of the quality indicator thus exceeded that of publications by immigrants (2.02) and returnees (1.89). Publications by non-mobile authors had the lowest average value of the quality indicator in 2019 (1.63). Source: Own representation based on Coda-Zabetta et al. (2024). © EFI – Commission of Experts for Research and Innovation 2024.



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Fig. B2-5 Average value of the quality indicator for publications by authors by type of cooperation (relating to Germany) 2006–2020



Legend: In 2019, the value of the quality indicator for publications by an international team of authors was 1.94 on average. For publications by a team of authors, all of whom stated affiliation with a German organization, this value was 1.32 on average. For publications authored by a single author, this value averaged 0.63 in 2019. Source: Own representation based on Coda-Zabetta et al. (2024). © EFI – Commission of Experts for Research and Innovation 2024.

cally in view of the aforementioned possibility of unintended knowledge outflows and potential impairment of Germany’s technological sovereignty.

Authors who leave Germany often continue to collaborate with colleagues in Germany. For example, around 50 percent of those outgoers continue to work with colleagues working in Germany even two years after changing their organizational affiliation. This percentage is particularly high for those who move to leading research institutions²⁸⁷ in the target countries.²⁸⁸

The analysis makes it clear why simply looking at the mobility balance of a location is not enough to capture the effects of international mobility. International mobility leads to larger research networks, which in turn can have a positive effect on the quality of research output.²⁸⁹

More Mobile Scientists in Top Positions

Professorships funded by the Alexander von Humboldt Foundation and fellowships under the Emmy

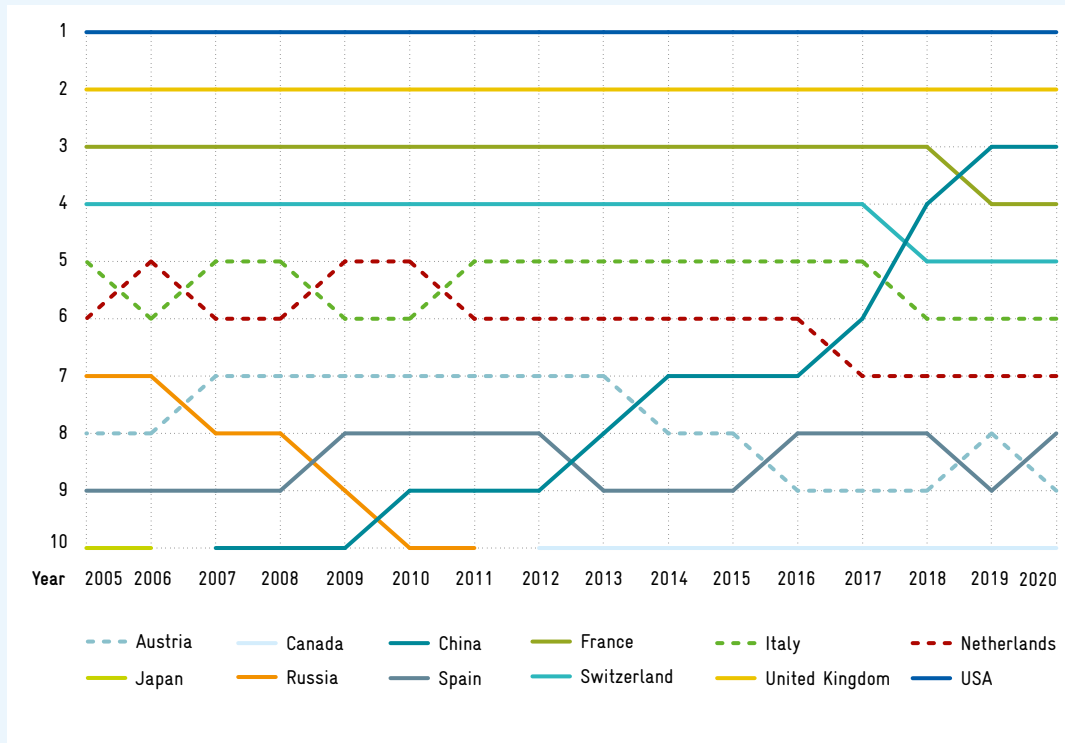
Noether Programme of the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) are among the most internationally renowned positions in the German science system. A professorship at a particularly research-intensive German university also offers top international scientists an attractive research environment. An above-average number of authors in such positions are either immigrants or returnees.²⁹⁰

Science locations benefit directly from attracting particularly high-performing scientists. Analyses conducted for the Commission of Experts also indicate that these scientists have a positive impact on their new environment. For instance, increases in the average quality of a faculty’s scientific publications can be observed following the appointment of a new Alexander von Humboldt Professor.²⁹¹ Increased standards as well as co-authorships and the transfer of knowledge at the new location are possible explanations. The reputation of top scientists and the resulting increased appeal of the location can also attract other high-performing scientists.²⁹²

Fig. B2-6 Germany's top 10 partner countries for scientific co-authorships 2005–2020



[Download Data](#)



Legend: Over the entire period, authors who stated a German organizational affiliation were most frequently co-authors with their US colleagues. France ranked third among the partner countries in 2017 but was overtaken by China in the following year. In 2020, more authors with a Chinese organizational affiliation published joint publications with authors from German research institutions than authors with a French organizational affiliation. Source: Own representation based on Coda-Zabetta et al. (2024). © EFI – Commission of Experts for Research and Innovation 2024.

B2-3 Patent Applications: International Mobility of Inventors

Like the data on the mobility of authors of scientific publications analyzed above, the international mobility of R&D employees can be approximated using the information on inventors in patent documents. When R&D employees are mobile between organizations or countries, they take their knowledge with them to their new place of work. This benefits companies or countries that attract new R&D employees. Companies or countries that lose R&D employees may experience short-term setbacks in their innovation potential, but in the long term they too can benefit from an exchange of knowledge and expertise.²⁹³

This section analyzes the international mobility of patent-active inventors in the German science and innovation system based on a study²⁹⁴ conducted on behalf of the Commission of Experts. The PATSTAT

database of the European Patent Office provides the basis for the analyses,²⁹⁵ whereby the focus is on the registration of transnational patents²⁹⁶ in the period from 2000 to 2020.²⁹⁷ Similar to the above analysis of publication data, mobile and non-mobile inventors are compared here too and a distinction is made between different types of mobility (immigrants, returnees, emigrants, visitors).

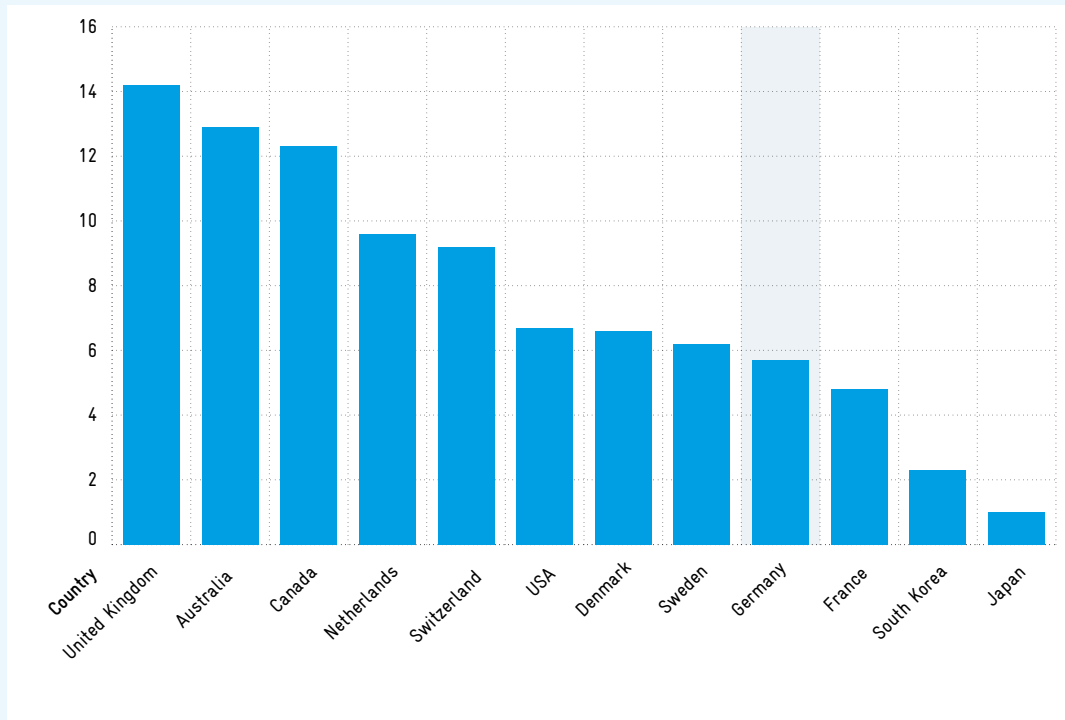
Net Emigration of Inventors

In the period between 2000 and 2020, 5.7 percent of all patent-active inventors in Germany were internationally mobile (cf. figure B2-7). This means that Germany has a rather low mobility rate compared to other countries. For example, the UK (14.2 percent), Canada (12.3 percent) and the USA (6.7 percent) have higher mobility rates. Among the countries compared, only France (4.8 percent), South Korea (2.3 percent) and Japan (1.0 percent) have even lower mobility rates than Germany.²⁹⁸

Fig. B2-7 Percentage of mobile inventors, differentiated by country 2000–2020



[Download Data](#)



Legend: 5.7 percent of all inventors in Germany between 2000 and 2020 were internationally mobile.
Source: Own representation based on Karaulova et al. (2024).
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Over the entire period from 2000 to 2020, Germany recorded a net emigration of inventors: 5.6 percent fewer inventors came to Germany than left it. Japan, France and the UK also experienced net emigration. In contrast, Switzerland, the Netherlands and South Korea recorded a net immigration. Switzerland, for example, attracted 22.7 percent more inventors than it lost.²⁹⁹

Looking at the mobility balances³⁰⁰ of the same countries separately for each year, it can be seen that Switzerland and South Korea have consistently positive balances (cf. figure B 2-8). Countries with largely balanced inward and outward flows of inventors are Australia, Denmark and Sweden. Together with Japan, the UK and the USA, Germany is one of the countries that consistently record more outward than inward flows of inventors. However, the net outward flows of inventors from Germany have decreased since 2014, and a small net inward flow was recorded for the first time in 2020. This development differs significantly from that in the UK and the USA, both of which are experiencing increasing net outward flows.

Female Inventors Less Mobile

Around 10 percent of all inventors in Germany are women. Of all mobile inventors, however, only 6.7 percent are women. Interestingly, only 2.9 percent of all returnees are women.³⁰¹ Women are therefore not only underrepresented overall, but also especially among mobile inventors. After a slight increase in the percentage of mobile female inventors in the early 2000s, this has been stagnating since 2010. There has therefore been no alignment with the mobility behaviour of male inventors.

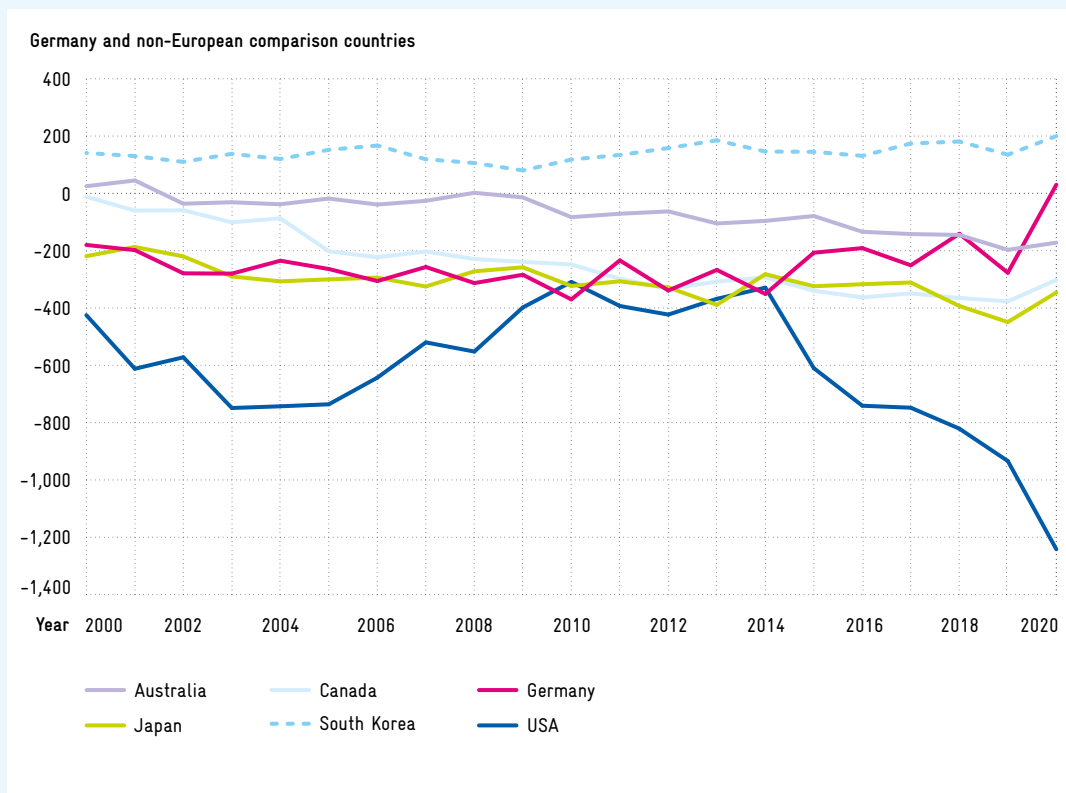
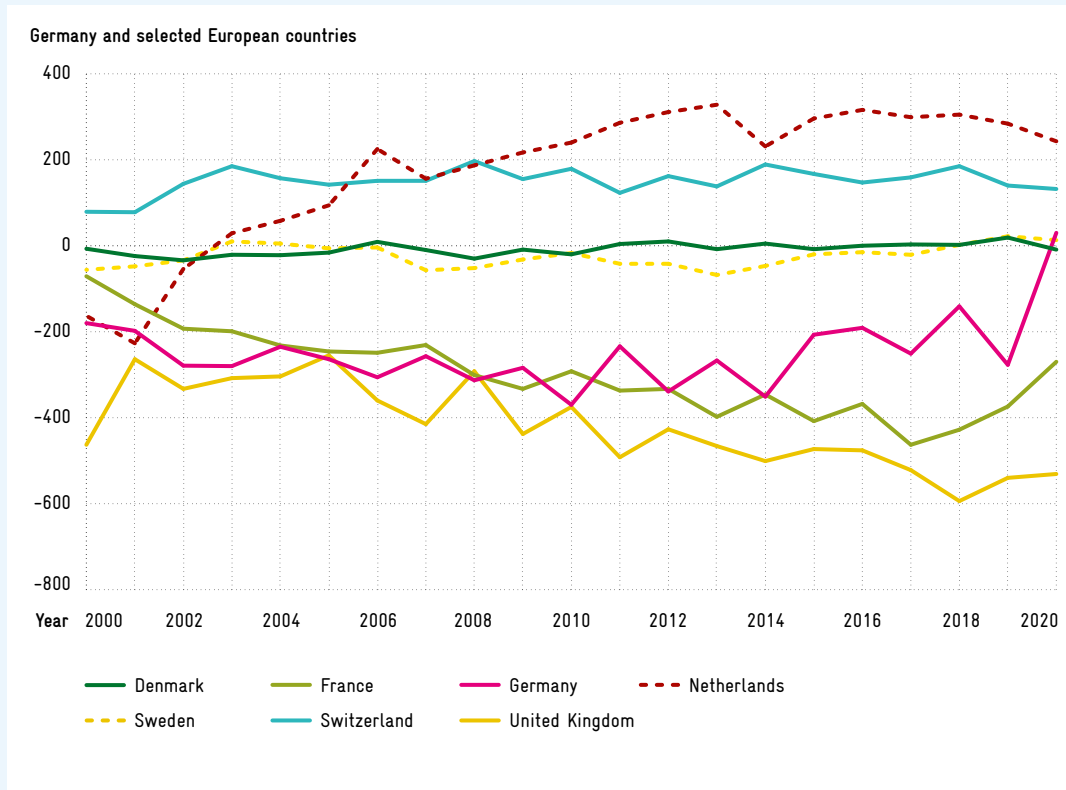
Inventors Mostly Mobile Within Companies

Figure B 2-9 shows the inward and outward flows of inventors to and from Germany for selected countries in the observation period 2000 to 2020.³⁰² Strong bilateral migration flows of inventors exist primarily between Germany on the one hand and the USA, Austria, the UK, France and the Netherlands on the other. While there are net outward flows from Germany to the USA and the Netherlands, net inward flows can be seen from Austria, the UK and

Fig. B2-8 Annual mobility balances of incoming and outgoing inventors 2000–2020



[Download Data](#)



Legend: In 2017, the mobility balance (the difference between incoming and outgoing inventors) in Germany was -251. This means that more inventors left Germany that year than came to Germany.
 Source: Own representation based on Karaulova et al. (2024).
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France. Compared to the European and North American regions, the Asian region is less significant for inventor mobility to and from Germany.

The companies in which the inventors work play a decisive role in the mobility of inventors. Over 90 percent of mobile inventors in selected countries³⁰³ have changed countries within the same multinational corporation. In Germany, this figure is even higher at 95 percent. As most mobile inventors continue to work for the same multinational corporation in another country, their knowledge is retained within the business.

Many Inventors Returning to Germany

To make statements about brain circulation, outgoers are further divided into emigrants and visitors and incomers into immigrants and returnees.³⁰⁴ Important indicators here are again the stay ratio and the return ratio. Figure B 2-10 illustrates these

ratios for selected countries in the period between 2000 and 2020.³⁰⁵

Across all countries analyzed, the return ratio is between 0.20 and 0.40 and the stay ratio is between 0.60 and 0.82. Returnees are of foremost importance for the exchange of knowledge and the all-important brain circulation. At 0.40, Germany has the highest return ratio in an international comparison, together with South Korea.³⁰⁶ The picture is somewhat different for the stay ratio. Here, Germany ranks in the international midfield at 0.71.

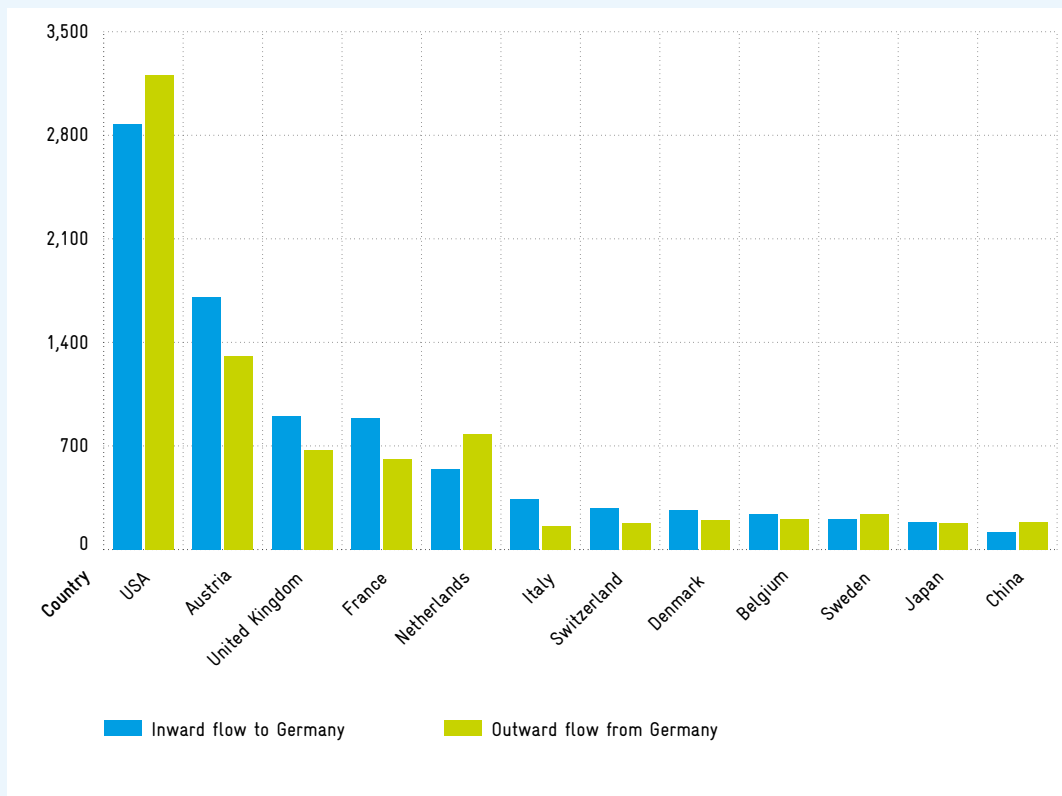
Mobile Inventors Are Higher Performing

For Germany's innovation potential, it is not only of significant importance how many R&D employees move in and out, but also what inflow and outflow of innovation-relevant performance is associated with this. In the study conducted on behalf of the Commission of Experts, innovation-relevant capa-

Fig. B2-9 Bilateral inward and outward flows of inventors (relating to Germany) 2000–2020



[Download Data](#)

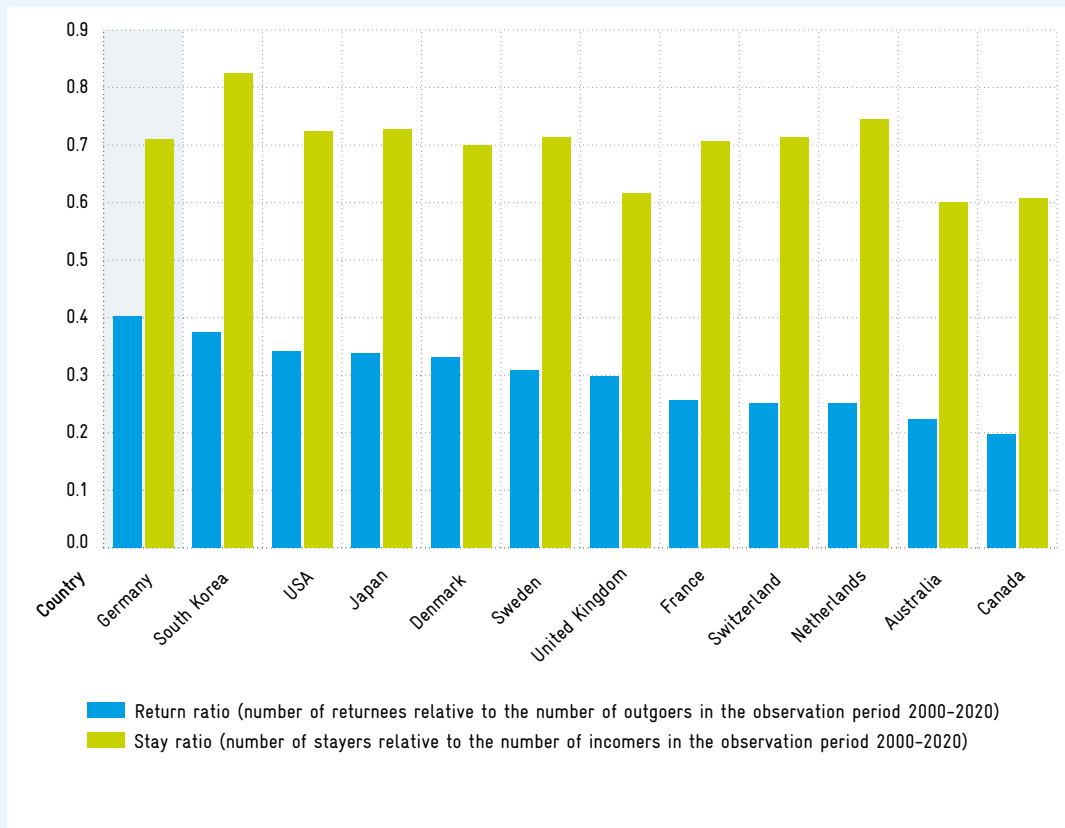


Legend: In the period between 2000 and 2020, 3,206 inventors moved from Germany to the USA and 2,876 came from the USA to Germany.
Source: Own representation based on Karaulova et al. (2024).
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Fig. B2-10 Return ratio of outgoing inventors and stay ratio of incoming inventors, differentiated by country 2000–2020



[Download Data](#)



Legend: For every 100 inventors who left Germany in the period between 2000 and 2020 there are 40 returnees. For every 100 inventors who came to Germany, 71 remain in Germany by the end of the survey period.
Source: Own representation based on Karaulova et al. (2024).
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bility is approximated by the number and quality of an inventor’s patents. The number of citations received within four years of application is used as an indicator of the quality of a patent.

Figure B2-11 shows the average number and average quality of patents by country and by mobility type.³⁰⁷ Across all countries, mobile inventors register more patents than non-mobile inventors.³⁰⁸ Returnees and visitors have a higher number of patents than immigrants and emigrants. In an international comparison, both mobile and non-mobile inventors in Germany have an above-average number of patents. Those returning to Germany have a particularly high number of patents in an international comparison.

The average quality of patents differs less between countries and mobility types. Patents by non-mobile inventors are cited less frequently than patents

by mobile inventors across all countries. Within the group of mobile inventors, no significant differences in the quality of patents can be observed. An international comparison reveals that patents from Germany are cited less frequently than average across almost all types of mobility. This difference between the number and quality of patents is particularly evident among returnees to Germany. They have the most patents in an international comparison, albeit of the lowest quality.

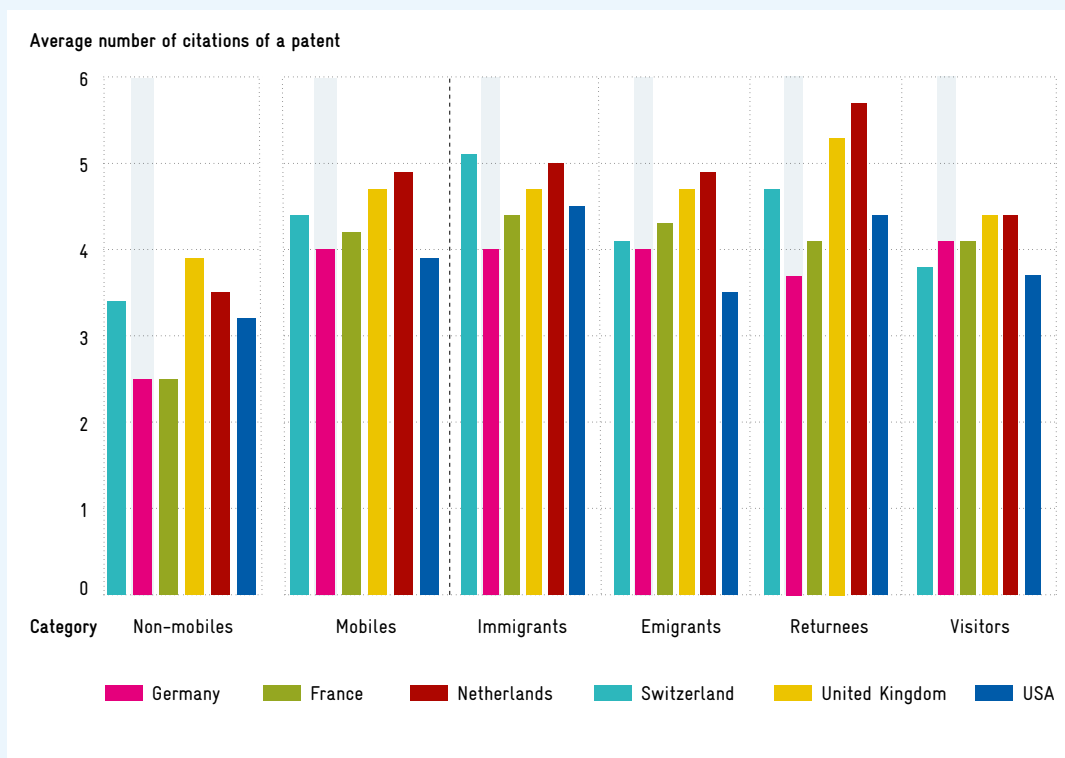
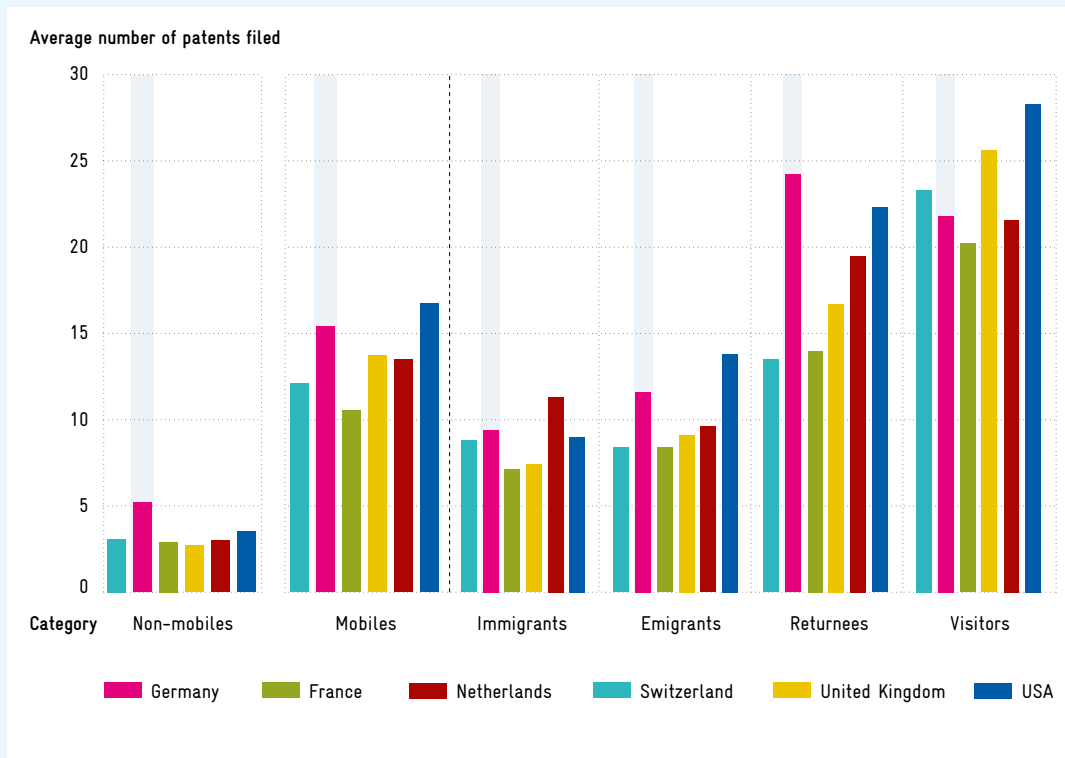
B2-4 Developments Since the 2014 Annual Report

The Commission of Experts previously addressed international mobility in the German science and innovation system in its 2014 Annual Report. It concluded that Germany was not a particularly attractive location for top scientists and inventors.



[Download Data](#)

Fig. B2-11 Number and quality of patents by inventors of different mobility types, differentiated by country 2000–2020



Legend: Inventors immigrating to Germany are named in an average of 9.4 patent applications. The patents of inventors immigrating to Germany are cited an average of four times.
Source: Own calculation and representation based on Karaulova et al. (2024).
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The main reasons for scientists to relocate internationally are related to the excellence of the science system in the respective countries of origin and destination. These motivations were already explained in detail in the 2014 Annual Report.³⁰⁹ Scientists are attracted to where they find the best research conditions.³¹⁰ These include, above all, good career prospects, the reputation of the research institutions, the research infrastructure as well as freedom of expression and freedom in the selection and implementation of research projects. Empirical studies show that R&D employees primarily relocate to countries where they find exceptionally good research and innovation conditions – approximated by high R&D expenditure in relation to gross domestic product.³¹¹

The Commission of Experts' recommendations for action from 2014 were therefore aimed at a substantial and consistent expansion of the strengths of the German science and innovation system in order to facilitate internationally competitive research conditions, especially for the top segment. Over the past ten years, various measures have indeed been introduced to make Germany more attractive as a

centre of science and innovation for top international talent.

Improved General Conditions for International Mobility

Regarding the inward flows of foreign scientists, academics and R&D employees, a number of adjustments have been made to the regulatory framework since 2014 with the objective of reducing administrative barriers (cf. box B 2-12).

Special funding programmes such as the Alexander von Humboldt Professorships have been introduced, expanded and continuously funded for the recruitment of scientists from abroad, including returnees. Excellence-oriented measures to increase the general attractiveness of the science location, such as the Emmy Noether Programme, the support activities as part of the Excellence Initiative and the Excellence Strategy of the Federal Government and the Länder and the Tenure Track Programme, all promote the recruitment of internationally mobile scientists (cf. box B 2-13). Study results indicate that these programmes have succeeded

Box B 2-12 Regulatory Changes for International Mobility for Research and Development Purposes

In 2014, the Commission of Experts identified various legal issues and challenges that impaired the process of recruiting and integrating researchers and R&D employees. The main issues included ambiguous and complex regulatory conditions, a lack of efficient information provision and strict income requirements.³¹² In the meantime, regulatory changes have been made to facilitate residence for research purposes. In particular, the introduction of Sections 18d, 18e and 18f of the Residence Act (Aufenthaltsgesetz) and the ICT (Intra-Corporate Transfer) card have brought significant improvements in the regulation of residence and work permits.

Sections 18d-f of the Residence Act relate to residence permits for research purposes. Under Section 18d, a residence permit for research purposes is issued without the approval of the Federal Employment Agency (Bundesagentur für Arbeit) being required if there is an effective

hosting agreement with a recognized research institution and the costs are borne by the research institution. Section 18e enables foreign researchers who already have a residence permit for the purpose of research in an EU Member State to conduct research in Germany for up to 180 days without having to apply for an additional residence permit. Section 18f regulates the residence permit for researchers who wish to stay in Germany for longer than 180 days and offers a way to obtain the necessary permits.

The ICT card, regulated in Sections 19, 19a and 19b of the Residence Act, is another important instrument. It is a residence permit for the purpose of an intra-company transfer of third-country nationals within an international enterprise or group. The ICT card considerably facilitates and simplifies the secondment of highly qualified individuals who are resident outside the EU. This is particularly relevant for the mobility of R&D employees because it provides clear conditions and criteria for secondment and at the same time enables short-term stays of up to 90 days without the need for an additional residence permit.

in increasing the attractiveness of the science system.³¹³

Increased Migration Balance, Major Demographic Challenges

A comparison between the findings of this report and the results of the 2014 Annual Report reveals clear developments towards greater international mobility of authors of scientific publications.³¹⁴ The number of authors moving to and from Germany increased from around 40,000 in the period from 2005 to 2020 to around 70,000 in the period from 1996 to 2011.³¹⁵

Germany has developed from a net donor to a net receiving country. While the 2014 Annual Report still indicated a net emigration of around 4,000 authors between 1996 and 2011,³¹⁶ the period from 2005 to 2020 shows a net immigration of over 5,000 authors.³¹⁷ The mobility rate of inventors has hardly changed over the past two decades and remained fairly stable at 6 percent between 2000 and

2020. The net outward flows of inventors have decreased over time. A net inward flow was recorded for the first time in 2020.³¹⁸

However, it is unclear whether these positive developments will be sufficient to meet the challenges posed by demographic ageing and the general shortage of skilled labour in the German science and innovation system.³¹⁹

B 2-5 Remaining Barriers

Germany has experienced a net immigration of authors over the past 15 years. It has also been possible to attract many top researchers back to Germany. Overall, however, those immigrating to Germany are on average performing less well than those leaving Germany. This indicates that there is still potential to improve the excellence and attractiveness of Germany as a centre of science and research across the board.

Box B 2-13 Select Support Programmes in the Science System

The Commission of Experts already pointed out in 2014 that measures under the Excellence Initiative, launched in 2005, can prove particularly attractive to researchers from abroad.³²⁰ The Excellence Initiative provided considerable funding over two phases and several funding lines (graduate schools, clusters of excellence and institutional strategies) to promote projects at select universities, improve research cooperation and increase research productivity.³²¹ The Excellence Initiative was replaced by the Excellence Strategy in 2016.³²²

The Alexander von Humboldt Professorship, which was introduced in 2008, aims to attract world-leading scientists working abroad for long-term employment in the German science system. An Alexander von Humboldt Professorship is funded with up to €5 million over a period of five years and a potential two-year extension.³²³

The Emmy Noether Programme³²⁴ was established in 1999 to enable particularly qualified young scientists to conduct a phase of independent research after completing their doctorate. The programme enables the recipients to lead their own junior research group for a period of usually six years and thereby qualify for a professorship. The Emmy Noether Programme promotes international mobility by requiring applicants to have international research experience and supporting the establishment of international networks.

The Federal Government and Länder programme (Bund-Länder-Programm)³²⁵ introduced in 2016 aims at establishing tenure track professorships more structurally in order to create more transparent and predictable career paths in science. The programme enables participants to be appointed directly to a lifetime professorship after a successful probationary phase. The programme is designed to create attractive conditions for talented scientists.

Administrative Processes Inefficient and Complicated

Current surveys among foreign skilled workers who are willing to come to Germany show that lengthy, complex and sometimes non-transparent administrative processes are among the biggest current barriers to the inward flow of skilled workers.³²⁶ In expert interviews, reference was made to the lengthy procedures for issuing visas at German diplomatic missions abroad. Overburdened foreigners authorities and different interpretations of laws, regulations and processes depending on the location were also cited as hindrances.³²⁷ At least larger employers such as corporations and universities can often minimize these, albeit with considerable effort, by approaching the authorities directly.³²⁸

Switching Between Social Security Systems Complex

Insufficiently harmonized recognition procedures between national social security systems make it difficult for foreign scientists and R&D employees

to come to Germany and thus represent a barrier to mobility.³²⁹ Complex and opaque crediting procedures for pension and pension entitlement periods as well as inconsistent regulations on taking existing pension entitlements with you when you later leave the civil service and move to a third country constitute an obstacle for potential incoming scientists in particular.³³⁰

Incomers Hindered by Language Barriers

A recent study on the challenges of coming into the German science system also emphasizes that the German language is one of the biggest hurdles that international scientists face in appointment procedures, in administration, in academic self-administration and in teaching.³³¹

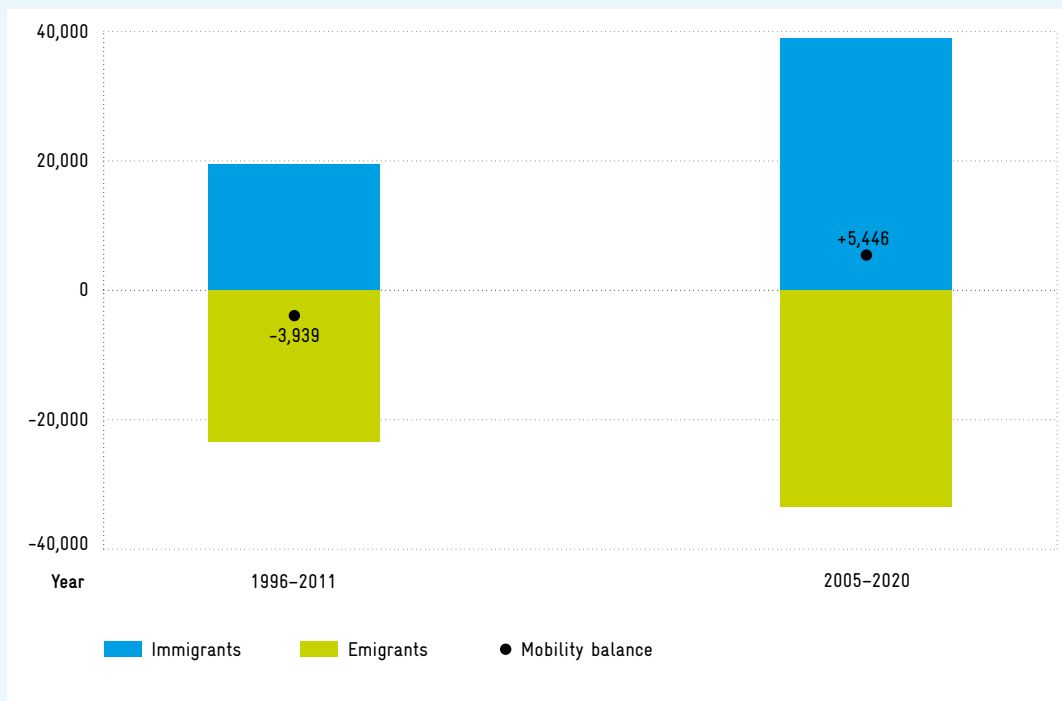
Importance of Communicating Location Advantages

Neither internationally competitive working and research conditions nor an excellent research environment will improve Germany's position in the

Fig. B2-14 Number of emigrating and immigrating authors and the migration balance in comparison between 1996–2011 and 2005–2020



[Download Data](#)



Legend: In the period between 2005 and 2020, 38,973 authors came into the German science system and remained here. In the same period, 33,527 authors left the German science system and did not return. This results in a positive migration balance of 5,446.
Source: Own representation based on Coda-Zabetta et al. (2024).
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international competition for scientists and R&D employees if they are not aware of the advantages of Germany as a location. In addition to employers, the key actors coordinating the recruitment, attraction and integration into the German science and innovation system³³² are the foreign representative offices of institutions such as the DFG and the German Academic Exchange Service (Deutscher Akademischer Austauschdienst, DAAD).³³³ The regular threat of budget cuts at many of these institutions restricts their room for manoeuvre.

B2-6 Recommendations for Action

The analyses presented in this chapter indicate that Germany is competing intensively with a number of other countries for leading scientists and R&D employees and is definitely successful in this respect. Overall, Germany is on a favourable trajectory. However, there is still considerable potential to increase the attractiveness of the location. The Federal Government has a key role to play here, as it shapes the political framework conditions for the international mobility of scientists and R&D employees.

Simplify Regulations for International Mobility and Accelerate Administrative Processes

Complicated and lengthy administrative processes and, in some cases, differently interpreted legislation impede the international mobility of scientists and R&D employees. This impairs the recruitment of top international talent from outside the EU. Complex regulations for residence permits and long waiting times at diplomatic missions abroad as well as lengthy administrative processes at immigration authorities are particular obstacles. The Commission of Experts recommends the following measures:

- A digital system based on the Online Access Act (Onlinezugangsgesetz, OZG), which in future may also be supported by AI, should be set up to link all parties involved in the process (diplomatic missions abroad, foreigners authorities, registration offices, research institutions or businesses and persons wishing to come to Germany). Provision should be made for individual sub-processes, such as the recognition of foreign educational and professional qualifications, to be digitized, accelerated and integrated into an overall process.

- To ensure that visa applications are processed promptly, diplomatic missions abroad should be strengthened in terms of organization and, if necessary, staffing.
- Comprehensive and up-to-date information on topics such as visa processes, work and residence permits, health and pension insurance and social security should be made available digitally in English and other relevant languages.

Particularly when it comes to the international mobility of scientists, the civil servant status, which per se is attractive in international comparison, can lead to administrative problems, for example due to uncertainty about the extent to which previous periods of employment result in pension entitlements. The Commission of Experts recommends:

- The Federal Government should work with the Länder to introduce standardized and digitized procedures in order to speed up these decisions and provide international applicants with certainty about their pension entitlements at an early stage.

Promote Harmonization of Regulations at EU Level

The lack of harmonization of regulatory frameworks at EU level is a major obstacle to the international mobility of scientists and R&D employees. The Commission of Experts expressly welcomes the National Action Plan for the European Research Area recently adopted by the Federal Government, which also plans to reduce bureaucratic hurdles.³³⁴ However, the Action Plan does not go far enough for a general simplification of international mobility and remains too vague on key points.

- The Federal Government should work at EU level to harmonize the regulations on the transferability of combined qualifying periods for pension insurance. In addition, the claiming of pension information and pension entitlements in cases of entitlement in several EU countries should be centralized rather than requiring separate claims for each country.
- The Federal Government should work with the Länder to create uniform regulations for supplementary pension insurance in the event

of voluntary termination of civil servant status (e.g. old-age payment (Altersgeld) regulations). These should also cover all cases where civil servants take up a new job in a non-EU country.

Expanding Excellence Promotion in the Science System

The existing support measures help to attract international researchers and keep them in Germany. Excellent tertiary education and research institutions, faculties and research teams are a key factor in attracting top researchers from abroad. They can also encourage scientists who have moved away from Germany to return.

- Initiatives and programmes of the Alexander von Humboldt Foundation and the DFG to recruit and win back high-performing scientists from abroad should be further expanded.
- The Federal Government-Länder programme for the creation of tenure track professorships should be expanded with a clear focus on making the newly created positions consistently compatible with the international labour mar-

ket in order to support international research careers and attract international scientists. To this end, positions should be advertised as salaried positions with attractive pay.

- The tenure track principle should also be utilized to a greater extent for mid-level academic positions in order to increase the international appeal of Germany as a centre of science below the level of professorship.³³⁵

Safeguarding Financial Conditions

The institutions of the German science system need the financial conditions to contribute to internationalization and to promote the international mobility of scientists.

- The Federal Government should work to ensure that the internationalization of tertiary education is given high priority in Federal Government-Länder agreements on tertiary education funding.
- The increases in the DAAD's basic funding stipulated in the coalition agreement should be adhered to and secured in the long term.

B3 Social Innovation – A Key Element To Address Societal Challenges

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B3 Social Innovation – A Key Element To Address Societal Challenges

In recent years, there has been a growing awareness in society and politics that the transformations associated with major societal challenges such as climate change, demographic ageing and digitalization cannot be implemented by means of technological changes alone. Rather, changes in individual and collective behaviour are also required, which, often in conjunction with innovative technologies, drive these transformations forward. Such changes are known as social innovations. Politics and society are increasingly focussing on these. As early as 2011, the European Union (EU) emphasized that social innovations play a key role in overcoming societal and economic challenges.³³⁶ Since then, the importance of social innovations in research and innovation policy (R&I policy) debates in the EU has increased. More recently, the missions that have been included as new elements in “Horizon Europe”, the EU’s key funding programme for research and innovation, underline the growing interest in social innovations across the EU.³³⁷ Transformative missions in particular rely on the combination of technological and social innovations to drive forward the necessary transformations in fields such as energy supply, mobility, health and food supply.³³⁸

The Federal Government has recognized the importance of social innovations and adopted the National Strategy for Social Innovations and Social Enterprises (Nationale Strategie für Soziale Innovationen und Gemeinwohlorientierte Unternehmen) in September 2023.³³⁹

In its 2016 Annual Report, the Commission of Experts highlighted the importance of social innovations for tackling the major societal challenges.³⁴⁰ This chapter examines the topic in greater detail. Despite a broad consensus on the relevance of so-

cial innovations for social change, there is disagreement as to what is actually meant by a social innovation.³⁴¹ This disagreement has an impact on data collection and therefore on data availability and makes quantitative research and impact measurement more difficult. An evidence-based R&I policy in relation to social innovations therefore lacks a solid empirical basis.

To make better use of the potential of social innovations for society, the Commission of Experts recommends the development of a uniform set of indicators and data basis on social innovations, the opening of existing programmes to promote innovation for social innovations as well as measures for promoting awareness and generalization of social innovations. The Federal Government’s recently published National Strategy for Social Innovations and Social Enterprises is already providing important impetus in this regard.

B3-1 Social Innovations and Social Enterprises

Social Innovations: New Solutions for Social and Economic Problems

Social innovations have various definitions in the literature. Some definitions focus on new individual and collective behaviours and thus on change processes.³⁴² Other definitions see social innovations exclusively as new approaches to overcoming societal challenges and focus on their objectives.³⁴³ Finally, there are also definitions that emphasize both the change processes and the objectives of social innovations.³⁴⁴ When clarifying the concept of social innovation, it is not uncommon to dispense

with a clear definition and merely refer to examples. Some examples of social innovations are provided in box B3-1.

The spectrum of initiators of social innovations is broad. It ranges from individuals and households, informal groups and movements to organizations including social as well as profit-oriented enterprises.³⁴⁵ The motives for social innovations vary greatly and range from the search for innovative solutions to societal and economic problems to profit-making and reinvestment intentions.³⁴⁶

Social innovations are therefore not necessarily developed in an institutionalized and formalized context but can also emerge from society in a self-organized manner. They are often linked to technological innovations. In many cases, social innovations can be observed at a local or neighbourhood level, where new approaches and ideas have emerged in response to local challenges, such as food banks³⁴⁷ or car-sharing schemes to promote mobility.³⁴⁸ In addition, social innovations can also be seen in a supra-regional context, especially when it comes to digitally supported social innovations such as crowdfunding.

Based on these conceptual considerations, the Commission of Experts defines social innovations as new individual and collective behaviours and forms of organization that contribute to solving societal or economic problems and thus create added value

for society. They are developed by different actors such as individuals, households, groups and companies. They may or may not be related to technological innovations.

Based on a frequently used process model,³⁴⁹ the development of social innovations can be divided into three typical phases: niche formation, niche maturation and generalization.³⁵⁰ In the first phase, niche formation, social problems are identified and initial ideas on how these problems could be solved are operationalized. In this phase of initiation, development and early operational work, creative ideas and solutions are developed that go beyond conventional ways of thinking and established structures. Users of social innovations are also actively involved in the development, which can contribute to increased acceptance and thus a higher probability of successful implementation of the innovation. In this phase, the ideas and solutions of the social innovation actors are tested in practice in a limited space and, if necessary, adapted to the respective problem.³⁵¹ In the second phase, niche maturation, the social innovations emerge from the testing context. Lastly comes the third phase, generalization, which involves testing the social innovations in other contexts and adapting them where necessary. In this phase, the social innovation actors interact more intensively with the institutional and political environment and can thus bring about societal change.³⁵² The generalization of social innovations can be supported by new technological develop-

Box B3-1 Examples of Social Innovations

- Multi-generation houses: Multi-generation houses are places where people of different ages come together to learn from each other, support each other and carry out joint activities. They promote dialogue between the generations and help to strengthen social cohesion.
- Community energy cooperatives: Community energy cooperatives are associations of citizens who jointly develop and operate renewable energy projects. They enable people to actively participate in the energy transition and promote the local energy supply.
- Online networking platforms: Online networking platforms are a digital social innovation. They connect people digitally and enable the exchange of information, ideas and resources.
- Crowd economy: The crowd economy enables individuals to share resources, finance projects and offer services. By involving a large number of people, innovative ideas can be implemented that might otherwise not be realized.

ments. Digital social innovations, for example, rely on digital technologies to drive their generalization.³⁵³

The effects of social innovations are often not limited to those directly involved in them. The successes achieved, for example in combating climate change, protecting the environment or facilitating access to education and healthcare, improve the living conditions of large sections of society. However, such so-called positive external effects are not reflected in the market prices for the services of social innovations. This can reduce the willingness of social innovators to become more involved in these projects financially or by providing in-kind donations.

For the sustainable provision of social innovations, the problem of free-riding behaviour can also arise if the services of a social innovation represent a public good for the beneficiaries (cf. box B3-2). They can use these services without contributing

financially or providing in-kind donations. Both the positive external effects and free-riding behaviour can impede the emergence of social innovations as well as their dissemination and generalization.³⁵⁴

When providing social innovations, the problem can arise that socially undesirable or at least controversial results and solutions emerge. Impact measurement and impact assessment of social innovations must therefore also endeavour to take these undesirable or ambivalent effects into account. Just as the positive effects of social innovations can be accompanied by external effects that lead to too little innovation activity or dissemination of specific social innovations, social innovations can also trigger negative external effects. If these are not internalized, social innovations with negative social effects can spread. The impact assessment of social innovations must therefore not be limited to measuring the positive effects intended by the innovation, but must also consider the negative effects, especially if these are not limited to the group of users.³⁵⁵

Box B3-2 External Effects, Public Goods and Free-Riding Behaviour

Technological external effects of an action exist when the consequences of one's own actions affect more than just the person acting. These effects are positive if the benefits of an action (also) extend to other people without the person taking the action receiving compensation from the beneficiaries. This means that the joint benefit of an action is greater than the benefit accruing to the person taking the action. If persons base their decision primarily on their own advantages and disadvantages of the action, they may decide against an action because the individual disadvantages outweigh the advantages – even though the overall societal advantages outweigh the overall societal disadvantages. The action would be optimal from the viewpoint of society as a whole, but from the individual viewpoint of the person taking the action, it is not worthwhile. In the context of social innovations, this implies that the provision of these innovations is not optimal for society as a whole and can manifest itself in the fact that too few projects are initiated or that the projects that are initiated are implemented on too small a scale. To resolve the discrepancy between private and

society-wide incentives, the beneficiaries could decide to contribute to the implementation costs or compensate the implementers for the benefits to society as a whole. This is referred to as 'internalization' of the external effect. Such compensation is not always possible on a voluntary basis, e.g. when a public good is provided.

A public good is said to exist if there is non-rivalry in use and non-excludability from use. Non-rivalry means that the use by one person does not restrict the use of others.³⁵⁶ For example, the benefit that an individual derives from a cleaner environment or a society with less poverty is not diminished by the fact that others also appreciate a clean environment and a society with less poverty. Non-excludability is when no one can be excluded from the use of a good once the good is provided. For example, it is not possible to exclude others from the benefits of better air quality.

In cases of non-excludability, there is the possibility of free-riding, i.e. the possibility of benefiting from the success of an innovation without participating in its financing.

Transformations Supported by Social Innovations

Overcoming grand societal challenges such as climate change, demographic ageing and digitalization requires not only innovative technologies but also new individual and collective behaviours. These new behaviours are often necessary to enable the use of radically new technological solutions and to reduce undesirable technological and societal side effects and consequences. Social innovations are therefore particularly necessary in the area of societal transformations.³⁵⁷

This specific link between social innovations and transformations has led to some definitions of social innovations explicitly naming the contribution that they should make to overcoming the grand societal challenges. The Federal Government follows this logic by defining social innovations as “new social practices and organizational models” that “contribute to viable and sustainable solutions for the challenges facing our society.”³⁵⁸ It places its thoughts about social innovations directly in the context of the 17 Sustainable Development Goals (SDGs) and thus in the context of transformations.³⁵⁹ The Commission of Experts recognizes the importance of this context and points out that in its 2021 Annual Report³⁶⁰ it emphasized social innovations as a key mechanism in the concept of the market-oriented catalytic mission orientation of R&I policy. However, the conceptual considerations presented in this chapter also show that the importance of social innovations goes beyond this context.

Social Enterprises with a Societal Orientation

As with social innovations, there is no generally recognized and therefore uniform definition of social enterprises, either globally or within the EU.³⁶¹ The European Commission defines social enterprises as companies “for who the social or societal objective of the common good is the reason for the commercial activity, often in the form of a high level of social innovation”.³⁶² In addition, according to the European Commission’s definition, social enterprises are characterized by the fact that they largely reinvest their profits in order to achieve the desired social objective. The organizational and ownership structures further reflect this goal, as social enterprises are aligned with the principles of co-determination, employee participation and social justice.³⁶³ The definition of the Social Entrepreneurship Net-

work Germany (SEND), which is equally used in Germany, defines social entrepreneurship by the goal of overcoming a societal challenge. This goal “is achieved through the continuous utilization of entrepreneurial means and results in new and innovative solutions. Steering and control mechanisms ensure that the social objectives are pursued internally and externally.”³⁶⁴

Accordingly, social enterprises have the primary goal of tackling societal challenges, whereby their actions are guided by entrepreneurial principles.³⁶⁵ Social enterprises therefore pursue two objectives: financial sustainability and a social purpose.³⁶⁶

Social enterprises are perceived by policymakers as actors that generate social innovations or support their dissemination to a particular extent. In its National Strategy for Social Innovations and Social Enterprises, the Federal Government emphasized the diversity of actors that drive social innovations. The Federal Government thereby highlights the importance of social enterprises, which it equates with companies that are oriented towards the common good. On the one hand, social enterprises are drivers of social innovations by providing transformative impetus within existing structures and thus creating fertile ground for such innovations. On the other hand, social enterprises can emerge as a direct consequence of a social innovation or serve as a platform for its sustainable implementation.³⁶⁷

The typical development of a social enterprise can be divided into three phases. It starts with the business idea, which is primarily derived from existing societal challenges. When evaluating the business idea, the entrepreneurs place greater emphasis on the expected societal changes than profit-oriented enterprises. In the consolidation phase, the business idea is translated into a business model by defining social entrepreneurial as well as guiding values and by selecting an appropriate legal entity for the social enterprise. In the growth phase, the social enterprise is scaled up in order to increase its positive social impact. The growth phase is less strongly driven by sales and the market than in profit-oriented enterprises.³⁶⁸

In contrast to purely profit-oriented enterprises, the societal added value is the primary business objective for social enterprises.³⁶⁹ In their value creation, they combine the provision of private goods or services with a contribution to a public good.

They may do this, for example, by contributing to environmental protection through strict compliance with ecological standards over and above the regulatory requirements. This coupling can alleviate or completely solve the problem of financing public goods and thus ensure continuity. This also makes social enterprises politically interesting, as the partial financing of public goods from market-economy activity reduces the demand for public funds, donations or grants accordingly.

B3-2 Empirical Findings on Social Innovations and Social Enterprises

Evidence-based R&I policy requires representative, comparable and long-term data in order to develop recommendations and strategies, compare developments between regions, countries and actors and evaluate the effects of policy measures. However, data and the resultant empirical evidence on social innovations and actors are rarely available and, if they are, they are neither systematically collected nor representative. Reasons for the lack of an empirical basis include the fact that social innovations are defined inconsistently, and the range of actors is diverse. Even with a given definition, social innovations are a difficult phenomenon to measure.³⁷⁰ This problem is less pronounced in the case of technological innovations, as they can be measured indirectly via indicators such as expenditure on research and development as well as patents. Similar approximations are not yet available for social innovations. Even the term ‘social enterprise’ is defined in several ways, which makes evidence-based statements difficult.³⁷¹

The following section begins by discussing the data problem caused by the diversity of definitions of social innovations. Based on data from the European Commission, the distribution of social enterprises in Europe is outlined. To determine the spatial distribution of companies with social innovations, hereinafter referred to as socially innovative enterprises,³⁷² in Germany, data from ISTAR.AI³⁷³ is used. Results on the motives behind social innovations are presented on the basis of data from SI-Drive,³⁷⁴ while conclusions on the societal objectives of social enterprises are drawn using data from the German Social Entrepreneurship Monitor (Deutscher Social Entrepreneurship Monitor, DSEM)³⁷⁵ and the

European Social Enterprise Monitor (ESEM). Profit-oriented enterprises as a source of social innovations can in turn be identified using data from the Mannheim Innovation Panel. Finally, the role of other actors as initiators of social innovations, e.g. in the context of demand-side innovations (user innovations), is recognized, even if no data is available for Germany.

Social Innovations: Difficult Empirical Measurement

In the literature, social innovations are mainly discussed conceptually and theoretically. However, measuring and quantifying social innovations also requires reliable and meaningful data in order to record the societal added value and impact of innovations. Empirically sound literature on the functioning and role of social innovations in overcoming grand societal challenges or in the context of mission- and transformation-oriented R&I policy is rare.³⁷⁶

Currently, only isolated data sets relating to specific subject areas, regions or definitions are available. This is due to the often difficult distinction between social innovations and other innovations (e.g. the inconsistent categorization of car sharing as a social innovation). In addition, there is diversity in the subject areas relevant to social innovations. Finally, the comparability of the available data is made more difficult by the considerable number of different innovators involved and the different definitions of social innovations.³⁷⁷

The development of suitable indicators and methods for measuring social innovations requires careful selection and adaptation to the respective context. To measure the impact of social innovations, the number of people who benefit from a social innovation, the change in the level of education through a social innovation or the economic impact of a social innovation are recorded, among other things. The Federal Government has recognized the relevance of indicators. The Federal Ministry of Education and Research (BMBF), for instance, has funded the IndiSI (Indikatorik Sozialer Innovationen – Indicators of Social Innovations)³⁷⁸ and IndiSI+³⁷⁹ projects, which have addressed the measurement of social innovations and developed novel approaches to measuring them.³⁸⁰

Socially Innovative Enterprises: Predominantly in Cities

The number of social innovations and social enterprises in Germany, as well as in other European countries, can only be approximated. The European Commission estimates the number of social enterprises in Germany at 77,459 in 2017, which corresponds to 936 social enterprises per million inhabitants.³⁸¹ This puts Germany behind Italy (1,694 social enterprises per million inhabitants, 2017 estimate), Hungary (1,621, 2016), Luxembourg (1,546, 2017–2018), France (1,414, 2015–2017) and Lithuania (1,237, 2016–2017) in a European comparison.³⁸²

With the help of current data from ISTARI.AI, which was taken from the websites of companies based in Germany as of November 25, 2023, socially innovative enterprises can be identified and aggregated at district level.³⁸³ Figure B3-3 shows the percentage of socially innovative enterprises among all companies at district level for Germany. The percentage of socially innovative enterprises is higher in western Germany than in eastern Germany (with the exception of Berlin and the neighbouring districts) and higher in urban and urbanizing regions³⁸⁴ than in rural³⁸⁵ regions. The share of socially innovative enterprises among all companies in Germany is 17.1 percent. In urban regions, it is above average at 20.2 percent,³⁸⁶ while it is slightly below average in urbanizing regions at 16.9 percent³⁸⁷ and below average in rural regions at 14.8 percent.³⁸⁸

Social Innovations: Primarily Motivated by Societal Challenges

A non-representative survey of social innovation initiatives as part of the SI-Drive project, which was conducted worldwide in 2015/2016 with a focus on Europe, showed that for 61.9 percent of respondents, social innovations³⁸⁹ are motivated by societal challenges. Almost as many social innovations are motivated by social needs (61.2 percent). Social innovations are triggered to a much lesser extent by new ideas (28.1 percent) and new technologies (23 percent) (cf. figure B3-4).

Social Enterprises: Quality Education Most Common Sustainability Goal

In 2015, the United Nations (UN), including Germany, adopted the Agenda 2030 and committed to

the 17 SDGs.³⁹⁰ These sustainability goals require partly radical innovative technologies and fundamental changes in the use of technologies and the behaviour of all actors. Global sustainability aspects of varying degrees, e.g. in the fields of poverty reduction, healthcare, climate change and environmental damage,³⁹¹ have thereby gained a high political priority also in Germany. According to the DSEM survey 2021/2022, nearly all of the German social enterprises surveyed contribute to achieving at least one of the SDGs. Of the social enterprises surveyed in Germany, 51.6 percent pursue the goal of ‘quality education’, while only 40 percent of social enterprises in Europe³⁹² do so. SDG 11, which aims to achieve inclusive, safe, resilient and sustainable cities and settlements, is targeted by 33.9 percent of the social enterprises surveyed in Germany and 33.6 percent of the social enterprises surveyed in Europe. The goal of taking immediate action to combat climate change and its impacts (SDG 13) is mentioned by 28.3 percent of the companies surveyed in Germany and thus slightly more frequently than by the social enterprises surveyed in Europe, where 26.5 percent pursue this goal. A significantly greater difference emerges for the goal of building a resilient infrastructure, inclusive and sustainable industrialization and promoting innovation (SDG 9). This goal is stated by 26.5 percent of the German social enterprises surveyed and only 17 percent of the European social enterprises surveyed (cf. figure B3-5).

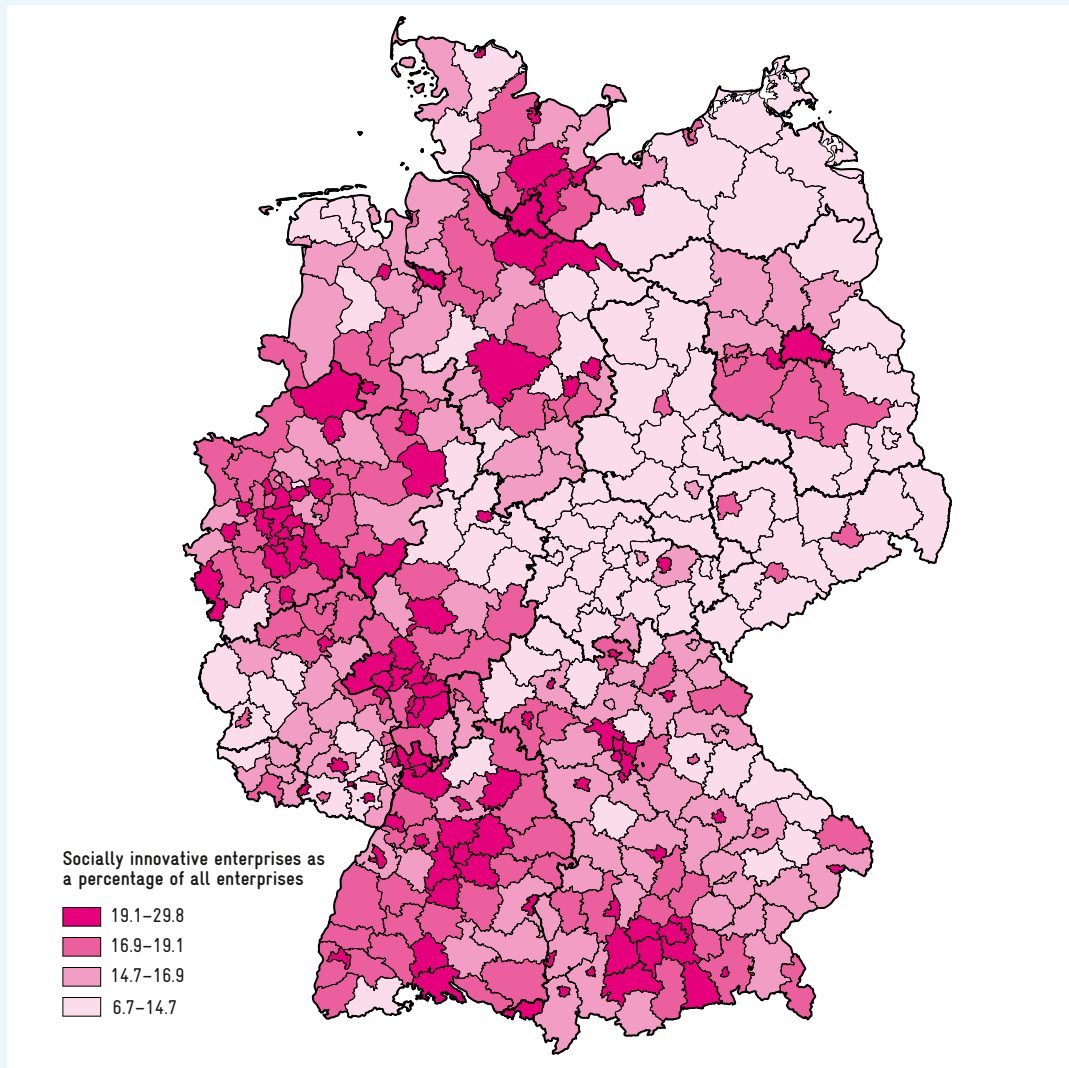
Social Innovations: Common Among Profit-Oriented Enterprises Too

Social innovations can also play a significant role in profit-oriented enterprises. In their internal company processes they can utilize social innovations that they have generated themselves or adopted from others. In addition, these profit-oriented enterprises can offer products and services developed by themselves or by others, which in turn promote social innovations.

Figure B3-6 illustrates the percentage of all companies with and without social innovations in research-intensive and other industries as well as in knowledge-intensive and other services. A distinction is also made between companies with and without process and/or product innovations. Firstly, it becomes clear that companies in research-intensive industry and knowledge-intensive services in particular introduce social innovations. Secondly, there is a complementarity between process and/or prod-

Fig. B3-3 Districts by percentage of socially innovative enterprises in all enterprises

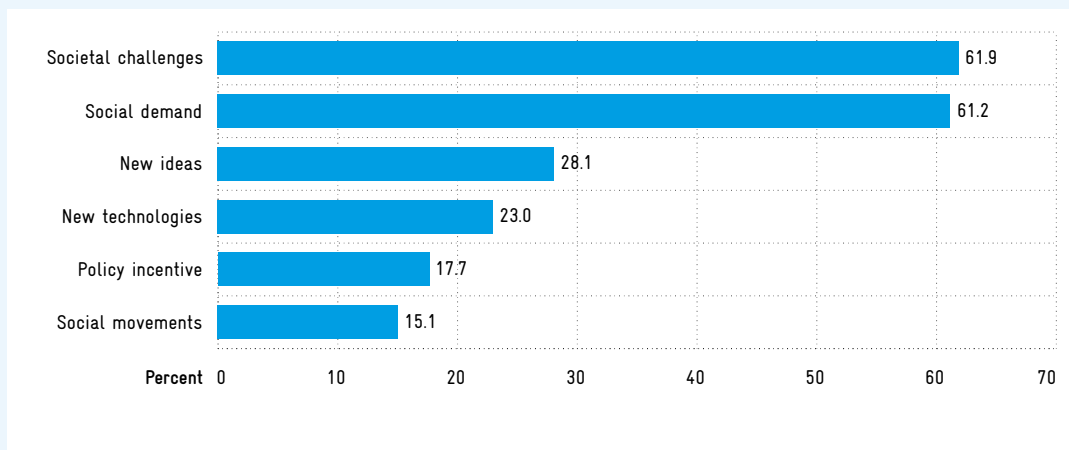
 [Download Data](#)



Socially innovative enterprises as of 25 November 2023.
Source: ISTARI.AI, BBSR. Own representation.
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Fig. B3-4 Motives and triggers of social innovations in percent

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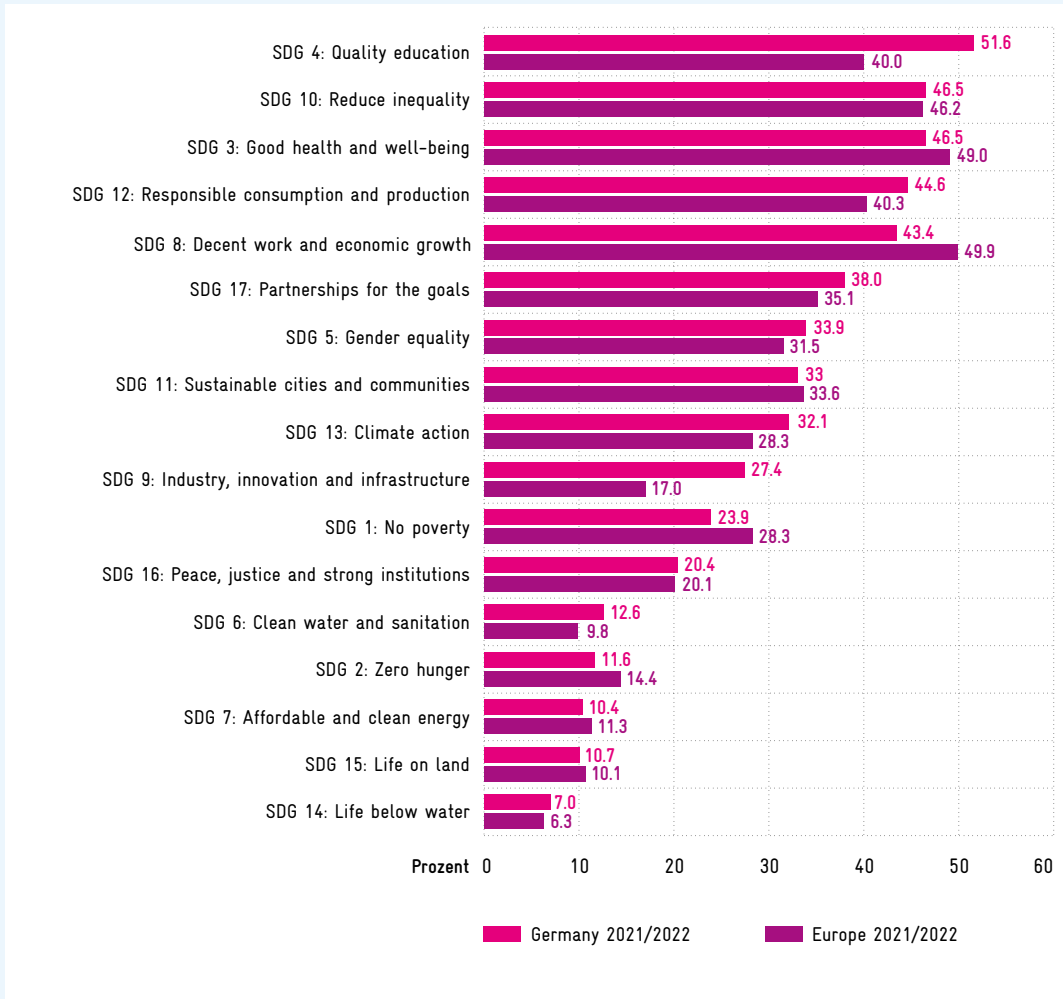


The data set contains social projects and initiatives (innovation initiatives) worldwide with a focus on Europe.
Answer to question: What was the initial motivation/trigger for initiating the project? Multiple answers possible.
Legend: 61.9 percent of social innovation initiatives are motivated by societal challenges.
Source: SI-Drive, 2015/2016 survey. Representation based on Weber et al. (2024). Own representation. N=979.
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Fig. B3-5 Sustainable Development Goals (SDGs) of social enterprises in percent



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Answer to question: What kind of social/environmental impact does your organization want to achieve? Multiple answers possible.
 Legend: 51.6 percent of social enterprises stated that they are pursuing the SDG "Quality education".
 Source: German Social Entrepreneurship Monitor, 2021/2022 survey and European Social Enterprise Monitor, 2021/2022 survey.
 Own calculations. Own representation.
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uct innovations and social innovations: For example, in research-intensive industry, 67.6 percent of companies with process and/or product innovations also have social innovations, while only 52.6 percent of companies that do not implement process and/or product innovations are socially innovative. This discrepancy is even more pronounced in other industries, with 58.6 percent and 29.2 percent, respectively.

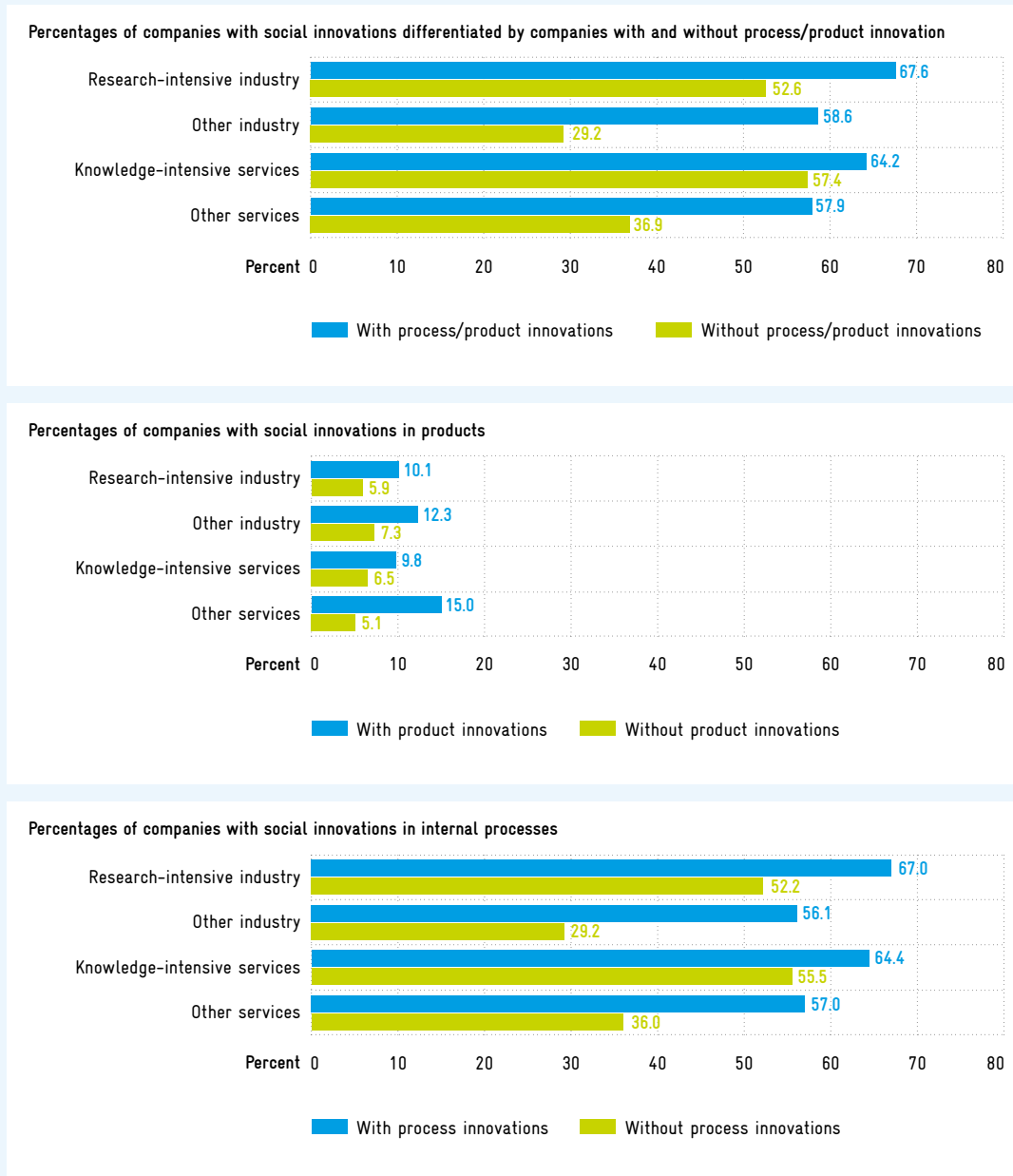
Figure B3-6 also shows that social innovations primarily take place in internal company processes.³⁹³ This applies in particular to the research and knowledge-intensive industries: In research-intensive in-

dustry, social innovations in internal company processes are found in 67 percent of companies with process innovations and 52.2 percent of companies without such innovations. In knowledge-intensive services, 64.4 percent of companies with process innovations are socially innovative in internal processes, but only 55.5 percent of companies without process innovations. A similar picture emerges for social innovations in products,³⁹⁴ albeit at a significantly lower level: Socially innovative product offerings can be found, for example, in the research-intensive industry at 10.1 percent of companies with product innovations and at 5.9 percent of companies without product innovations.³⁹⁵



[Download Data](#)

Fig. B3-6 Companies with social innovations since 2020 in percent



Examples of social innovations in internal company processes: home office, flexible working life models, mentoring programmes, inclusive workplaces, bridging internships.

Examples of social innovations in form of product offerings: telecare, sustainable tourism, swap shops, multi-generation houses, e-health, car sharing, community buses, crowdfunding.

Legend: 67.6 percent of companies in the research-intensive industry with product and/or process innovations have also introduced social innovations since 2020.

Source: ZEW, Mannheim Innovation Panel, 2023 survey – calculations by ZEW. Own representation.

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Social innovations: Also Relevant for User Innovations

Individuals and households can likewise generate social innovations.³⁹⁶ However, these activities have so far been difficult to capture empirically.³⁹⁷ The literature on so-called user innovations provides

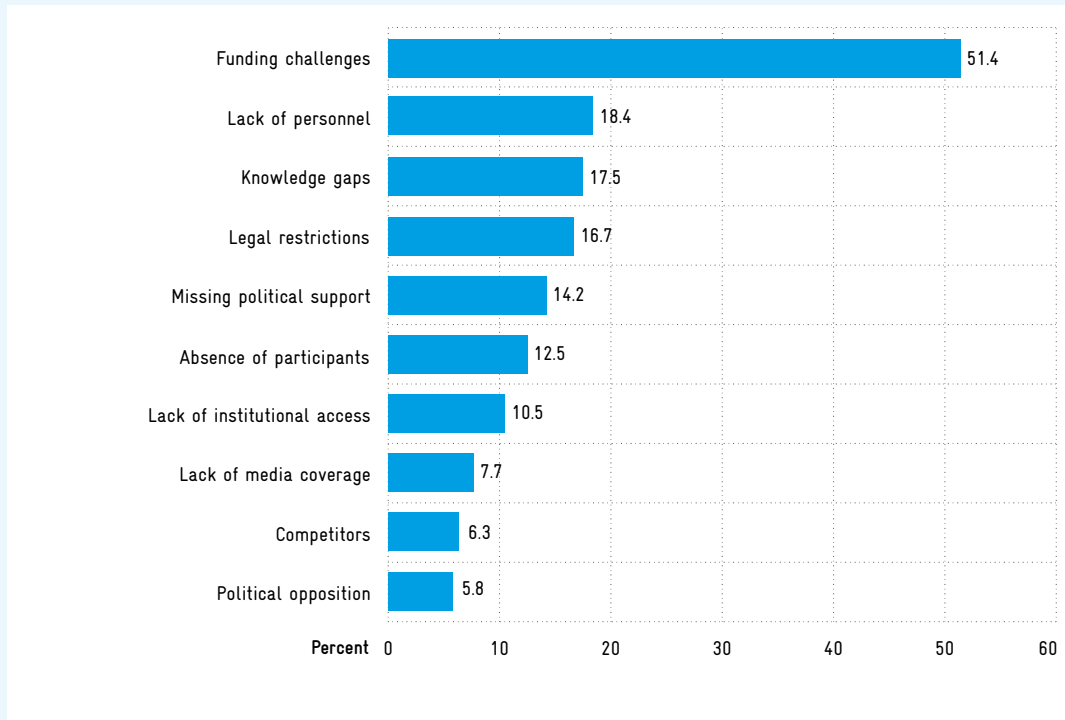
conceptual clues.³⁹⁸ Here, users actively participate in the design of products, services or solutions to societal problems and thus contribute their needs and ideas to the innovation process.³⁹⁹

The literature shows that in the context of user innovation, individuals work alone, in social groups or

Fig. B3-7 Barriers to social innovations in percent



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The data set contains social projects and initiatives (innovation initiatives) worldwide with a focus on Europe. Answer to question: Does the project face any barriers? If so, what are the most important barriers to the project? Multiple answers possible.
 Legend: 51.4 percent of the social innovators surveyed stated that funding challenges exist.
 Source: SI-Drive, 2015/2016 survey. Representation based on Weber et al. (2024).
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together with companies on ideas to solve societal problems⁴⁰⁰ and reflect on the societal impact of innovations and challenges.⁴⁰¹

B3-3 Barriers

To make the best possible use of the potential of social innovations and social enterprises, it is necessary to identify barriers in the development, generalization and scaling processes and, if necessary, to implement suitable political interventions.

Social Innovations: Financing Difficult

A major structural barrier to social innovations is the difficulty of obtaining adequate financing. This is due to both the positive external effects of a social innovation that are not taken into account in market prices and the free-riding behaviour of the direct users of the benefits of a social innovation (cf. box B3-2). Both can explain why social innovations are not made available to the societally optimal extent. This may be a reason for state intervention.

Figure B3-7 shows that more than half of the social innovation initiatives surveyed cited financing difficulties as a barrier to social innovations,⁴⁰² making this by far the most frequently cited barrier. Another barrier that should not be neglected is the lack of personnel, which at 18.4 percent is mentioned much less frequently than financing barriers but is likely to increase in importance for social innovations due to the worsening skilled labour shortage in Germany.⁴⁰³

Social Innovations: Generalization Impeded by Coordination Issues

When generalizing social innovations, it is important to involve different stakeholders, e.g. neighbourhoods, regional political actors, non-governmental organizations. These actors may differ in their objectives, their formalization and their communication style, among other things. The success of social innovations in generalization now depends on coordinating these different actors time and again in new contexts.

The most common type of generalization mentioned by the social innovation initiatives surveyed was the expansion (within) the target group (69.7 percent). For the social innovation initiatives surveyed, the diffusion and generalization of social innovations often takes place via an expansion of the network (48.5 percent), i.e. the social innovation is implemented in cooperation with additional network partners. 40.3 percent of the social innovation initiatives surveyed scale by means of organizational growth (cf. figure B3-8). Data on successfully generalized social innovations are currently not available.

Social Enterprises: Access to Public Funding Difficult

On the one hand, social enterprises are confronted with the same obstacles as profit-orientated companies, but on the other hand they face specific challenges due to their objectives: Traditional start-up financing, which in many cases provides for external investors to enter and exercise a say, can jeopardize the social enterprise's objectives for the common

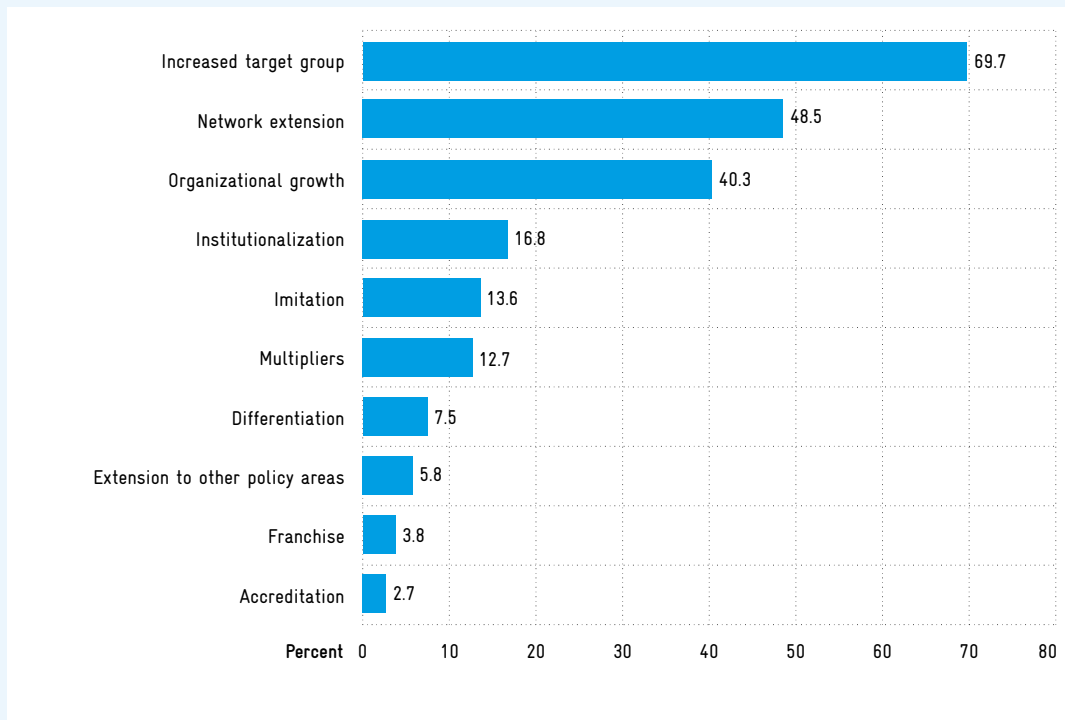
good (risk of so-called mission drift). Therefore, traditional start-up financing is often unsuitable for social enterprises.⁴⁰⁴ Instead, social enterprises frequently use silent partnerships or subordinated loans. The data from the DSEM⁴⁰⁵ show that social enterprises frequently name financing difficulties as a barrier. For example, 39 percent cited a lack of financial options at the time of establishment, 41.8 percent a lack of financing options after establishment and 39.9 percent of the social enterprises surveyed cited a lack of patient capital as a barrier (cf. figure B3-9).⁴⁰⁶

The goods and services provided by social enterprises can have external effects if the benefits of their consumption are not limited to their customers alone. For example, the societal added value that results from social enterprises complying with higher environmental standards does not only benefit their customers. The prices that social enterprises can charge for their products on the market do not then reflect the environmental benefits of their production for society as a whole. This can lead

Fig. B3-8 Generalisation of social innovations in percent



[Download Data](#)



The data set contains social projects and initiatives (innovation initiatives) worldwide with a focus on Europe. Answer to question: How does the project scale its solution? Multiple answers possible.
 Legend: 69.7 percent of the social innovation initiatives surveyed try to generalize their social innovations by increasing their target group.
 Source: SI-Drive, 2015/2016 survey. Representation based on Weber et al. (2024). N=862.
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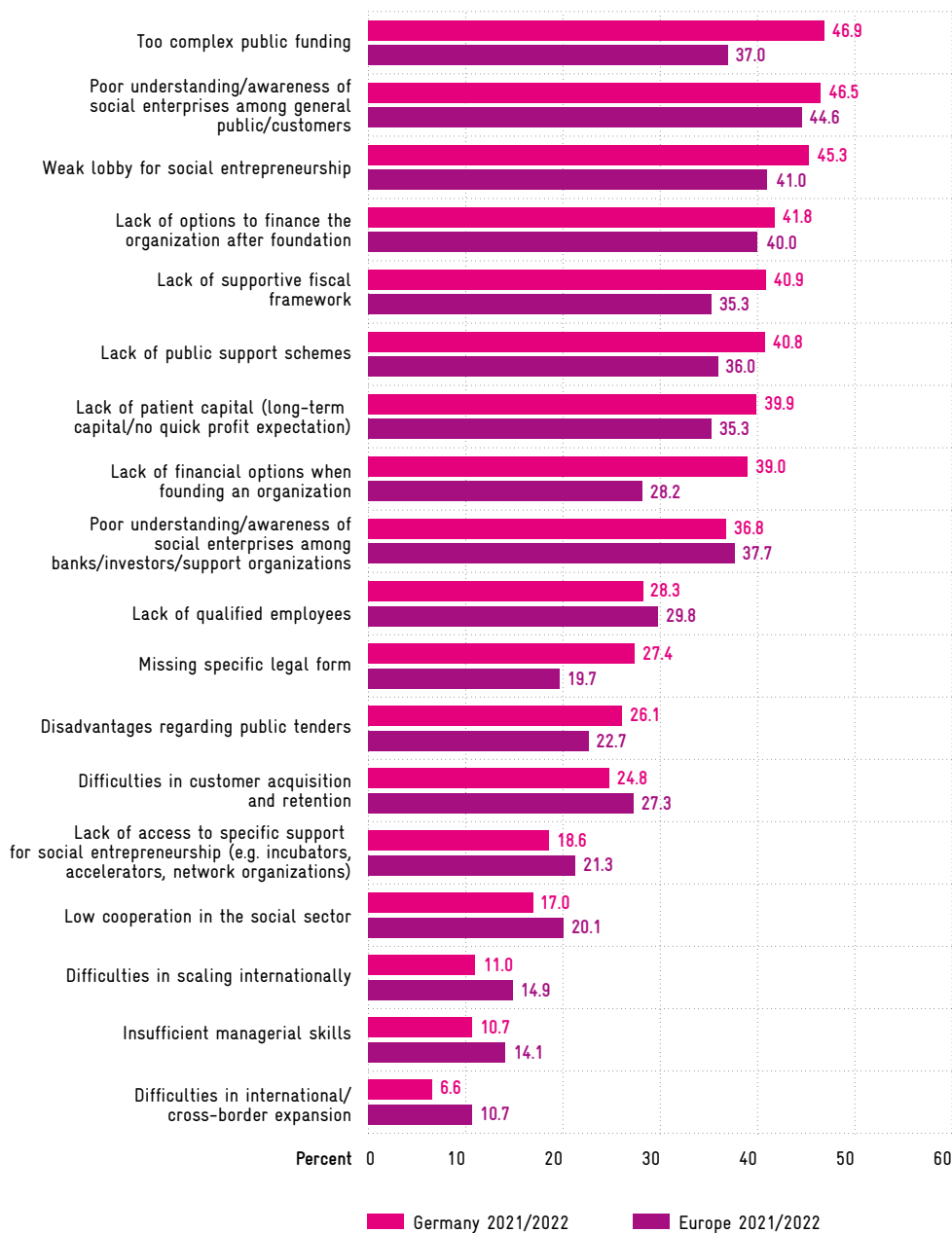
to environmentally friendly goods being produced to an extent that is too low from the point of view of society as a whole. In such cases, public support may be justified for reasons of efficiency. However, the DSEM data indicate that social enterprises encounter barriers when applying for funding. Of the German social enterprises surveyed, 46.9 per-

cent most frequently cited the complex allocation of public funding as a barrier, while in a European comparison⁴⁰⁷ only 37 percent of the social enterprises surveyed cited it as a barrier. 40.9 percent of the social enterprises surveyed in Germany perceive the lack of a supportive fiscal framework as a barrier.

Fig. B3-9 Barriers perceived by social enterprises in percent



[Download Data](#)



Answer to question: What barriers do you encounter in your organization? Please tick all the answers that apply to your organization. Evaluations are based on businesses that state that they are a social enterprise. Multiple answers possible. Legend: 46.9 percent of the social enterprises surveyed stated that the overly complex allocation of public funding is a barrier. Source: German Social Entrepreneurship Monitor, 2021/2022 survey and European Social Enterprise Monitor, 2021/2022 survey. Own calculations. Own representation. © EFI – Commission of Experts for Research and Innovation 2024.

Social Enterprises: Low Level of Awareness

The social enterprises surveyed also named insufficient understanding or awareness of social enterprises among the public and customers (46.5 percent) and a weak lobby (45.3 percent) as further barriers. In Europe, too, a lack of understanding was seen as a barrier by 44.6 percent of the social enterprises surveyed and a weak lobby by 41 percent (cf. figure B3-9). If customers fundamentally share the goals of social enterprises but are unaware of what social enterprises offer, this can lead to insufficient articulation of demand.

The lack of a suitable legal form is cited as an obstacle by 27.4 percent of all social enterprises surveyed in Germany.⁴⁰⁸ The discussion about a missing specific legal entity for social enterprises is not limited to Germany.⁴⁰⁹ For example, 19.7 percent of the social enterprises surveyed in Europe also consider a missing legal form as barrier (cf. figure B3-9). However, it is not clear from the survey what exactly social enterprises criticize regarding the available legal forms.⁴¹⁰ It remains unclear, for example, whether the currently discussed option of a legal form with asset commitment could be a better option for social enterprises. The fact that the legal form has to be determined at a time when it is difficult for the founders to assess what impact the legal form will have on the organizational structure and how it may limit the options for action in pursuing the social objective could prove to be a difficulty. However, such difficulties are not limited to social enterprises. Even purely profit-oriented enterprises often cannot find the ideal legal form for them but have to weigh up the advantages and disadvantages of the various alternatives.

B3-4 Political Framework

In German R&I policy, social innovations were addressed for the first time with the new High-Tech Strategy from 2014.⁴¹¹ This is not only associated with an R&I policy expansion of the concept of innovation to include social innovations, but also an emphasis on societal effects that go beyond purely economic benefits, such as working conditions or the treatment of nature. In this context, the strategy also emphasizes the active involvement of society as a key actor⁴¹² and strengthens essential elements such as social innovations and citizen

participation.⁴¹³ With the High-Tech Strategy 2025 from 2018, the Federal Government integrated social innovations into its concept of a mission-oriented R&I policy to tackle societal challenges.

In 2021, the Federal Government adopted the ministerial concept on social innovations in order to define these and to coordinate the understanding, objectives, instruments and fields of action across ministries.⁴¹⁴

The current Federal Government's Future Research and Innovation Strategy 2023 (Zukunftsstrategie Forschung und Innovation 2023) highlights the importance of social innovations for a variety of developments and places them in the context of the missions 'Enabling resource-efficient and on circular economy based competitive industry and sustainable mobility' and 'Strengthening social resilience, diversity and cohesion'. For the first time, social enterprises are also mentioned, which are ascribed a special role in the emergence and generalization of existing social innovations.⁴¹⁵

Against the backdrop of national and international initiatives, the Federal Government published the aforementioned National Strategy for Social Innovations and Social Enterprises in September 2023 (cf. box B3-10).

B3-5 Recommendations for Action

Social innovations are particularly important for tackling grand societal challenges such as climate change, demographic ageing and digitalization. Alongside innovative technologies, new individual and collective behaviours that essentially characterize social innovations are equally required. The Federal Government has long recognized the importance of social innovations. In the Future Research and Innovation Strategy adopted in 2023 and the National Strategy for Social Innovations and Social Enterprises, it now considers social enterprises as particularly relevant actors in this regard.

The Commission of Experts welcomes the strategy but sees a need for additional action. It therefore recommends that the Federal Government, and in particular the BMBF and BMWK (Federal Ministry of Economic Affairs and Climate Action) , take the following measures:

Box B3-10 National Strategy for Social Innovations and Social Enterprises

This strategy defines social innovations in line with the Federal Government’s ministerial concept for social innovations from 2021 and social enterprises that are oriented towards the common good in line with the European Commission’s Social Business Initiative from 2011. The promotion of social enterprises in the strategy focuses on small and medium-sized enterprises (SMEs) and on the establishment and growth of social enterprises. The restriction to SMEs is justified by the fact that they would otherwise be at a disadvantage compared to large companies due to a lack of resources, and by the fundamental eligibility of SMEs for support.⁴¹⁶

The strategy sets out seven guidelines. They recognize the contribution of social innovations and social enterprises to achieving the SDGs and sustainable transformations and emphasize the importance of impact measurement. It also highlights the diversity of actors in the emergence of social innovations, holds out the prospect of promoting participatory and collaborative processes and underlines the need to consider social and technological innovations as equal in

their joint impact and in principle.

The strategy lists the following eleven fields of action in which barriers are identified and solutions proposed, each followed by a list of specific measures:⁴¹⁷

1. Optimize the policy environment and remove structural impediments
2. Strengthen a socially innovative and socially oriented startup culture and the support structures
3. Promote networking, collaboration and transfer
4. Use public procurement as a lever
5. Develop and expand funding instruments as needed
6. Drive growth and impact through optimized financing offers
7. Expand research on social innovations and social enterprises
8. Promote skills development for social innovations and socially responsible business activities
9. Establish focus on impact and impact measurement as the standard
10. Increase visibility and recognition
11. Seek European and international solidarity

Develop Standardized Indicators and Data Basis

To investigate the dissemination and success factors of social innovations and social enterprises, research is dependent on standardized, representative and high-quality data on social innovations and social enterprises. The results of research based on this data enable policymakers to develop and implement specific evidence-based support measures. In addition, structured data on social innovations and social enterprises, for example as a collection of successful solutions to societal problems, can help to promote the visibility and dissemination of such innovations. The Commission of Experts therefore supports the development of a cross-ministerial set of indicators⁴¹⁸ and a meaningful scientific database as envisaged in the National Strategy for Social Innovations and Social Enterprises.⁴¹⁹ The Commission of Experts additionally recommends the following:

- Alongside the development of new indicators and the collection of new data on social innovations and social enterprises, the existing indicators and databases must be integrated into an overall concept in the best conceivable way.
- When developing indicators and collecting data on social innovation and social enterprises, care must be taken that appropriate performance measurement and impact analyses of policy measures promoting social innovation and social enterprises are made possible.
- The Federal Government should work towards developing an internationally standardized set of indicators,⁴²⁰ coordinated data collection and an international data space that enables comparability across geographical units.

- The Federal Government should support the increased inclusion of social innovation activities in existing household and business surveys.⁴²¹ The aim must be to establish a nationwide, representative database that is consistent over a longer period of time. In the case of household surveys, the German Socio-Economic Panel and the microcensus are particularly suitable. In the case of business surveys, the Mannheim Innovation Panel, the KfW Start-up Monitor and the DSEM are to be mentioned.

Open Existing Funding Formats for Social Innovations

One justification for R&I policy support for social innovations arises from the existing positive external effects, which can result in social innovations not being made available to the societally optimal extent. When it comes to funding, it should be noted that many social innovation initiatives and social enterprises are created and are active in local or regional contexts. Also relevant for funding is the fact that social innovations are often complementary to technological innovations. With this in mind, the Commission of Experts recommends:

- The funding of innovations should be focussed on objectives and not on specific instruments or measures. Accordingly, the promotion of social innovations does not primarily require new programmes that are exclusively reserved for social innovations. Rather, support for social innovations should be integrated into existing support programmes, as is already the case with the structural support programmes WIR! and TI-Räume, for example. This integration would also allow potential complementarities between technological and social innovations to be taken into account.
- The complementarities of social and technological innovations should also be promoted by giving social innovators and social enterprises access to regulatory sandboxes, as already envisaged by the Federal Government in its strategy.

- Existing support programmes should be supplemented by specific advisory services such as legal entity advice for social enterprises and region-specific advice.

Promote the Generalization of Social Innovations

The generalization of social innovations largely takes place via social relationships and networks. The Commission of Experts therefore supports the establishment of a platform for social innovations, as envisaged in the National Strategy for Social Innovations and Social Enterprises, in order to strengthen the dissemination of social innovations and increase the transparency of funding and support programmes. In addition, the Commission of Experts recommends:

- A trade fair, for example as a ‘Social Innovations Expo’, should be supported in order to present successful solutions, promote networking and thereby encourage generalization. This could include the presentation of experience reports and roadmaps covering the entire innovation process to allow other initiatives to learn from them.⁴²²

Rapidly Improve Financing Options for Social Enterprises

Social enterprises are not very attractive for profit-oriented investors, as the purpose to make a profit usually only plays a subordinate role. This can result in underfinancing. At the same time, the participation of investors with voting rights can sometimes be an unattractive option for social enterprises, as it can dilute the prioritization of social objectives (mission drift). The Commission of Experts therefore supports the promotion of alternative forms of financing provided for in the National Strategy for Social Innovations and Social Enterprises and recommends the following:

- The measures planned by the Federal Government to promote alternative forms of financing should be implemented swiftly in order to meet the specific needs of social enterprises.

B 4 Artificial Intelligence



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B 4 Artificial Intelligence

As a key enabling technology, artificial intelligence (AI) is characterized by highly dynamic development, has a broad range of applications such as in the automotive industry, financial services and medicine, and opens up a wide range of innovation and growth potential for user companies and industries.⁴²³ AI therefore has enormous transformative potential that can lead to fundamental structural change in the economy and society. Due to these characteristics, AI is often compared to key enabling technologies such as the steam engine, electricity and the internet. In particular, generative AI, which makes it possible to generate texts, images and programme codes, for example, from so-called foundation models, is considered to have great potential for innovation.

The Commission of Experts has already addressed the topic of AI in previous annual reports and discussed the extent to which Germany can keep pace internationally in AI development. This question arises again in light of the rapid developments in the field of generative AI: new players are producing successful innovations, established players are adapting their strategies and questions of political support and regulation are being discussed on a wider political level.

Research and development (R&D) in the field of AI requires extensive data and computing capacities. Basic research is carried out both in research institutions and in businesses. The USA and China dominate in the field of AI, while Germany and the other countries of the European Union (EU 27) are falling behind in international comparison and run the risk of becoming technologically dependent when it comes to AI and thus no longer being able to actively shape technological development. Germany

and Europe are therefore called upon to take measures to strengthen their technological sovereignty. This is also an important prerequisite for upholding European values such as non-discrimination, privacy and data protection in the development and use of AI.

To exploit the innovation and growth potential of AI, it needs to be used across the economy, i. e. in businesses of different sectors and sizes. Although many companies in Germany are planning to use AI, uncertainties and concerns regarding the maturity and reliability of AI still prevail.

To support an AI ecosystem, the Federal Government should continue to promote AI research and contribute to the development and expansion of the AI infrastructure in the form of data, computing capacity, venture capital and expertise. The AI Act should be adapted over time based on the knowledge and experience gained in regulatory practice in dialogue with actors from other economic and value areas. In doing so, a balance must be struck between legal certainty on the one hand and the creation and utilization of innovation potential on the other.

B 4-1 Dynamics of Technological Development

In recent years, science and industry have stepped up R&D activities in the field of AI overall. Favoured by the increasing availability of data and computing capacity, R&D activities have expanded enormously, particularly in the field of generative AI (cf. box B 4-1). This is reflected in an increase in the number of AI publications published in scientific

publications⁴²⁴ and an increase in applications for transnational AI patents.⁴²⁵

Figures B 4-2 and B 4-3 use index analyses to show how the volume of AI-related scientific publications and the number of transnational patent applications have developed worldwide, both for AI as a whole and for generative AI. Transnational patent applications are patent applications filed with the European Patent Office or the World Intellectual Property Organization.⁴²⁶ As no transnational patents were filed in the field of generative AI before 2013, the indices refer to the year 2013 and the patent figures for this base year are set to 100. The same procedure was followed for scientific publications and their number in 2013 is set equal to 100. The period under review

begins in 2010. The current margin is 2022 for publications and 2020 for transnational patent applications.

The index value for AI publications was 78 in 2010 and rose eightfold to 630 by 2022. In the field of generative AI, the index value for publications was 80 in 2010 and increased by a factor of 52 to 4,130 by 2022.

The index value for transnational AI patents rose from 50 in 2010 to 820 in 2020 – a sixteen-fold increase. While there were no applications for transnational patents in the field of generative AI in 2010, the index value amounted to 4,420 in 2020.

Box B 4-1 Artificial Intelligence Terminology

Artificial intelligence

The term artificial intelligence is used to describe processes, algorithms and technological solutions that make it possible to transfer complex tasks previously carried out by humans to learning machines and software.⁴²⁷

Generative AI

Generative AI is a form of AI that is used to generate or edit content such as text as well as images, video, audio and computer code. This can be unimodal (e.g. text to text) or multimodal (e.g. text to image or image to text).

Machine learning

Machine learning (ML) aims to use learning algorithms and data to train complex models, which are then applied to new, potentially unknown data of the same type.⁴²⁸

Foundation model

Researchers at Stanford University coined the term foundation model for AI models that have been trained on a broad pool of data and can form the basis for the development of a variety of specific applications.⁴²⁹ In German-speaking countries, such models are also known as *Grundlagenmodelle*.

Large language models and multimodal models

Large language models (LLM) are models that process and generate natural language. For example, they can compose and translate texts and answer questions. Multimodal models process and generate multiple modalities such as speech, audio and images. Large language models and multimodal models are forms of foundation models.

Parameters

Parameters are numerical values that are learnt by machine learning models during training.⁴³⁰ The Luminous language model by Aleph Alpha,⁴³¹ for example, comprises between 13 and 70 billion parameters, depending on the variant.⁴³² The GPT-4 language model by OpenAI is said to comprise around 1.8 trillion parameters.⁴³³

Edge AI

With Edge AI, data is analyzed where it is generated rather than in the cloud.⁴³⁴

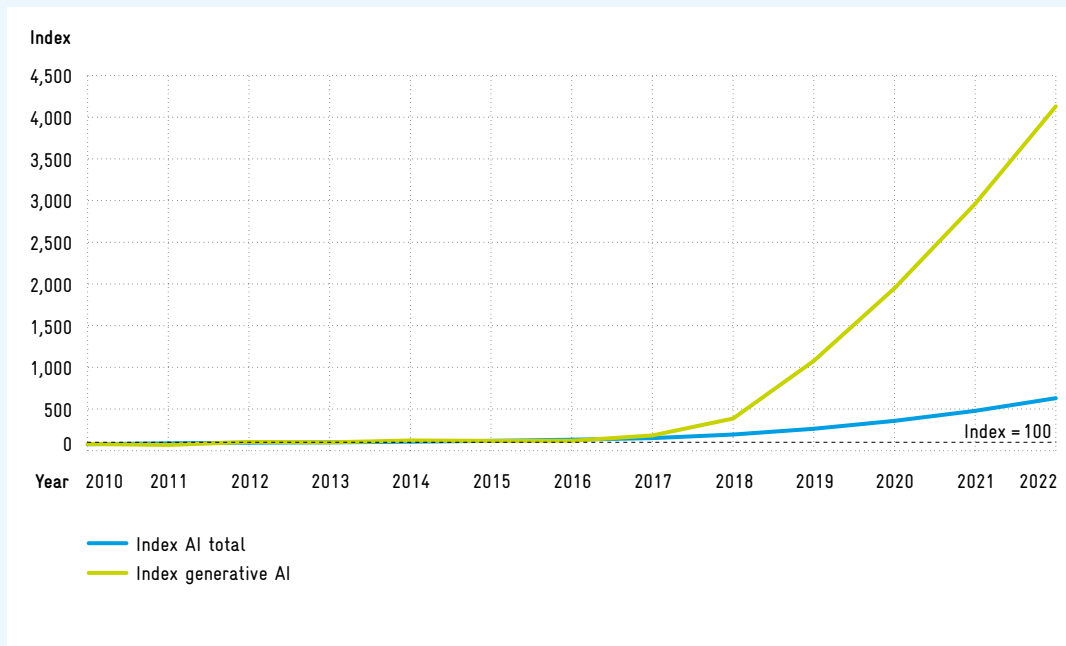
Federated learning

Federated learning is an ML process in which several units work together without directly exchanging data. A central server coordinates them.⁴³⁵

Fig. B4-2 Scientific publications in the field of AI worldwide 2010–2022 as index values



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Index: 2013=100.

Legend: In 2020, 3.6 times as many scientific publications were published worldwide in the field of AI as in 2013; in the field of generative AI, 19.5 times as many scientific publications were published in that year as in 2013.

Source: Clarivate Web of Science Database (used database editions: SCIE, SSCI, AHCI, CPCI) in XML format, 2010–2022.

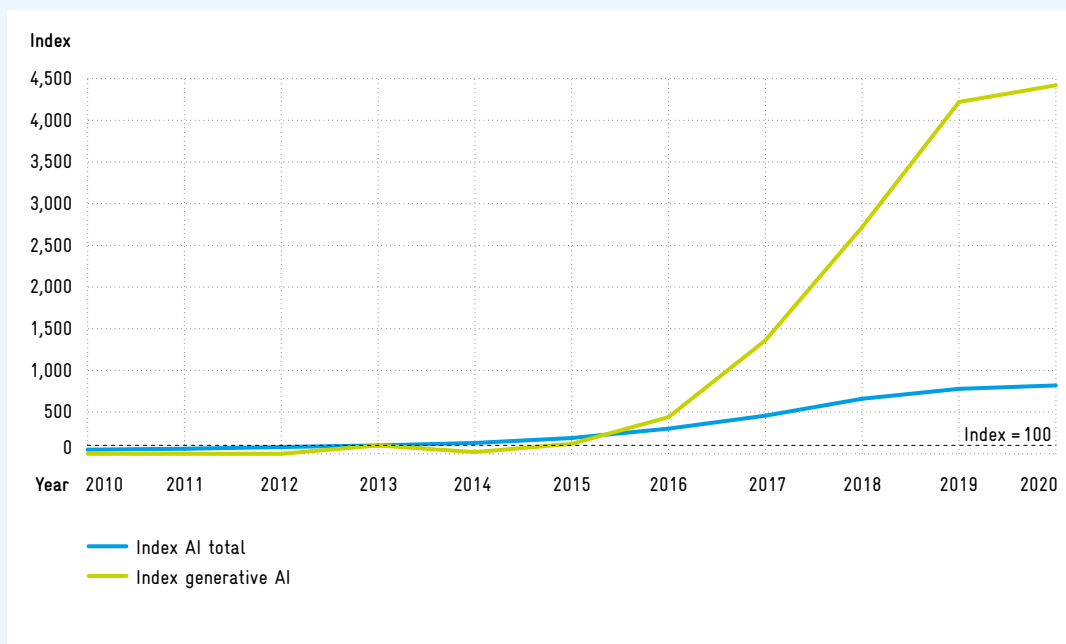
Own calculations within the context of the Competence Network for Bibliometrics (KB).

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Fig. B4-3 Transnational patent applications in the field of AI worldwide 2010–2020 as index values



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For the year 2020, an underreporting of patent applications cannot be ruled out, as it is possible that at the time of data collection in October 2023, it is possible that not all relevant patent applications from 2020 had already been published.

Index: 2013=100.

Legend: In 2020, 8.2 times as many patents were filed worldwide in the field of AI as in 2013; in the field of generative AI, 44.2 times as many patents were filed in that year as in 2013.

Source: PATSTAT. Own calculations.

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B 4-2 Positioning of Germany and the EU in AI

The positioning of Germany and the EU in AI can be illustrated using publication and patent data. In the field of generative AI, it is also useful to look at data on machine learning models (ML models).

AI Publications: Germany and EU Far Behind China

In 2022, 147,700 AI-related scientific publications appeared worldwide, of which China accounted for 36.4 percent (cf. figure B 4-4).⁴³⁶ Following far behind were the USA with 11.6 percent, India with 6.3 percent, South Korea with 3.5 percent and the UK with 3.4 percent. Germany only accounted for 2.7 percent of AI publications. The EU 27 together achieved a share of 14.5 percent.

While China was able to increase its share by 22.9 percentage points between 2010 and 2022, the USA's share fell by 5.3 percentage points. Germany recorded a decline of 1.4 percentage points. The share of the EU 27, which was still higher than China's in 2010, fell significantly by 11.8 percentage points between 2010 and 2022.⁴³⁷

In the field of generative AI, authors from Chinese organizations accounted for 40.3 percent of the scientific publications published in the period 2017 to 2022 (cf. figure B 4-5). The USA followed with a share of 14.4 percent. This means that more than half of the publications in this field came from China and the USA. Germany's share, as with AI publications overall, was only 2.7 percent. Authors from organizations from the EU 27 wrote 11.8 percent of the publications.

Most AI-related scientific publications can be traced back to authors working at tertiary education institutions.⁴³⁸ However, there are also areas within AI where companies are researching and publishing very intensively and which are closely linked to generative AI models. For example, Microsoft, Google, the Alibaba Group and Amazon were among the ten organizations that published the most papers in scientific journals in the field of natural language processing in 2021.⁴³⁹ In the field of speech recognition, Microsoft, Google, Tencent and Amazon were among the top ten publishing organizations.⁴⁴⁰ Neither German businesses nor companies from the EU

were among the ten organizations with the most scientific publications in either field.

AI Patent Applications: German and EU Shares Declining

The data on transnational AI patents filed in 2020 shows that the majority of inventors were based in China and the USA, with shares of 28.5 and 26.6 percent respectively (cf. figure B 4-6).⁴⁴¹ Germany had a share of 6.5 percent. At 16.2 percent, the share of the EU 27 was below that of China and the USA.

Between 2010 and 2020, China's share rose by 25 percentage points, while the USA's share fell by 6.7 percentage points. Germany's share fell by 4.1 percentage points. The share of the EU 27 also declined, falling by 9 percentage points in the period under review.⁴⁴²

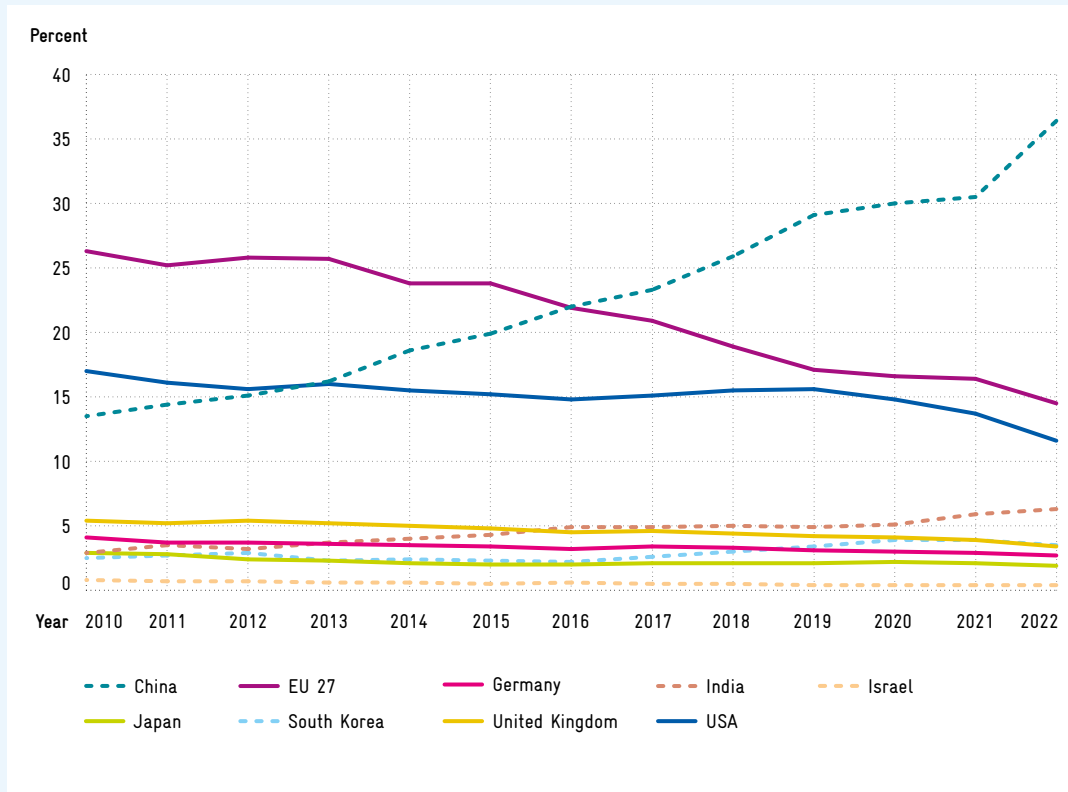
In the field of generative AI, the USA led the field with 32.9 percent of all transnational patents filed worldwide between 2017 and 2020, followed by China with 24.5 percent of applications (cf. figure B 4-7). Germany accounted for 6.1 percent and the EU 27 for a total of 15.3 percent of transnational patents filed in the field of generative AI.

As in other fields of technology, the majority of patents in AI are filed by companies. The 20 organizations that filed the most transnational AI patents between 2010 and 2020 include five Japanese and five US companies, four Chinese companies, two German and two South Korean companies and one Finnish and one Dutch company (cf. figure B 4-8). The two German companies are Siemens and Bosch.

With a comparatively small number of patents, the picture in the field of generative AI is similar to that of AI as a whole (cf. figure B 4-9). Seven US companies, four Chinese companies and one Chinese research institution, two German and two Japanese companies as well as one South Korean, one Dutch, one Swedish and one Finnish company are among the 20 organizations that filed the most transnational patents in this field between 2010 and 2020. The two German companies are again Siemens and Bosch, which are also among the top organizations for AI patents overall.

Fig. B4-4 Percentage of selected countries in scientific publications in the field of AI 2010–2022

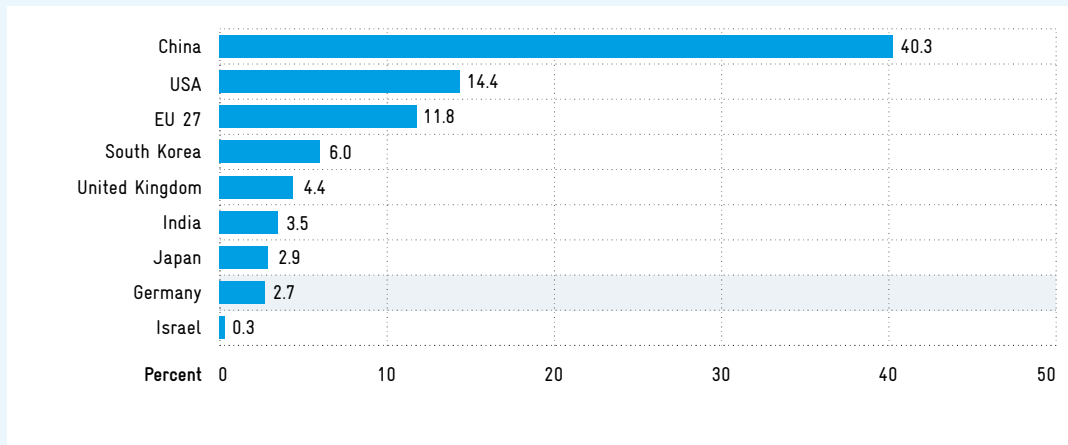
 [Download Data](#)



Legend: China's share of scientific publications in the field of AI increased from 13.5 percent in 2010 to 36.4 percent in 2022.
Source: Clarivate Web of Science Database (used database editions: SCIE, SSCI, AHCI, CPCI) in XML format, 2010–2022.
Own calculations within the context of the Competence Network for Bibliometrics (KB). Fractional counting.
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Fig. B4-5 Percentage of selected countries in scientific publications in the field of generative AI 2017–2022

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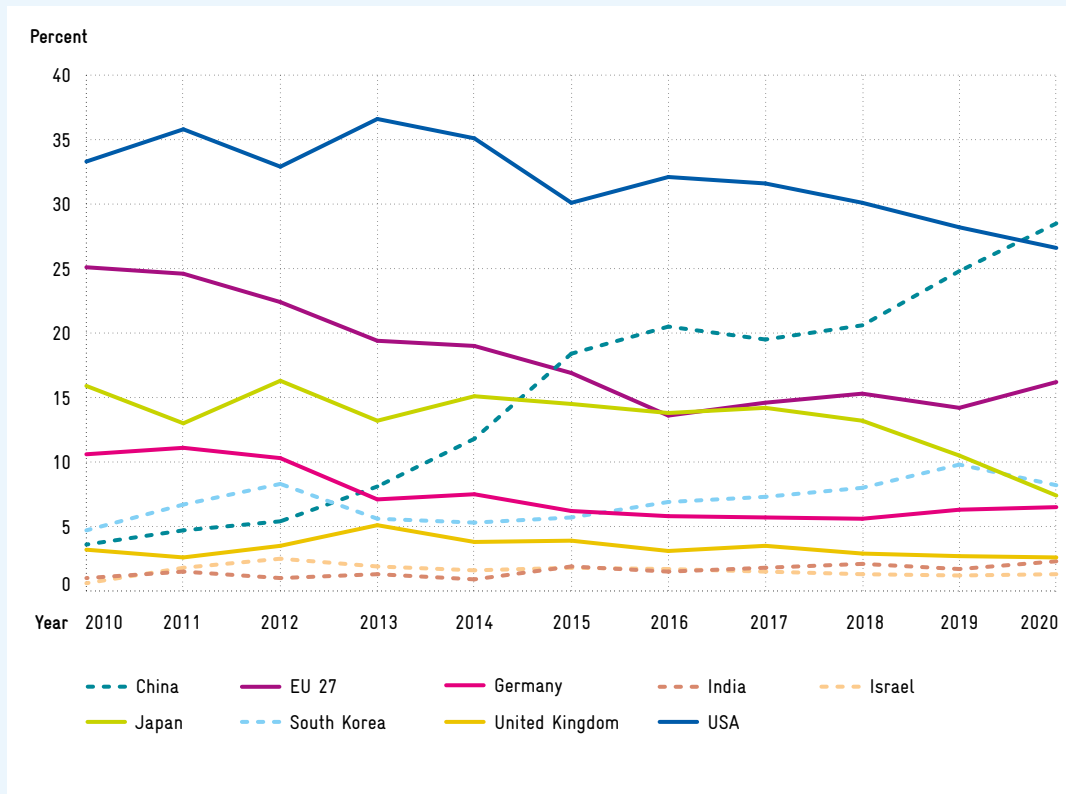


Legend: In the period from 2017 to 2022, India's share of scientific publications in the field of generative AI was 3.5 percent.
Source: Clarivate Web of Science Database (used database editions: SCIE, SSCI, AHCI, CPCI) in XML format, 2017–2022.
Own calculations within the context of the Competence Network for Bibliometrics (KB). Fractional counting.
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Fig. B4-6 Percentage of selected countries in transnational patent applications in the field of AI 2010–2020



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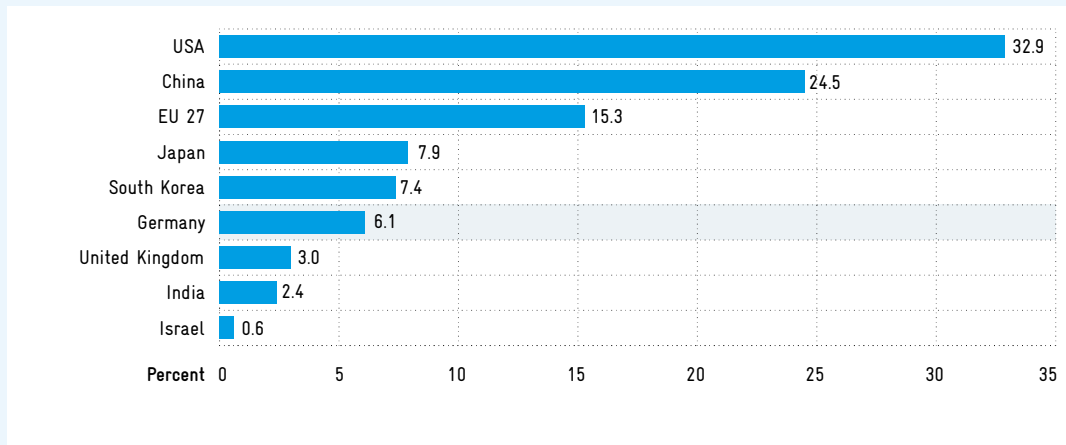


Legend: In 2019, the USA accounted for 28.2 percent of transnational patent applications in the field of AI.
Source: PATSTAT. Own calculations. Fractional counting.
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Fig. B4-7 Percentage of selected countries in transnational patent applications in the field of generative AI 2017–2020



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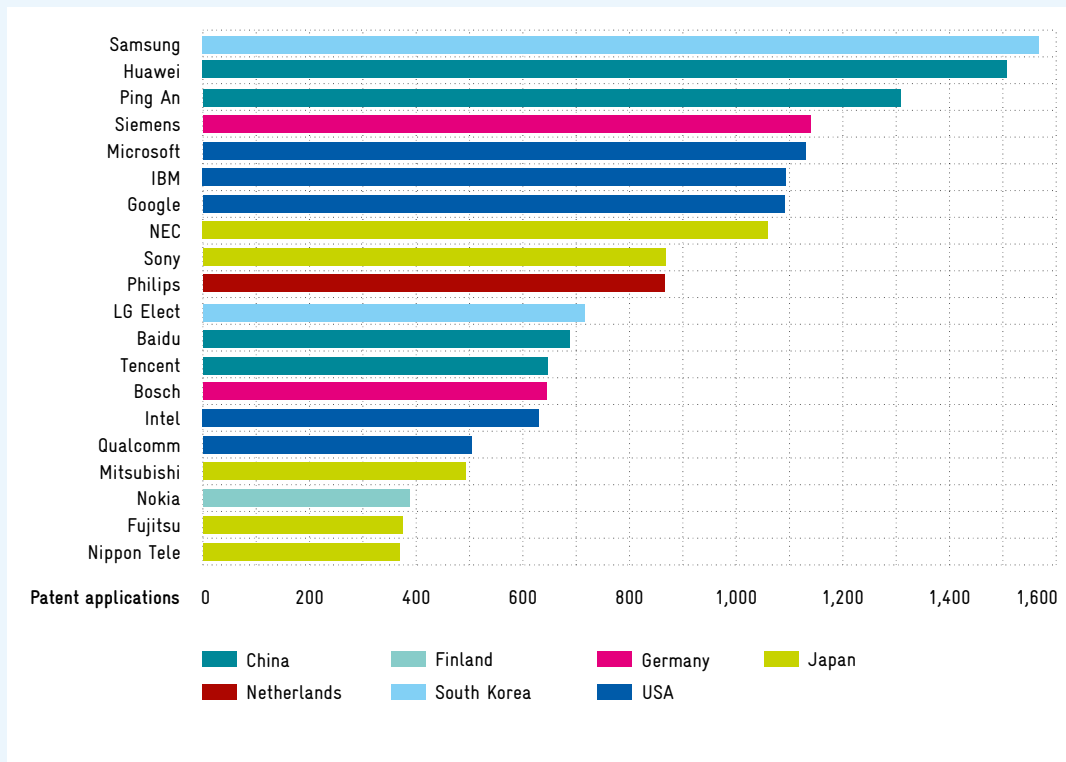


Legend: The EU 27 accounted for 15.3 percent of transnational patent applications in the field of AI between 2017 and 2020.
Source: PATSTAT. Own calculations. Fractional counting.
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Fig. B4-8 Transnational patent applications in the field of AI by filing organisations and their headquarters 2010–2020



[Download Data](#)



Legend: The Chinese company Huawei registered 1,508 AI patents in the period under review.
Source: PATSTAT. Own calculations. Fractional counting.
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AI Models: Germany and EU Only at the Beginning

Not all innovations and further developments in the field of AI are documented in publications or patents. For example, there are no scientific publications or patents on the model architecture of GPT-4, OpenAI’s large language model. To assess the international competitive situation, particularly in the field of generative AI, it is therefore useful to consider not only publications and transnational patents but also development leaps in the field of ML models (cf. box B4-1).

Based on data from Epoch AI, the Artificial Intelligence Index Report 2023 of the Stanford Institute for Human-Centered Artificial Intelligence (HAI) recorded the publication of 38 particularly significant ML models in 2022, 32 of which came from the business sector.⁴⁴³ Until 2014, the scientific sector still accounted for the largest share of ML models. Over time, the size, training effort and thus the

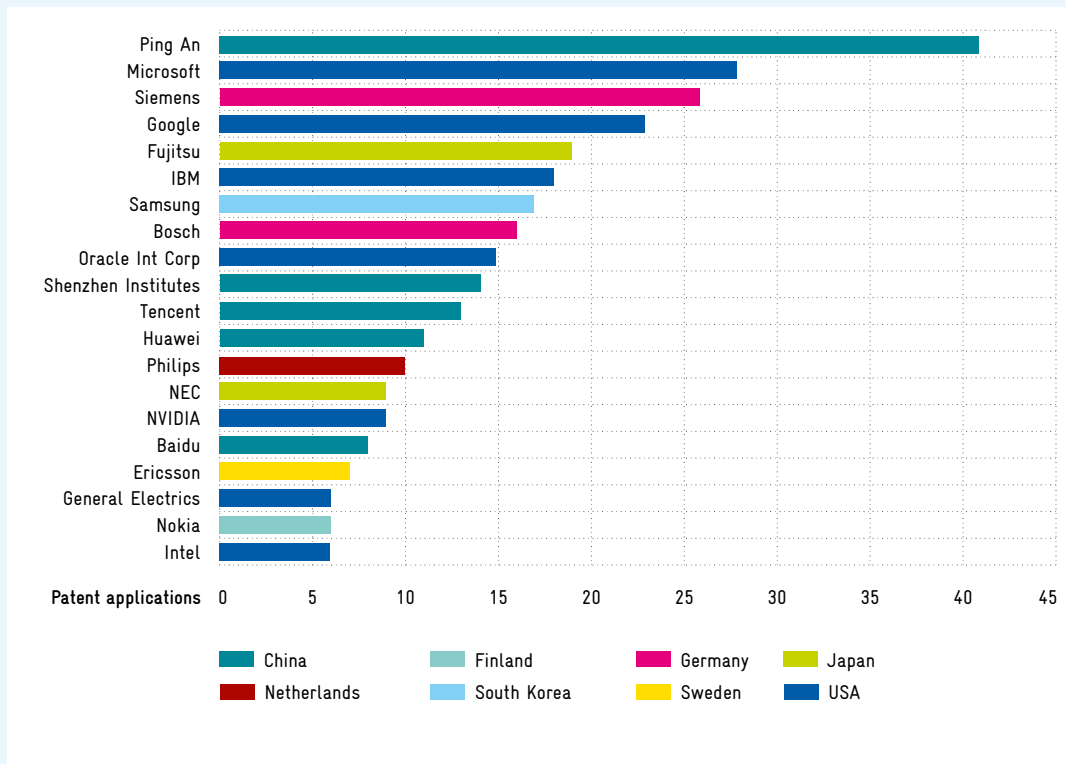
costs of such ML models have steadily increased⁴⁴⁴ and now amount to tens of millions of US\$.⁴⁴⁵ Tertiary education institutions and publicly funded non-university research institutions can reach their budget limits more quickly than large IT companies when developing such models. Start-ups too often lack the necessary financial resources for this.

Among the major ML models, large language models and multimodal models are gaining in relevance, as they are foundation models that can be adapted to a variety of subsequent tasks. The number of countries involved in the development of such models has increased over time. According to the Artificial Intelligence Index Report 2023, all major language models and multimodal models were developed in the USA in 2019.⁴⁴⁶ Of the major language models and multimodal models published in 2022, just over half still originated from the USA (54.2 percent). The UK (21.9 percent), China (8.0 percent), Canada (6.3 percent), Israel (5.8 percent), Germany (3.1 percent) and India (0.9 percent) were also involved

Fig. B 4-9 Transnational patent applications in the field of generative AI by filing organisations and their headquarters 2010–2020



[Download Data](#)



Legend: The US company Microsoft registered 28 patents in the field of generative AI during the period under review.
Source: PATSTAT. Own calculations. Fractional counting.
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in the development of large language models and multimodal models. Canada, Germany and India contributed to large-scale language and multimodal models for the first time in 2022 with Stable Diffusion, GPT-NeoX-20B and Imagen.⁴⁴⁷ In 2023, that is, outside the observation period of the Artificial Intelligence Index Report 2023, further countries followed suit. For example, the Technology Innovation Institute in the United Arab Emirates published Falcon 40B and Falcon 180B and the French start-up Mistral AI published Mistral 7b v0.1 as large language models.⁴⁴⁸

B 4-3 AI Utilization a Driver of Innovation and Growth

To exploit the innovation and growth potential of a new technology, this technology must be used across the economy. In contrast to key enabling technologies such as the steam engine and electricity, the spread of information and communication technologies has not yet led to major productivity boosts. There are

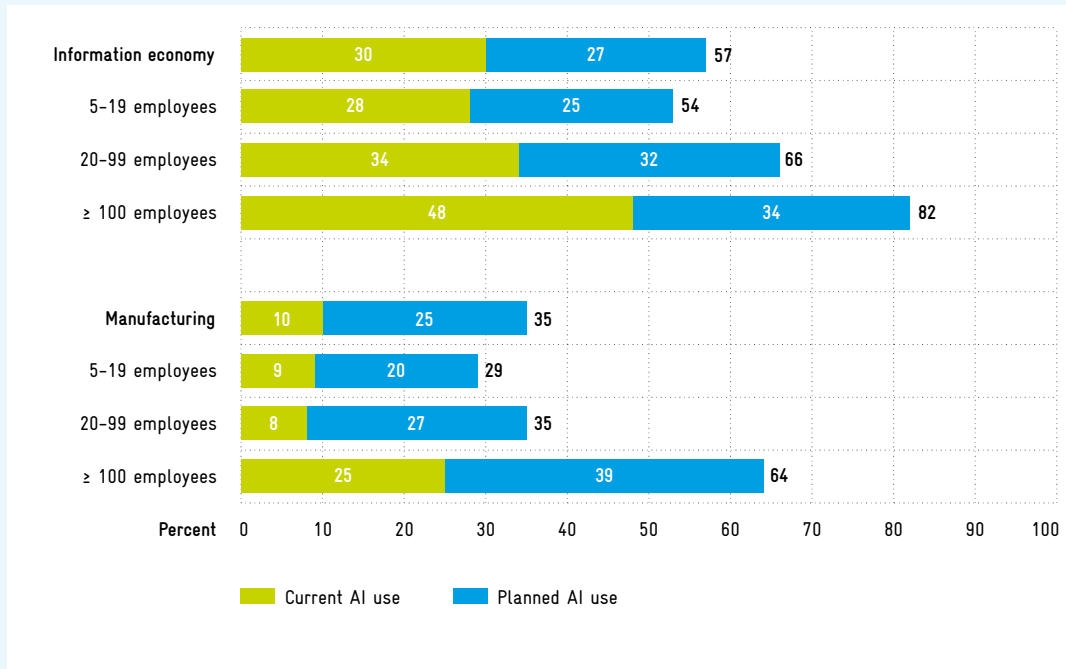
various explanations for this so-called productivity puzzle.⁴⁴⁹ The time factor plays an important role here. It can be assumed that the diffusion of a key enabling technology such as artificial intelligence will take a long time and only arrive unevenly in the various sectors.⁴⁵⁰ There are activities, particularly of a physical nature, that cannot be supported or replaced by AI. In addition, application-specific innovations and complementary investments, for example in interface technologies, work organization and human capital, are required in order to exploit the productivity potential of AI.⁴⁵¹ Econometric analyses for Germany show that companies that use AI are both more innovative and more productive, although this does not yet prove a causal effect of AI.⁴⁵²

A representative survey conducted on behalf of the Commission of Experts shows that in 2023, 10 percent of companies in the manufacturing sector and 30 percent of companies in the information economy in Germany have used AI (cf. figure B 4-10). However, these results do not allow any conclusions to be drawn about the degree of AI utilization in

Fig. B 4-10 Percentage of AI use in companies in Germany by company size in 2023



[Download Data](#)



The companies were asked about the use of AI in at least one of the following areas: "As part of own products/services", "In the improvement/development of new products/services", "In the improvement/development of new processes", "In other areas/for other purposes". Deviations in the total are possible due to rounding.
 Legend: In the information economy, 30 percent of companies stated that they use AI in at least one of the areas surveyed. In addition, 27 percent of companies in the information economy planned to use AI in the future.
 Source: ZEW Konjunkturumfrage Informationswirtschaft Q3 2023.
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companies.⁴⁵³ A further 27 percent of companies in the information economy and 25 percent of companies in the manufacturing sector planned to use AI in the future. The percentage of companies using or planning to use AI increases with the size of the company.⁴⁵⁴

The main barriers to the utilization of AI in both the information economy and the manufacturing sector were a lack of time or manpower (68 and 72 percent), uncertainty about the expected benefits (64 and 68 percent), concerns about the maturity or reliability of AI (60 and 56 percent) and a lack of knowledge and expertise within the company (53 and 60 percent) (cf. figure B 4-11). Companies in the manufacturing sector cited a lack of skilled labour being a barrier to the utilization of AI significantly more often than companies in the information economy (59 versus 50 percent).

Only 15 percent of companies in the information economy and 6 percent of companies in the manu-

facturing sector rated the international competitiveness of their own company in the field of AI as high or very high (cf. figure B 4-12). They were slightly more likely to attribute a very high or high level of competitiveness in the field of AI to companies in their own sector (around 21 and 7 percent) and to companies in Germany as a whole (around 24 and 25 percent).

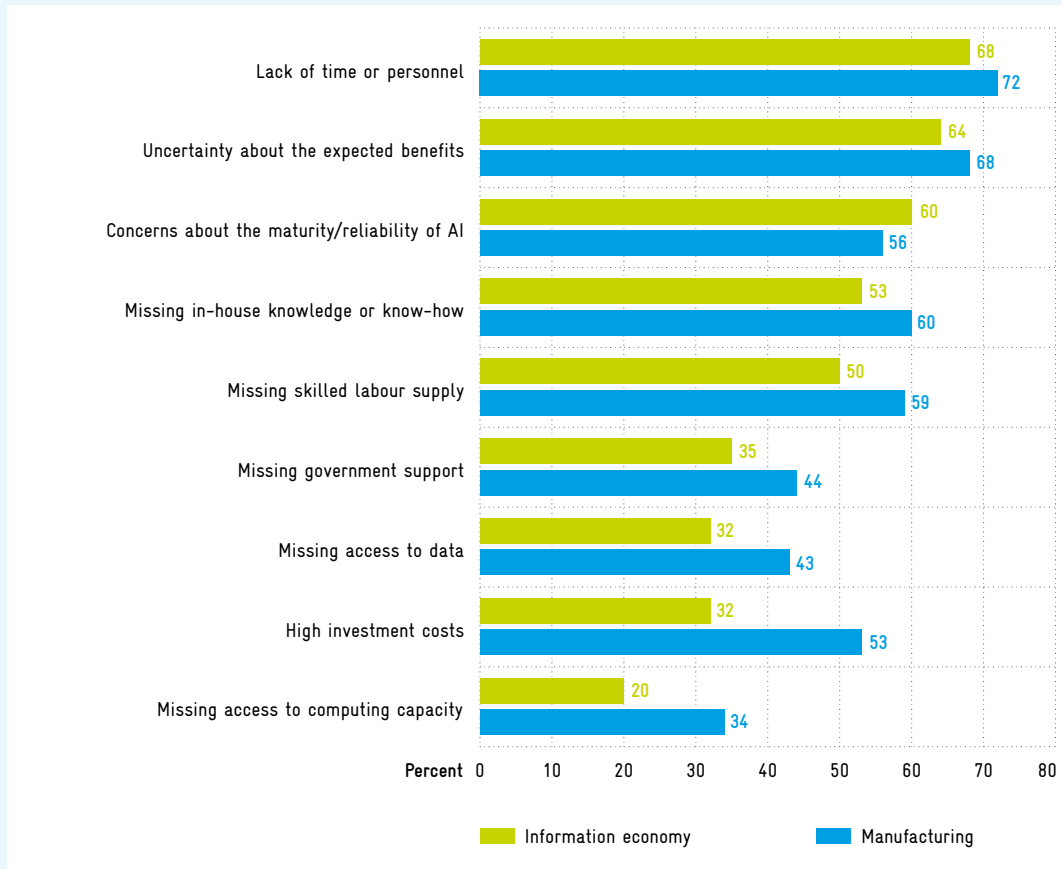
Another result of the survey is that 32 percent of companies in the information economy and 26 percent of companies in the manufacturing sector expected the increasing spread of AI to lead to increasing dependence on non-European AI providers.

The Commission of Experts states that a relatively large number of companies are currently planning to use AI. However, as the barriers to AI utilization identified by the companies show, concerns and uncertainty prevail. There is also a lack of AI expertise in companies.

Fig. B 4-11 Barriers to the use of AI in companies in Germany in 2023 in percent



[Download Data](#)



Legend: 68 percent of companies in the information economy stated that a lack of time or personnel capacity made the use of AI more difficult.

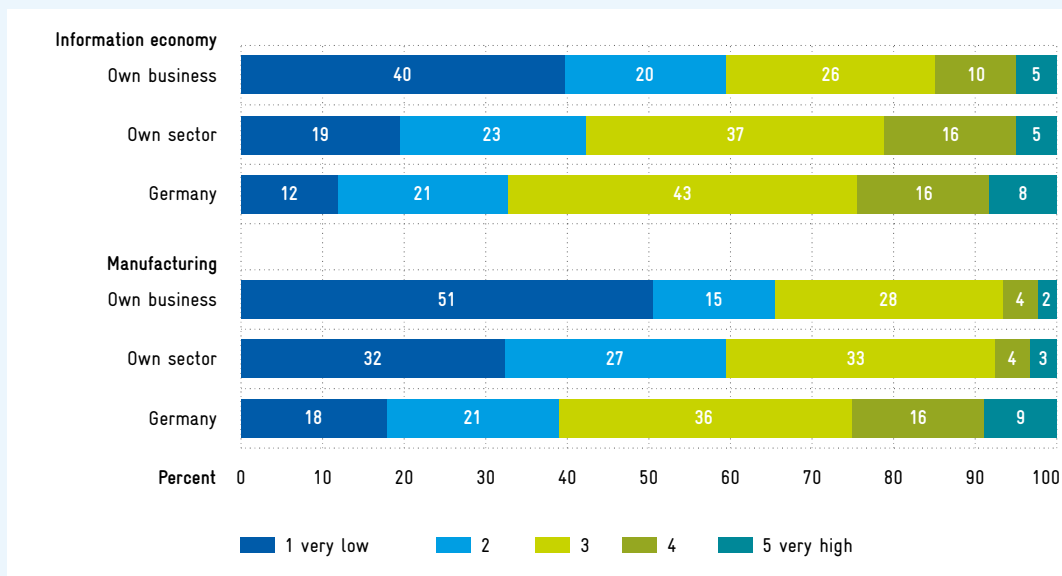
Source: ZEW Konjunkturumfrage Informationswirtschaft Q3 2023.

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Fig. B 4-12 Assessment of international competitiveness in the field of AI in 2023 in percent



[Download Data](#)



Deviations in the total are possible due to rounding.

Legend: 5 percent of companies in the information economy rated the international competitiveness of their own business in the field of AI as very high.

Source: ZEW Konjunkturumfrage Informationswirtschaft Q3 2023.

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B 4-4 Technological Sovereignty and European Values

AI is a key enabling technology that will have a decisive impact on technological and economic development in the coming years.⁴⁵⁵ AI is characterized by its breadth of application in a variety of technologies and industries, very often without an equivalent technological alternative. The high level of dynamism in R&D in the field of AI underlines the fact that there is still enormous potential for performance improvements in AI itself as well as in its areas of application, some of which are new.

As a key enabling technology, AI is highly relevant for future innovation and growth potential in Germany and Europe, as well as for the opportunities to actively shape economic and social transformation processes and thus contribute to solving grand societal challenges.⁴⁵⁶ To leverage this potential, Germany and Europe must demonstrate a high degree of technological sovereignty.

Technological sovereignty in the field of AI presupposes that Germany and Europe can maintain and further develop AI technologies themselves and participate in their standardization or have the ability to obtain and use these technologies without being unilaterally dependent on other economic areas. Mastering the technology is therefore an essential prerequisite for technological sovereignty, which requires corresponding competences in dealing with AI.⁴⁵⁷

The Commission of Experts is concerned that Germany and the EU 27 continue to fall behind in international comparison, both in the publication of scientific AI papers and in the registration of AI patents. Germany and Europe are also not international leaders in the development of significant ML models. Overall, there is a risk of losing technological sovereignty.⁴⁵⁸

AI applications can be associated with risks. For example, targeted misinformation can influence voting decisions or training data can reproduce prejudices that lead to discriminatory decisions. In developing and using AI, the European Union (EU) pursues a people-centred approach, the protection of EU values and fundamental rights such as non-discrimination, privacy and data protection as well as the sustainable and efficient use of resources.⁴⁵⁹ Technological sovereignty is therefore

also a prerequisite for developing AI models in one's own cultural context and thus ensuring that they are in line with European values.

B 4-5 Open-Source Models

Foundation models are very important for the development of AI applications. This means that developers of applications that are based on foundation models must either have their own foundation models or have access to the foundation models of others. If this is not the case in Germany and Europe, technological sovereignty is not guaranteed.

The development of AI foundation models such as the large language models requires a powerful computing infrastructure, which currently is mainly available via the large cloud providers. The related offerings are limited in Germany and Europe. It is therefore to be expected that, due to the ongoing scaling of foundation models, actors in science and industry will increasingly rely on non-European cloud providers, thereby reinforcing the gatekeeper role of these companies.⁴⁶⁰

The technological sovereignty of Germany and Europe can be weakened if there is a market concentration of non-European providers through vertical company integration⁴⁶¹ in the case of foundation models and applications based on them. In addition, European values may be jeopardized if foundation models lead to distorted results in applications that are based on these models and this cannot be remedied.

Open source is seen as very important for boosting technological sovereignty and for an AI that is in line with European values.⁴⁶² Foundation models can be available as closed- or open-source models. Unlike closed-source models, open-source models disclose the codes, training data and model architecture, with varying degrees of openness.⁴⁶³ Some foundation models from commercial providers also have a high degree of openness.⁴⁶⁴ However, in some cases, the transition to new versions involves a change from open- to closed-source models.⁴⁶⁵ For example, OpenAI published its GPT-2 XL foundation model as an open-source model, but GPT-3 and subsequent versions as closed-source models.⁴⁶⁶

Commercial enterprises are incentivized to develop foundation models if this results in opportunities to

generate revenue. This is the case if the companies enable external users, for example in connection with cloud services, to develop applications based on the foundation models for a fee. Revenue opportunities can also arise with open-source foundation models if, based on self-developed open-source models, proprietary AI applications are offered that are either subject to a fee or generate advertising revenue. Companies additionally benefit from the fact that external parties can participate in improving the model. It is not yet possible to predict how the market for foundation models and AI applications will develop.

Open-source models can intensify competition and offer more opportunities for innovation than closed-source models, as they are generally more adaptable.⁴⁶⁷ In addition, actors from science and industry, especially start-ups and SMEs, can benefit from the relatively low costs of open-source utilization and use existing open-source models to innovate on a domain-specific basis and increase productivity.⁴⁶⁸ This increases competition and the diversity of offerings and thus prevents monopolization tendencies. In addition, open-source models have the advantage that programming errors or potential distortions that arise when analyzing data can be identified and rectified more quickly. This is conducive to the transparency and reliability of AI models.⁴⁶⁹

Due to the aforementioned advantages, the (collaborative) development of large-scale open-source models in Germany and Europe can contribute to increasing technological sovereignty and to the utilization of AI in line with European values. Building on open-source models, German and European science and industry can secure access to AI without having to rely on the few large non-European providers. In addition, in-house AI capabilities can be further developed, which is essential for mastering a technology. This can make a significant contribution to catching up in the technological competition.⁴⁷⁰

The creation of foundation models is associated with high costs, particularly for computing capacity and training data (cf. section B 4-6). These costs are too high to be borne by an open-source developer community alone. It is also necessary to provide the required security architecture. Both factors represent a challenge for the development of foundation models based on open source, which are not initi-

ated and provided by large companies but by developer communities. Political support could help to incentivize the development of foundation models based on open source.

B 4-6 AI Innovation Ecosystem in Germany

To prevent falling further behind in the development and application of AI, Germany and Europe need to catch up in terms of scope as well as drive forward specializations and achieve technological leadership in these areas. Generative AI in particular, as a very young variant of AI, is still in the early stages of its technology life cycle. With the development of a powerful AI ecosystem, Germany and the EU still have opportunities to play a leading role in international technology development with innovations in both generative AI and AI applications. However, large AI companies, such as those in the USA and China, are not available. Germany and Europe therefore need strong AI innovation ecosystems.⁴⁷¹ An AI ecosystem comprises a large number of components. These include a science system with a network across Europe, AI expertise, an efficient AI infrastructure and venture capital.

AI Research Broadly Positioned in the Science System

AI research is conducted at many German tertiary education institutions and non-university research institutions. The AI map of Plattform Lernende Systeme, Germany's platform for artificial intelligence, lists 153 higher education institutions and 82 non-university research institutions that conduct research on AI topics.⁴⁷²

The Federal Government is funding the German Research Center for Artificial Intelligence (DFKI) as well as five Centres of Excellence for AI Research based at tertiary education institutions, namely the Berlin Institute for the Foundations of Learning and Data (BIFOLD), the Munich Center for Machine Learning (MCML), the LAMARR Institute for Machine Learning and Artificial Intelligence (formerly Kompetenzzentrum Maschinelles Lernen Rhein-Ruhr – ML2R), the Center for Scalable Data Analytics and Artificial Intelligence (ScaDS.AI) and the Tübingen AI Center.⁴⁷³ These latter five Centres of Excellence for AI Research are amalgamations of tertiary education institutions and non-university

Box B4-13 Examples of German and European Initiatives in the Field of Open Source

Silicon Economy (Fraunhofer-Institute for Material Flow and Logistics)

Silicon Economy is a digital ecosystem based on open source and AI that enables the automated negotiation, scheduling and control of commodity flows and aims to create new digital business models. It promotes the integration and networking of infrastructures, including secure data rooms and cloud infrastructures. The focus is on the development of automation and autonomization services for logistics and complete supply chains.⁴⁷⁴

Sovereign Tech Fund

The Sovereign Tech Fund is dedicated to sustainably strengthening the open-source ecosystem and focuses on security, stability and technological diversity. It promotes and invests in open, free and trustworthy digital infrastructures that serve as a cornerstone for cross-sector digitalization in

order to boost digital sovereignty and increase the resilience of the open-source ecosystem.⁴⁷⁵

OpenWebSearch.EU

The EU-funded OpenWeb-Search.EU project unites 14 European research and computing centres to create an open infrastructure for web search. The aim is to reduce the dominance of large tech companies in the web search sector by promoting a free, people-centred search engine market in order to strengthen Europe's digital sovereignty and capacity for innovation.⁴⁷⁶

OpenGPT-X

OpenGPT-X is a European R&D project funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK). It aims to develop and provide an AI language model that meets the specific needs, values and data protection requirements in Europe. The technical basis for this language model is provided by the European Gaia-X infrastructure. The founding members of OpenGPT-X are companies, research institutes and media organizations.⁴⁷⁷

research institutions. The Centres of Excellence for AI Research are intended to enable scientific breakthroughs, accelerate the transfer of knowledge and technology and train AI specialists. Together they form the Network of German Centres of Excellence for AI Research.⁴⁷⁸

The European Laboratory for Learning and Intelligent Systems (ELLIS) Society was launched in 2018 as a European initiative for research excellence in the field of machine learning and artificial intelligence. ELLIS is building a network of European AI research locations with the aim of connecting cutting-edge research and creating an internationally competitive AI ecosystem. These locations are either established at existing AI research institutions by way of so-called ELLIS Units or are newly founded as ELLIS Institutes.⁴⁷⁹

Another European initiative launched in 2018 is the Confederation of Laboratories for Artificial Intelligence Research in Europe (CLAIRE).⁴⁸⁰ CLAIRE is an alliance of artificial intelligence research labora-

tories that seek to promote European excellence in AI research and innovation.⁴⁸¹

High Demand for AI Skills

The development and application of AI technologies requires qualified professionals.

AI professors are important actors in the AI ecosystem as they conduct AI research and also train professionals with AI skills. As part of the AI Strategy launched in 2018, it was announced that at least 100 additional AI professorships would be created. According to the Federal Government, 150 additional AI professorships have since been established through various BMBF measures to support the Länder,⁴⁸² of which 54 have been filled by scientists from abroad.⁴⁸³

The BMBF is currently funding 42 AI junior research groups.⁴⁸⁴ In addition, there are Zuse Schools of Excellence in AI,⁴⁸⁵ the International Future Labs for Artificial Intelligence⁴⁸⁶ and the KI-Nachwuchs@FH

funding guideline as part of the Research at Universities of Applied Sciences programme.⁴⁸⁷

The AI map of the Plattform Lernende Systeme lists 41 designated AI degree courses, of which 14 are bachelor's and 27 master's degree courses.⁴⁸⁸ There are also 103 computer science degree courses with an AI focus and 21 other degree courses with AI content.

To bring AI into widespread use, AI skills are required in many professions. The penetration rate of AI skills is an indicator created by LinkedIn that measures the prevalence of AI-related skills in a profession.⁴⁸⁹ The relative penetration rate of AI skills indicates how prevalent AI skills are in different professions in a country in comparison to the global average.⁴⁹⁰

In the period from 2015 to 2022, the relative penetration rate of AI skills in Germany was 1.72 (cf. figure B 4-14). This means that the average penetration of AI skills in Germany was 1.72 times higher than the global average. This put Germany in third place among the comparison countries.⁴⁹¹ Only in India and the USA was the relative penetration rate of AI skills higher at 3.23 and 2.23. Nonetheless, many businesses perceive a lack of skilled workers as a barrier to the utilization of AI. The survey on behalf of the Commission of Experts shows that this applies to 50 percent of companies in the in-

formation economy and 59 percent of companies in the manufacturing sector (cf. figure B 4-11).

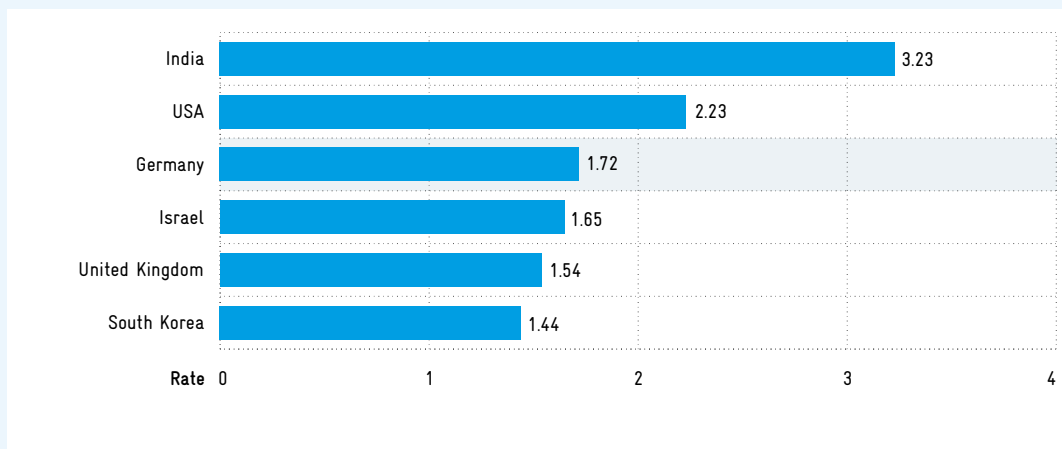
An analysis of online job advertisements in Germany reveals⁴⁹² that the number of job vacancies in the field of AI increased steadily from 2019 to 2022, from 11,056 in the first quarter of 2019 to 19,546 in the first quarter of 2022. In the first quarter of 2023, the number of job vacancies was 16,387, lower than in the previous year. This slight decline followed the overall trend in job vacancies.⁴⁹³ The largest share of open AI positions, 72 percent, were job advertisements in the fields of business intelligence and big data. Following at considerably lower percentages were the fields of consulting (20 percent), research and science (13 percent), robotics (12 percent), assisted driving (11 percent), image processing (7 percent) and speech processing (6 percent).

Data and Computing Capacity Limiting Factors

Computing capacity and data are required for the development of both foundation models and AI applications.

AI applications come with specific hardware requirements. Graphic processing units (GPUs) are particularly suitable for their calculations.⁴⁹⁴ The availability of computing capacity for training AI foundation models is currently a limiting factor.

Fig. B 4-14 Relative penetration rate of AI skills for selected countries 2015–2022



[Download Data](#)

The penetration rate of AI skills measures the prevalence of various AI-related skills in different occupations. The relative penetration rate of AI skills for a specific country indicates the sum of the penetration rates of the individual AI skills across the various occupations as a proportion of the global average in the respective same occupation.
 Legend: In the period from 2015 to 2022, the average penetration of AI skills in South Korea was 1.44 times higher than the global average.
 Source: Maslej et al. (2023: 182) based on LinkedIn data.
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Researchers and businesses that have access to powerful computing infrastructure have an advantage here.⁴⁹⁵ For example, OpenAI uses Microsoft’s cloud infrastructure for its calculations and has licensed its foundation model exclusively to Microsoft.⁴⁹⁶

In its AI Action Plan, the BMBF formulates the goals of providing an internationally more competitive high-performance computing infrastructure, significantly increasing the number of AI users on German and European HPC systems and specifically enabling the research and development of a significant proportion of large AI models in Germany and Europe.⁴⁹⁷ The expansion of computing infrastructure is a prerequisite for further research and application in the field of AI.

Training large language models or multimodal models requires large amounts of training data such as content from the internet or books.⁴⁹⁸ Specialized foundation models, for instance in the medical field, require specialized data. Data are also required to adapt pre-trained foundation models to specific applications. This could be the data of an organization that is developing or customizing an AI application for its own use. Equally, it can be data that start-ups and SMEs use to develop applications, which they then sell.

In an international comparison, German and European actors may find themselves at a competitive disadvantage when developing AI models or applications if existing data are not available or data use is regulated more restrictively than in other countries, for example, regarding data privacy and copyright. This can weaken technological sovereignty. In view of the protection of European values, restrictive management of data use has a double edge. On the one hand, it helps to protect the rights of data subjects. On the other hand, it can lead to AI models from non-European competitors being used in Germany and Europe that were not developed in accordance with European values.

The Commission of Experts has repeatedly pointed out that data in Germany must be made more readily available. The Federal Government and the legislature have already introduced measures such as the establishment of a data institute and the passing of the Health Data Use Act to improve the situation.⁴⁹⁹ Gaia-X, Catena-X and Manufacturing-X could also make a contribution to the development and expansion of an AI ecosystem.⁵⁰⁰ In its AI Action

Plan, the BMBF announces that it will increase data availability in science with the National Research Data Infrastructure (Nationale Forschungsdateninfrastruktur, NFDI), the European Open Science Cloud (EOSC) and other support measures, for example, in the health sector, and that by introducing a Research Data Act it will improve the findability, access and linkability of data.⁵⁰¹ In June 2023, the European Data Governance Act came into force,⁵⁰² based on which data trustee models can be developed.

AI Venture Capital Investment Low

It is often AI start-ups that develop new ideas and business models. For them, venture capital is an important source of financing to drive technology development and growth.

Between 2021 and 2023, an annual average of US\$79.6 billion in venture capital was invested in US-American AI start-ups (cf. figure B 4-15). This far exceeds venture capital investments in AI made in China (US\$28.5 billion) and the EU 27 (US\$12.4 billion) over the same period. Germany accounted for 29 percent of venture capital investments in the EU 27 (US\$3.6 billion).

According to ZEW, the number of economically active AI start-ups in Germany increased significantly within 14 years – from around 1,200 in 2007 to around 3,000 in 2021.⁵⁰³ A slight decrease was observed in 2022 and 2023.⁵⁰⁴ In the ZEW’s AI start-up survey 2023, 32 percent stated they had venture capital.⁵⁰⁵ The appliedAI initiative estimates that, given a narrower definition of AI start-ups based on data, talent, AI methods, scalability and overall quality, the AI ecosystem in Germany included around 500 relevant AI start-ups in 2023.

B 4-7 AI Policy and Regulation

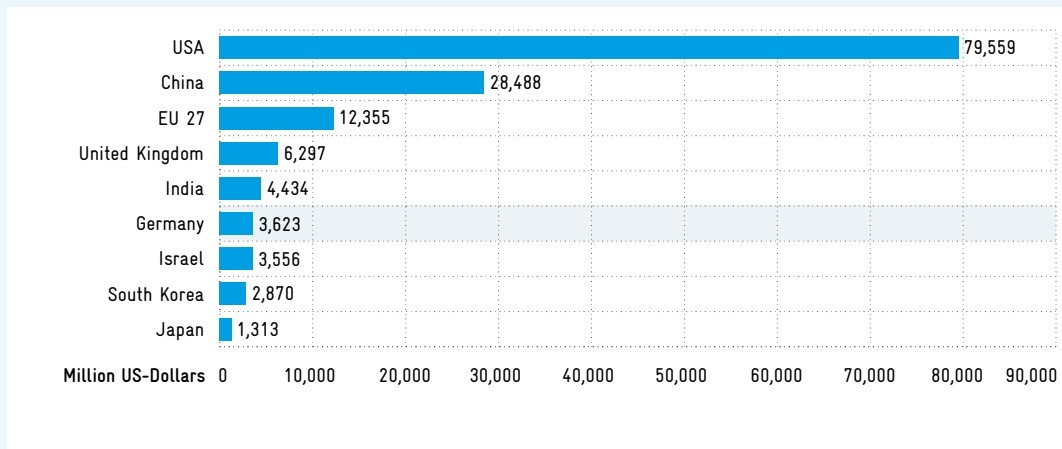
Interdepartmental Coordination on Generative AI Should Be Expanded

The Federal Government aims to strengthen the AI ecosystem in Germany with a number of strategies (cf. box A 2-16). The Federal Government’s AI Strategy was adopted in 2018. Generative AI was not yet the focus of this or the subsequent update. The AI Action Plan published in 2023 now takes current developments such as generative AI into account and identifies key areas of action. However,

Fig. B 4-15 Average annual venture capital investment in AI for selected countries 2021–2023 in US\$ millions



[Download Data](#)



The data for 2023 included in the 2021–2023 mean value is an estimate.
 Legend: In the USA, an annual average of around US\$79.6 billion in venture capital was invested in AI between 2021 and 2023.
 Source: OECD.AI (accessed on 27 Nov. 2023) based on data by Preqin. Own calculations.
 © EFI – Commission of Experts for Research and Innovation 2024.

it refers exclusively to the field of responsibility of the BMBF and therefore cannot do justice to the broad scope of application of AI as a key enabling technology. The Federal Government has not yet undertaken an interdepartmental update or redesign of the AI Strategy.

EU AI Act Proposed as World's First AI Law

The EU is aiming to pass the first-ever legal framework on AI – the Artificial Intelligence Act (AI Act). In December 2023, the European Council and the EU Parliament reached a provisional agreement on regulating AI. This still needs to be formally decided before the AI Act can come into force. The AI Act is intended to become effective two years after its entry into force, with the exception of certain specific provisions. Bans come into effect after just six months and the regulations on general purpose AI after twelve months.

At the time this annual report went to press, the Commission of Experts did not have the text of the agreement on the AI Act, but only information on the AI Act from the European Council, the European Parliament and the European Commission.⁵⁰⁶ This forms the basis for the Commission of Experts' position on the AI Act.

The main elements of the planned AI Act can be summarized as follows:

- **Field of application:** The AI Act applies to public and private actors who develop or deploy AI systems. The obligations contained in the AI Act are not intended to apply to research, development and prototyping activities that precede the market launch. There are also to be isolated exceptions for developers of open-source models.
- **Risk categories:** The EU pursues a risk-based approach. A distinction is made between AI systems with unacceptable risk, high risk and minimal risk. AI systems with unacceptable risk are banned. These are AI systems that violate EU values, e. g. by enabling social scoring by authorities and businesses or recognizing emotions in the workplace. AI systems that pose a high risk to health, safety or fundamental rights must fulfil a number of requirements. These include assessing the impact on the protection of fundamental rights, data governance and transparency. The EU considers AI systems in law enforcement or in the operation and management of critical infrastructures to be high-risk systems, for example. AI systems that are associated with minimal risk, such as video games and spam filters, are not regulated. Special transparency requirements will be introduced for AI systems such as chatbots so that citizens are made aware when they interact with artificial intelligence.

Box B 4-16 Federal Government Strategies Related to AI

AI Strategy

In November 2018, the then Federal Cabinet adopted the 'Federal Government's National Artificial Intelligence Strategy' (AI Strategy).⁵⁰⁷ One year later, the Federal Government published an interim report providing information on individual measures currently being implemented and those planned.⁵⁰⁸ In December 2020, the Federal Cabinet decided to update the AI Strategy.⁵⁰⁹ The Federal Government's measures associated with the AI Strategy are presented on the website www.ki-strategie-deutschland.de. As part of the AI Strategy, the AI competence centres have been further developed and new AI professorships have been created. Other key projects of the AI Strategy include the establishment of a data infrastructure and support for knowledge and technology transfer.

BMBF AI Action Plan

In November 2023, the BMBF published its own AI Action Plan, in which it announced that it would intensify its involvement in the AI Strategy with the aim of providing new impetus for the German AI ecosystem and its points of intersections with industry, education, science and research.⁵¹⁰ The AI Action Plan identifies eleven fields of action in the spheres of infrastructure,

application and transfer as well as conditions for success and underpins them with targets and measures.⁵¹¹

Future Strategy Research and Innovation

The Future Strategy for Research and Innovation adopted by the Federal Cabinet in February 2023 contains a number of references to AI.⁵¹² For example, transformation processes are to be actively structured with the help of AI and technological sovereignty is to be safeguarded.

Digital Strategy

Artificial intelligence is one of the strategic topics to be prioritized in the Federal Government's Digital Strategy, which was presented in August 2022 and updated in April 2023. It was announced that it would support skills development in the field of AI and further develop the AI Campus as a learning platform for artificial intelligence.⁵¹³ Artificial intelligence is also to be used for innovative services in the judiciary and to make environmental policy measures more efficient.

Data Strategy

The Federal Government adopted a new Data Strategy in August 2023. This aims to provide both more and better data than before and also explicitly refers to the importance of (high-quality) data for AI.⁵¹⁴

- **General purpose AI:** General purpose AI systems (GPAI systems) and the foundation models on which they are based (GPAI models) must fulfil transparency requirements, which include the creation of technical documentation, compliance with EU copyright law and the dissemination of detailed summaries of training data. In the case of very powerful GPAI models that could present systemic risks, additional obligations must be accepted, for example regarding risk management, the monitoring of serious incidents and the performance of model evaluations.
 - **Governance:** The market surveillance authorities responsible at national level will monitor the implementation of the regulations at national level. A new organization will be created within the European Commission to assume coordination at European level. This organization will also monitor the implementation and enforcement of the regulation of GPAI models. In doing so, it will be advised by a newly established committee of independent experts.
 - **Regulatory sandboxes:** In a controlled environment, regulatory sandboxes are intended to enable innovative AI systems to be developed, tested and validated and the regulatory framework to be adapted to facilitate the roll-out of innovative AI systems.
- The Commission of Experts welcomes the fact that the EU reached a provisional agreement on the AI Act in December 2023 and thus before the start of the European election campaign. The EU faced

the challenge of ensuring safety in the development and use of AI and safeguarding the European value system, while at the same time not restricting incentives for innovation too much.

The Commission of Experts believes that restricting the scope of the AI Act with regard to open-source development and research activities makes sense in principle. However, adjustments to these exceptions should be possible.

The Commission of Experts is generally in favour of the risk-based approach, according to which AI systems are assigned to different risk classes depending on their application.

In a departure from the otherwise risk-based approach, the EU regulates general purpose AI systems and models, which include large language models and multimodal models, not at the application level, but at the technology level. This includes transparency obligations for the developers of AI foundation models, which must now be specified in further negotiations. Care must be taken to ensure that the transparency obligations are kept within limits and that start-ups and SMEs in particular are not disadvantaged in comparison to larger companies.

According to the draft of the AI Act, foundation models are categorized as high-performance GPAI models solely based on the computing capacity used for training. However, this is of limited use as a sole indicator of the potential risk of foundation models. It is therefore important to consider further criteria when categorizing foundation models, as provided for in the provisional agreement on the AI Act.

When establishing new governance structures at EU level, there is a risk of cumbersome and bureaucratic structures being created that impede agile action and any adjustments that may become necessary over time.

It is to be welcomed that the AI Act provides for the instrument of regulatory sandboxes, as they facilitate innovation and at the same time enable regulatory learning.

B 4-8 Recommendations for Action

AI, which is developing very dynamically, is a key enabling technology. It is therefore important for Germany and Europe to boost their technological sovereignty in this area in order to maintain innovation and growth potential. It is essential not to lose touch with technological developments and to avoid becoming even more dependent on non-European providers. The aim should be to support the development of an efficient AI ecosystem. Since Germany and Europe hardly have any large IT companies, the stimuli from the scientific system, the contributions of SMEs and start-ups as well as open-source AI have a crucial role to play.

Reinforce Basic Research

The Federal Government should continue to firmly support basic AI research. This would give Germany the opportunity to successfully position itself in the international innovation competition for new technology variants and generations. The Commission of Experts welcomes the fact that the Federal Government is funding the Centres of Excellence for AI Research on a permanent basis.

- The Centres of Excellence for AI Research should be equipped in such a way that they can conduct cutting-edge research in the long term. This requires not only financial resources, but also an appropriate infrastructure, in particular computing centres and data.
- The goal formulated in the AI Action Plan of advancing research into efficient and resource-saving AI systems should be pursued as quickly as possible with corresponding targeted funding programmes. Germany and Europe should drive forward the development of AI models that are adapted to the given local conditions with as yet underdeveloped data and computing infrastructure such as Edge AI (cf. box B 4-1), federated learning (cf. box B 4-1) and AI applications on encrypted data.

Support Provision of Computing Capacities

There is a lack of computing capacity in Germany, which is a prerequisite for training and applying AI models.

- Powerful computing capacities must be created to accelerate the safe development of next-generation foundation models under controlled and transparent conditions and in line with European values, and to enable the development of open-source foundation models on a large scale.
- The commissioning of exascale-class supercomputers announced in the BMBF's AI Action Plan⁵¹⁵ must be driven forward quickly. SMEs and start-ups must be guaranteed access to these computers and services associated with their use must be provided.

Improve Data Basis for AI Applications

Given that extensive data sets are essential for the development of AI applications, it is essential to establish a powerful and competitive data infrastructure that can be used by science and industry, and in particular by SMEs and start-ups.

- The Federal Government as well as the Länder and local authorities should accelerate the provision of their own data.
- The Federal Government should provide a set of its own data and launch a call for proposals to support various teams, for example as part of 'challenges', that develop and test AI models and applications based on this data.
- The Federal Government should vigorously drive forward the measures it has initiated to improve the data infrastructure, for example in its AI Action Plan and Data Strategy.
- The Federal Government and actors such as Gaia-X, Catena-X and Manufacturing-X should swiftly develop data trustee models under the European Data Governance Act.

Expand AI Skills

The Commission of Experts emphasizes that an AI ecosystem is dependent on well-qualified professionals who conduct AI research, develop AI technologies and safely utilize AI applications.

- The modernization of the education system increasingly includes teaching skills in the utilization of AI. The Federal Government should work towards ensuring that appropriate programmes are provided in school, academic and vocational education.
- As established businesses clearly remain concerned and uncertain about the utilization of AI, they should be supported with advice and use cases, for instance via the SME competence centres (Kompetenzzentren Mittelstand).

Promote Open-Source AI

Open source harbours immense potential for strengthening Germany's and Europe's technological sovereignty. Open source is also seen as playing a significant role in the development of AI foundation models that guarantee transparency and are in line with European values. However, further initiatives are needed to promote the spread of open source and utilize the potential of open-source AI.

- Initiatives that reinforce the open-source developer community and are aimed at Germany's and Europe's technological sovereignty, such as the Sovereign Tech Fund financed by the BMWK, should be supported.
- The Federal Government should set up programmes to support the security architecture of open-source models via competitive tendering procedures.
- Research projects should be launched to better understand the development of open-source AI and its contribution to the AI ecosystem.
- The measures implemented to support open-source AI should be evaluated in order to promptly adapt funding measures.

Allow Regulatory Learning and Increase Legal Certainty

The European Parliament and the European Council have reached a provisional agreement on the AI Act.

- The AI Act should be adapted over time based on the knowledge and experience gained in regulatory practice in dialogue with actors from other economic and value areas. Without room for adaptability, regulation is unlikely to do justice to the dynamic development of this technology. If necessary, the allocation of applications to risk classes should be adjusted.
- In terms of governance, care must be taken to ensure that the bureaucratic burden for the stakeholders subject to the AI Act remains within reasonable limits, especially for start-ups and SME.
- The regulatory sandboxes provided for in the AI Act should be used as an instrument for regulatory learning as quickly as possible.
- The provisions of the AI Act should be dovetailed with existing regulations such as the Digital Markets Act, the GDPR and the Data Act to ensure consistent jurisdiction. In addition, competition law regulations should apply consistently in the AI sector.
- Since AI innovations in companies are hampered by legal uncertainty, especially in the fields of copyright law, the GDPR and the AI Act, the Federal Government should commission the creation of practical guidelines that facilitate the management of AI-relevant legal frameworks.

C

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C2 List of Abbreviations

5G	Fifth generation of mobile telephony
AHCI	Advanced Host Controller Interface
AI	Artificial Intelligence
ARWU	Academic Ranking of World Universities
ASJC	All Science Journal Classifications
BAND	Business Angels Netzwerk Deutschland e. V.
BEPA	Bureau for Economic Policy Analysis
BfN	Federal Agency for Nature Conservation (Bundesamt für Naturschutz)
BIFOLD	Berlin Institute for the Foundations of Learning and Data
BMBF	Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung)
BMDV	Federal Ministry for Digital and Transport (Bundesministerium für Digitales und Verkehr)
BMEL	Federal Ministry of Food and Agriculture (Bundesministerium für Ernährung und Landwirtschaft)
BMF	Federal Ministry of Finance (Bundesministerium der Finanzen)
BMI	Federal Ministry of the Interior and Community (Bundesministerium des Innern und für Heimat)
BMUV	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz)
BMWi	Federal Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie)
BMWK	Federal Ministry for Economic Affairs and Climate Action (Bundesministerium für Wirtschaft und Klimaschutz)
BVerwG	Federal Administrative Court (Bundesverwaltungsgericht)
CAP	Common Agricultural Policy
CLAIRE	Confederation of Laboratories for Artificial Intelligence Research in Europe
CO₂	Carbon Dioxide
CPC	Cooperative Patent Classification
CPCI	Conference Proceedings Citation Index
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats

DAAD	German Academic Exchange Service (Deutscher Akademischer Austauschdienst)
DARPA	Defense Advanced Research Projects Agency
DATI	German Agency for Transfer and Innovation (Deutsche Agentur für Transfer und Innovation)
DFG	German Research Foundation (Deutsche Forschungsgemeinschaft e.V.)
DFKI	German Research Center for Artificial Intelligence (Deutsches Forschungszentrum für Künstliche Intelligenz GmbH)
DIHK	Association of German Chambers of Industry and Commerce (Deutscher Industrie- und Handelskammertag)
DNA	Deoxyribonucleic Acid
DSEM	German Social Entrepreneurship Monitor (Deutscher Social Entrepreneurship Monitor)
DSS	Decision Support Systems
DWD	German Weather Service (Deutscher Wetterdienst)
EFI	Commission of Experts for Research and Innovation (Expertenkommission Forschung und Innovation)
EFSA	European Food Security Agency
ELLIS	European Laboratory for Learning and Intelligent Systems
EOSC	European Open Science Cloud
EPO	European Patent Office
ESEM	European Social Enterprise Monitor
EU ETS	European Union Emissions Trading System
EU	European Union
EU 27	27 Member States of the European Union
EUIPO	European Union Intellectual Property Office
EuroHPC	European High Performance Computing
FAO	Food and Agriculture Organization
FH	Senior technical college/University of applied sciences (Fachhochschule)
FMIS	Farm Management and Information Systems
FRAND	Fair, Reasonable And Non-Discriminatory
GBER	General Block Exemption Regulation
GDNG	Health Data Use Act (Gesundheitsdatennutzungsgesetz)
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GMO	Genetically Modified Organisms
GPAI	General Purpose Artificial Intelligence
GPS	Global Positioning System
GPT	Generative Pretrained Transformer
GPU	Graphic Processing Unit
HAI	Human-Centred Artificial Intelligence
HPC	High Performance Computing
IAIS	Fraunhofer Institute for Intelligent Analysis and Information Systems (Fraunhofer-Institut für Intelligente Analyse- und Informationssysteme)
IBM	International Business Machines Corporation
ICT	Information and Communication Technology

ICT	Intra-Corporate Transfer
ID	Identification number
IEEE	Institute of Electrical and Electronics Engineers
IEKE	International Expert Commission for the Evaluation of the Excellence Initiative (Internationale Expertenkommission zur Evaluation der Exzellenzinitiative)
IIS	Fraunhofer Institute for Integrated Circuits (Fraunhofer-Institut für integrierte Schaltungen)
IndiSI	Indicators of Social Innovations (Indikatorik Sozialer Innovationen)
InnoProb	Innovation Probability
IoT	Internet of Things
IP	Intellectual Property
IPCC	Intergovernmental Panel on Climate Change
ISI	Fraunhofer Institute for Systems and Innovation Research (Fraunhofer Institut für System- und Innovationsforschung)
IT	Information Technology
KB	Competence Network for Bibliometrics (Kompetenznetzwerk Bibliometrie)
KfW	Kreditanstalt für Wiederaufbau
KPRES	Krajowy Program Rozwoju Ekonomii Społecznej
KTF	Climate and Transformation Fund (Klima- und Transformationsfonds)
LLM	Large Language Models
MCML	Munich Center for Machine Learning
MIP	Mannheim Innovation Panel (Mannheimer Innovationspanel)
MIT	Massachusetts Institute of Technology
ML	Machine Learning
ML2R	Maschinelles Lernen Rhein-Ruhr
MLP-SI	Multi-Level Perspective on Social Innovation
NFDI	National Research Data Infrastructure (Nationale Forschungsdateninfrastruktur)
NGT	New Genomic Techniques
NSB	National Science Foundation
NURI	Non-University Research Institution
ODM	Oligonucleotide-Directed Mutagenesis
OECD	Organisation for Economic Co-operation and Development
OZG	Online Access Act (Onlinezugangsgesetz)
PATSTAT	Patent Statistical Database
PCT	Patent Cooperation Treaty
PISA	Programme for International Student Assessment
PLS	Platform Learning Systems – Germany’s platform for artificial intelligence (Plattform Lernende Systeme)
R&D	Research and Development
R&I	Research and Innovation
RCT	Randomized Controlled Trial
ScaDS.AI	Center for Scalable Data Analytics and Artificial Intelligence
SCIE	Science Citation Index Expanded

SDG	Sustainable Development Goal
SDN	Site-Directed Nuclease
SEND	Social Entrepreneurship Netzwerk Deutschland e.V.
SEP	Standard Essential Patent
SI	Social Innovation
SME	Small and Medium-sized Enterprises
SPRIND	Agency for Disruptive Innovation (Agentur für Sprunginnovationen)
SSCI	Social Sciences Citation Index
TI-Räume	Transfer Spaces for the Future of Regions (Transferräume für die Zukunft von Regionen)
TALEN	Transcription Activator-Like Effector Nuclease
TFEU	Treaty on the Functioning of the European Union
TU9	Alliance of leading Universities of Technology in Germany
U15	Alliance of 15 leading research-intensive and medically leading universities in Germany
UAS/HAW	University of Applied Sciences (Hochschule für Angewandte Wissenschaften)
UN	United Nations
UNEP	United Nations Environment Programme
UNFPA	United Nations Fund for Population Activities
US	United States
USA	United States of America
WDR	Westdeutscher Rundfunk (German public-broadcasting institution)
WIPO	World Intellectual Property Organization
WIR!	Change Through Innovation in the Region (Wandel durch Innovation in der Region)
ZALF	Leibniz Centre for Agricultural Landscape Research (Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF) e. V.)
ZEW	Leibniz Centre for European Economic Research (Leibniz-Zentrum für Europäische Wirtschaftsforschung GmbH Mannheim)
ZFN	Zinc-Finger Nuclease
ZIM	Central Innovation Programme for Small and Medium-sized Enterprises (Zentrales Innovationsprogramm Mittelstand)

C 3 Glossary

Agenda 2030

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

Agriculture 4.0

Various definitions of agriculture 4.0 exist. The term is sometimes used synonymously with smart farming but is also seen as the agricultural equivalent of industry 4.0. Agriculture 4.0 is then more comprehensive than smart farming and includes the intelligent, data-based networking of companies along the entire agricultural value chain. The AI-supported exchange and analysis of data on platforms are key components of agriculture 4.0 and should enable faster and better reactions to changing market conditions.

Agrobiodiversity

Agrobiodiversity comprises the biological diversity that is relevant to agriculture, the agroecosystem and nutrition. This includes crops and other cultivated plants, farmed animals and their related wild species (cf. there).

AI ecosystem

An AI ecosystem comprises a large number of components. These include a science system with a network across Europe, AI expertise, an efficient AI infrastructure and venture capital.

Area coverage

The area coverage indicates how much area an agricultural machine can process per unit of time.

Artificial intelligence (AI)

The term artificial intelligence is used to describe processes, algorithms and technological solutions that make it possible to transfer complex processes previously carried out by humans to learning machines and software.

Beleihung

The state often works together with private organisations to perform public tasks. This cooperation can take various forms, with or without the transfer of sovereign powers. Co-operation in which sovereign powers are transferred is known as a *Beleihung* in German.

Bibliometrics

Bibliometrics is the study of quantitative analyses for the purpose of evaluating publications, authors and institutions – usually using statistical methods. It is a branch of scientometrics, the quantitative study of science and scientific processes.

Biodiversity

Biodiversity or biological diversity refers to the variation and variability of life. This includes three levels: genetic diversity, species diversity and the diversity of ecosystems.

Brain circulation, brain drain, brain gain

From the viewpoint of an economy, brain drain (gain) refers to the outflow (inflow) of human capital – usually caused by the physical migration of groups of people. Brain circulation can be defined as the circular migration of groups of people who change the location of their productive activity several times between national economies.

Catch crop

Catch crops are crops that are grown between two main crops, e.g. cereals, potatoes, beets. The catch crop is often not used for sale, but as animal feed or fertiliser.

Causal analysis

Causal analysis refers to statistical methods for determining cause-and-effect relationships between different variables. In policy analysis, causal analysis is used to determine whether and to what extent a certain intervention, such as an R&I policy meas-

ure (the independent variable), has a direct effect on the desired result (the dependent variable).

Common Agricultural Policy (CAP)

The CAP is an EU policy area in which agricultural policy measures are adopted at European level. The CAP pursues three fundamental objectives: to provide safe and high-quality food, to ensure a fair standard of living for farmers and to contribute to the conservation of natural resources and environmental protection. The CAP is implemented in the EU Member States via national strategy plans.

Competence

Competence can be defined as the ability and skill of an individual to deal with a specific problem or problem area as well as the associated motivational, volitional and social readiness and abilities to be able to apply problem solving in a variety of ways. Competence is always related to a specific field of application. Therefore, a reference designation is often prefixed (e.g. social competence, digital competence).

Control group

Cf. Causal analysis.

Counterfactual state

The counterfactual state describes the hypothetical situation an entity (e.g. a person, a group, a region) affected by an intervention (the so-called treatment) would be in if it had not been exposed to the intervention.

CRISPR

The CRISPR system (short for: Clustered Regularly Interspaced Short Palindromic Repeats) is a genome editing method that can be used to specifically cut the gene sequence of an organism in order to change it at this point.

Crowd economy

The crowd economy refers to new forms of business that are created through the interaction of people via the internet. It encompasses various concepts such as crowdsourcing, crowdfunding and the shared economy.

Cultivated plant/crop

Cultivated plants and crops are bred and cultivated by humans for use as useful or ornamental plants. They differ in their genetic characteristics from their related wild plants.

Double-strand break

A double-strand break refers to the breakage of a DNA sequence in which both strands are broken. A double-strand break can be caused by radiation, chemical substances, mechanical forces or nucleases.

Dual use

Dual use goods are goods, software and technology that are usually used for civilian purposes but can also be used in the military sector.

Econometrics

Econometrics is a fundamental empirical discipline in economics. It uses mathematical and statistical methods to test economic models on the basis of statistical data and to make statements about economic relationships at a statistically sound level.

Enterprises for the common good

Enterprises for the common good are companies that pursue social and ecological goals in addition to economic success. In the Federal Government's National Strategy for Social Innovation and Social Enterprises from 2023, they are seen as synonymous with social enterprises.

EU 27

The EU 27 refers to the 27 Member States of the European Union.

European Emissions Trading System (EU ETS)

Since 2005, the European Emissions Trading System (EU ETS) has been the key element of the EU's climate protection programme. The aim is to reduce greenhouse gas emissions by trading CO₂ certificates. One CO₂ certificate entitles the holder to emit one tonne of CO₂ equivalent. The certificates are freely traded on the market, resulting in a price that incentivizes businesses to reduce greenhouse gas emissions. To date, the energy sector, energy-intensive industries, aviation and, since 2024, maritime transport have participated in the EU ETS.

European Social Enterprise Monitor

The European Social Enterprise Monitor (ESEM) is the first monitor for social enterprises at European level. The ESEM is a regular meta-study that describes the results of European online surveys and compares data on social enterprises and start-ups. The German Social Entrepreneurship Monitor (cf. there) is part of the European Social Enterprise Monitor.

Experimental methods

Randomized experiments, often referred to as randomized controlled trials (RCTs), are used in research to test the effectiveness of an intervention under controlled environmental conditions. When appropriately designed and conducted, randomized experiments provide the strongest evidence for causal effects of an intervention.

Experimentation clause

An experimentation clause is a legal norm in administrative law that allows deviations from generally applicable regulations when testing innovative ideas and projects. The validity of experimentation clauses is usually limited in time.

External effects

An external effect exists when the consumption or production decision of an economic entity has an impact on the benefit of other economic entities. Technological externalities occur when other economic entities are advantaged or disadvantaged without this benefiting or being charged to the originator via the price system.

Foundation model

Researchers at Stanford University coined the term foundation model for AI models that have been trained on a broad pool of data and can form the basis for the development of a variety of specific applications.

Fractional counting

Fractional counting is used when, for example, patents or publications are attributed proportionately to authors, inventors, organisations or countries.

Frascati Manual

The OECD's so-called Frascati Manual contains methodological guidelines for the collection and analysis of data on research and development. In 1963, experts from the OECD met for the first time with members of the NESTI group (National Experts on Science and Technology Indicators) in Frascati, Italy, to define essential terms such as research and development. The result of these discussions became known as the first Frascati Manual. Since then, the Frascati Manual has been revised several times. The most recent edition dates from 2015.

Free-riding

In cases of non-excludability, (cf. Public goods) there is the possibility of free-riding, i.e. the possibility of benefiting from the success of a good without participating in its financing.

Gene gun

In genetic engineering, plants are bombarded with particles to which gene sequences are attached in order to introduce these sequences into the bombarded organism.

Generative AI

Generative AI is a form of AI that is used to generate or edit content such as text as well as images, video, audio and computer code. This can be unimodal (e.g. text to text) or multimodal (e.g. text to image or image to text).

Genome sequencing

Genome sequencing determines the structure of the entire genetic information.

German Social Entrepreneurship Monitor

The German Social Entrepreneurship Monitor (Deutscher Social Entrepreneurship Monitor, DSEM) is a survey on social enterprises that has been conducted regularly since 2018. The DSEM is published by the Social Entrepreneurship Network Germany (Social Entrepreneurship Netzwerk Deutschland, SEND). The survey is not representative.

Governance

Governance refers to the management and regulation system in the sense of structures (organisational and operational structure) of a political-social unit such as the state, administration, municipality, private and public organisations. The term is often also used in the sense of steering and regulation of any organisation (such as a corporation or business).

Green Deal

The EU Green Deal is a package of political initiatives with the aim of making the EU climate-neutral by 2050. It was launched in 2019 and includes initiatives such as the Farm-to-Fork Strategy, the EU Biodiversity Strategy, the European Climate Law and the Fit for 55 package.

Green genetic engineering

Green genetic engineering refers to the use of genetic engineering techniques in plants.

Gross domestic product

Gross domestic product (GDP) is the value of all goods and services produced by an economy within one year. GDP is an indicator of the economic performance of an economy in international comparison.

Herbicide tolerance

Herbicide tolerance can be created in plants by changing the gene sequence. It ensures that the modified plant is resistant to a herbicide, which therefore has no effect on the plant.

Human capital

In economics, human capital refers to all economically utilizable skills and knowledge of groups of people.

Information asymmetries

Information asymmetries exist when one side of the market is better informed than the other. This occurs, for example, in the financing of R&I activities by third parties. External investors can assess the chances of success of R&I projects less reliably than the companies engaging in R&I.

Insect resistance

Insect resistance can be created in plants by changing the gene sequence. Insect resistance ensures that plants become resistant to certain insects and can therefore no longer be damaged by them.

Intellectual property

Intellectual property refers to rights to intangible goods such as ideas, concepts and inventions. These goods are legally protected if the legal system grants corresponding rights, e.g. through patents or copyrights. The holder of such a right is, for example, the applicant for a patent or the creator of a copyrighted work.

Internet of Things

The use of information and communication technologies in everyday objects has created the link between the real and virtual worlds. This linking of devices with people is called the Internet of Things (IoT) or the Internet of Things and Services. Examples include embedded computer systems that monitor the wearer's vital signs in clothing, imprinted chip codes that allow parcel tracking over the internet, and refrigerators that autonomously regulate the reordering of food when stocks are low.

Interoperability

Interoperability is the ability of a system to interact with other systems without access restrictions or other barriers and to exchange information in a meaningful way.

Key enabling technology

Three criteria can be used to identify key enabling technologies: broad applicability in a large number of technology fields or sectors; strong, non-substitutable complementarity (cf. there) to a large number of other technologies; high potential for performance enhancement in a key enabling technology itself and in its fields of application.

Large language model

Large language models (LLM) are models that process and generate natural language. For example, they can compose and translate texts and answer questions. Large language models are forms of foundation models (cf. there).

Licensing

In the context of licensing, a patent holder transfers an exploitation licence to another legal entity. In return, the patent holder receives licence fees.

Machine learning

Machine learning (ML) aims to use learning algorithms and data to train complex models, which are then applied to new, potentially unknown data of the same type.

Mannheim Innovation Panel

The Mannheim Innovation Panel (MIP) is the innovation survey conducted annually since 1993 by ZEW – Leibniz Centre for European Economic Research. However, in addition to the data to be reported to Eurostat, the MIP also includes data for enterprises with five to nine employees.

Matching procedures

Matching procedures are statistical techniques whereby, for each unit of observation in the treatment group, (cf. there) one or more units are found in the control group (cf. there) that are similar with regard to certain observed variables. Matching procedures can help to reduce distortions caused by non-random participation in measures. In the context of causal analyses, they (cf. there) are used in addition to quasi-experimental methods (cf. there). Matching alone does not solve the problem that participation in measures can be influenced by non-observable variables.

Mission-oriented R&I policy

An R&I policy is considered mission-oriented if R&I activities are supported to achieve politically defined objectives. A classic example of this is the Apollo programme launched by the USA in 1961, which aimed to put a man on the Moon and bring him back before the end of the 1960s. While technology-oriented missions were pursued primarily from the 1940s to the 1960s, R&I policy has focussed more strongly on societal issues since the 1990s.

Multi-modal model

Multimodal models process and generate multiple modalities such as speech, audio and images and are variants of foundation models (cf. there).

Mutation

A mutation is a heritable change in the gene sequence that can occur spontaneously in a natural way, specifically through genome editing or unintentionally through external influences such as chemicals or radiation.

National Strategy for Social Innovations and Social Enterprises

The National Strategy for Social Innovation and Social Enterprises (Nationale Strategie für Soziale Innovationen und Gemeinwohlorientierte Unternehmen) was adopted by the Federal Cabinet on 13 September 2023. The aim of this strategy is to promote social innovation and enterprises for the common good and to emphasize their importance for society. The National Strategy comprises a total of seven guidelines and eleven fields of action.

(Non-substitutable) complementarity

Complementarity describes, from an economic perspective, the idea that two things complement each other and together create more value than the sum of the values when the two are used individually. Non-substitutable complementarity means that the things that complement each other to create a higher added value cannot be replaced by alternatives.

Off-target effect

Off-target effects are when the DNA is cut at sites in the genome that are similar to the actual target sequence but are not themselves the target of the intervention.

One-stop shop

A one-stop shop in business or public administration means that all the bureaucratic steps required to achieve an objective can be completed at a single point.

Oslo Manual

The OECD's Oslo Manual contains guidelines for the statistical recording of innovation activities. This manual goes beyond the R&D concept of the Frascati Manual (cf. there) and differentiates between different forms of innovation. The Oslo Manual is the basis of the Community Innovation Surveys. The most recent revision of the Oslo Manual dates from 2018.

Positive-sum game

Cf. Zero-sum game/positive-sum game.

Project Executing Agencies

In their role as administrative agencies, project executing agencies support the project funding of the ministries. This is done, for example, by providing technical and administrative advice to applicants, preparing funding decisions, administering funding and controlling.

Public goods

A public good is said to exist if there is non-rivalry in use and non-excludability from use. Non-rivalry means that one person's use does not restrict the use of others. Non-excludability is when no one can be excluded from the use of a good once the good is provided.

Quasi-experimental methods

In contrast to experimental methods (cf. there), quasi-experimental methods conducted as part of causal analyses (cf. there) are not based on genuine randomization (cf. there). Instead, constellations are analyzed where participation in an intervention was 'quasi-random' and could hardly be influenced by the participants. For example, in the case of interventions that were limited to individual regions, the possibility of participation is quasi-randomized by belonging to the region. Therefore, comparable units from other regions can be used as a control group. Subject to certain conditions, which differ depending on the method, causal effects of interventions can be estimated in this way.

Randomization

In the context of a causal analysis (cf. there), randomization means that the participants in a measure are randomly assigned to two groups – the treatment group and the control group. The treatment group is subject to the intervention the effect of which is being analyzed. The control group is either not subject to any intervention or is subject to a different intervention than the one analyzed. The results of the control group are used to approximate the counterfactual state (cf. there) of the treatment group in order to measure the effect of the intervention or to compare the effect of the different interventions. Randomization is intended to ensure that there are no systematic differences between the groups before the intervention. This means that all known and unknown variables that could influence the result are evenly distributed across both groups.

Reference genome

A reference genome is the complete assembly of a gene sequence that represents the genetic information of an organism or a small group of organisms. This sequenced genome is used as a reference when sequencing other genomes of the same species to identify genetic variations and differences.

Research and Development (R&D)

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

Research and Innovation (R&I)

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

Scaling

The scaling of a company means that it grows or increases its turnover without the need for higher fixed costs or major investments.

Section control

Section control is a system for the precise application of inputs on cultivated areas.

Selection

Selection in plant breeding involves selecting individual plants with desirable traits that are used for further breeding.

Self-management funds

At state level, self-management funds are those funds in the budget that are available beyond the current budget year.

Social enterprises

Social enterprises are businesses that solve societal or environmental problems by entrepreneurial means. Their aim is to create a benefit for society and give this back to society, rather than just making a profit. Social enterprises work in an impact-oriented manner. No legal definition of a social enterprise currently exists in Germany.

Social innovations

Social innovations are new individual and collective behaviours and forms of organisation that contribute to solving societal or economic problems and thus create added value for society. They are developed by different actors such as individuals, households, groups and companies. They may or may not be related to technological innovations.

Spillover

Spillover effects occur in research and innovation in the form of knowledge transfers, for example when company A is able to generate economic returns from the R&D activities of another company B.

Start-ups

Start-ups are young companies with innovative business ideas and high growth potential.

State aid

In the EU, state aid is defined as financial resources from a Member State that are transferred to a company and can distort competition. State aid includes direct financial contributions, tax breaks, debt relief and guarantees.

Stress tolerance

Stress tolerance is the ability of plants to withstand stress caused by, for example, a lack of water, excessive sunlight or pest infestation.

Sustainable Development Goals (SDGs)

In 2015, the global community adopted the 2030 Agenda, which contains 17 SDGs. These are: End

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

Technological sovereignty

An economy is sovereign in a technology if it can itself provide and further develop this technology, which contributes significantly to its welfare and competitiveness or is critical in the sense of systemic relevance, and if it can participate in its standardization or has the possibility to obtain and apply this technology without unilateral dependence on other economic areas.

Transnational patent applications

Transnational patent applications are applications in patent families with at least one application to the World Intellectual Property Organization (WIPO) via the PCT procedure or one application to the European Patent Office. For the export-oriented German economy, such patents are of particular importance because they involve the protection of the invention beyond the home market.

Transport bacteria

Bacteria such as *Agrobacterium tumefaciens* are used in genetic engineering as vehicles for transporting gene sequences.

Treatment group

Cf. Causal analysis.

Vegetation period

The period during which plants grow, flower and bear fruit is known as the vegetation period. This phase is determined by climatic conditions that allow plant growth.

Vertical integration

Vertical integration means that a company integrates upstream or downstream production or trading stages.

Zero-sum game/positive-sum game

A zero-sum game can be described as a situation in which the sum of all losses and the sum of all gains generated by participants when changing from one state to another are always equal in value. In a positive-sum game, the sum of all gains is greater than the sum of all losses. Whereas in political contexts, zero-sum games are purely a matter of redistribution, positive-sum games are characterized by increases in efficiency.

C4 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 'Studies on the German innovation system' (Studien zum deutschen Innovationssystem). The findings are integrated into the Report of the Commission of Experts.

1-2024

Kerst, C.; Meier, D. H. (2024): Bildung und Qualifikation als Grundlage der technologischen Leistungsfähigkeit Deutschlands 2024. Studien zum deutschen Innovationssystem. Berlin: EFI.

2-2024

De Monte, E.; Murmann, S. (2024): Unternehmensdynamik in der Wissenswirtschaft in Deutschland 2022. Studien zum deutschen Innovationssystem. Berlin: EFI.

3-2024

Schiersch, A.; Gulden, V. S. (2024): FuE-intensive Industrien und wissensintensive Dienstleistungen im internationalen Vergleich. Studien zum deutschen Innovationssystem. Berlin: EFI.

4-2024

Geppert, F.; Krachunova T.; Bellingrath-Kimura, S. (2024): Digital and Smart Technologies in Agriculture in Germany: Identification of Key Recommendations for Sustainability Actions. Studien zum deutschen Innovationssystem. Berlin: EFI.

5-2024

Hartung, F.; Krause, D.; Sprink, T.; Wilhelm, R. (2024): Kurzstudie über Anwendungen der Grünen Gentechnik in der Landwirtschaft – Potenziale und Risiken. Studien zum deutschen Innovationssystem. Berlin: EFI.

6-2024

Dederer, H.-G. (2024): Kurzstudie zu Gentechnikrecht und Patentrecht bei Pflanzen. Studien zum deutschen Innovationssystem. Berlin: EFI.

7-2024

Zyontz, S. (2024): Mapping CRISPR Research, Innovation, and Diffusion Activities in Agriculture – Cross-national. Studien zum deutschen Innovationssystem. Berlin: EFI.

8-2024

Coda-Zabetta, M.; Lissoni, F.; Miguelez, E. (2024): International Mobility and Collaboration of German Scientists, 2005–2020. Studien zum deutschen Innovationssystem. Berlin: EFI.

9-2024

Karaulova, M.; Kroll, H.; Garcia Chavez, C.; Berghäuser, H. (2024): Researcher Mobility and Cooperation in the Science System. Studien zum deutschen Innovationssystem. Berlin: EFI.

10-2024

Weber, M.; Giesecke, S.; Havas, A.; Schartinger, D.; Albiez, A.; Horak, S.; Blind, K.; Bodenheimer, M.; Daimer, S.; Shi, L.; Stadler, M.; Schmitz, D. (2024): Social Innovation – (Accompanying) Instrument for Addressing Societal Challenges? Studien zum deutschen Innovationssystem. Berlin: EFI.

11-2024

Büchle, S.; Bünstorf, G.; Cantner, U.; Dreier, L.; Meurer, P.; Neumann, L. P. (2024): Commissioned Project Evaluations of Research and Innovation Policy in Germany: A Review. Studien zum deutschen Innovationssystem. Berlin: EFI.

12-2024

Stiller, J.; Eilers, L.; Heiny, F.; Oslislo, C. (2024): Indikatoren zum deutschen Forschungs- und Innovationssystem – Forschung und Entwicklung in Staat und Wirtschaft, Patentanmeldungen und Fachpublikationen. Berlin: EFI.

C5 Literature

- Abadie, A. (2021): Using Synthetic Controls. Feasibility, Data Requirements, and Methodological Aspects. *Journal of Economic Literature*. 59(2). pp. 391–425.
- Abadie, A.; Diamond, A.; Hainmueller, J. (2010): Synthetic Control Methods for Comparative Case Studies. Estimating the Effect of California's Tobacco Control Program. *Journal of the American Statistical Association*. 105(490). pp. 493–505.
- Acemoglu, D.; Autor, D.; Patterson, C. (2023): Bottlenecks: Sectoral Imbalances and the US Productivity Slowdown. NBER Macroeconomics Annual 2023. Volume 38. University of Chicago Press.
- Adams, J. (2012): Collaborations. The Rise of Research Networks. *Nature*. 490(7420). pp. 335–336.
- Agrawal, A.; Cockburn, I.; McHale, J. (2006): Gone But Not Forgotten. Knowledge Flows, Labor Mobility, and Enduring Social Relationships. *Journal of Economic Geography*. 6(5). pp. 571–591.
- Agrawal, A.; McHale, J.; Oettl, A. (2017): How Stars Matter. Recruiting and Peer Effects in Evolutionary Biology. *Research Policy*. 46(4). pp. 853–867.
- Ahmed, N.; Wahed, M. (2020): The De-democratization of AI: Deep Learning and the Compute Divide in Artificial Intelligence Research. *arXiv preprint arXiv:2010.15581*.
- Ahmed, N.; Wahed, M.; Thompson, N. C. (2023): The Growing Influence of Industry in AI Research. *Science* (New York, N. Y.). 379(6635). pp. 884–886.
- Akademie für Künstliche Intelligenz im KI Bundesverband (2023): Große KI-Modelle für Deutschland. Funded by the BMWK based on a decision by the Deutscher Bundestag. Berlin: KI Bundesverband.
- Alperstedt, G. D.; Andion, C. (2021): Social Innovation Ecosystems: A Literature Review and Insights for a Research Agenda. In: Howaldt, J.; Kaletka, C.; Schröder, A.: A Research Agenda for Social Innovation.
- Aufderheide, E.; Neizert, B. (2016): Internationalisierung der Forschung. In: Simon, D.; Knie, A.; Hornbostel, S.; Zimmermann, K.: *Handbuch Wissenschaftspolitik*. Wiesbaden: Springer Fachmedien Wiesbaden.
- Azoulay, P.; Fuchs, E.; Goldstein, A.; Kearney, M. (2018): Funding Breakthrough Research: Promises and Challenges of the "ARPA Model". NBER Working Paper. 24674 Cambridge: NBER.
- BAND – Business Angels Netzwerk Deutschland (2022): Immer Ärger mit den Patenten!? Wie den IP-Transfer aus Hochschulen und Forschungseinrichtungen für Ausgründungen optimieren? BAND im Fokus. 01/2022. Essen: BAND.
- Barbu, Y.; Vergniolle, O.; Guillaud, N. (2021): Deutsche Forschungszulage vs. französischer Crédit d'Impôt Recherche. Eine vergleichende Analyse steuerlicher F&E-Anreizsysteme in Deutschland und Frankreich. *IWB(15)*. pp. 605–613.
- Barrows, G.; Sexton, S.; Zilberman, D. (2014): Agricultural Biotechnology. The Promise and Prospects of Genetically Modified Crops. *Journal of Economic Perspectives*. 28(1). pp. 99–120.
- Bauder, H. (2015): The International Mobility of Academics. A Labour Market Perspective. *International Migration*. 53(1). pp. 83–96.
- Beine, M.; Docquier, F.; Rapoport, H. (2001): Brain Drain and Economic Growth. Theory and Evidence. *Journal of Development Economics*. 64(1). pp. 275–289.
- Benus, J.; Shen, T.; Zhang, S.; Chan, M.; Hansen, B. (2009): Growing America Through Entrepreneurship: Final Evaluation of Project GATE. Submitted to: U.S. Department of Labor. Columbia: IMPAQ International, LLC.
- Bertschek, I.; Bonin, H.; Cantner, U.; Häussler, C.; Hölzle, K.; Requate, T. (2022): DATI: Wenn schon, denn schon!. *Policy Brief*. 2-2022. Berlin: EFI.
- Bertschek, I.; Bünstorf, G.; Cantner, U.; Häussler, C.; Requate, T.; Welter, F. (2023a): Konsequente Entfesselung der SPRIND. Transformationen vorantreiben und Zeichen für agile F&I-Politik in Deutschland setzen. *Policy Brief*. 2-2023. Berlin: EFI.
- Bertschek, I.; Bünstorf, G.; Cantner, U.; Häussler, C.; Requate, T.; Welter, F. (2023b): Mit welchen Governance-Strukturen lässt sich die Agilität der missionsorientierten F&I-Politik steigern? F&I-Politik steht vor komplexen Aufgaben. *Policy Brief*. 1-2023. Berlin: EFI.
- Bertschek, I.; Bruder Müller, M.; Jaghuber, S.; Süssenguth, F. (2023c): Lernende Regulatorik als Innovationstreiber – Anregungen zur Ausgestaltung des Reallabore-Gesetzes, acatech – Deutsche Akademie der Technikwissenschaften e. V., Berlin.
- Biggeri, M.; Testi, E.; Bellucci, M. (2017): Enabling Ecosystems for Social Enterprises and Social Innovation. A capability approach perspective. *Journal of Human Development and Capabilities*. 18(2). pp. 299–306.
- Bitkom Research (2020): Digitalisierung in der Landwirtschaft 2020. Berlin: Bitkom e. V.; Deutscher Bauernverband; Landwirtschaftliche Rentenbank.
- Bitkom Research (2022): Die Digitalisierung der Landwirtschaft. Berlin: Bitkom e. V.
- Blind, K.; Böhm, M.; Grzegorzewska, P.; Katz, A.; Muto, S.; Patsch, S.; Schubert, T. (2021): The Impact of Open Source Software and Hardware on Technological Independence, Competitiveness and Innovation in the EU Economy. Final Study Report. Brussels: European Commission.
- BMBF – Bundesministerium für Bildung und Forschung (2021a): Ressortkonzept zu Sozialen Innovationen. Bonn, Berlin: BMBF.
- BMBF – Bundesministerium für Bildung und Forschung (2021b): Karliczek: Energiesparende KI-Chips ausgezeichnet. Press release dated 11 March 2021.
- BMBF – Bundesministerium für Bildung und Forschung (2023a): BMBF Aktionsplan Künstliche Intelligenz. Neue Herausforderungen chancenorientiert angehen. Berlin: BMBF.

- BMBF – Bundesministerium für Bildung und Forschung (2023b): FAQ – DATIpilot. Berlin: BMBF.
- BMBF – Bundesministerium für Bildung und Forschung (2023c): Umsetzung der Zukunftsstrategie Forschung und Innovation. Bericht der Bundesregierung. Bonn, Berlin: BMBF.
- BMEL – Bundesministerium für Bildung und Agriculture (2021): Ackerbaustrategie 2035. Perspektiven für einen produktiven und vielfältigen Pflanzenbau. Berlin: BMEL.
- BMEL – Bundesministerium für Ernährung und Landwirtschaft (2022a): Den Wandel gestalten! Zusammenfassung zum GAP-Strategieplan 2023–2027. Berlin: BMEL.
- BMEL – Bundesministerium für Ernährung und Landwirtschaft (2022b): Ernstebericht 2022 – Mengen und Preise. Berlin: BMEL.
- BMUV – Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz (2023): Nationale Wasserstrategie. Berlin: BMUV.
- BMUV; BfN – Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz; Bundesamt für Naturschutz (2023): Naturbewusstsein 2021. Bevölkerungsumfrage zu Natur und biologischer Vielfalt. Berlin: BMUV; BfN.
- BMWi – Bundesministerium für Wirtschaft und Energie (2013): Evaluierung wirtschaftspolitischer Fördermaßnahmen als Element einer evidenzbasierten Wirtschaftspolitik. Gutachten des Wissenschaftlichen Beirats beim Bundesministerium für Wirtschaft und Energie. Berlin: BMWi.
- BMWi – Bundesministerium für Wirtschaft und Energie (2020): Neue Forschungszulage in Deutschland. Deutschland gewinnt als Standort für Forschung und Innovationen weiter an Attraktivität. Schlaglichter. Februar 2020. Berlin: BMWi.
- BMWK – Bundesministerium für Wirtschaft und Klimaschutz (2023a): Grünbuch Reallabore. Konsultation für ein Reallabore-Gesetz und ergänzende Maßnahmen. Berlin: BMWK.
- BMWK – Bundesministerium für Wirtschaft und Klimaschutz (2023b): One-Stop-Shop Reallabore. Problemanalyse und Handlungsbedarf. Berlin: BMWK.
- Böcker, T.; Finger, R. (2016): European Pesticide Tax Schemes in Comparison. An Analysis of Experiences and Developments. *Sustainability*. 8(4). p. 378.
- Bodenheimer, M. (2019): Transition Towards Socially Sustainable Behavior? A Comparison of Cases from the Smartphone and Garment Industries. Working Paper Sustainability and Innovation.
- Bommasani, R.; Hudson, D.A.; Adeli, E.; Altman, R.; Arora, S.; Arx, S. von; Bernstein, M.S.; Bohg, J.; Bosselut, A.; Brunskill, E.; Brynjolfsson, E.; Buch, S.; Card, D.; Castellon, R.; Chatterji, N.; Chen, A.; Creel, K.; Davis, J.Q.; Demszky, D.; Donahue, C.; Doumbouya, M.; Durmus, E.; Ermon, S.; Etchemendy, J.; Ethayarajh, K.; Fei-Fei, L.; Finn, C.; Gale, T.; Gillespie, L.; Goel, K.; Goodman, N.; Grossman, S.; Guha, N.; Hashimoto, T.; Henderson, P.; Hewitt, J.; Ho, D.E.; Hong, J.; Hsu, K.; Huang, J.; Icard, T.; Jain, S.; Jurafsky, D.; Kalluri, P.; Karamcheti, S.; Keeling, G.; Khani, F.; Khat-tab, O.; Koh, P.W.; Krass, M.; Krishna, R.; Kudithipudi, R.; Kumar, A.; Ladhak, F.; Lee, M.; Lee, T.; Leskovec, J.; Levent, I.; Li, X.L.; Li, X.; Ma, T.; Malik, A.; Manning, C.D.; Mirchandani, S.; Mitchell, E.; Munyikwa, Z.; Nair, S.; Narayan, A.; Narayanan, D.; Newman, B.; Nie, A.; Niebles, J.C.; Nilforoshan, H.; Nyarko, J.; Ogut, G.; Orr, L.; Papadimitriou, I.; Park, J.S.; Piech, C.; Portlance, E.; Potts, C.; Raghunathan, A.; Reich, R.; Ren, H.; Rong, F.; Roohani, Y.; Ruiz, C.; Ryan, J.; Ré, C.; Sadigh, D.; Sagawa, S.; Santhanam, K.; Shih, A.; Srinivasan, K.; Tamkin, A.; Taori, R.; Thomas, A.W.; Tramèr, F.; Wang, R.E.; Wang, W.; Wu, B.; Wu, J.; Wu, Y.; Xie, S.M.; Yasunaga, M.; You, J.; Zaharia, M.; Zhang, M.; Zhang, T.; Zhang, X.; Zhang, Y.; Zheng, L.; Zhou, K.; Liang, P. (2022): On the Opportunities and Risks of Foundation Models. Stanford: Center for Research on Foundation Models, Stanford Institute for Human-Centered Artificial Intelligence, Stanford University.
- Bommasani, R.; Kapoor, S.; Klyman, K.; Longpre, S.; Ramaswami, A.; Zhang, D.; Schaake, D.; Ho, D.E.; Narayanan, A.; Liang, P. (2023): Considerations for Governing Open Foundation Models. Stanford: Issue Brief HAI Policy & Society.
- Borjas, G.J.; Doran, K.B. (2012): The Collapse of the Soviet Union and the Productivity of American Mathematicians. *Quarterly Journal of Economics*. 127(3). pp. 1143–1203.
- Bornmann, L. (2016): Is the Promotion of Research Reflected in Bibliometric Data? A Network Analysis of Highly Cited Papers on the Clusters of Excellence Supported under the Excellence Initiative in Germany. *Scientometrics*. 107(3). pp. 1041–1061.
- Boudreau, K.J.; Brady, T.; Ganguli, I.; Gaule, P.; Guinan, E.; Hollenberg, A.; Lakhani, K.R. (2017): A Field Experiment on Search Costs and the Formation of Scientific Collaborations. *Review of Economics and Statistics*. 99(4). pp. 565–576.
- Brynjolfsson, E.; Rock, D.; Syverson, C. (2019): Artificial Intelligence and the Modern Productivity Paradox: A Clash of Expectations and Statistics. In: Agrawal, A.; Gans, J.; Goldfarb, A. (Eds.), *The Economics of Artificial Intelligence: An Agenda*. National Bureau of Economic Research conference report. Chicago: The University of Chicago Press.
- Büchel, J.; Engler, J.; Mertens, A. (2023): KI-Einsatzbereiche in Deutschland. Eine Analyse von KI-Stellenanzeigen. Gutachten im Projekt „Entwicklung und Messung der Digitalisierung der Wirtschaft am Standort Deutschland“. Berlin: BMWK.
- Büchele, S.; Bünstorf, G.; Cantner, U.; Dreier, L.; Meurer, P.; Neumann, L.P. (2024): Commissioned Project Evaluations of Research and Innovation Policy in Germany: A Review. Studien zum deutschen Innovationssystem. No. 11–2024. Berlin: EFI.
- Bureau of European Policy Advisor (2010): Empowering People, Driving Change: Social Innovation in the European Union.
- Carayol, N.; Maublanc, F. (2022): Can Money Buy Scientific Leadership? The Impact of Excellence Programs on German and French Universities. Bordeaux: Université de Bordeaux.
- Card, D.; Krueger, A.B. (1994): Minimum Wages and Employment: A Case Study of the Fast-Food Industry in New Jersey and Pennsylvania. *The American Economic Review*. 84(4). pp. 772–793.
- Chai, S.; Freeman, R.B. (2019): Temporary Colocation and Collaborative Discovery. Who Confers at Conferences. *Strategic Management Journal*. 40(13). pp. 2138–2164.
- Coad, A.; Nightingale, P.; Stilgoe, J.; Vez-zani, A. (2021): Editorial. The Dark Side of Innovation. *Industry and Innovation*. 28(1). pp. 102–112.
- Coda-Zabetta, M.; Lissoni, F.; Miguelez, E. (2024): International Mobility and Collaboration of German Scientists, 2005-2020. Studien zum deutschen Innovationssystem. No. 8-2024. Berlin: EFI.
- Conde Gallego, B.; Drexler, J.; Harhoff, D. (2015): Standardessentielle Patente: Die Rolle von Standardsetzungsorganisationen. Munich: MPG.
- Curtis, T.; Bull, M.; Nowack, V. (2023): The Rising Tide of Criticality in Social Entrepreneurship and Social Innovation. *NOvation-Critical Studies of Innovation*. 4. pp. 8–34.
- Czarnitzki, D.; Fernández, G.P.; Rammer, C. (2023): Artificial Intelligence and Firm-level Productivity. *Journal of Economic Behavior & Organization*. 211. pp. 188–205.
- Dallendörfer, M.; Dieken, S.; Henseleit, M.; Siekmann, F.; Venghaus, S. (2022): Investigating Citizens' Perceptions of the Bioeconomy in Germany – High Support but Little Understanding. Sustainable Production and Consumption. 30(2). pp. 16–30.

- Dederer, H.-G. (2024): Kurzstudie zu Gentechnikrecht und Patentrecht bei Pflanzen. Studien zum deutschen Innovationssystem. No. 6–2024. Berlin: EFI.
- DellaVigna, S.; Linos, E. (2022): RCTs to Scale. Comprehensive Evidence From Two Nudge Units. *Econometrica*. 90(1). pp. 81–116.
- Destatis – Statistisches Bundesamt (2023): Volkswirtschaftliche Gesamtrechnungen. Inlandsproduktberechnung Lange Reihen ab 1970. Wiesbaden: Destatis.
- Deutsche Akademie der Naturforscher Leopoldina e.V.; Deutsche Forschungsgemeinschaft; Union der Deutschen Akademien der Wissenschaften e.V (2019): Stellungnahme – Wege zu einer wissenschaftlich begründeten, differenzierten Regulierung genomeditierter Pflanzen in der EU. Schriftenreihe zur wissenschaftsbasierten Politikberatung. Halle (Saale), Berlin, Mainz: Leopoldina.
- Deutscher Bundestag (1936): Patentgesetz. PatG.
- Deutscher Bundestag (2008): Verordnung über die gute fachliche Praxis bei der Erzeugung gentechnisch veränderter Pflanzen. GenTPfAEV.
- Deutscher Bundestag (2021a): Gesetz zur Regelung der Gentechnik. GenTG.
- Deutscher Bundestag (2021b): Sortenschutzgesetz.
- Deutscher Bundestag (2022): Verordnung zur Regelung des Betriebs von Kraftfahrzeugen mit automatisierter und autonomer Fahrfunktion und zur Änderung straßenverkehrsrechtlicher Vorschriften.
- Deutscher Bundestag (2023a): Antwort der Bundesregierung auf die Kleine Anfrage der Fraktion der CDU/CSU. Aktueller Umsetzungsstand der Zukunftsstrategie Forschung und Innovation. Drucksache. 20/8152.
- Deutscher Bundestag (2023b): Bericht zur Halbzeit der Agenda 2030 für nachhaltige Entwicklung. Mit Mut gemeinsam Zukunft gestalten – weiter Fahrt aufnehmen. Drucksache. 20/8719.
- Deutscher Bundestag (2023c): Entwurf eines Gesetzes über die Arbeitsweise der Bundesagentur für Sprunginnovationen und zur Flexibilisierung ihrer rechtlichen und finanziellen Rahmenbedingungen (SPRIND-Freiheitsgesetz – SPRINDFG). Beschlussempfehlung und Bericht des Ausschusses für Bildung, Forschung und Technikfolgenabschätzung (18. Ausschuss). Drucksache. 20/9362.
- Deutscher Bundestag (2023d): Entwurf eines Gesetzes zur Stärkung von Wachstumschancen, Investitionen und Innovation sowie Steuervereinfachung und Steuerfairness (Wachstumschancengesetz). Gesetzentwurf der Bundesregierung. Drucksache. 20/8628.
- Die Bundesregierung (2014): Die neue Hightech-Strategie – Innovationen für Deutschland. Berlin/Bonn: Die Bundesregierung.
- Die Bundesregierung (2018): Strategie Künstliche Intelligenz der Bundesregierung. Berlin/Bonn: Die Bundesregierung.
- Die Bundesregierung (2019): Zwischenbericht ein Jahr KI-Strategie.
- Die Bundesregierung (2020): Strategie Künstliche Intelligenz der Bundesregierung. Fortschreibung 2020. Berlin: Die Bundesregierung.
- Die Bundesregierung (2022): Erreichung der 17 globalen Nachhaltigkeitsziele wichtiger denn je – Einrichtung von Transformationsteams beschlossen. Press release dated 13 September 2022.
- Die Bundesregierung (2023a): Fortschritt durch Datennutzung. Strategie für mehr und bessere Daten für neue, effektive und zukunftsweisende Datennutzung. Berlin: BMDV.
- Die Bundesregierung (2023b): Nationale Strategie für Soziale Innovationen und Gemeinwohlorientierte Unternehmen. Berlin: BMWK; BMBF.
- Die Bundesregierung (2023c): Nationaler Aktionsplan für den Europäischen Forschungsraum. Bonn: BMBF.
- Die Bundesregierung (2023d): Zukunftsstrategie Forschung und Innovation. Berlin: BMBF.
- DIHK – Deutscher Industrie- und Handelskammertag (2022): Mit Innovationen Krisen meistern. Kurzbefragung zur Forschungszulage. Berlin, Brussels: DIHK.
- DIN (2019): Leitfaden für standardessentielle Patente. Press release dated 26 June 2019.
- Döbel, I.; Leis, M.; Vogelsang, M.; Neustroev, D.; Petzka, H.; Riemer, A.; Rüpping, S.; Voss, A.; Wegele, M.; Welz, J. (2018): Maschinelles Lernen. Eine Analyse zu Kompetenzen, Forschung und Anwendung. Funded by the Federal Ministry of Education and Research. Munich: Fraunhofer-Gesellschaft.
- Doherty, B.; Haugh, H.; Lyon, F. (2014): Social Enterprises as Hybrid Organizations. A Review and Research Agenda. *International Journal of Management Reviews*. 16(4). pp. 417–436.
- DWD – Deutscher Wetterdienst (2022a): 6 Nationaler Klimareport. Offenbach: DWD.
- DWD – Deutscher Wetterdienst (2022b): Was wir 2022 über das Extremwetter in Deutschland wissen. Offenbach: DWD.
- Edler, J.; Ostertag, K.; Schuler, J. (2023): Social Innovation, Transformation, and Public Policy. Towards a Conceptualization and Critical Appraisal. *Science and Public Policy*. 1-9.
- Edwards-Schachter, M.; Wallace, M.L. (2017): ‘Shaken, But Not Stirred’: Sixty Years of Defining Social Innovation. *Technological Forecasting and Social Change*. 119 pp. 64–79.
- EFI – Expertenkommission Forschung und Innovation (2012): Report on Research, Innovation and Technological Performance in Germany 2012. Berlin: EFI.
- EFI – Expertenkommission Forschung und Innovation (2013): Report on Research, Innovation and Technological Performance in Germany 2013. Berlin: EFI.
- EFI – Expertenkommission Forschung und Innovation (2014): Report on Research, Innovation and Technological Performance in Germany 2014. Berlin: EFI.
- EFI – Expertenkommission Forschung und Innovation (2016): Report on Research, Innovation and Technological Performance in Germany 2016. Berlin: EFI.
- EFI – Expertenkommission Forschung und Innovation (2017): Report on Research, Innovation and Technological Performance in Germany 2017. Berlin: EFI.
- EFI – Expertenkommission Forschung und Innovation (2018): Report on Research, Innovation and Technological Performance in Germany 2018. Berlin: EFI.
- EFI – Expertenkommission Forschung und Innovation (2019): Report on Research, Innovation and Technological Performance in Germany 2019. Berlin: EFI.
- EFI – Expertenkommission Forschung und Innovation (2021): Report on Research, Innovation and Technological Performance in Germany 2021. Berlin: EFI.
- EFI – Expertenkommission Forschung und Innovation (2022): Report on Research, Innovation and Technological Performance in Germany 2022. Berlin: EFI.
- EFI – Expertenkommission Forschung und Innovation (2023): Report on Research, Innovation and Technological Performance in Germany 2023. Berlin: EFI.
- Euclid Network – Dupain, W.; Scharpe, K.; Gazeley, T.; Bennett, T.; Mair, J.; Raith, M.; Bosma, N. (2022): The State of Social Enterprise in Europe –. *European Social Enterprise Monitor 2021–2022*: Euclid Network.
- Europäische Kommission (2011): Schaffung eines „Ökosystems“ zur Förderung der Sozialunternehmen als Schlüsselakteure der Sozialwirtschaft und der sozialen Innovation. Initiative für soziales Unternehmertum. Mitteilung der Kommission an das Europäische Parlament, den Rat, den

- Europäischen Wirtschafts- und Sozialausschuss und den Ausschuss der Regionen. COM(2011) 682 final.
- Europäische Kommission (2014): Verordnung (EU) Nr. 651/2014 der Kommission vom 17. Juni 2014 zur Feststellung der Vereinbarkeit bestimmter Gruppen von Beihilfen mit dem Binnenmarkt in Anwendung der Artikel 107 und 108 des Vertrags über die Arbeitsweise der Europäischen Union.
- Europäische Kommission (2019): Durchführungsverordnung der Kommission über die Vorschriften und Verfahren für den Betrieb unbemannter Luftfahrzeuge. EU 2019/947.
- Europäische Kommission (2020): Sozialunternehmen und ihre Ökosysteme in Europa. Zusammenfassung des Synthesenberichts. Amt für Veröffentlichungen der Europäischen Union. Luxembourg.
- Europäische Kommission (2023a): Vorschlag für eine Verordnung des Europäischen Parlaments und des Rates über mit bestimmten neuen genomischen Techniken gewonnene Pflanzen und die aus ihnen gewonnenen Lebens- und Futtermittel sowie zur Änderung der Verordnung (EU) 2017/625. EU 2023/0226.
- Europäische Kommission (2023b): Vorschlag für eine Verordnung des Europäischen Parlaments und des Rates über standardessenzielle Patente und zur Änderung der Verordnung (EU) 2017/1001.
- Europäische Kommission (2023c): Schutz des geistigen Eigentums: EU-Kommission legt Vorschlag für neue Patentvorschriften vor. Press release dated 27 April 2023.
- Europäische Kommission; Joint Research Centre (2020): Pilot Study for Essentiality Assessment of Standard Essential Patents. Luxembourg: Publications Office of the European Union.
- Europäischer Gerichtshof (2018): Absichtliche Freisetzung genetisch veränderter Organismen in die Umwelt – Mutagenese – Richtlinie 2001/18/EG: Europäischer Gerichtshof.
- European Parliament (2001): Directive 2001/18/EC of the European Parliament and of the Council of 12 March 2001 on the deliberate release into the environment of genetically modified organisms and repealing Council Directive 90/220/EEC. 2001/18/EC.
- European Parliament (2018): Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007. (EU) 2018/848.
- European Parliament (2023): Regulation (EU) 2023/2854 of the European Parliament and of the Council of 13 December 2023 on harmonised rules on fair access to and use of data and amending Regulation (EU) 2017/2394 and Directive (EU) 2020/1828 (Data Act). (EU) 2023/2854.
- European Commission – José Manuel Durão Barroso (2011): Europe Leading Social Innovation: European Commission.
- European Commission (2017a): Commission Recommendation on the European Pillar of Social Rights. C (2017) 2600 final.
- European Commission (2017b): Social Innovation as a Trigger for Transformations – The role of Research.
- European Commission (2021a): Annexes to the Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions Fostering a European Approach to Artificial Intelligence. Brussels: European Commission.
- European Commission (2021b): Study on the Status of New Genomic Techniques under Union Law and in Light of the Court of Justice Ruling in Case C-528/16. Brussels: European Commission.
- European Commission Directorate-General Research and Innovation (2010): A Decade of EU-funded GMO Research (2001-2010). Brussels: European Commission.
- European Commission Regulatory Scrutiny Board (2023): Impact Assessment/Legislation for Plants Produced by Certain New Genomic Techniques. Brussels: European Commission.
- European Parliament, The Council of the European Union (2021): Regulation (EU) 2021/695 of the European Parliament and of the Council of 28 April 2021 Establishing Horizon Europe–The Framework Programme for Research and Innovation, Laying down its Rules for Participation and Dissemination, and Repealing Regulations (EU) No 1290/2013 and (EU) No 1291/2013. Official Journal of the European Union, L 170. pp. 1–68.
- FAO – Food and Agriculture Organization of the United Nations (2022): Drivers and Triggers for Transformation. The future of food and agriculture. Rome: FAO.
- Finger, L.; Schmitt, J.; Stenke, G. (2023): Drei Jahre Forschungszulage: Ein erstes Fazit zur Resonanz. Essen: Stifterverband.
- Finger, R. (2023): Digital Innovations for Sustainable and Resilient Agricultural Systems. European Review of Agricultural Economics. 50(4). pp. 1277–1309.
- Fountas, S.; Sorensen, C. G.; Tsiropoulos, Z.; Cavalari, C.; Liakos, V.; Gemtos, T. (2015): Farm Machinery Management Information System. Computers and electronics in agriculture. 110. pp. 131–138.
- Franzoni, C.; Scellato, G.; Stephan, P.E. (2012): Foreign Born Scientists: Mobility Patterns for Sixteen Countries. Cambridge, MA: NBER.
- Franzoni, C.; Scellato, G.; Stephan, P.E. (2014): The Mover's Advantage. The Superior Performance of Migrant Scientists. Economics Letters. 122(1). pp. 89–93.
- Fursov, K.; Linton, J. (2022): Social Innovation. Integrating Product and User Innovation. Technological Forecasting and Social Change. 174. p. 121224.
- Ganguli, I. (2015): Immigration and Ideas. What Did Russian Scientists "Bring" to the United States? Journal of Labor Economics. 33(1). pp. 257–288.
- Gault, F. (2012): User Innovation and the Market. Science and Public Policy. 39(1). pp. 118–128.
- Geels, F.W.; Schot, J. (2007): Typology of Sociotechnical Transition Pathways. Research Policy. 36(3). pp. 399–417.
- Geppert, F.; Krachunova T.; Bellingrath-Kimura, S. (2024): Digital and Smart Technologies in Agriculture in Germany: Identification of Key Recommendations for Sustainability Actions. Studien zum deutschen Innovationssystem. No. 4–2024. Berlin: EFI.
- Granstrand, O.; Holgersson, M. (2020): Innovation Ecosystems. A Conceptual Review and a New Definition. Technovation. 90-91(11). p. 102098.
- Groysberg, B.; Lee, L.-E. (2009): Hiring Stars and Their Colleagues. Exploration and Exploitation in Professional Service Firms. Organizational Ambidexterity. 20(4). pp. 740–758.
- Guthrie, S.; Lichten, C.; Harte, E.; Parks, S.; Wooding, S. (2017): International Mobility of Researchers. A Survey of Researchers in the UK. Santa Monica, CA, Cambridge, UK: Rand Corporation.
- Hallmann, C.A.; Sorg, M.; Jongejans, E.; Siepel, H.; Hofland, N.; Schwan, H.; Stenmans, W.; Müller, A.; Sumser, H.; Hörrn, T.; Goulson, D.; Kroon, H. de (2017): More than 75 percent decline over 27 years in total flying insect biomass in protected areas. PLoS one. 12(10). e0185809.
- Harhoff, D.; Kagermann, H.; Stratmann, M. (2018): Impulse für Sprunginnovationen in Deutschland. acatech DISKUSSION. Munich: Herbert Utz Verlag.
- Hartung, F.; Krause, D.; Sprink, T.; Wilhelm, R. (2024): Kurzstudie über Anwendungen der Grünen Gentechnik in der Landwirtschaft – Potenziale und Risiken. Studien zum deutschen Innovationssystem. No. 5–2024. Berlin: EFI.

- Havas, A.; Molnár, G. (2020): A Multi-Channel Interactive Learning Model of Social Innovation. CERS-IE WP 24
- Hellfeier, M.; Hendricks, S. (2022): We-geisend. Das Urteil zur Beamtenversorgung bei Wechsel ins EU-Ausland. *Forschung & Lehre* (11). pp. 874–875.
- Herrero, M.; Thornton, P.K.; Mason-D’Croz, D.; Palmer, J.; Bodirsky, B.L.; Pradhan, P.; Barrett, C.B.; Benton, T.G.; Hall, A.; Pikaar, I.; Bogard, J.R.; Bonnett, G.D.; Bryan, B.A.; Campbell, B.M.; Christensen, S.; Clark, M.; Fanzo, J.; Godde, C.M.; Jarvis, A.; Loboguerrero, A.M.; Mathys, A.; McIntyre, C.L.; Naylor, R.L.; Nelson, R.; Obersteiner, M.; Parodi, A.; Popp, A.; Ricketts, K.; Smith, P.; Valin, H.; Vermeulen, S.J.; Vervoort, J.; van Wijk, M.; van Zanten, H.H.E.; West, P.C.; Wood, S.A.; Rockström, J. (2021): Articulating the Effect of Food Systems Innovation on the Sustainable Development Goals. *The Lancet Planetary Health*. 5(1).
- Hippel, E. von (1976): The Dominant Role of Users in the Scientific Instrument Innovation Process. *Research Policy*. 5(3). pp. 212–239.
- Hippel, E. von (1988): *The Sources of Innovation*: Oxford University Press.
- Hippel, E. von (2005): *Democratizing Innovation*. MIT Press, Cambridge, MA.
- Hirschfeld, J.; Schulze, N.; Hock, A. (2021): Priorisierung einzelner Schadens- und Kostendimensionen der Folgen des Klimawandels. Kurzstudie im Rahmen des Projektes Kosten durch Klimawandelfolgen in Deutschland. Berlin: BMUV.
- Hoisl, K. (2007): Tracing Mobile Inventors. The Causality Between Inventor Mobility and Inventor Productivity. *Research Policy*. 36(5). pp. 619–636.
- Howaldt, J.; Kaletka, C.; Schröder, A.; Zirngiebl, M. (2019): *Atlas of Social Innovation*. 2nd Volume. A World of New Practices: oekom verlag.
- Howaldt, J.; Schwarz, M. (2010). Social Innovation: Concepts, Research Fields and International Trends. In: K. Henning & F. Hees (Eds.), *Studies for Innovation in a Modern Working Environment* (Vol. 5): IMA/ZLW & IfU.
- Huang, H. (2017): Invisible Constraints. The Relationship among Non-Competition Agreements, Inventor Mobility, and Patent Commercialization. *Science and Public Policy*. 44(3). 341–353.
- Hunter, R.S.; Oswald, A.J.; Charlton, B.G. (2009): The Elite Brain Drain. *The Economic Journal*. 119(538). pp. 231–251.
- IEKE – Internationale Expertenkommission zur Evaluation der Exzellenzinitiative (2016): *Endbericht*. Berlin: IEKE.
- Imbens, G.W.; Wooldridge, J.M. (2009): Recent Developments in the Econometrics of Program Evaluation. *Journal of Economic Literature*. 47(1). pp. 5–86.
- Jägermeyr, J.; Müller, C.; Ruane, A.C.; Elliott, J.; Balkovic, J.; Castillo, O.; Faye, B.; Foster, I.; Folberth, C.; Franke, J.A.; Fuchs, K.; Guarin, J.R.; Heinke, J.; Hoogenboom, G.; Iizumi, T.; Jain, A.K.; Kelly, D.; Khabarov, N.; Lange, S.; Lin, T.-S.; Liu, W.; Mialyk, O.; Minoli, S.; Moyer, E.J.; Okada, M.; Phillips, M.; Porter, C.; Rabin, S.S.; Scheer, C.; Schneider, J.M.; Schyns, J.F.; Skalsky, R.; Smerald, A.; Stella, T.; Stephens, H.; Webber, H.; Zabel, F.; Rosenzweig, C. (2021): Climate Impacts on Global Agriculture Emerge Earlier in New Generation of Climate and Crop Models. *Nature Food*. 2(11). pp. 873–885.
- Jaudzims, S.; Oberschelp, A. (2023): Internationale Wissenschaftlerinnen und Wissenschaftler an deutschen Hochschulen: Von der Postdoc-Phase zur Professur (InWiDeHo). Eine Analyse von Herausforderungen und Gelingensbedingungen. DAAD Studien. Bonn: DAAD.
- Joint Research Centre; Brothoarts, W.; Jacchia, S.; Angers, A.; Petrillo, M.; Querci, M.; Savini, C.; van den Eede, G.; Emons, H. (2021a): *New Genomic Techniques – State-of-the-art Review*. Brussels: European Commission.
- Joint Research Centre; Parisi, C.; Rodriguez-Cerezo, E. (2021b): *Current and Future Market Applications of New Genomic Techniques*. Brussels: European Commission.
- Jung, C.; Till, B. (2021): Mutagenesis and Genome Editing in Crop Improvement. Perspectives for the Global Regulatory Landscape. *Trends in Plant Science*. 26(12). pp. 1258–1269.
- Karaulova, M.; Kroll, H.; Garcia Chavez, C.; Berghäuser, H.; Schilling, N.; Gruber, S.; Frietsch, R.; Rothengatter, O.; Neuhäusler, P. (2024): *Researcher Mobility and Cooperation in the Science System*. Studien zum deutschen Innovationssystem. No. 9-2024. Berlin: EFI.
- Kato-Nitta, N.; Tachikawa, M.; Inagaki, Y.; Maeda, T. (2023): Public Perceptions of Risks and Benefits of Gene-edited Food Crops. An International Comparative Study between the US, Japan, and Germany. *Science, Technology, & Human Values*. 48(6). pp. 1360–1392.
- Kaufmann, Tanja, Katharina Schiller, Linda Widdel (2022): *Towards successful bottom-up transitions: Conceptualizing transformative capacities of individuals in social innovations Working Paper Sustainability and Innovation*. S08/2022.
- Kehl, C.; Meyer, R.; Steiger, S. (2021a): *Digitalisierung der Landwirtschaft. Teil I: Technologischer Stand und Perspektiven*. TAB-Arbeitsbericht (193).
- Kehl, C.; Meyer, R.; Steiger, S. (2021b): *Digitalisierung der Landwirtschaft. Teil II: Gesellschaftliche Voraussetzungen, Rahmenbedingungen und Effekte*. TAB-Arbeitsbericht (194).
- Khanal, S.; KC, K.; Fulton, J.P.; Shearer, S.; Ozkan, E. (2020): Remote Sensing in Agriculture—Accomplishments, Limitations, and Opportunities. *Remote Sensing*. 12(22). p. 3783.
- Kinne, J.; Axenbeck, J. (2020): *Web Mining for Innovation Ecosystem Mapping. A Framework and a Large-Scale Pilot Study*. *Scientometrics*. 125(3). pp. 2011–2041.
- Kliem, L.; Krachunova, T.; Lange, S.; Wagner, J.; Bellingrath-Kimura, S. (2023): *Chancen und Risiken der Digitalisierung in der Landwirtschaft aus Sicht des Umwelt- und Naturschutzes*. Bonn: Bundesamt für Naturschutz.
- Klümper, W.; Qaim, M. (2014): A Meta-analysis of the Impacts of Genetically Modified Crops. *PLoS one*. 9(11). 111629
- Krizhevsky, A.; Sutskever, I.; Hinton, G.E. (2012): *Imagenet Classification with Deep Convolutional Neural Networks*. *Advances in Neural Information Processing Systems*. 25. pp. 1097–1105.
- Krlev, G.; Mildenerger, G.; Maier-Lohmann, I. (2020): *Indikatorik Soziale Innovationen: Ergebnisse der Messung regionaler Innovationskapazitäten*. Heidelberg: Universität Heidelberg, Forschungsstelle Centrum für Soziale Investitionen und Innovationen.
- Krlev, G.; Mildenerger, G.; Strambach, S.; Terstriep, J.; Thurmann, J.; Wloka L. (2021): *Codebuch Indikatorik Soziale Innovation (IndiSI) – Zur Messung sozialer Innovationen*. Gelsenkirchen: Westfälische Hochschule Gelsenkirchen.
- Kuittinen, H.; Polt, W.; Weber, M. (2018): *Mission Europe? A Revival of Mission-Oriented Policy in the European Union*. *Rethinking Europe. Positions on Shaping an Idea*. pp. 197–213.
- Larsson, O.S.; Brandsen, T. (2016): *The Implicit Normative Assumptions of Social Innovation Research. Embracing the Dark Side*. In: Brandsen, T.; Cattacin, S.; Evers, A.; Zimmer, A.: *Social Innovations in the Urban Context*.
- Lee, D.S.; Lemieux, T. (2010): *Regression Discontinuity Designs in Economics*. *Journal of Economic Literature*. 48(2). pp. 281–355.

- Lee, M.; Huang, L. (2018): Gender Bias, Social Impact Framing, and Evaluation of Entrepreneurial Ventures. *Organization Science*. 29(1). pp. 1–16.
- Lepori, B.; Seeber, M.; Bonaccorsi, A. (2015): Competition for Talent. Country and Organizational-Level Effects in the Internationalization of European Higher Education Institutions. *Research Policy*. 44(3). pp. 789–802.
- Lerner, J.; Tirole, J. (2002): Some Simple Economics of Open Source. *The Journal of Industrial Economics*. 50(2). pp. 197–234.
- LexisNexis (2023): Who Is Leading the 5G Patent Race? 2023 New York: LexisNexis.
- Luitse, D.; Denkena, W. (2021): The Great Transformer. Examining the Role of Large Language Models in the Political Economy of AI. *Big Data & Society*. 8(2). 205395172110477
- Malmström, M.; Voikane, A.; Johansson, J.; Wincent, J. (2020): What Do They Think and What Do They Say? Gender Bias, Entrepreneurial Attitude in Writing and Venture Capitalists' Funding Decisions. *Journal of Business Venturing Insights*. 13 00154
- Maslej, N.; Fattorini, L.; Brynjolfsson, E.; Etchemendy, J.; Ligett, K.; Lyons, T.; Maniyika, J.; Ngo, H.; Niebles, J. C.; Parli, V.; Shoham, Y.; Wald, R.; Clark, J.; Perrault, R. (2023): The AI Index 2023 Annual Report. Stanford: AI Index Steering Committee, Institute for Human-Centered AI, Stanford University.
- Mayr, K.; Peri, G. (2009): Brain Drain and Brain Return. Theory and Application to Eastern-Western Europe. *The B. E. Journal of Economic Analysis & Policy*. 9(1). pp. 1–52.
- Metzger, G. (2019): Social Entrepreneurs in Deutschland: Raus aus der Nische – 154.000 „junge“ Sozialunternehmer im Jahr 2017: KfW Research, Fokus Volkswirtschaft, (238).
- Möller, T.; Schmidt, M.; Hornbostel, S. (2016): Assessing the Effects of the German Excellence Initiative with Bibliometric Methods. *Scientometrics*. 109(3). pp. 2217–2239.
- Moretti, E.; Steinwender, C.; van Reenen, J. (2019): The Intellectual Spoils of War? Defense R&D, Productivity and International Spillovers. Cambridge, MA: National Bureau of Economic Research.
- Mountford, A. (1997): Can a Brain Drain Be Good for Growth in the Source Economy? *Journal of Development Economics*. 53(2). pp. 287–303.
- Netz, N.; Hampel, S.; Aman, V. (2020): What Effects Does International Mobility Have on Scientists' Careers? A Systematic Review. *Research Evaluation*. 29(3). pp. 327–351.
- Netzwerk der Projektträger (2023): Administrative Fesseln der Innovationsförderung abstreifen: SPRIND-Freiheitsgesetz breiter denken. Diskussionsimpuls des Netzwerks der Projektträger. Düsseldorf: Netzwerk der Projektträger.
- Nielsen, H. Ø.; Konrad, M. T. H.; Pedersen, A. B.; Gyldenkerne, S. (2023): Ex-post Evaluation of the Danish Pesticide Tax. A Novel and Effective Tax Design. *Land Use Policy*. 126(1). 106549
- No author (2023): Digitalstrategie. Gemeinsam digitale Werte schöpfen.
- OECD – Organisation for Economic Co-operation and Development (2017): OECD Science, Technology and Industry Scoreboard 2017. The Digital Transformation. Paris: OECD.
- OECD – Organisation for Economic Co-operation and Development (2022): Designing Legal Frameworks for Social Enterprises.
- Otto, B.; Seidelmann, J.; Schmelting, J.; Sauer, O. (2023): Vorstudie Datenraum Manufacturing-X. Architektur, Basisdienste und Organisation unter Berücksichtigung der Spezifika der ausrustenden Industrie. Frankfurt a. M.: Fraunhofer, VDMA, ZVEI.
- Pallante, G.; Russo, E.; Roventini, A. (2023): Does Public R&D Funding Crowd-in Private R&D Investment? Evidence from Military R&D Expenditures for US States. *Research Policy*. 52(8). p. 104807.
- Phills Jr., J. A.; Deiglmeier, K.; Miller, D. T. (2008): Rediscovering Social Innovation. *Stanford Social Innovation Review*. 6(4). pp. 34–43.
- Poitras, C.; Larivière, V. (2023): Research Mobility to the United States. A Bibliometric Analysis. *Scientometrics*. 128(4). pp. 2601–2614.
- Purnhagen, K. P.; Clemens, S.; Eriksson, D.; Fresco, L. O.; Tosun, J.; Qaim, M.; Visser, R. G. F.; Weber, A. P. M.; Wesseler, J. H. H.; Zilberman, D. (2021): Europe's Farm to Fork Strategy and Its Commitment to Biotechnology and Organic Farming. Conflicting or Complementary Goals? *Trends in Plant Science*. 26(6). pp. 600–606.
- Qaim, M. (2020): Role of New Plant Breeding Technologies for Food Security and Sustainable Agricultural Development. *Applied Economic Perspectives and Policy*. 42(2). pp. 129–150.
- Rammer, C. (2023a): Das Ökosystem für KI-Startups in Deutschland. Vermarktung, Finanzierung, Fachkräfte und Vernetzung in Unternehmensgründungen im Bereich Künstliche Intelligenz. Berlin: BMWK.
- Rammer, C. (2023b): Erfahrungen mit der Umsetzung der Forschungszulage im Maschinen- und Anlagenbau. Ergebnisse einer Befragung des VDMA. Mannheim: ZEW.
- Rammer, C. (2023c): Innovationsindikatoren Chemie und Pharma. Schwerpunktthema: Steuerliche Forschungsförderung. Mannheim, Hannover: ZEW; Leibniz Universität Hannover.
- Rammer, C.; Fernández, G. P.; Czarnitzki, D. (2022): Artificial Intelligence and Industrial Innovation. Evidence from German Firm-level Data. *Research Policy*. 51(7). p. 104555.
- Rassenfosse, G. de; Pellegrino, G. (2024): International Mobility of Inventors and Innovation. Empirical Evidence from the Collapse of the Soviet Union. *Economics Letters*. 234(9). p. 111450.
- RatSWD – Rat für Sozial- und Wirtschaftsdaten (2023): Forschungsdatengesetz: Was zentral ist. Ergebnis des Konsultationsprozesses aus Sicht des RatSWD. Berlin: RatSWD.
- Renko, M. (2013): Early Challenges of Nascent Social Entrepreneurs. *Entrepreneurship Theory and Practice*. 37(5). pp. 1045–1069.
- RfII – Rat für Informationsinfrastrukturen (2023): Anforderungen an die Ausgestaltung eines Forschungsdatengesetzes und eines Dateninstituts. Diskussionsimpuls. Göttingen: RfII.
- Rivieccio, G.; Raies, K.; Schiavone, F. (2023): Are You Attractive Enough? An Empirical Analysis on User Innovators' Characteristics and the Creation of New Social Ventures. *Technological Forecasting and Social Change*. 189 p. 122383.
- Rueede, D.; Lurtz, K. (2012): Mapping the Various Meanings of Social Innovation: Towards a Differentiated Understanding of an Emerging Concept. EBS Business School Research Paper No. 12-03. 2012(12-03).
- Saiz-Rubio, V.; Rovira-Más, F. (2020): From Smart Farming towards Agriculture 5.0. A Review on Crop Data Management. *Agronomy*. 10(2). p. 207.
- Sardo, S.; Callegari, B.; Misganaw, B. A. (2023): Everything and Nothing. A Critical Review of the “Social” in Innovation and Entrepreneurship Studies. *NOvation-Critical Studies of Innovation*. 4 p. 63.
- Scellato, G.; Franzoni, C.; Stephan, P. (2015): Migrant Scientists and International Networks. *Research Policy*. 44(1). pp. 108–120.
- Schlepphorst, S.; Welter, F.; Holz, M. (2022): Die gesellschaftliche Wertschöpfung des Mittelstands: IfM-Materialien.

- Schmitt, J.; Offermann, F.; Söder, M.; Frühauf, C.; Finger, R. (2022): Extreme Weather Events Cause Significant Crop Yield Losses at the Farm Level in German Agriculture. *Food Policy*. 112 102359
- Schweitzer, F.; Rau, C.; Gassmann, O.; van den Hende, E. (2015): Technologically Reflective Individuals as Enablers of Social Innovation. *Journal of Product Innovation Management*. 32(6). pp. 847–860.
- Seger, E.; Dreksler, N.; Moulange, R.; Dardaman, E.; Schuett, J.; Wei, K.; Winter, C.; Arnold, M.; Ó hÉigeartaigh, S.; Korinek, A.; Anderljung, M.; Bucknall, B.; Chan, A.; Stafford, E.; Koessler, L.; Ovadya, A.; Garfinkel, B.; Bluemke, E.; Aird, M.; Levermore, P.; Hazell, J.; Gupta, A. (2023). Open-Sourcing Highly Capable Foundation Models: An Evaluation of Risks, Benefits, and Alternative Methods for Pursuing Open-Source Objectives. *arXiv preprint arXiv:2311.09227*.
- Sengers, F.; Turnheim, B.; Berkhout, F. (2021): Beyond experiments: Embedding outcomes in climate governance. *Environment and Planning C: Politics and Space*. 39(6). pp. 1148–1171.
- Siqueira, A. C. O.; Guenster, N.; Vanacker, T.; Crucke, S. (2018): A Longitudinal Comparison of Capital Structure between Young For-Profit Social and Commercial Enterprises. *Journal of Business Venturing*. 33(2). pp. 225–240.
- Snellman, K.; Solal, I. (2023): Does Investor Gender Matter for the Success of Female Entrepreneurs? Gender Homophily and the Stigma of Incompetence in Entrepreneurial Finance. *Organization Science*. 34(2). pp. 680–699.
- Spök, A.; Sprink, T.; Allan, A. C.; Yamaguchi, T.; Dayé, C. (2022): Towards Social Acceptability of Genome-Edited Plants in Industrialised Countries? Emerging Evidence from Europe, United States, Canada, Australia, New Zealand, and Japan. *Frontiers in Genome Editing*. 4 899331
- SPRIND – Bundesagentur für Sprunginnovationen (2022): Gesucht: Koalition der Willigen in Politik, Forschungseinrichtungen und Hochschulen für einen IP-Transfer 3.0. Leipzig: SPRIND.
- SPRIND – Agentur für Sprunginnovationen (2023): Neue Wege im IP-Transfer an deutschen Wissenschaftseinrichtungen. Policy Paper. 11/23. Berlin: SPRIND.
- Stephan, U.; Uhlauer, L. M.; Stride, C. (2015): Institutions and Social Entrepreneurship. The Role of Institutional Voids, Institutional Support, and Institutional Configurations. *Journal of International Business Studies*. 46. pp. 308–331.
- Stitteneder, T. (2023): Die ökologische und soziale Transformation. Mit Sozialunternehmen auf dem Weg in eine nachhaltige Zukunft. *ifo Schnelldienst*. 76(07). pp. 44–50.
- Stolper, W. F. (1991): The Theoretical Bases of Economic Policy. The Schumpeterian Perspective. *Journal of Evolutionary Economics*. 1(3). pp. 189–205.
- Strambach, S.; Thurmann, J. (2021): Indikatorik Soziale Innovationen: Resonanzanalyse als Frühindikatorik.
- SVR – Sachverständigenrat zur Begutachtung der gesamtwirtschaftlichen Entwicklung (2023): Wachstumsschwäche überwinden – in die Zukunft investieren. Jahresgutachten 2023/24. Wiesbaden: SVR.
- Terstriep, J.; Kleverbeck, M.; Deserti, A.; Rizzo, F. (2015): Comparative Report on Social Innovation across Europe. Deliverable D3. 2. pp. 201–212.
- Terstriep, J.; Wloka, L.; Geme, Y.; Rico Palacios, J. S. (2020): Indikatorik Soziale Innovationen: Ergebnisse der Messung organisationaler Innovativität. Gelsenkirchen: Westfälische Hochschule Gelsenkirchen, Institut Arbeit und Technik.
- The Economist Intelligence Unit (2016): Social Innovation Index. Old Problems, New Solutions: Measuring the Capacity for Social Innovation across the World.
- Thistlethwaite, D. L.; Campbell, D. T. (1960): Regression-Discontinuity Analysis. An Alternative to the Ex Post Facto Experiment. *Journal of Educational Psychology*. 51(6). pp. 309–317.
- Touvron, H.; Lavril, T.; Izacard, G.; Martinet, X.; Lachaux, M.-A.; Lacroix, T.; Rozière, B.; Goyal, N.; Hambro, E.; Azhar, E.; Rodriguez, A.; Joulin, A.; Grave, E.; Lample, G. (2023): LLaMA: Open and Efficient Foundation Language Models. *arXiv preprint arXiv:2302.13971*.
- UFZ – Helmholtz-Zentrum für Umweltforschung (2021): Klima und Biodiversität. Kurzfassung Workshop-Bericht IPCC und IPBES. Leipzig: UFZ.
- UNEP – Umweltprogramm der Vereinten Nationen (2015): Sustainable Development Goals in UN Environment. New York: UNEP.
- UNFPA – United Nations Population Fund (2023): State of World Population 2023. 8 Billion Lives, Infinite Possibilities: The Case for Rights and Choices. New York: UNFPA.
- Unterberg, M.; Richter, D.; Spiess-Knafl, W.; Säger, R.; Förster, N.; Jahnke, T. (2015): Herausforderungen bei der Gründung und Skalierung von Sozialunternehmen. Welche Rahmenbedingungen benötigen Social Entrepreneurs. Studie von Evers & Jung GmbH, iq consult, ism und Zeppelin
- Universität im Auftrag des Bundesministeriums für Wirtschaft und Energie. Hamburg: evers & jung GmbH.
- van der Have, R. P.; Rubalcaba, L. (2016): Social Innovation Research. An Emerging Area of Innovation Studies? *Research Policy*. 45(9). pp. 1923–1935.
- Vivalt, E. (2020): How Much Can We Generalize From Impact Evaluations? *Journal of the European Economic Association*. 18(6). pp. 3045–3089.
- Voegtlin, C.; Scherer, A. G.; Stahl, G. K.; Hawn, O. (2022): Grand Societal Challenges and Responsible Innovation. *Journal of Management Studies*. 59(1). pp. 1–28.
- Walter, A.; Finger, R.; Huber, R.; Buchmann, N. (2017): Opinion. Smart Farming is Key to Developing Sustainable Agriculture. *Proceedings of the National Academy of Sciences of the United States of America*. 114(24). pp. 6148–6150.
- Warta, K.; Geyer, A.; Gorraiz, J. (2017): Evaluation des Programms Alexander von Humboldt-Professur – Internationaler Preis für Forschung in Deutschland. Endbericht. Vienna: Technopolis Group.
- Weber, M.; Giesecke, S.; Havas, A., Scharfing, D.; Albiez, A.; Horak, S.; Blind, K.; Bodenheimer, M.; Daimer, S.; Shi, L.; Stadler, M.; Schmitz, D. (2024): Social Innovation – (Accompanying) Instrument for Addressing Societal Challenges? Studien zum deutschen Innovationssystem. No. 10–2024. Berlin: EFI.
- Wegener, J. K.; Hörsten, D. von; Urso, L.-M. (2018): Mit Spot Farming zur nachhaltigen Intensivierung in der Pflanzenproduktion. H. Nordmeyer, & L. Ulber (Eds.). 28. pp. 19–23.
- Weiss, M.; Jacob, F.; Duveiller, G. (2020): Remote sensing for agricultural applications: A meta-review. *Remote Sensing of Environment*. 236(5). p. 111402.
- Widder, D. G.; West, S.; Whittaker, M. (2023): Open (For Business). Big Tech, Concentrated Power, and the Political Economy of Open AI. SSRN Electronic Journal.
- Wilkinson, C.; Medhurst, J.; Henry, N.; Wihlborg, M.; Braithwaite, B. W. (2014): Ein Überblick über Sozialunternehmen und ihre Ökosysteme in Europa. Zusammenfassung. European Commission: Brussels.
- WIPO – World Intellectual Property Organization (2013): Special Section. The International Mobility of Inventors. Geneva: WIPO.
- Wissenschaftliche Dienste (2021): Darstellung der Besteuerungssysteme für Pflanzenschutzmittel in Dänemark und Frankreich. Berlin: Deutscher Bundestag.

Wuchty, S.; Jones, B. F.; Uzzi, B. (2007): The Increasing Dominance of Teams in Production of Knowledge. *Science*. 316(5827). pp. 1036–1039.

Yahyaoui, Y.; Jakob, E. A.; Steinmetz, H.; Wehner, M. C.; Isidor, R.; Kabst, R. (2023): The Equivocal Image of Young Social Enterprises—How Self-Versus Other-Oriented Values Influence External Perceptions. *Nonprofit Management and Leadership*. 33(4). pp. 755–781.

Zhai, Z.; Martínez, J. F.; Beltran, V.; Martínez, N. L. (2020): Decision Support Systems for Agriculture 4.0. Survey and Challenges. *Computers and Electronics in Agriculture*. 170(7). p. 105256.

Zhao, X.; Akbaritabar, A.; Kashyap, R.; Zaghni, E. (2023): A Gender Perspective on the Global Migration of Scholars. *Proceedings of the National Academy of Sciences of the United States of America*. 120(10). e2214664120.

Zyontz, S. (2024): Mapping CRISPR Research, Innovation, and Diffusion Activities in Agriculture – Cross-national. *Studien zum deutschen Innovationssystem*. No. 7–2024. Berlin: EFI.

C 6 Endnotes

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- 1 Cf. Die Bundesregierung (2023d).
- 2 The KTF represents one of the main budgets for the sustainability-orientated transformations that now appear to be at risk.
- 3 Cf. EFI (2021) and EFI (2023).
- 4 The Sustainability Strategy was adopted in 2021 and the transformation teams were formed in 2022. Cf. <https://www.bundesregierung.de/breg-de/themen/erreichung-der-17-globalen-nachhaltigkeitsziele-wichtiger-denn-je-einrichtung-von-transformationsteams-beschlossen-2125282> (last accessed on 15 January 2024).
- 5 Cf. EFI (2023).
- 6 Cf. Stolper (1991).
- 7 Cf. EFI (2021).
- 8 Cf. EFI (2019).
- 9 Cf. EFI (2023).
- 10 Cf. EFI (2021).

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- 11 Publication of the Future Strategy in February 2023. Cf. Die Bundesregierung (2023d).
- 12 Cf. Die Bundesregierung (2023d).
- 13 The #Zukunftsstrategie forum comprises 21 members from science, business and civil society and began its work in September 2023. Cf. BMBF (2023c).
- 14 Cf. BMBF (2023c).
- 15 “At the strategy level, the governance of the Future Strategy pursues an open and reflexive approach. The Future Strategy for Research and Innovation is an umbrella strategy that bundles the objectives, priorities and milestones of the Federal Government’s research and innovation policy. In an exchange between the ministries, ongoing activities are integrated and new projects are initiated in the implementation of the Future Strategy. In accordance with the coalition agreement, it places particular emphasis on the measurability of its results using target criteria that are as internationally comparable as possible. In the spirit of a “learning strategy”, the ambitious indicators of the

Future Strategy are to be continuously developed further during implementation and adapted to new requirements. Cf. Die Bundesregierung (2023d: 15), own translation.

- 16 In addition to the six transformation teams assigned to the six transformation areas, an additional team has been set up for international transformation issues. Cf. Die Bundesregierung (2022) and <https://www.bundesregierung.de/breg-de/themen/nachhaltigkeitspolitik/staatssekretarsausschuss-2154374> (last accessed on 15 January 2024).
 - 17 Cf. <https://www.bundesregierung.de/breg-de/themen/nachhaltigkeitspolitik/steuerung-nachhaltigkeitsstrategie-419776> (last accessed on 15 January 2024) and Deutscher Bundestag (2023b).
 - 18 Transformation areas of the Sustainability Strategy: (1) Human well-being and skills, social justice; (2) Energy revolution and climate protection; (3) The circular economy; (4) Sustainable construction and the transport revolution; (5) Sustainable agriculture and food systems; (6) A pollutant-free environment. Additional topic: International responsibility and cooperation as a lever for transformation. Cf. Deutscher Bundestag (2023b) <https://www.bundesregierung.de/breg-de/themen/nachhaltigkeitspolitik/grundsatzbeschluss-deutsche-nachhaltigkeitsstrategie2145820#:~:text=Die%20Transformationsteams%20beziehen%20sich%20auf,und%20Verkehrswende%3B%20nachhaltige%20Agrar%2D%20und> (last accessed on 15 January 2024).
- Missions of the Future Strategy: (1) Enabling resource-efficient and on circular economy based competitive industry and sustainable mobility; (2) Spearheading climate protection, climate adjustment, food security and the preservation of biodiversity; (3) Improving health for everyone; (4) Securing Germany’s and Europe’s technological sovereignty and harnessing the potential of digitalization; (5) Strengthening astronautics, exploring, protecting and sustainably using space and oceans; (6) Strengthening social resilience, diversity and cohesion. Cf. https://www.bmbf.de/bmbf/de/forschung/zukunftsstrategie/zukunftsstrategie_node.html (last accessed on 15 January 2024).

- 19 Achieving the objectives set out in the Future Strategy for Research and Innovation is therefore the responsibility of the relevant ministries, which fund the objectives through appropriate measures based on the applicable budget and financial planning approaches. Cf. Deutscher Bundestag (2023a). All measures resulting from the strategy are carried out in line with constitutional responsibilities and are subject to funding. Insofar as specific measures or related future measures lead to expenditure in the federal budget, they are subject to the availability of budget funds or posts/positions and are without prejudice to current or future budget negotiations. Cf. Die Bundesregierung (2023d).
- 20 Cf. Die Bundesregierung (2023d).
- 21 DATI: With the DATIpilot project, an experimental space was created in July 2023 to serve as a repository of experience and ideas for the conception of the planned German Agency for Transfer and Innovation. Cf. https://www.bmbf.de/bmbf/de/forschung/datipilot/datipilot_node.html (last accessed on 15 January 2024). SPRIND: The ‘Energy-efficient AI System’ project was announced as a pilot innovation competition in March 2019. SPRIND was established in December 2019. Cf. BMBF (2021b).
- 22 Cf. Bundesregierung (2023: 4 f.).
- 23 In its package for reducing bureaucracy, the then Federal Government decided on 13 April 202 to check for each law in future whether real-world laboratories could be made possible by including an experimentation clause. Nevertheless, the decision on the experimentation clause check has not yet had any binding effect. Cf. BMWK (2023a: 8).
- 24 Cf. Bertschek et al. (2023c).
- 25 Cf. BMWK (2023b).
- 26 For the current status see <https://www.bmwk.de/Redaktion/DE/Dossier/reallabore-testraeume-fuer-innovation-und-regulierung.html> (last accessed on 15 January 2024).
- 27 Cf. Deutscher Bundestag (2023c).
- 28 Cf. Harhoff et al. (2018).
- 29 Cf. Azoulay et al. (2018).
- 30 Cf. Deutscher Bundestag (2023c).
- 31 Cf. Deutscher Bundestag (2023c).
- 32 Cf. Bertschek et al. (2023a).
- 33 Cf. Netzwerk der Projektträger (2023).
- 34 Cf. Bertschek et al. (2023b) and EFI (2023).
- 35 Cf. BMBF (2023b).
- 36 Cf. https://www.bmbf.de/bmbf/de/forschung/datipilot/datipilot_node.html (last accessed on 15 January 2024).
- 37 Cf. <https://table.media/professional-briefing/dati-60-millionen-mehr-gwk-laender-zahlen-bei-hawfoerderung-mit-offensive-der-ua11/> (last accessed on 15 January 2024).
- 38 Cf. BMBF (2023b).
- 39 Cf. https://www.bmbf.de/bmbf/de/forschung/datipilot/datipilot_node.html (last accessed on 15 January 2024).
- 40 Cf. Bertschek et al. (2022).
- 41 Cf. Deutscher Bundestag (2023d).
- 42 The Growth Opportunities Act was referred to the Mediation Committee (Vermittlungsausschuss) by the Bundesrat in November 2023. Cf. <https://www.vermittlungsausschuss.de/VA/DE/homepage/homepage-node.html> (last accessed on 15 January 2024).
- 43 It remains to be seen how the extension of the research allowance to include material costs will be organised. Cf. <https://www.zew.de/presse/pressearchiv/forschungszulage-ist-gewinn-fuer-den-innovationsstandort-deutschland> (last accessed on 15 January 2024).
- 44 The increase can be applied for by businesses that fall under the EU’s definition of SMEs. Cf. Europäische Kommission (2014).
- 45 Cf. Deutscher Bundestag (2023d).
- 46 Cf. Deutscher Bundestag (2023d).
- 47 Cf. BMWi (2020) and <https://www.bescheinigung-forschungszulage.de/forschungszulage> (last accessed on 15 January 2024).
- 48 The research allowance is to be evaluated on a scientific basis by 2025 at the latest. Cf. Research Allowance Act (FZulG): Section 17, subs. 1.
- 49 Cf. DIHK (2022), Finger et al. (2023), Rammer (2023b) and Rammer (2023c).
- 50 2020: ca. 600 applications (application was only possible from September 2020); 2021 ca. 4.500 applications; 2022: ca. 6.600 applications. Cf. Finger et al. (2023: 7).
- 51 Data from the Certification Body shows that between a quarter and a fifth of all applications are not approved each year. Cf. Finger et al. (2023: 9) and Rammer (2023c: 4).
- 52 47 percent of recipients of the research allowance (as per mid-2022) have not previously received any direct R&D funding (2019-2022). Cf. Rammer (2023c: 5).
- 53 In 2021, only 57 percent of companies with up to 249 employees were aware of the existence of the research allowance, compared to 74 percent of companies with 250 to 499 employees and 81 percent of companies with 500 or more employees. Cf. Finger et al. (2023: 4 f.).

- 54 Cf. Finger et al. (2023: 7f.).
- 55 Cf. Finger et al. (2023) and DIHK (2022).
- 56 SMEs often do not have specialized staff for the acquisition of funding. A practical definition of R&D terms and active support from the Federal Government's Research and Innovation Funding Advisory Service or the Certification Body Research Allowance could help companies that have little or no funding experience. Cf. <https://table.media/research/analyse/forschungszulage-versprochene-foerdermilliarden-verpuffen/> (last accessed on 15 January 2024), DIHK (2022) and Rammer (2023b).
- 57 The model of the French research allowance (Crédit d'Impôt Recherche) with its one-step application procedure can serve as a model for simplifying the application procedure for the research allowance. Cf. Barbu et al. (2021).
- 58 Cf. <https://www.e-fi.de/dashboard/innovationsverhalten/innovatorenquote> (last accessed on 15 January 2024).
- 59 Cf. EFI (2019).
- 60 In Germany, research and tertiary education institutions have so far only been able to break even on their transfer centres in absolutely exceptional cases. Even in the USA, the number of cost-effective transfer centres is limited to a few large universities.
- 61 Cf. SPRIND (2022).
- 62 The revised version of the General Block Exemption Regulation (GBER) of March 2023 allows – “in addition to start-up aid limited in type and amount – aid for business start-ups in the form of a transfer of intellectual property or the granting of the associated access rights on favourable terms. A scientific institution can make this transfer or grant of rights free of charge or below market value if this brings a new product or service onto the market. The aid related to the market price of the IP may not exceed €1 million.” Cf. SPRIND (2023), own translation.
- 63 Cf. SPRIND (2022: 3) and BAND (2022).
- 64 Cf. SPRIND (2022: 3).
- 65 Cf. https://www.tu-darmstadt.de/universitaet/aktuelles_meldungen/archiv_2/2022/2022quartal1/news_archiv_de_352512.de.jsp and <https://www.businessinsider.de/gruenderszene/business/wissen-gegen-anteile-ip-for-shares/> (each last accessed on 15 January 2024).
- 66 Cf. SPRIND (2023) and SPRIND (2022).
- 67 Cf. here also EFI (2019).
- 68 Cf. https://www.sprind.org/de/artikel/ip_transfer_werkzeug/ (last accessed on 15 January 2024).
- 69 Cf. https://www.sprind.org/de/artikel/ip_transfer_werkzeug/ (last accessed on 15 January 2024).
- 70 Cf. <https://www.darpa.mil/about-us/budget-and-finance> (last accessed on 15 January 2024).
- 71 DARPA is considered the model for the Federal Agency for Disruptive Innovation (SPRIND), founded in 2019, and the Agency for Innovation in Cybersecurity. Unlike DARPA, however, SPRIND does not act on behalf of the Ministry of Defence or the Bundeswehr and only funds civilian research projects.
- 72 Cf. Moretti et al. (2019).
- 73 It should be noted, however, that DARPA funding also includes private-sector R&D projects in order to utilize their developments in the military sector in line with the dual-use approach. Cf. Pallante et al. (2023).
- 74 Cf. <https://www.cyberagentur.de/> (last accessed on 15 January 2024).
- 75 Cf. EFI (2023: 31).
- 76 This chapter is based on an unpublished paper by the Chairman of the Commission of Experts, Prof. Uwe Cantner, dated 30 September 2023. The paper was written as a follow-up to a presentation at the BMBF entitled: Relationship between Civilian and Military Research – Options for Germany.
- 77 The market success of a standard depends largely on the quality of the technologies included in the standard and on its widespread implementation. Cf. Conde Gallego et al. (2015).
- 78 Cf. DIN (2019).
- 79 Cf. LexisNexis (2023).
- 80 Cf. DIN (2019) and https://ec.europa.eu/commission/presscorner/detail/en/ip_23_2454 (last accessed on 15 January 2024).
- 81 The problem is exacerbated when an enormous number – often several thousand – have been declared for a single standard, which are also in the hands of different rights holders. Cf. Conde Gallego et al. (2015).
- 82 Cf. Europäische Kommission (2023b).
- 83 Cf. Conde Gallego et al. (2015).
- 84 Cf. Europäische Kommission (2023b).
- 85 Cf. Europäische Kommission (2023b).
- 86 Cf. Europäische Kommission (2023c).
- 87 Cf. Europäische Kommission (2023b).
- 88 Cf. Europäische Kommission (2023b).
- 89 Cf. Europäische Kommission and Joint Research Centre (2020).
- 90 Cf. EFI (2022: chapter B3 and B4) and EFI (2023: chapter A).
- 91 See roadmap on page 37 <https://bmdv.bund.de/SharedDocs/DE/Anlage/K/nationale-daten>

- strategie.pdf?__blob=publicationFile (last accessed on 15 January 2024).
- 92 Cf. SVR (2023: chapter 6), RatSWD (2023) and RfII (2023).
- A 2**
- 93 The Alfred Nobel Memorial Prizes in Economic Sciences were awarded in 2019 and 2021 for contributions to the development of experimental or quasi-experimental methods of causal analysis. Cf. <https://www.nobelprize.org/prizes/lists/all-prizes-in-economic-sciences/> (last accessed on 15 January 2024).
- 94 Cf. e.g. EFI (2012: chapter A7), EFI (2013: chapter A6), EFI (2014: chapter A2) and EFI (2017: chapter B5-3).
- 95 Cf. BMWi (2013). In 2019, the Advisory Board reaffirmed its requirements and made specific proposals for their institutional implementation. These include the creation of an evaluation competence centre, cross-departmental exchange, guidelines on the process and criteria of evaluations as well as ensuring the availability of data. Cf. https://www.bmwk.de/Redaktion/DE/Downloads/Wissenschaftlicher-Beirat/brief-moderne-wirtschaftspolitik-braucht-evaluierung.pdf?__blob=publicationFile&v=4 (last accessed on 15 January 2024).
- 96 Cf. e.g. Benus et al. (2009), <https://www.nesta.org.uk/project/innovation-growth-lab/> (last accessed on 15 January 2024) and others.
- 97 Cf. EFI (2013: 41).
- 98 This could also address the concerns of the Bundesrechnungshof regarding randomization. Cf. https://www.bundesrechnungshof.de/SharedDocs/Downloads/DE/Berichte/2022/bemerkungen/bemerkung-06.pdf?__blob=publicationFile&v=2 (last accessed on 15 January 2024).
- 99 For example, the group of applicants for a support measure can be divided into three groups – a first group with very high suitability, a middle group, which is also eligible for support, and a third group, which is not eligible for support. The very good applicants are all supported. The middle group of those also eligible is suitable for randomized selection. The ineligible group does not receive support. If measures are introduced at different times, the order of support can also be randomized for the causal analysis. Cf. EFI (2013: 45).
- 100 Some of the completed evaluation studies are available to the public only in summarized form or not at all.
- 101 Cf. Büchele et al. (2024).
- 102 Various types of organisations are involved in evaluations. Non-university research institutions are involved in around 30 percent of all evaluations, private companies in 75 percent, tertiary education institutions in 13 percent and public authorities in 9 percent. Non-university research institutions are more frequently involved in more recent evaluation studies, i. e. those conducted in 2019 and later, than in older studies (35 versus 23 percent). This also applies to private companies (83 versus 64 percent). In contrast, public authorities were less frequently involved in the preparation of the more recent evaluation studies than in the older ones (2 versus 18 percent). The proportion of studies that were produced as part of collaborations between different types of organisations is 30 percent overall and is higher in the younger studies than in the older ones (35 versus 24 percent).
- 103 There are hardly any differences between studies based on different methodological approaches or between older (before 2019) and more recent (since 2019) studies.
- 104 It should be noted that, due to publication bias, the scientific literature also tends to be biased in favour of positive evaluation results. Cf. e.g. Vivalt (2020) or DellaVigna and Linos (2022).
- 105 Quasi-experimental designs include difference-in-differences designs, regression discontinuity designs and the comparison of units covered by an intervention with a synthetic control group. Cf. for classic works e.g. Thistlethwaite and Campbell (1960), Card and Krueger (1994) and Abadie et al. (2010), and for overview articles e.g. Imbens and Wooldridge (2009), Lee and Lemieux (2010) and Abadie (2021).
- 106 Matching procedures belong to the balancing procedures that are used to harmonize the observable characteristics of the observation units in the treatment and control groups in order to better estimate the effect of participation in the programme.
- 107 In recent years, the share of evaluation studies based on a methodology suitable for causal analyses has increased. In the evaluation studies analyzed, which were produced in 2018 and earlier, it is 12 percent, while in the more recent studies it is 21 percent. However, the share of evaluation studies in which results are interpreted causally has also increased, although the underlying methodology does not allow this (47 versus 60 percent). Cf. Büchele et al. (2024).
- 108 Cf. EFI (2014: 28f.).
- 109 Cf. EFI (2014: 29).
- 110 For example, synthetic control groups can be formed for the units concerned in order to analyze

their development – possibly also in an international comparison.

111 Cf. EFI (2014: 29).

112 Cf. EFI (2014: 29).

113 Cf. EFI (2014: 29).

114 Cf. EFI (2017: 27).

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115 Cf. Finger (2023).

116 In addition, a change in the farming system and the associated farming practices is also necessary. However, this report focusses on the transformation through agricultural technologies.

117 Alongside the SDG to end hunger, other SDGs such as 'Life on Land' also address the transformation of agriculture. Cf. UNEP (2015), Herrero et al. (2021), <https://www.bmu.de/themen/nachhaltigkeit/nachhaltigkeitsziele-sdgs/sdg-2-kein-hunger> (last accessed on 15 January 2024). In addition, other national and European strategies set targets for more sustainable agriculture, such as the European Green Deal, the Farm-to-Fork Strategy or, at national level, the German CAP Strategic Plan, the Arable Farming Strategy 2035 and the Organic Strategy. Cf. BMEL (2022a), BMEL (2021), https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en, <https://www.consilium.europa.eu/de/policies/from-farm-to-fork/> (each last accessed on 15 January 2024).

118 Cf. FAO (2022), Hartung et al. (2024).

119 Cf. UNFPA (2023).

120 Cf. DWD (2022a), DWD (2022b).

121 Cf. BMEL (2022b), Geppert et al. (2024), Hartung et al. (2024).

122 Potatoes, maize and sugar beet, for example, react sensitively to drought during the growth phase, which leads to yield losses. Cf. Geppert et al. (2024), Hartung et al. (2024).

123 Cf. Geppert et al. (2024), Hartung et al. (2024).

124 Cf. Geppert et al. (2024), Schmitt et al. (2022), Jägermeyr et al. (2021), Hirschfeld et al. (2021), <https://www.umweltbundesamt.de/themen/klima-energie/klimafolgen-anpassung/folgen-des-klimawandels/klimafolgen-deutschland/klimafolgen-handlungsfeld-landwirtschaft#weitere-klimawirkungen> (last accessed on 15 January 2024).

125 A shift in the distribution of plant species in particular can be observed in favour of plants that react positively to nitrogen inputs and displace other, slower-growing species. Cf. Hallmann et al. (2017).

126 Examples include the pollination of cultivated and wild plants by insects, the build-up and breakdown of biomass and natural pest control. Cf. Geppert et al. (2024).

127 Healthy ecosystems and abundant biodiversity are the basis for storing greenhouse gases in the environment, thereby helping to mitigate climate change. Cf. Geppert et al. (2024), Hartung et al. (2024), UFZ (2021), <https://bmz.de/de/themen/biodiversitaet/klimaschutz> (last accessed on 15 January 2024).

128 Cf. <https://www.umweltbundesamt.de/themen/wasser/extremereignisse/klimawandel/trockenheit-in-deutschland-fragen-antworten>, <https://www.umweltbundesamt.de/themen/wasser/grundwasser>, https://www.destatis.de/DE/Presse/Pressemitteilungen/2023/10/PD23_414_32311.html (last accessed on 15 January 2024).

129 Cf. BMUV (2023), <https://correctiv.org/aktuelles/klimawandel/2022/10/25/klimawandel-grundwasser-in-deutschland-sinkt/> (last accessed on 15 January 2024).

130 Cf. Finger (2023).

131 For example, sensors can receive and forward information that is then analyzed by analysis tools in order to control machines.

132 Cf. Destatis (2023), https://www.destatis.de/DE/Themen/Laender-Regionen/Internationales/Thema/Tabellen/Basistabelle_LWWertschoepfung.html (last accessed on 15 January 2024).

133 Half of the labour force worked in individual companies with family structures; the other half was made up equally of permanent non-family employees and seasonal workers. Cf. https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Landwirtschaft-ForstwirtschaftFischerei/Landwirtschaftliche-Betriebe/_inhalt.html (last accessed on 15 January 2024).

134 Cf. <https://www.umweltbundesamt.de/umweltatlas/umwelt-landwirtschaft/einfuehrung/landwirtschaft-in-deutschland/wie-viele-menschen-arbeiten-in-der-landwirtschaft>, https://www.destatis.de/DE/Presse/Pressemitteilungen/2021/01/PD21_001_13321.html (each last accessed on 15 January 2024).

135 Cf. https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Landwirtschaft-Forstwirtschaft-Fischerei/Landwirtschaftszaehlung2020/_inhalt.html (last accessed on 15 January 2024).

136 Methane and nitrous oxide account for the largest share of agricultural greenhouse gas emissions. 76.7 percent of methane emissions and 77.5 percent of nitrous oxide emissions in Germany come from

- agriculture. Cf. <https://www.umweltbundesamt.de/daten/land-forstwirtschaft/beitrag-der-landwirtschaft-zu-den-treibhausgas#treibhausgas-emissionen-aus-der-landwirtschaft> (last accessed on 15 January 2024).
- 137** Funds totalling €11.95 billion are available for the so-called second pillar, which are used for rural development. The second pillar of the CAP finances, among other things, area-related support measures for climate protection, soil protection and water quality as well as projects to support structural change and the competitiveness of agriculture. Cf. BMEL (2022a).
- 138** Cf. Kliem et al. (2023).
- 139** Cf. Finger (2023).
- 140** Data on a farm's agricultural land is recorded in field maps and merged with data from implemented measures. The specific requirements of plants and heterogeneous cultivation conditions can thus be taken into account in further agricultural measures. Cf. Kehl et al. (2021b).
- 141** Cf. Kliem et al. (2023).
- 142** Cf. Kliem et al. (2023).
- 143** Kehl et al. (2021b) and Walter et al. (2017) propose a broad definition of smart farming that also includes markets and policy measures.
- 144** Cf. Kehl et al. (2021b).
- 145** Cf. Kliem et al. (2023).
- 146** Cf. Kehl et al. (2021b).
- 147** Cf. Kehl et al. (2021b).
- 148** Remote sensing can be used to collect information on fields via satellites or drones, for example, which can then be used to implement measures. Cf. Khanal et al. (2020), Weiss et al. (2020).
- 149** Cf. Kehl et al. (2021a).
- 150** E.g. in young game rescue and population monitoring. Cf. Bitkom Research (2022).
- 151** Cf. Kehl et al. (2021a).
- 152** Cf. Saiz-Rubio and Rovira-Más (2020), Fountas et al. (2015).
- 153** Cf. Zhai et al. (2020), Saiz-Rubio and Rovira-Más (2020), Fountas et al. (2015).
- 154** The survey was conducted in the form of an online survey to which companies and other actors were invited based on contact lists from ZALF and ZEW Mannheim, among others. A total of 168 people from farms and contractors (71 participants), associations and non-governmental organisations (13), politics and administration (17) and research and industry (67) took part in the survey. In addition, some of the participating organisations forwarded the link to the online survey to their members. Due to this survey design, it is not possible to calculate an exact response rate for the overall survey. In terms of agricultural businesses, however, a response rate of less than 2 percent can be assumed, as over 4,000 businesses were invited to participate. Distortions are therefore possible if, for example, mainly people or farms took part in the survey who have already engaged more intensively with the topic of digitalization in agriculture.
- 155** A total of 82 percent of the agricultural holdings surveyed currently use at least one of the digital and smart technologies listed. The results of this survey are therefore in line with a Bitkom Research survey of 500 farms from 2022, in which the representative extrapolated share of farmers using digital technologies was 79 percent. Cf. Bitkom Research (2020), Bitkom Research (2022).
- 156** For example, 38.2 percent of the agricultural holdings surveyed stated that an unstable internet connection is a (very) big obstacle to the use of digital and smart technologies. Among the other respondents, this figure is 83.7 percent.
- 157** Cf. https://www.bmel.de/SharedDocs/Praxisbericht/DE/experimentierfelder/karte-experimentierfelder/karte_experimentierfelder_table.html (last accessed on 15 January 2024).
- 158** Cf. Kliem et al. (2023).
- 159** One of the highest forms of precision farming is spot farming. This involves identifying sub-areas with largely similar characteristics, e.g. in terms of soil quality or sunlight, and adjusting the use of inputs specifically to these spots, whereby it is also possible to grow different crops or crop rotations on different spots. Cf. Wegener et al. (2018).
- 160** Cf. Kehl et al. (2021a).
- 161** Cf. Kehl et al. (2021a).
- 162** Cf. Bitkom Research (2022).
- 163** Cf. Wissenschaftliche Dienste (2021), Nielsen et al. (2023), Böcker and Finger (2016), <https://www.umweltbundesamt.de/presse/pressemitteilungen/neue-eu-verordnung-weniger-pestizide-geht-nur> (last accessed on 15 January 2024).
- 164** Cf. Bitkom Research (2020), Bitkom Research (2022).
- 165** In a survey of 500 farmers conducted by Bitkom Research, 90 percent of participants consider the promotion of digital skills in training and further education to be (very) important. Cf. Bitkom Research (2022).
- 166** Cf. Bitkom Research (2022).
- 167** Cf. Deutscher Bundestag (2022).
- 168** Take-off weight greater than 25 kg.
- 169** Cf. Europäische Kommission (2019).
- 170** Cf. European Parliament (2023).

- 171 Applications in patent families with at least one application to the World Intellectual Property Organization via the PCT procedure or one application to the European Patent Office. Patent applications were identified using the CPC classification and a keyword search in patent titles and abstracts.
- 172 Due to the very small number of cases, the FMIS and DSS areas are summarized in this analysis.
- 173 Cf. Hartung et al. (2024).
- 174 Nowadays, genome editing refers to a wide range of techniques for the targeted modification of genetic information. In addition to the well-known CRISPR/Cas gene scissors, this also includes methods such as ZFN (zinc finger nuclease), TALEN (transcription activator-like effector nuclease) and ODM (oligonucleotide-directed mutagenesis). Prime and base editing are also part of genome editing. These two methods are not taken into further consideration in this report.
- 175 These include the new genomic techniques (NGT), which comprise all methods developed since 2001. Cf. European Commission (2021b), Joint Research Centre et al. (2021a).
- 176 Cf. Hartung et al. (2024). The definition of conventional plant breeding is not standardized. Conventional plant breeding often also includes mutation breeding. However, as mutation breeding is of vital importance in the discourse on green genetic engineering, it is considered separately in this text.
- 177 Cf. Hartung et al. (2024).
- 178 Short for deoxyribonucleic acid.
- 179 Site-specific nucleases such as ZFN, TALEN, ODM and CRISPR are used to create the break in the DNA sequence. Cf. Hartung et al. (2024).
- 180 Short for Clustered Regularly Interspaced Short Palindromic Repeats.
- 181 Cf. Hartung et al. (2024).
- 182 Cf. Hartung et al. (2024).
- 183 Cf. Hartung et al. (2024).
- 184 Cf. Hartung et al. (2024).
- 185 Cf. Hartung et al. (2024).
- 186 The development of a new variety through conventional breeding takes around 13 years; this time can be reduced to two to three years using genome editing and transgenesis. In addition, genome editing permits several changes to be made at different parts of the genome at the same time. This technique is called multiplexing and has not yet been widely used in practice.
- 187 Cf. <https://www.ncbi.nlm.nih.gov/genbank/> (last accessed on 15 January 2024).
- 188 The sequencing of genetic material has not yet been completed for all plants. Genome editing is also frequently used to identify gene functions. Once the genetic material of a plant has been sequenced, this accelerates the breeding process and supports breeding planning. In the case of mutation breeding and conventional breeding, no information about the gene sequence of the plants is required. Cf. Hartung et al. (2024).
- 189 Cf. European Commission (2021b), Joint Research Centre et al. (2021a), Jung and Till (2021), Hartung et al. (2024).
- 190 Genetic engineering is regulated at European level. The directives adopted must then be adopted into national law in each Member State – in Germany in the Genetic Engineering Act (Gentechnikgesetz). Cf. Deutscher Bundestag (2021a), European Parliament (2001).
- 191 The costs for approval as feed and food in the EU amount to between €6 million and €20 million, while cultivation is estimated to cost between €17.5 million and €28 million. In addition, up to €1 million per year is spent on monitoring measures. Approval procedures take several years. Cf. European Commission Regulatory Scrutiny Board (2023), Hartung et al. (2024).
- 192 The safety review analyzes the following points: persistence and invasiveness, gene transfer from plants to microorganisms, interaction with target and non-target organisms, changes in cultivation management, human and animal health. Cf. https://ec.europa.eu/commission/presscorner/detail/de/MEMO_04_102 (last accessed on 15 January 2024).
- 193 The approved genetically modified maize is only cultivated in Portugal and Spain. Cf. https://ec.europa.eu/commission/presscorner/detail/de/MEMO_04_102 (last accessed on 15 January 2024).
- 194 Cf. European Parliament (2001), Deutscher Bundestag (2021a).
- 195 Cf. Deutsche Akademie der Naturforscher Leopoldina e. V. et al. (2019).
- 196 One of the reasons given by the European Court of Justice for its decision was that plants derived from mutation breeding have a long history of safe applications. Cf. Hartung et al. (2024), Europäischer Gerichtshof (2018). In Germany, according to the Genetic Engineering Act, mutation breeding is not considered a method of modifying genetic material and is therefore not covered by the legal provisions. Cf. Deutscher Bundestag (2021a).
- 197 Cf. Hartung et al. (2024), <https://www.isaaa.org/gmapprovaldatabase/approvedeventsin/default.asp?CountryID=EU> (last accessed on 15 January 2024).

- 198 Cf. Hartung et al. (2024).
- 199 The main countries of cultivation are the USA with 71.5 million hectares, Brazil with 52.8 million hectares and Argentina with 24 million hectares. The main crops are soya (91.9 million hectares), maize (60.9 million hectares), cotton (25.7 million hectares) and rapeseed (10.1 million hectares). Cf. Hartung et al. (2024).
- 200 Cf. Hartung et al. (2024).
- 201 Cf. Joint Research Centre et al. (2021b).
- 202 A meta-analysis shows that the cultivation of genetically modified plants with herbicide tolerance or insect resistance increases farmers' yields and profits, particularly in developing countries. The profit of farmers in developing countries increases by 78 percent, while it only increases by 34 percent in industrialized countries. The amount of pesticides used decreases by 42 percent in developing countries and by 18 percent in industrialized countries. Cf. Klümper and Qaim (2014), Qaim (2020).
- 203 For example, the fatty acid composition can be changed so that oils contain fewer unsaturated fatty acids or the vitamin A content in staple foods increases. Cf. Hartung et al. (2024).
- 204 Conventional genetic engineering often focuses on insect resistance, whereas genome editing has so far focussed on fungi and viruses. This is due to the fact that insect resistance is achieved through transgenesis and genome editing has rarely been used for transgenesis. In around 90 percent of applications, genome editing is only used to switch off genes. This in turn is due to the fact that genome editing is still a relatively new application. Cf. Hartung et al. (2024).
- 205 Cf. Hartung et al. (2024).
- 206 Cf. Hartung et al. (2024).
- 207 Cf. Hartung et al. (2024).
- 208 Cf. Hartung et al. (2024), European Commission (2021b), Joint Research Centre et al. (2021a).
- 209 Cf. Hartung et al. (2024).
- 210 Cf. Klümper and Qaim (2014).
- 211 Cf. Hartung et al. (2024).
- 212 Wild plants usually have a much larger gene pool than the related bred plants. Cf. Qaim (2020).
- 213 Cf. Hartung et al. (2024).
- 214 Cf. Qaim (2020).
- 215 Cf. Deutsche Akademie der Naturforscher Leopoldina e. V. et al. (2019), European Commission Directorate-General Research and Innovation (2010).
- 216 Cf. Deutsche Akademie der Naturforscher Leopoldina e. V. et al. (2019), Hartung et al. (2024), Qaim (2020), European Commission (2021b).
- 217 Cf. Joint Research Centre et al (2021a), European Commission. (2021b).
- 218 For this purpose, the damage potential and the probability of damage occurring are determined. Both factors depend on the interaction between the plant and the change in characteristics. Moreover, the direct application itself is decisive for the probability of occurrence. It is therefore not possible to create a general risk profile for bred plants. In the EU, safety assessments are carried out by the European Food Safety Authority (EFSA) and the relevant national authorities – in Germany by the Federal Office of Consumer Protection and Food Safety. Both environmental compatibility and safety for humans and animals are examined. Cf. Hartung et al. (2024), https://ec.europa.eu/commission/presscorner/detail/de/MEMO_04_102 (last accessed on 15 January 2024).
- 219 Cf. https://ec.europa.eu/commission/presscorner/detail/de/MEMO_04_102 (last accessed on 15 January 2024).
- 220 Cf. Hartung et al. (2024), https://bvl.bund.de/DE/Arbeitsbereiche/06_Gentechnik/02_Verbraucher/04_GVO_nach_Genehmigung/06_Ueberwachung/gentechnik_Ueberwachung_node.html (last accessed on 15 January 2024).
- 221 The rules of good professional practice for the production of GMOs include compliance with isolation distances, monitoring for second growth in the following year, regulations on the harvesting, storage and transport of genetically modified plants and a duty to inform neighbouring farmers. Cf. Deutscher Bundestag (2008), Barrows et al. (2014).
- 222 Cf. https://www.bvl.bund.de/DE/Arbeitsbereiche/06_Gentechnik/02_Verbraucher/04_GVO_nach_Genehmigung/04_Koexistenz/gentechnik_koexistenz_node.html (last accessed on 15 January 2024).
- 223 Since 2019, the CRISPR method has been used almost exclusively for genome editing, primarily in the SDN-1 variant. Cf. Hartung et al. (2024).
- 224 Cf. Zyontz (2024).
- 225 Cf. Hartung et al. (2024), Deutsche Akademie der Naturforscher Leopoldina e. V. et al. (2019), European Commission (2021b), Joint Research Centre et al. (2021a).
- 226 Cf. Deutsche Akademie der Naturforscher Leopoldina e. V. et al. (2019), Dederer (2024).
- 227 Cf. Hartung et al. (2024).
- 228 Cf. European Commission Regulatory Scrutiny Board (2023).
- 229 The EU defines newgenomic techniques as methods by which the genetic material of an organism can be modified and which have been created or developed since 2001. These include genome editing methods and synthetic biology methods. Cf. European

- Commission (2021b), Joint Research Centre et al. (2021a).
- 230 Cf. Spök et al. (2022), Dederer (2024), Hartung et al. (2024).
- 231 Cf. Deutsche Akademie der Naturforscher Leopoldina e. V. et al. (2019), Hartung et al. (2024).
- 232 Cf. Deutsche Akademie der Naturforscher Leopoldina e. V. et al. (2019), Hartung et al. (2024).
- 233 Cf. European Commission Regulatory Scrutiny Board (2023).
- 234 Cf. Deutsche Akademie der Naturforscher Leopoldina e. V. et al. (2019).
- 235 Cf. https://zag.bvl.bund.de/freisetzung/index.jsf;jsessionid=LocteqoohzyH7w7JKPb9y5gcQTza_5vzIP8xI8In.s-9200m?dswid=3121&dsrid=155 (last accessed on 15 January 2024).
- 236 Cf. European Commission Regulatory Scrutiny Board (2023).
- 237 The proposal does not refer to transgenesis using NGT. Cf. Dederer (2024), Europäische Kommission (2023a).
- 238 This number is not based on scientific limits. Cf. Hartung et al. (2024).
- 239 Herbicide-tolerant plants are exempt from this regulation. Cf. Europäische Kommission (2023a).
- 240 Cf. Europäische Kommission (2023a).
- 241 Cf. Dederer (2024).
- 242 Cf. European Parliament (2018).
- 243 Cf. Purnhagen et al. (2021), Spök et al. (2022).
- 244 Cf. Dallendörfer et al. (2022), Kato-Nitta et al. (2023), BMUV and BfN (2023).
- 245 Cf. BMUV and BfN (2023).
- 246 Cf. https://www.enga.org/fileadmin/user_upload/pdf/Retailers_Resolution_03_11102021.pdf (last accessed on 15 January 2024).
- 247 Dallendörfer et al. (2022) report that 72 percent of respondents in Germany have never heard of CRISPR-Cas and 50 percent have never heard of genetic engineering in agriculture. Kato-Nitta et al. (2023) show that 59.9 percent of respondents in Germany have no knowledge of genome editing and that awareness of the benefits of genome editing is very low.
- 248 Cf. Deutscher Bundestag (1936), Deutscher Bundestag (2021b).
- 249 Cf. <https://www.praxis-agrar.de/pflanze/pflanzenbau/sortenschutz-oder-patent-was-ist-was> (last accessed on 15 January 2024), Deutscher Bundestag (2021b).
- 250 The process must not be based entirely on natural phenomena such as cross-breeding or selection. Then it is a biological process and not patentable. This does not apply to NGT. Cf. Dederer (2024).
- 251 Cf. Dederer (2024).
- 252 Cf. Dederer (2024).
- 253 Cf. https://ec.europa.eu/commission/presscorner/detail/de/qanda_23_3568 (last accessed on 15 January 2024).
- 254 Cf. EFI (2021).

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- 255 Due to data limitations, it is only possible to record individual relocations of scientists and R&D employees in a roundabout way. As an approximation of actual mobility patterns, the studies presented here record changes in the organisational affiliation stated in scientific publications and the addresses stated in patent applications. They thus follow the relevant international research. The procedure is based on a series of assumptions, which are made explicit at the appropriate point.
- 256 The analyses presented here provide a comprehensive, but not complete, picture of mobility. They only allow statements to be made about the mobility of those scientists and R&D employees who published scientific papers and/or patents via relevant journal publishers or patent offices during the observation period.
- 257 Cf. Lepori et al. (2015).
- 258 Cf. Netz et al. (2020).
- 259 Cf. Guthrie et al. (2017).
- 260 Cf. e.g. Franzoni et al. (2014). The performance or quality of research is approximated here using a quality indicator of publications (cf. also B 2-2). Potential reasons for a causal positive effect of mobility on average research quality lie in expanded networks, new combinations of knowledge and improved match quality, i.e. an improved fit between employer and employee due to the international expansion of labour markets. Mobility does not always have to lead directly to quality improvements. Empirical studies show that, depending on the field of activity and working environment, the adjustment costs at the new workplace can also initially lead to a temporary reduction in quality. Cf. e.g. Groyberg and Lee (2009).
- 261 Cf. e.g. Rassenfosse and Pellegrino (2024). However, Borjas and Doran (2012) also show that the increase in human capital in a country caused by immigration does not necessarily lead to an improvement in overall research performance if the research performance of local authors decreases at the same time.

- 262 The idea behind this argument is discussed in the literature under the concept of tacit knowledge, which can generally only be transmitted or exchanged through direct dialogue between authors. Cf. e.g. Ganguli (2015).
- 263 In the literature, such channels for the positive effects of brain drain are discussed under Beneficial Brain Drain (cf. Mountford (1997); Beine et al. (2001); Mayr and Peri (2009)).
- 264 Cf. Agrawal et al. (2006). The fact that a location from which scientists and R&D employees have emigrated benefits over time through international research cooperation with the outgoers is discussed in the scientific literature as the so-called diaspora effect.
- 265 The empirical results presented in section B 2-2 provide evidence that many outgoing authors do indeed return to Germany after some time. In the case of inventors in multinational corporations, whose international mobility is largely based on internal company relocations (B 2-3), the country of departure can also benefit directly from the outward flow. For example, if an R&D employee moves from the company's headquarters to a foreign location within the same group, thereby increasing their own productivity, the company as a whole and consequently also the location of the headquarters – i. e. the country of departure – generally benefit directly from the positive effects of mobility.
- 266 Cf. here and below Coda-Zabetta et al. (2024).
- 267 The analysis is based on data from the Scopus publication database. The analysis included authors for whom at least two scientific publications were available in the database, so that it was possible to check whether they indicated an organisational affiliation from the same or different countries in their publications. It should be noted that mobility rates can be overestimated using this method if publication activity and mobility are positively correlated, for example if authors who are more active in publishing move to foreign locations more frequently than authors who are less active in publishing.
- 268 To differentiate between mobility types, the authors' publication analyses were supplemented with information from the IBM Global Name Recognition database. In the database, each first and last name is linked to all the countries in which it appears. Based on the frequency distribution of the names, it is therefore possible to draw conclusions about the nationality or ethnicity of the authors. For example, 'Fowler' is often found in the United Kingdom and 'Rajiv' is often found in India, so that these countries would be selected as associations for an author named Rajiv Fowler. This procedure corresponds to the current methodological standard in research on academic mobility. Immigrating authors are therefore authors without a typical German first name or surname who first published outside Germany and later came to Germany and remained here. Emigrants are authors with typical German first names or surnames who first published in Germany and then left Germany and did not return. Returnees are authors with typical German first names or surnames who first published outside Germany and later came to Germany and stayed here, or authors with first names and surnames atypical for Germany who first published in Germany, then left Germany and later returned. Visitors are authors who first published outside Germany, then stayed in Germany for a certain period of time and then left Germany again.
- 269 However, this does not mean that all authors identified as mobile changed their organisation during this period. The analysis is based on the entire publication history. For example, a researcher who stated only a German organisational affiliation in publications between 2005 and 2020, but who stated a non-German organisational affiliation in her first publication (before 2005), is categorized as an immigrant or returnee. 16.6 percent of all mobile authors belong to this subgroup.
- 270 To calculate this migration balance, only authors immigrating and emigrating during the observation period were taken into account. Additional consideration of returnees and visitors brings the total net inward flow to 3,713 authors.
- 271 In contrast to the previous paragraph, the annual analyses take into account inward and outward flows and not just immigration and emigration.
- 272 Cf. OECD (2017). Authors are assigned to a mobility type based on their immediately preceding publication and the organisational affiliation reported therein. For example, where a researcher reported an organisational affiliation with a research institution in Germany in a publication in 2015 and an organisational affiliation with a research institution abroad in a publication in 2017, she is included in the 2017 mobility balance as an emigrant. If she again indicated an organisational affiliation with a research institution in Germany in a publication in 2020, she is included in the 2020 mobility balance as an immigrant. Due to differences in methodology between Coda-Zabetta et al. (2024) and OECD (2017), the absolute values of Germany's mobility balances differ. However, the observed trend is consistent. While Coda-Zabetta et al. (2024)

include in their study all publications by authors who indicated a German organisational affiliation in at least one publication between 2005 and 2020, the OECD data basis (2017) goes back to 1996. For example, a researcher who stated a German organisational affiliation until 2004, but from 2005 to 2020 exclusively stated an organisational affiliation at a research institution outside Germany, is not included in Coda-Zabetta et al. (2024). This may lead to a slight underestimation of outward flow in the first years of the period analyzed.

- 273** Various indicators, such as the number of visas issued and the proportion of foreign doctoral graduates, seem to suggest that the influx of R&D employees to the USA decreased in the short term after the financial crisis between 2007 and 2009. Cf. <https://www.nsf.gov/statistics/2018/nsb20181/report/sections/science-and-engineering-labor-force/immigration-and-the-s-e-workforce> (last accessed on 15 January 2024) The financial crisis could be a possible cause of the sudden net emigration of authors from the USA in 2011 and the subsequent stagnation in net immigration in the years 2012 to 2014, as publication analyses can only reflect such developments with a delay. The sharp decline in the net immigration of authors in the USA in 2019 could be linked to decisions made by the Trump administration. Cf. Poitras and Larivière (2023).
- 274** When interpreting the return ratio, it should be noted that a return ratio of 0.45 does not necessarily mean that 45 out of 100 outgoers in the observation period actually returned, as some of the returnees left Germany before the beginning of the observation period and therefore do not belong to the group of outgoers.
- 275** The IBM Global Name Recognition database enables probability-based assessments of the gender of authors. Based on the frequency distribution of a first name, the database indicates the probability of whether the first name is more likely to be associated with the female or male gender. If the female association is more likely, the person in question is categorized as a female scientist.
- 276** This difference could also be partially due to name changes. For example, if a female scientist changes her surname after marriage, this can make it difficult to correctly attribute subsequent publications. Coda-Zabetta et al. (2024: 16) address this problem with name disambiguation using the Scopus Author Identifier, an identification number for authors in the Scopus publication database.
- 277** Cf. Coda-Zabetta et al. (2024). Zhao et al. (2023) analyze the international mobility of authors over the period between 1998 and 2017 in terms of gender. They also come to the conclusion that female scientists are less likely to return to Germany or stay abroad longer than their male colleagues.
- 278** The return ratio for female scientists is 0.47, while the return ratio for male scientists is 0.58. The stay ratio for female scientists is 0.50, while the stay ratio for male scientists is 0.45.
- 279** For this purpose, the so-called SJR value of the SCImago Journal Ranking of the Scopus publication database is determined. The highest SJR value in 2022 was the *Ca: A Cancer Journal for Clinicians* with 86,091, followed by the *Quarterly Journal of Economics* with 36,730 and *Nature Reviews Molecular Cell Biology* with 34,201. Cf. <https://www.scimagojr.com/journalrank.php> (last accessed on 15 January 2024).
- 280** The indicator makes it possible to include recently published works in the quality assessment.
- 281** Coda-Zabetta et al. (2024) use the All Science Journal Classification (ASJC) scheme of Scopus to differentiate the scientific disciplines. When a journal is registered in Scopus, it is assigned to a specific scientific discipline based on expert judgement. This assignment is based on the title of the journal and the content published in it. Each scientific branch in Scopus comprises several specialized sub-sectors. For example, the scientific branch *Medical and Health Sciences* includes the sub-sectors *Medicine, Nursing, Veterinary Medicine, Dentistry, Public Health and Interdisciplinary Topics*. Cf. https://service.elsevier.com/app/answers/detail/a_id/12007/supporthub/scopus/ (last accessed on 15 January 2024).
- 282** Cf. Coda-Zabetta et al. (2024: 32 ff.).
- 283** Cf. here and below Coda-Zabetta et al. (2024).
- 284** Cf. Chai and Freeman (2019) and Boudreau et al. (2017).
- 285** Cf. Wuchty et al. (2007).
- 286** Cf. Adams (2012).
- 287** The categorization of research institutions is based on the Academic Ranking of World Universities (ARWU). Leading research institutions in this context are the top 500 ARWU institutions. Cf. Coda-Zabetta et al. (2024: 49 f.).
- 288** Cf. Coda-Zabetta et al. (2024: 48 f.).
- 289** Cf. Netz et al. (2020) and Scellato et al. (2015). The career phase in which mobility takes place is also relevant for the network effect of mobility.
- 290** The tertiary education institution's membership in the U15 and TU9 networks was used as a proxy for tertiary education institutions that are particularly strong in research. Compared to all other profes-

- sors, the percentage of immigrants among TU9 and U15 professors is around three times higher and the percentage of returnees around four times higher. Among all junior research group leaders with Emmy Noether funding, there are around three times more immigrants and around ten times more returnees compared to all authors. In addition, compared to all authors, the number of emigrants is only about half as high. Own calculations based on Karaulova et al. (2024).
- 291 Cf. Coda-Zabetta et al. (2024: 75 f.). Publications written by or with newly appointed Alexander von Humboldt Professors at the tertiary education institution were not included in the analysis.
- 292 Cf. Agrawal et al. (2017).
- 293 Cf. Huang (2017) and Hoisl (2007).
- 294 Cf. here and below Karaulova et al. (2024).
- 295 An inventor is internationally mobile if the country indicated in the patent applications for the inventor's place of residence has changed. International movements are analyzed annually, with the most frequently reported country being taken into account if several addresses are given in one year. The country of origin assigned to an inventor is the country stated in the first patent application. This country does not necessarily need to be the country of birth of the respective inventor. By definition, to be classified as mobile, inventors need at least two patent applications in different years with different country details. Inventors with a single patent application are by definition non-mobile.
- 296 Transnational patents are patents that are filed with the European Patent Office for European countries or as patent applications under the Patent Cooperation Treaty (PCT) for non-European countries. Applicants choose a transnational patent application if the invention is to be used in different national markets.
- 297 To precisely track and analyze the mobility of inventors over time, a two-stage name disambiguation process was used. In the first stage, the names were grouped within a year based on several criteria (name, region, technology classes, inventor ID). In a second stage, this information was aggregated into superordinate groups across the various years. Using this double aggregation, the patents can be assigned to a person within a year and across the years.
- 298 Cf. Karaulova et al. (2024).
- 299 Cf. Karaulova et al. (2024).
- 300 In contrast to the previous paragraph, the annual analyses take into account inward and outward flows and not just immigration and emigration.
- 301 Cf. Karaulova et al. (2024).
- 302 Own calculations based on Karaulova et al. (2024).
- 303 Global selection of countries. Cf. Karaulova et al. (2004).
- 304 According to this definition, returnees are thus initially counted as outgoing and later as incoming, while visitors are initially counted as incoming and later as outgoing.
- 305 Own calculations based on Karaulova et al. (2024).
- 306 As described in section B2-1, a positive effect of mobility can be expected in the case of in-house inventor mobility even without a return.
- 307 Cf. Karaulova et al. (2024).
- 308 When comparing the different types of mobility, it must be considered that, by definition, inventors must have registered at least two patents in order to be classified as mobile. For returnees and visitors on the other hand, it is at least three. This difference resulting from the methodology of the study limits the validity of comparisons between the different types of mobility.
- 309 The general causes of international skilled labour migration include country differences in the general quality of life, the social and family policy framework, the attractiveness of the prevailing lifestyle, employment opportunities and working conditions as well as wage levels in the relevant sectors. As with international skilled workers in general, the individual migration decisions of internationally mobile scientists and R&D employees are embedded in complex structures of employment relationships as well as social and cultural contexts. Cf. Bauder (2015).
- 310 In the 2014 Annual Report, survey results were presented by Franzoni et al. (2012), which show that the international mobility of scientists was primarily professionally motivated. A survey by Guthrie et al. (2017) in the UK came to the same conclusion: mobility is primarily professionally motivated among the scientists surveyed. Aspects of career development and the expansion of their own scientific network play a particular role. The majority of respondents expect international mobility to benefit their individual career opportunities, whereby this expectation is independent of disciplinary and institutional affiliation as well as their own mobility experiences.
- 311 Cf. Hunter et al. (2009).
- 312 Cf. EFI (2014).
- 313 Cf. IEKE (2016), Bornmann (2016), Möller et al. (2016), Carayol and Maublanc (2022) and Warta et al. (2017). The study by Carayol and Maublanc (2022) allows causal conclusions to be drawn about

the impact of the Excellence Initiative and confirms a positive effect on the research output of funded universities.

- 314 Due to different methodological approaches in the underlying analyses of researcher mobility, it is not possible to compare the individual findings. The statements in this chapter are therefore limited to a comparison of the core statements.
- 315 This is a comparison of absolute gross figures without a relation to the total population.
- 316 Cf. EFI (2014: 88).
- 317 Cf. Coda-Zabetta et al. (2024). Returnees and visitors were not included in the calculation of net immigration. In addition to analyzing the publication history of a scientist, Coda-Zabetta et al. (2024) also carried out a name analysis in order to distinguish more precisely between mobility types. In the analyses of the Commission of Experts' 2014 Annual Report, only the publication history was analyzed for the identification of mobility types. If, for the period between 2005 and 2020, only the publication history is analyzed for the identification of mobility types, the shares of immigrants and emigrants increase equally by 2 percentage points and therefore have no noticeable effect on the calculation of the migration balance. Cf. Coda-Zabetta et al. (2024: 86).
- 318 Due to a different methodological approach in the analyses of the 2014 Annual Report, a direct comparison is not possible. The 2014 Annual Report refers to WIPO (2013) when analyzing inventor mobility. In contrast to Karaulova et al. (2024), however, no elaborate name disambiguation of inventors was carried out there; instead, mobility was analyzed using name aggregates.
- 319 Cf. EFI (2023).
- 320 Cf. EFI (2014: 90).
- 321 Cf. <https://www.dfg.de/foerderung/foerderinitiativen/exzellenzinitiative/> (last accessed on 15 January 2024).
- 322 Cf. <https://www.dfg.de/foerderung/foerderinitiativen/exzellenzstrategie/> (last accessed on 15 January 2024).
- 323 Cf. <https://www.humboldt-foundation.de/bewerben/foerderprogramme/alexander-von-humboldt-professur> (last accessed on 15 January 2024).
- 324 Cf. https://www.dfg.de/foerderung/programme/einzelfoerderung/emmy_noether/ (last accessed on 15 January 2024).
- 325 Cf. <https://www.tenuretrack.de/de/startseite> (last accessed on 15 January 2024).
- 326 In a panel survey conducted by the OECD, only 4 percent of the skilled workers surveyed who were willing to immigrate had fulfilled the administrative requirements for coming to Germany after six months. Cf. <https://blog.oecd-berlin.de/wer-will-nach-deutschland-zweite-befragung-von-auslaendischen-fachkraefte> (last accessed on 15 January 2024). For many of those surveyed, the lengthy administrative processes are a reason to abandon their planned move to Germany. The problem of lengthy, non-transparent and insufficiently standardized and digitized intermediate steps was confirmed to the Commission of Experts in professional discussions with counselling agencies for skilled workers seeking to immigrate. The result is sometimes seemingly arbitrary administrative processes in visa and recognition procedures that make it difficult for skilled workers to move to Germany.
- 327 Cf. also Jaudzims and Oberschelp (2023).
- 328 However, as was already explained in detail in the 2014 Annual Report, the visa regulations applicable in Germany are extremely liberal by international standards, especially for highly qualified individuals, and do not represent a major legal barrier for most R&D employees. If a job offer is available, there are in fact no longer any significant legal hurdles for scientists, for example.
- 329 One obstacle, for example, is that combined insurance periods from EU and non-EU countries with bilateral social security agreements often cannot be counted together as a period for pension entitlement. Cf. <https://www.deutscherentenversicherung.de/DRV/DE/Rente/Ausland/Rente-im-Ausland/rente-im-ausland-zeiten-detailseite.html> (last accessed on 15 January 2024).
- 330 Cf. Hellfeier and Hendricks (2022). For instance, only six Länder provide for the transfer of pension entitlements in the event of voluntary resignation from civil servant status (old-age payment (Altersgeld) regulation) in order to work in a non-EU country. In other Länder, supplementary pension insurance is provided in the statutory pension insurance scheme (without supplementary pension insurance in the Pension Institution of the Federal Republic and the Federal States (Versorgungsanstalt)). The Federal Administrative Court has granted civil servants who make use of the freedom of movement for workers under Art. 45 TFEU by leaving the civil servant relationship established in Germany in order to pursue gainful employment in another EU Member State an entitlement to appropriate supplementary pension insurance (Judgement: BVerwG 2 C 3.21). However, this judgement does not apply to taking up employment in a non-EU country.

- 331 Cf. Jaudzims and Oberschelp (2023).
- 332 Cf. e. g. Aufderheide and Neizert (2016).
- 333 In 2022, for example, the DAAD supported the international mobility of a total of around 66,500 people from abroad, of whom around 18,000 had doctoral or postdoctoral status, and around 24,000 people from Germany, of whom around 5,500 had doctoral or postdoctoral status. These figures do not include Erasmus+ funding.
- 334 Cf. Die Bundesregierung (2023c).
- 335 Cf. EFI (2023).

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- 336 Cf. Europäische Kommission (2011).
- 337 Cf. European Parliament, The Council of the European Union (2021).
- 338 Cf. Kuittinen et al. (2018).
- 339 Cf. Die Bundesregierung (2023b).
- 340 Cf. EFI (2016).
- 341 Cf. Weber et al. (2024).
- 342 Cf. Howaldt and Schwarz (2010) and Weber et al. (2024).
- 343 Cf. Havas and Molnár (2020), European Commission (2017a), Weber et al. (2024).
- 344 Cf. Bureau of European Policy Advisor (2010), Rueede and Lurtz (2012), Edwards-Schachter and Wallace (2017), Weber et al. (2024).
- 345 Cf. Weber et al. (2024).
- 346 Cf. Alperstedt and Andion (2021), Terstriep et al. (2015).
- 347 Tafel Deutschland is a non-profit organisation that distributes consumer goods (especially food) that are no longer needed, either free of charge or for a small fee. These food banks are organised in the umbrella organisation Tafel Deutschland e. V. Cf. <https://www.tafel.de/> (last accessed on 15 January 2024).
- 348 The Mitfahrbank (ride-sharing benches) is an initiative that involves placing benches on roads or bus stops to offer ride-sharing opportunities. People looking for a lift can sit on the bench and signal that they need a lift. Drivers travelling in the same direction can stop and give the person a lift. The Mitfahrbank is intended to help improve mobility in rural areas and reduce the number of vehicles on the roads. It is estimated that there are around 1,000 such ride-sharing benches in Germany. Cf. <https://taz.de/Mobilitaet-auf-dem-Dorf/!5953209/> (last accessed on 15 January 2024).
- 349 Multi-Level Perspective on Social Innovation (MLP-SI) model. Cf. Weber et al. (2024: 53), Bodenheimer (2019) and Geels and Schot (2007).
- 350 The concept of generalisation is proposed in Sengers et al. (2021). Generalisation represents a wider view of system change that goes beyond individual products, production processes and services, as it addresses system innovations.
- 351 During this early phase of social innovation, networks will develop within the social innovation initiatives and there will also be collaboration with external actors such as scientists who contribute their expertise. For some societal challenges and problems, it is likely that different approaches exist and complement each other, for example by actors organising themselves into associations, exchanging knowledge or competing with each other. A discourse on how the societal problem can best be solved can lead to a selection process in which certain approaches prevail or initiatives work together.
- 352 Cf. Weber et al. (2024), Bodenheimer (2019), Geels and Schot (2007).
- 353 Examples include simple messenger app groups, car sharing, blockchain-based supply chains, online platforms for networking and collaboration between people and the use of data analysis and artificial intelligence to solve societal problems.
- 354 Cf. Weber et al. (2024), Phills Jr. et al. (2008), The Economist Intelligence Unit (2016).
- 355 Cf. <https://www.bmbf.de/bmbf/de/forschung/soziale-innovationen-und-zukunftsanalyse/insight/insight.html#searchFacets> (last accessed on 15 January 2024).
- 356 This non-rivalry in the case of public goods means that their provision is accompanied by positive external effects, because not only those who provide the good can benefit from it.
- 357 Cf. European Commission (2017b), Die Bundesregierung (2023b), Edler et al. (2023). Some definitions of social innovations therefore go so far as to include not only the objective, but also an actual positive contribution of a social innovation to a specific social transformation as a criterion for social innovation. This normative view is not uncontroversial in the literature and can lead to acceptance problems when implementing social innovations or promoting them politically. One criticism is that it predetermines which behavioural changes should be classified as ‘good’ or ‘right’. This can lead to certain groups or viewpoints being neglected or marginalized. Those who do not fit into the predetermined ideas of social innovation can be excluded from the benefits of these innovations or evaluate the impact of the corresponding innovation differently. The literature refers to this as the ‘dark side of social innovation’. Cf. Coad et al.

(2021), Curtis et al. (2023); Voegtlin et al. (2022), Larsson and Brandsen (2016), Sardo et al. (2023). Furthermore, a normative perspective ignores the fact that social innovations can also have unexpected and undesirable consequences.

- 358 Die Bundesregierung (2023b: 4), own translation.
- 359 Cf. Die Bundesregierung (2023b: 8).
- 360 Cf. EFI (2021: 38 ff.).
- 361 Cf. for example Euclid Network (2022: 20 f.) regarding country-specific definitions of social enterprises as part of the European Social Enterprise Monitor.
- 362 Europäische Kommission (2011: 3), own translation.
- 363 Cf. Europäische Kommission (2011: 3 f.).
- 364 <https://www.send-ev.de/social-entrepreneurship/definition-kriterien/> (last accessed on 15 January 2024), own translation.
- 365 Management and control mechanisms are often used to ensure that social objectives are not only met within the social enterprise, but also in controllable areas outside the social enterprise such as supply chains.
- 366 Cf. Doherty et al. (2014) and Yahyaoui et al. (2023).
- 367 Cf. Die Bundesregierung (2023b: 4) and <https://www.send-ev.de/social-entrepreneurship/definition-kriterien/> (last accessed on 15 January 2024).
- 368 Cf. here also Unterberg et al. (2015).
- 369 It is difficult to make a clear distinction between companies, because most companies, even those that do not consider themselves to be social enterprises, do not have the sole intention of making a profit and their contribution to society is not limited to an economic contribution. Cf. Stitteneder (2023), Schlepphorst et al. (2022), Unterberg et al. (2015).
- 370 Cf. Weber et al. (2024).
- 371 In 2014, the European Commission published a broad-based study on social enterprises and their respective ecosystems. The study was the first to attempt to compare national ecosystems with one another. It examined the legal framework, social capital market, impact measurement and reporting, networks and mutual support mechanisms, specialized support services for business model development and certification systems and labels. The study concluded that the national differences make comparison difficult in view of the different understanding of social entrepreneurship and the historically evolved structures – especially with regard to the role of (semi-)state actors in the provision of social services – and that the adaptation of good practices is extremely difficult. Cf. Wilkinson et al. (2014).
- 372 The analysis is based on about 1.29 million observations. This mainly includes companies, but also associations, clubs and tertiary education institutions. On the representativeness of the data, cf. Kinne and Axenbeck (2020).
- 373 ISTARI is a ZEW spin-off and provides real-time market and company information. ISTARI.AI's platform uses AI technology to scan over 20 million company websites in Europe and North America.
- 374 Cf. <https://www.si-drive.eu/> (last accessed on 15 January 2024), mapping of data in the Atlas of Social Innovation, <https://www.socialinnovationatlas.net/> (last accessed on 15 January 2024) and Howaldt et al. (2019).
- 375 Cf. <https://www.send-ev.de/projekte-items/dsem/> (last accessed 15 January 2024).
- 376 Cf. Stephan et al. (2015), Renko (2013), Siqueira et al. (2018).
- 377 van der Have and Rubalcaba (2016).
- 378 Cf. Krlev et al. (2020) and Terstriep et al. (2020).
- 379 Cf. Strambach and Thurmann (2021) and <https://www.si-metrics.eu/de/indisi/> (last accessed on 15 January 2024).
- 380 Input indicators can include, for example, investments in social innovations, social activities that pursue sustainable goals, personal involvement and economic motives. Output indicators can be, for example, the number of beneficiaries of social innovations, the number of paying customers, the campaigns implemented and network formation. Cf. Krlev et al. (2021).
- 381 Cf. Europäische Kommission (2020).
- 382 In Germany, the use of social entrepreneurship concepts and their acceptance is rated as low. Data reliability is rated as very high for the UK and high for Spain, Poland, Luxembourg, Greece and Finland. Cf. Europäische Kommission (2020). For instance, how the acceptance of social enterprises is measured is not explained in detail. The legal and organisational forms for social enterprises vary depending on the legal systems of the countries covered. Poland, for example, has a specific legal form for social enterprises (social cooperatives) and proposes in draft legislation the creation of a legal status for social enterprises (National Program for Social Economic Development, Krajowy Program Rozwoju Ekonomii Społecznej – KPRES). Italy is the only European country to have both a law on social cooperatives (legal form) and a law on social enterprises (legal status). Cf. Wilkinson et al. (2014).
- 383 ISTARI.AI collects the data via a so-called neural network, the webAI InnoProb agent, which is trained to derive the status of enterprises as innovators from

- their websites and map it as an individual innovation probability score (InnoProb). The webAI agent for social innovation was trained by ISTAR.AI to derive their commitment to social innovation from enterprises' websites and to display it as an individual Social InnoProb Score. This indicator ranges from 0.0 to 1.0 and reflects the probability that an enterprise is a social innovator. The Social InnoProb Score calculated in this way would be close to 0.0 for a company that is very unlikely to be a socially innovative enterprise. A very likely socially innovative enterprise, on the other hand, would have a Social InnoProb Score close to 1.0. Cf. <https://docs.istari.ai/indicators/social-innovation> (last accessed on 15 January 2024). The analyses presented define enterprises as socially innovative if the Social InnoProb Score is above 0.5. Due to fundamentally different survey methods, a comparison with innovator rates for technological innovations is not useful.
- 384** Cf. <https://www.bbsr.bund.de/BBSR/DE/forschung/raumbeobachtung/Raumabgrenzungen/deutschland/regionen/siedlungsstrukturelle-regionstypen/regionstypen.html> (last accessed on 15 January 2024).
- 385** The share of socially innovative enterprises is highest in urban districts, particularly in Bonn (29.8 percent), Hamburg (28.6 percent), Stuttgart (28.2 percent) and Munich (28.1 percent). The share of socially innovative enterprises is lowest in the rural regions of Altenburger Land (6.7 percent), Euskirchen (8.5 percent), Jerichower Land (9.2 percent) and Sächsische Schweiz-Osterzgebirge (9.6 percent).
- 386** Based on 101 districts.
- 387** Based on 213 districts.
- 388** Based on 117 districts.
- 389** The evaluations are based on the SI-Drive data set. The data were collected in 2015/16 using an online questionnaire. The data is not representative. The survey was not anonymous. The project was funded with funds from the seventh framework programme of the European Community for research and technological development including demonstration activities (FP7) under the grant agreement No. 612870. When it comes to measuring social innovations, the attribution may vary based on respondents' understanding. Initiatives include all socially innovative actors, such as citizens' initiatives, social enterprises, associations, for-profit companies with social innovations. Cf. here also <https://www.si-drive.eu/> (last accessed on 15 January 2024).
- 390** Cf. [https://www.bundesregierung.de/breg-de/themen/nachhaltigkeitsziele-erklaert-232174](https://www.bundesregierung.de/breg-de/themen/nachhaltigkeitspolitik/nachhaltigkeitsziele-erklaert-232174) (last accessed on 15 January 2024).
- 391** Cf. https://www.globalcompact.de/fileadmin/user_upload/Dokumente_PDFs/SDG-Compass_German.pdf (last accessed on 15 January 2024).
- 392** Europe includes here and below the 21 countries that are part of the 2021/2022 ESEM survey (in alphabetical order): Austria, Bulgaria, Croatia, Denmark, Estonia, France, Germany, Hungary, Ireland, Italy, Latvia, the Netherlands, Poland, Portugal, Serbia, Slovenia, Spain, Sweden, Switzerland, Turkey and the UK. Germany is therefore included in the European average. Cf. also Euclid Network (2022).
- 393** Examples of social innovations in internal company processes include: home office, work/leisure combination, flexible working life models, mentoring programmes, girls'/boys' day, inclusive workplaces, bridging internships.
- 394** Examples of social products include: telecare, sustainable tourism, swap shops, multi-generation houses, swapping education for housing, recycling discarded food, e-health, community buses, car sharing, tutoring video platforms, walking home phone line, microloans, crowdfunding.
- 395** Data basis is the Mannheim Innovation Panel (MIP). In 2023, the question was asked for the first time whether social innovations have been introduced within the company since 2020 and whether a company offers products or services that enable or support socially innovative behaviour among the users of the products or services. The results are representative.
- 396** Cf. Hippel (1976), Kaufmann, Tanja, Katharina Schiller, Linda Widdel (2022).
- 397** Cf. Fursov and Linton (2022) Rivieccio et al. (2023).
- 398** Cf. Hippel (1988) and Hippel (2005).
- 399** Cf. Biggeri et al. (2017).
- 400** Cf. for example Gault (2012) and <https://reconnectproject.medium.com/identifying-nbs-innovations-with-lead-user-method-ad2b0a3faceb> (last accessed on 15 January 2024).
- 401** Cf. Schweitzer et al. (2015).
- 402** The analysis is based on the SI-Drive data set. Due to the nature of the data collection, it cannot be assumed that the results are representative.
- 403** The analyses are based on the SI-Drive data set. The SI-Drive is an international, non-representative survey. A detailed analysis by topic area can be found in Weber et al. (2024: 154 ff.).
- 404** In addition to the conflict of objectives between profit-oriented financiers and social enterprises focused on the common good, the financing difficulties of social enterprises could also be exacer-

bated by the fact that social enterprises are more frequently run by women than ‘conventional’ enterprises. Studies such as Malmström et al. (2020) and Snellman and Solal (2023) show a disadvantage in access to financing for women-led enterprises. However, Lee and Huang (2018) show that this disadvantage is less pronounced in social enterprises.

- 405 The DSEM is not representative. Only companies that answered yes to the question of whether they are a social enterprise were included in the results presented. Multiple answers were possible for the barriers listed.
- 406 Based on the KfW Start-up Monitor, Metzger (2019) shows that ‘young’ social entrepreneurs require capital, in particular up to €25,000, more frequently than other young entrepreneurs. The term ‘young’ social enterprises covers social entrepreneurs who started their own business no more than five years previously with a project that was still active in 2017. The focus of the project is on social or ecological causes, with commercial objectives taking second place. Social enterprises account for 9 percent of all new businesses.
- 407 Europe here refers to the 21 European countries participating in the ESEM: Cf. here Euclid Network (2022).
- 408 The analysis of the legal form of the social enterprises surveyed in the DSEM reveals that 22 percent of the social enterprises surveyed state that their legal form is a GmbH (limited liability company), 20.4 percent are a non-profit GmbH, 16.7 percent are a non-profit association and 12 percent are corporate companies (limited liability; German: Unternehmensgesellschaft). Other legal forms mentioned include sole proprietorship, non-profit corporate company, civil law partnership, non-profit registered association, co-operatives and joint stock companies.
- 409 Cf. OECD (2022).
- 410 When asked whether a special legal form for social enterprises exists and would be useful, 56.6 percent of the social enterprises surveyed in the DSEM responded that there is no legal form for social enterprises, but that there should be one in the future. 8.4 percent say that there is a legal form for social enterprises and that it is useful. 8.7 percent are of the opinion that the existing legal form is unsuitable. 12.5 percent of the social enterprises surveyed see no need to introduce a specific legal form for social enterprises.
- 411 Cf. Bundesregierung (2014).
- 412 Cf. Bundesregierung (2014: 11).
- 413 Cf. Bundesregierung (2014).

- 414 Cf. BMBF (2021a).
- 415 Cf. Die Bundesregierung (2023b: 1).
- 416 Cf. Die Bundesregierung (2023d: 27).
- 417 Cf. Die Bundesregierung (2023b: 4, here in particular Footnote 11).
- 418 Cf. Die Bundesregierung (2023b: 42 ff.).
- 419 Cf. Die Bundesregierung (2023b: 38 ff.).
- 420 Cf. Weber et al. (2024).
- 421 The Mannheim Innovation Panel (MIP) already focussed on social innovation activities in the 2023 survey edition.
- 422 Cf. Die Bundesregierung (2023b: 22 ff.) and Die Bundesregierung (2023b: 44 ff.).

B 4

- 423 Cf. here and below EFI (2022: chapter B 1).
- 424 The analyses of AI publications contained in this chapter are based on data from the Web of Science.
- 425 In Europe, software or a computer program alone cannot be protected by a patent. However, inventions that utilize software can be patented. This also means that inventions that utilize AI can be patented. They fall under computer-implemented inventions. These are defined as inventions involving computers, computer networks or other programmable devices, where at least one feature is realized by a program. Cf. <https://www.epo.org/de/news-events/in-focus/ict/artificial-intelligence> (last accessed on 15 January 2024).
- 426 Transnational patent applications are patent applications that are filed at the European Patent Office or as a Patent Cooperation Treaty (PCT) application for non-European countries. An applicant chooses a transnational patent application if the invention is to be exploited in different national markets. The use of data from the international offices (European Patent Office – EPO and World Intellectual Property Organization – WIPO) has two advantages for patent statistics and the associated indicators. First, the transnationally registered patents are of greater relevance. Second, this basis enables better comparability between national economies than on the basis of national patent data.
- 427 Cf. EFI (2019: 27).
- 428 Cf. Döbel et al. (2018: 8).
- 429 Cf. Bommasani et al. (2022).
- 430 Cf. Maslej et al. (2023: 54).
- 431 Aleph Alpha was one of the 20 outstanding AI start-ups named in 2023 as part of the publication of the Sixth Annual AI Startup Landscape by the appliedAI Institute for Europe. Cf. <https://>

- www.appliedai-institute.de/hub/2023-ai-german-startup-landscape (last accessed on 15 January 2024). The start-ups selected by a jury include Aleph Alpha, askUI, Brighter AI, Celus, Deepset, Frequenz, Helsing, HQS Quantum Simulations, Hyperganic, Luminovo, Navvis, Parloa, Paretos, Qdrant, Scoutbee, SPREAD, Taktile, Twice, Ultimate.ai and ZenML.
- 432 Cf. <https://docs.aleph-alpha.com/docs/introduction/model-card/#training-details> (last accessed on 15 January 2024).
- 433 Cf. <https://the-decoder.com/gpt-4-architecture-datasets-costs-and-more-leaked/> (last accessed on 15 January 2024). There is no official information about the model size of GPT-4.
- 434 Cf. <https://www.iis.fraunhofer.de/de/magazin/serien/kuenstliche-intelligenz-ki-serie/edge-ai-uebersicht.html> (last accessed on 15 January 2024).
- 435 Cf. <https://www.hhi.fraunhofer.de/en/departments/ai/research-groups/efficient-deep-learning/research-topics/federated-learning.html> (last accessed on 15 January 2024).
- 436 The publications are assigned to the country of the first stated organisational affiliation of the authors. In the case of publications by several authors, a pro rata allocation is made.
- 437 Among the EU 27 countries, the shares fell most sharply in Spain (-2.5 percentage points), France (-2.0 percentage points), Germany (-1.4 percentage points), Italy (-1.1 percentage points) and Greece (-0.7 percentage points).
- 438 Cf. Maslej et al. (2023: 44 ff.).
- 439 Cf. Maslej et al. (2023: 47). Ahmed et al. (2023) report that the share of research papers with at least one author from industry at leading AI conferences has increased from 22 percent in 2000 to 38 percent in 2020.
- 440 Cf. Maslej et al. (2023: 48).
- 441 Patents are attributed to a country if the inventors' place of residence is there.
- 442 Among the EU 27 countries, France's share fell by 2.5 percentage points and Finland's share by 1.5 percentage points. Italy's, Spain's and Denmark's shares fell by around 1 percentage point each. By contrast, the Netherlands' share rose by around 1.5 percentage points.
- 443 Cf. here and below Maslej et al. (2023: 50). Of the six systems that cannot be attributed to the business sector, three originate from the academic sector, two from research collectives and one from cooperation between the business sector and the academic sector. In the development of these models, the business sector is more of a driving force than it was ten years ago. The 38 major machine learning models published in 2022 are categorized as follows. Language: 23; Multimodal: 4; Drawing: 3; Vision: 2; Speech: 2; Text-to-Video: 1; Other: 1; Games: 1; without category: 1 Cf. Maslej et al. (2023: 49).
- 444 Cf. Maslej et al. (2023: 56 f.), <https://epochai.org/blog/machine-learning-model-sizes-and-the-parameter-gap> and <https://epochai.org/blog/trends-in-the-dollar-training-cost-of-machine-learning-systems> (each last accessed on 15 January 2024).
- 445 Cf. <https://www.semianalysis.com/p/the-ai-brick-wall-a-practical-limit> and https://thegradient.pub/why-transformative-artificial-intelligence-is-really-really-hard-to-achieve/?mj_campaign=nl_ref&mj_content=zeitde_text_link_x&mj_medium=nl&mj_source=int_zonaudev_Nat%C3%BCrlich%20intelligent (each last accessed on 15 January 2024).
- 446 Cf. here and below Maslej et al. (2023: 58).
- 447 Cf. Maslej et al. (2023: 59). The HAI's Artificial Intelligence Index Report 2023 assigns Stable Diffusion to Germany, GPT-NeoX-20B to the USA, the UK, Germany and India, and Imagen to Canada.
- 448 Cf. <https://falconllm.tii.ae/index.html> and <https://docs.mistral.ai/> (each last accessed on 15 January 2024).
- 449 Cf. EFI (2018: chapter B 1).
- 450 Cf. e.g. Acemoglu et al. (2023).
- 451 Cf. e.g. Brynjolfsson et al. (2019).
- 452 Cf. Rammer et al. (2022) and Czarnitzki et al. (2023).
- 453 The possible maturity levels of AI use in companies are defined, for example, by the appliedAI initiative. Cf. <https://www.appliedai.de/loesungen-services/strategie-transformation> (last accessed on 15 January 2024).
- 454 A current survey by the Federal Statistical Office arrives at similar results. Cf. https://www.destatis.de/DE/Presse/Pressemitteilungen/2023/11/PD23_453_52911.html (last accessed on 15 January 2024).
- 455 Cf. and below EFI (2022: chapter B 1).
- 456 Cf. here and below EFI (2022: chapter B 1).
- 457 Cf. EFI (2022: 41 f.).
- 458 Cf. EFI (2022: chapter B 1).
- 459 Cf. European Commission (2021a: 31).
- 460 Cf. e.g. Luitse and Denkena (2021).
- 461 Cf. e.g. Bommasani et al. (2023) and <https://spectrum.ieee.org/open-source-llm-not-open> (last accessed on 15 January 2024).
- 462 Cf. Blind et al. (2021).
- 463 Cf. e.g. Bommasani et al. (2023) and <https://spectrum.ieee.org/open-source-llm-not-open> (last accessed on 15 January 2024).

- 464 Cf. e.g. Bommasani et al. (2023) and <https://spectrum.ieee.org/open-source-llm-not-open> (last accessed on 15 January 2024).
- 465 Cf. e.g. Widder et al. (2023). It is also possible to switch to a more open licence system. For example, Microsoft placed its Ph-2 Small Language Model under the MIT licence in January 2024. This licence originated at the Massachusetts Institute of Technology (MIT) and enables uncomplicated and very liberal further developments and implementations of MIT-licensed source code in own applications.
- 466 Cf. GPT-2: 1.5B release (openai.com) and openai-community/gpt2-xl · Hugging Face (each last accessed on 15 January 2024).
- 467 Cf. e.g. Bommasani et al. (2023) and <https://spectrum.ieee.org/open-source-llm-not-open> (last accessed on 15 January 2024). A current overview of the literature on open source software is provided, for example, by Blind et al. (2021).
- 468 Two examples of Python modules with a focus on machine learning that are developed on Github are the packages Scikit-Learn <https://github.com/scikit-learn/scikit-learn> and Keras <https://github.com/keras-team/keras> (each last accessed on 15 January 2024).
- 469 One disadvantage of open source foundation models is the potentially increased security risk due to the wider user base. As the algorithm is publicly accessible, it could also be misused by malicious actors. Cf. e.g. Seger et al. (2023: 13).
- 470 Cf. <https://www.techopedia.com/de/llama-killer-falcon-180b-open-source-ki-ist-mit-aufholjagd-fertig> (last accessed on 15 January 2024).
- 471 Definition based on Granstrand and Holgersson (2020).
- 472 Cf. <https://www.plattform-lernende-systeme.de/ki-landkarte.html?FIT=1> (last accessed on 15 January 2024).
- 473 Cf. here and below <https://www.bmbf.de/bmbf/shareddocs/kurzmeldungen/de/2022/06/50-millionen-foerderung-fuer-ki-kompetenzzentren.html> (last accessed on 15 January 2024). The DFKI is funded by the BMBF and the host countries via project funds. The other five AI competence centres have been institutionally funded by the BMBF and the respective host country since mid-2022.
- 474 Cf. <https://www.ihl.fraunhofer.de/de/unser-institut/projekte/silicon-economy.html> (last accessed on 15 January 2024).
- 475 Cf. <https://www.sovereigntechfund.de/de/> (last accessed on 15 January 2024). The Sovereign Tech Fund established in September 2022 is funded by the BMWK and is organised by SPRIND GmbH.
- 476 Cf. <https://openwebsearch.eu/> (last accessed on 15 January 2024).
- 477 Project partners are Aleph Alpha, ControlExpert, DFKI, Fraunhofer IAIS, Fraunhofer IIS, KI Bundesverband, Ionos, Forschungszentrum Jülich, WDR and Center for Information Services and High Performance Computing (ZIH). Cf. <https://opengpt-x.de/> (last accessed on 15 January 2024).
- 478 Cf. <https://ki-zentren.net/> (last accessed on 15 January 2024).
- 479 An ELLIS Unit has an annual budget of €1.5 million. An ELLIS Institute has significantly greater resources at its disposal. In addition to the development of new research infrastructures, an annual budget of up to €30 million is made available. Cf. <https://ellis.eu/sites> (last accessed on 15 January 2024). There are currently 41 ELLIS Units in 16 European countries, including ten in Germany alone. In Germany, ELLIS Units are represented in Tübingen, Freiburg, Heidelberg, Munich, Stuttgart, Darmstadt, Potsdam, Berlin, Jena and Saarbrücken. Cf. <https://ellis.eu/units> (last accessed on 15 January 2024). The long-term objective is to establish a number of additional ELLIS Institutes as local beacons for cutting-edge AI research. Cf. <https://ellis.eu/> (letzter Abruf am 15. January 2024). The network's first ELLIS Institute was established in Tübingen in July 2023; it will complement the Cyber Valley innovation campus. Cf. <https://mwk.baden-wuerttemberg.de/de/service/presse/pressemitteilung/pid/europaweit-erstes-ellis-institut-geht-in-tuebingen-an-den-start> (last accessed on 15 January 2024).
- 480 Cf. here and below <https://claire-ai.org/vision/>, <https://claire-ai.org/about/>, <https://futurium.ec.europa.eu/system/files/ged/claire-in-a-nutshell.pdf> (each last accessed on 15 January 2024).
- 481 CLAIRE aims to create a pan-European network of centres of excellence in AI and to establish a CLAIRE Hub as a central unit with a state-of-the-art infrastructure. Cf. <https://claire-ai.org/vision/> and <https://claire-ai.org/about/?lang=de> (each last accessed on 15 January 2024). One of eight CLAIRE offices is located at the DFKI in Saarbrücken. Around 60 German organisations are members of the alliance. Cf. <https://claire-ai.org/office-saarbruecken/#membersde> (last accessed on 15 January 2024).
- 482 Cf. here and below <https://www.ki-strategie-deutschland.de/home.html> (last accessed on 15 January 2024). The majority (85) of these professorships were appointed via the tenure-track programme. 24 professorships were appointed to

- Centres of Excellence for AI Research, 15 professorships were created in cooperation between non-university research institutions and tertiary education institutions and eight professorships through programmes of the German Research Foundation. It was also possible to appoint 18 Alexander von Humboldt Professorships for AI.
- 483 Cf. <https://www.plattform-lernende-systeme.de/ki-indikatoren-include-elemente/articles/include-element-vom-bund-eingerichtete-ki-professuren.html> (last accessed on 15 January 2024). Scientists in the field of AI in particular show a relatively high level of international mobility. Cf. Coda-Zabetta et al. (2024).
- 484 Cf. here and below BMBF (2023a: 26).
- 485 Cf. <https://zuseschoolrelai.de/> (last accessed on 15 January 2024).
- 486 Cf. <https://www.bmbf.de/bmbf/de/europa-und-die-welt/vernetzung-weltweit/internationalisierungsstrategie/internationale-zukunftslabore/internationale-zukunftslabore-kuenstliche-intelligenz.html> (last accessed on 15 January 2024).
- 487 Cf. <https://www.forschung-fachhochschulen.de/fachhochschulen/de/massnahmen/ki-nachwuchs-fh/ki-nachwuchs-fh.html> (last accessed on 15 January 2024).
- 488 Cf. here and below <https://www.plattform-lernende-systeme.de/ki-landkarte.html?STU=1> (last accessed on 15 January 2024).
- 489 LinkedIn generates this key figure by calculating the frequency of skills added by LinkedIn users themselves in a specific field and then reweights these numbers using a statistical model to determine the 50 most representative skills in that selected occupation. Cf. Maslej et al. (2023: 182).
- 490 The relative penetration rate of AI skills for a specific country shows the sum of the penetration rates of the individual AI skills across the various occupations as a proportion of the global average in the same occupation.
- 491 The relative penetration rate of AI skills is not available for all the countries analyzed in this chapter. China and Japan are missing. There is also no value for the EU 27.
- 492 Cf. here Büchel et al. (2023: 7).
- 493 The number of vacancies based on online job advertisements was around 4.5 million in the first quarter of 2022 and around 4.2 million in the first quarter of 2023. Cf. Büchel et al. (2023: 6).
- 494 Cf. Akademie für Künstliche Intelligenz im KI Bundesverband (2023) and Krizhevsky et al. (2012).
- 495 Ahmed and Wahed (2020) speak of a compute divide when large companies and elite tertiary education institutions can afford access to computing capacity, while research by start-ups and medium-sized and small tertiary education institutions is made more difficult. Complementary to the computing infrastructure, expertise is also needed in the field of GPU.
- 496 Cf. <https://developer.nvidia.com/blog/openai-presents-gpt-3-a-175-billion-parameters-language-model/> (last accessed on 15 January 2024).
- 497 To this end, the BMBF plans to promote targeted cooperation between public and private actors and also to further strengthen the Gauss Centre for Supercomputing, National Supercomputing and European Cooperation within the framework of EuroHPC as the foundation of the German computing infrastructure and to expand it to include applications, particularly in a European context. In addition, starting with JUPITER, the construction of high-performance computers in the exascale class is to be promoted and access to AI-specific computing infrastructure is to be created across the board via the AI service centres. Cf. BMBF (2023a).
- 498 Common Crawl and Wikipedia are frequently used sources for training foundation models. As a basis for pre-training the Llama meta-model, Common Crawl accounts for 67 percent and Wikipedia for 4.5 percent of the data material (sampling proportion). Cf. Touvron et al. (2023).
- 499 The German Bundestag approved the funding for the data institute planned by the BMI and BMWK in May 2023. It is intended to promote data sharing and data evaluation, especially across different sectors, and to develop the necessary governance models. Use cases are to be started as early as during the set-up phase. Cf. <https://www.bmi.bund.de/DE/themen/it-und-digitalpolitik/it-des-bundes/dateninstitut/dateninstitut-node.html> (last accessed on 15 January 2024). One of the aims of the Health Data Use Act is to make decentralized stored health data easier to find and to reduce bureaucratic barriers for data users. Reference is also made to the potential of artificial intelligence. Cf. here and below <https://www.bundesgesundheitsministerium.de/presse/pressemitteilungen/bundestag-verabschiedet-digitalgesetz-pm-14-12-23.html> (last accessed on 15 January 2024). A Mobility Data Act is also planned, which the BMDV expects to be passed in the course of 2024. Cf. <https://bmdv.bund.de/SharedDocs/DE/Pressemitteilungen/2022/081-wissing-mobiliitaetsdatengesetz.html> (last accessed on 15 January 2024).
- 500 The Gaia-X 4 KI project, funded by the EU and the BMWK, is already researching the development

of a data and service ecosystem for training and validating AI applications. Cf. <https://www.gaia-x4ki.eu/> (last accessed on 15 January 2024). In the preliminary study Data Room Manufacturing-X, pre-trained AI models for monitoring systems and components are named as a relevant use case. Cf. Otto et al. (2023: 41).

501 Cf. BMBF (2023a: 11).

502 Cf. <https://digital-strategy.ec.europa.eu/de/policies/data-governance-act> and <https://digital-strategy.ec.europa.eu/de/policies/data-governance-act-explained> (each last accessed on 15 January 2024).

503 Cf. here and below Rammer (2023a). In addition to the appliedAI platform, other sources were used to calculate the number of AI start-ups, including the Learning Systems platform, Crunchbase and a web-based analysis of company activities with ISTARI webAI. Companies were classified on the basis of their current activities and business models. The AI activity therefore does not need to have already existed at the time of foundation.

504 The ZEW attributes the decrease to the greater number of market exits in the years of the Covid-19 pandemic and the economic slowdown in 2022. Cf. Rammer (2023a: 9f.).

505 The main reason for not utilizing venture capital was the desire for full control over strategic decisions. Cf. Rammer (2023a: 22).

506 Cf. here and below <https://www.consilium.europa.eu/en/policies/artificial-intelligence/>, <https://www.consilium.europa.eu/de/press/press-releases/2023/12/09/artificial-intelligence-act-council-and-parlia>

[ment-strike-a-deal-on-the-first-worldwide-rules-for-ai/](https://www.consilium.europa.eu/en/policies/artificial-intelligence/), https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6473, <https://www.europarl.europa.eu/news/en/press-room/20231206IPR15699/artificial-intelligence-act-deal-on-comprehensive-rules-for-trustworthy-ai>, https://ec.europa.eu/commission/presscorner/detail/en/QANDA_21_1683 (each last accessed on 15 January 2024).

507 Cf. Bundesregierung (2018).

508 Cf. Bundesregierung (2019).

509 Cf. Bundesregierung (2020).

510 Cf. here and below BMBF (2023a).

511 The fields of action are in the sphere of infrastructure: 'Consistently strengthen the research base', 'Design a research agenda for new perspectives and approaches', 'Expand targeted AI infrastructure', 'Intensify the development of AI-related expertise and competencies'; in the sphere of application and transfer: 'Promote AI-related knowledge transfer to support economic growth and future opportunities', 'AI in the area of health care: unlock societal benefits for all', 'Exploit the social and scientific benefits of AI in a targeted manner', 'Investigate and design AI-based technologies for the educational sector'; in the sphere of conditions for success: 'Seek even closer alliance with European and international partners', 'Promote social dialogue and multidisciplinary research', 'Enact appropriate, agile, innovation-friendly regulation'. Cf. BMBF (2023a).

512 Cf. Die Bundesregierung (2023d).

513 Cf. here and below No author (2023).

514 Cf. Die Bundesregierung (2023a).

515 Cf. BMBF (2023a).

C7 R&I Dashboard

Documenting the performance of Germany as a location for research and innovation is an integral part of the Commission of Experts’ reporting. The representation is based on various indicators that enable an understanding of the performance and dynamics of the German research and innovation system at the national level and in international comparison with important economies.

The indicators updated for the 2024 reporting year can be accessed on the R&I Dashboard at <https://www.e-fi.de/dashboard> and using the following QR code:



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