OECD Reviews of Innovation Policy

GERMANY

2022

BUILDING AGILITY FOR SUCCESSFUL TRANSITIONS

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OECD Reviews of Innovation Policy: Germany 2022

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Please cite this publication as:
OECD (2022), *OECD Reviews of Innovation Policy: Germany 2022: Building Agility for Successful Transitions*, OECD Reviews of Innovation Policy, OECD Publishing, Paris, https://doi.org/10.1787/50b32331-en.

ISBN 978-92-64-31566-2 (print)
ISBN 978-92-64-95887-6 (pdf)
ISBN 978-92-64-67156-0 (HTML)
ISBN 978-92-64-52274-9 (epub)

OECD Reviews of Innovation Policy
ISSN 1993-4203 (print)
ISSN 1993-4211 (online)

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Foreword

The OECD Review of Innovation Policy: Germany 2022 is the 33rd in a series of OECD Country Reviews of Innovation Policy and is the first to cover Germany, following a request from the Federal Ministry of Economic Affairs and Energy (latterly the Federal Ministry for Economic Affairs and Climate Action, BMWK).

The COVID-19 pandemic and the Ukraine war have revealed vulnerabilities in Germany's economic model: undiversified energy supply, an over-reliance on fossil fuels, delayed digitalisation and disruptable supply chains. Digital technologies may significantly disrupt manufacturing industries Germany has dominated for decades, threatening future competitiveness. The green transition also requires significant industrial transformations. Germany can call upon one of the world's most advanced innovation systems in dealing with these challenges, but a new more agile and experimental approach to STI policy is needed. This Review outlines how to develop such an approach and what STI policies need to focus on: create markets for future innovations, more significant and more risk-tolerant finance for innovation, inter-disciplinary knowledge exchange, improved data infrastructure and capabilities. Given the internationally shared challenges of dealing with transitions, the insights presented in the review will be of interest to policymakers, stakeholders and analysts from Germany and across the OECD.

This Review is relevant to a broad array of stakeholders in Germany, including government officials and policymakers, as well as representatives of the private sector and civil society. Owing to the globally important nature of the German STI system, the findings of this Review is also of interest to policymakers from across the OECD and beyond as many challenges Germany faces are shared and solutions identified can serve as inspiration in other contexts. The Review was launched on the 4th October 2022 at an event in Berlin, hosted by the BMWK.

The Review was led by Caroline Paunov, Head of the OECD-TIP Secretariat and Senior Economist. The main authors of the Review were Caroline Paunov and Luke Mackle, Policy Analyst at the OECD, drawing on various key contributions. The Review draws on an extensive background report prepared by Christian Rammer of the Leibniz Centre for European Economic Research (ZEW) and Stephanie Daimer, Rainer Frietsch, Hennig Kroll and Rainer Walz of the Fraunhofer Institute for Systems and Innovation Research (Fraunhofer ISI). Sylvia Schwaag Serger, Professor at Lund University, provided invaluable inputs to the report, particularly to chapters 5 and 15. Pluvia Zuniga, Senior Consultant to the OECD, contributed in particular to chapters 10, 11, 12 and 13. Erik Arnold, Senior Partner at Technopolis and Honorary Professor at the Manchester Institute of Innovation Research, contributed to chapters 5 and 14. All provided critical research, analytical and drafting support to numerous sections of the Review. Jan Einhoff, external consultant to the OECD, provided valuable research and drafting support to the Review, particularly to chapter 8, and supported the organisation of the two rounds of interviews. Laura Kreiling, Policy Analyst at the OECD, similarly provided valuable and extensive support to chapter 13 and to the organisation of the interviews. Nikolas Schmidt, Policy Analyst at the OECD, provided significant research, drafting, and preparation support in all sections of the Review.

The Review team is grateful to the request from the BMWK to conduct this Review and the support provided by the BMWK throughout the process. In particular Ole Janssen, Deputy Director General of the

Department for Innovation and Technology Policy and Ulrich Romer, Head of Unit and their team, including Rebecca Leinen, Verena Mertins, and Magda Kemper were a constant source of support.

The Review and its eventual publication would not have been possible without the support of colleagues within the OECD Directorate for Science, Technology and Innovation (STI). Andrew Wyckoff, Director of the OECD STI, Dirk Pilat, former Deputy Director, and Alessandra Colecchia, Head of the Division for Scientific and Technological Policy of the OECD STI provided substantial comments. Blandine Serve provided extensive statistical and data visualisation support. The Review team is indebted to Romy de Courtay for her excellent editorial services. Sylvain Fraccola and Sebastian Ordelheide supported on the communications and design elements of the Review process.

The Review also benefited from feedback and comments from numerous colleagues, within the OECD and externally. As part of the Review process, the OECD Working Party on Innovation and Technology Policy (TIP) discussed the Review at its meetings in June 2021, December 2021 and June 2022 and organised several peer group review sessions with TIP delegates. The Review team is grateful to the contributions received from Christian Busch, Jacopo Cricchio, Alberto Di Minin, Göran Marklund, Byeongwon Park, Lennart Stenberg and to participants in TIP sessions on the Review and for the valuable inputs they provided. The Secretariat is also grateful to colleagues from the OECD Economics Department, the OECD Directorate for Trade and Agricultural Policy, the International Energy Agency (IEA) and colleagues from other divisions of the STI Directorate, all of whom provided valuable guidance and feedback on various sections of the Review. Similarly, the Review Team is grateful to the BMWK and the German Federal Ministry of Education and Research (BMBF) for their timely and valuable feedback on all sections of the Review. The Review team is also grateful for the revision and official declassification of the Review by the members of the OECD Committee for Science and Technological Policy (CSTP).

The TIP Secretariat would like to particularly thank the more than 100 people that participated in the fact-finding interviews of this Review in April/May 2021 and November 2021. The participation of those involved helped the Review team to ensure that the Review reflected the experiences and concerns of a diverse range of stakeholders.

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Reader's guide

This Review of Innovation Policy of Germany is split into six parts. With the exception of the first part – the Overall Assessment and Recommendations – each of these sections has a thematic focus relevant to the Recommendations of the Review, and is split into one or more chapters, with the Review comprising sixteen chapters in total. This Reader's Guide gives an overview of the Review structure and contents.

The Review uses a number of patent- and investment-related indicators in the sections of the Review that involve benchmarking or an assessment of innovative performance. The strengths and weaknesses of these indicators will be familiar to many readers who are well acquainted with science, technology and innovation (STI) debates. However, for Readers that are not familiar with these indicators, an introduction to them can be found in Box 3.1 of Chapter 3.

Figure A. Structure of the Review

Part 1 - The Overall Assessment and Recommendations

The first part of the Review contains one chapter: the Overall Assessment and Recommendations (OAR). This section contains the key findings of the Review and an overview of ten Recommendations that respond to these findings. The OAR condenses the information and messages of the other Review chapters, with the majority of the evidence that underpin these messages being found in the respective thematic chapters.

Part 2 – The innovation system in international context: performance, capabilities, and policy

The second part of the Review contains four chapters: Chapter two *The Socio-economic context for innovation*, Chapter three *Benchmarking innovation performance*, Chapter four *The research base for innovation,* and Chapter five *Strategies and the policy mix for innovation*.

Part 3 – Getting the conditions right for innovative entrepreneurship

The third part of the Review contains three chapters: Chapter six *Framework conditions for innovation: regulation, infrastructure and skills*, Chapter seven *Financing innovation in Germany*, and Chapter eight *Setting standards: quality infrastructure and German innovation*.

The chapters in this part of the book each introduce a recommendation. Chapter six introduces a recommendation on broadening and mainstreaming the use of agile policy tools to support innovative SMEs, as well as addressing bureaucratic hurdles that may lower SME contributions to German innovation. Chapter seven introduced a recommendation on promoting financial markets that are conducive to scaling high-impact and potentially breakthrough innovation. Chapter eight introduces a recommendation on digitalising and modernising German quality infrastructure, as well as using quality infrastructure as a strategic international instrument.

Part 4 – The international dimension of Germany's innovation system

The fourth part of the Review contains one chapter: Chapter nine *The international dimension of German innovation*.

This chapter does not contain a recommendation, but does discuss a number of systemically important aspects of the German innovation system, including: trade and domestic innovation, global value chains and their role in the innovative private sector, and the importance of bottlenecks, energy and disruption for German STI

Part 5 – Innovation and the transformation of the German private sector

The fifth part of the Review introduces a further four chapters: Chapter ten *Raising the contribution of the Mittelstand to innovation in the digital transition,* Chapter eleven *German business sector innovation for the green transition: challenges, performance and opportunities*, Chapter twelve *From incrementalism to breakthrough: new challenges, new approaches to innovation*, and Chapter thirteen *Technology and knowledge transfer for industry innovation and transformation.*

The chapters in this part of the book introduce two recommendations. Chapter ten introduces a recommendation on improving data infrastructure and data access for private sector innovation. Chapter eleven introduces a recommendation on the use of public procurement as a demand-side instrument for innovation.

Part 6 – Steering the ship: Inclusive governance for transition

The fifth part of the Review contains three chapters: Chapter fourteen *National STI Governance, EU leadership and international commitments*, Chapter fifteen *Agile and experimental policy for innovation*, and Chapter sixteen *More seats at the table: participation and inclusivity in German innovation*.

The chapters in this part of the Review introduce three recommendations. These recommendations in many ways provide the overarching structure and vision for many of the other recommendations in this Review. Chapter fourteen introduces a recommendation on creating a whole-of-government vision for Germany in 2030 and 2050 that establishes the role of STI in achieving this. Chapter fifteen introduces a recommendation on the creation of a public-private laboratory for policy experimentation, acting as the institutional arm of the previously-mentioned recommendation. Chapter sixteen in turn introduces a recommendation on greater societal inclusion and participation in STI policy design and implementation.

Abbreviations and Acronyms

Acatech	National Academy of Science and Engineering
AI	Artificial intelligence
AiF	German Federation of Industrial Research Associations (*Arbeitsgemeinschaft industrieller Forschungsvereinigungen „Otto von Guericke“*)
ANSI	American National Standards Institute
BAM	Federal Institute for Materials Research and Testing
BERD	Business expenditure on research and development
BMAS	Federal Ministry of Labour and Social Affairs
BMBF	Federal Ministry of Education and Research
BMDV	Federal Ministry for Digital and Transport
BMEL	Federal Ministry of Food and Agriculture
BMFT	Federal Ministry for Research and Technology
BMI	Federal Ministry of the Interior and Community
BMVg	Federal Ministry of Defence
BMWK	Federal Ministry for Economic Affairs and Climate Action
BMWi	Federal Ministry for Economic Affairs and Energy
CAGR	Compound annual growth rate
CCA	Climate Change Act
CERN	European Organization for Nuclear Research
CNIPA	China National Intellectual Property Administration
CNRS	French National Centre for Scientific Research (*Centre national de la recherche scientifique*)
DAkks	German Accreditation Body (*Deutsche Akkreditierungsstelle GmbH*)
DARPA	U.S. Defense Advanced Research Projects Agency
DFG	German Research Foundation (*Deutsche Forschungsgemeinschaft*)
DKE	German Commission for Electrical, Electronic & Information Technologies
DSL	Digital subscriber line technology
DZHW	German Centre for Higher Education Research and Studies (*Deutsche Zentrum für Hochschul- und Wissenschaftsforschung*)
EFI	Commission of Experts for Research and Innovation (*Expertenkommission Forschung und Innovation*)
EIB	European Investment Bank
EIF	European Investment Fund
EMBL	European Molecular Biology Laboratory
EPO	European Patent Office
ERP	European Recovery Programme
ESOP	Employee stock ownership option plans
EUR	Euro
EXIST	EXIST - University-Based Business Start-Ups (*Existenzgründungen aus der Wissenschaft*) support programme
FhG	Fraunhofer Society
FTE	Full-time employment
GBARD	Government budget allocations for research and development
GRBARD	Government real budget allocations for research and development
GDP	Gross domestic product
GDR	German Democratic Republic
GERD	Gross expenditure on research and development
GHG	Greenhouse gas emissions

GNI	Gross national income
GWK	Joint Science Conference (Gemeinsame Wissenschaftskonferenz)
HEI	Higher education institution
HTGF	High-Tech Founders Fund (*High-Tech Gründerfonds*)
HTS	High-Tech Strategy
ICT	Information and communication technology
IGF	Industrial Collective Research (Industrielle Gemeinschaftsforschung)
IGP	Innovation Program for Business Models and Pioneering Solutions (*Innovationsprogramm für Geschäftsmodelle und Pionierlösungen*)
INVEST	Invest – Grant for Venture Capital (*Zuschuss für Wagniskapital*)
IPCEI	Important Project of Common European Interest
IT	Information technology
ITF	International Transport Forum
JPO	Japan Patent Office
KATS	Korean Agency for Technology and Standards
KPO	Korean Patent Office
KSA	Korea Standards Association
Mbps	Megabits per second
ML	Machine learning
PCT	Patent Cooperation Treaty
PIAAC	OECD Programme for the International Assessment of Adult Competencies
PPP	Purchasing power parity
PPP	Public-private partnership
PRO	Public research organisation
RTA	Revealed technological advantage
PTB	National Metrology Institute of Germany (*Physikalisch-Technische Bundesanstalt*)
R&I	Research and innovation
REEs	Rare earth elements
RRF	Recovery and Resilience Facility of the European Union
SME	Small and medium-sized enterprise
SPRIND	Federal Agency for Disruptive Innovation (*Agentur für Sprunginnovationen*)
STI	Science, technology and innovation
SWOT	Strengths, weaknesses, opportunities and threats
TNO	Netherlands Organisation for Applied Scientific Research
TTO	Technology transfer office
TU	Technical university
USD	United States dollar
USPTO	United States Patent and Trademark Office
VC	Venture capital
VDE	Association for Electrical, Electronics & Information Technologies (*Verband der Elektrotechnik, Elektronik und Informationstechnik*)
VET	Vocational education and training
VTT	Technical Research Centre of Finland
WGL	Leibniz Association (*Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz*)
ZEW	Leibniz Centre for European Economic Research
ZIM	Central Innovation Programme for SMEs (*Zentrales Innovationsprogramm Mittelstand*)
ZLS	Central Authority of the Federal States for Safety Engineering (*Zentralstelle der Länder für Sicherheitstechnik*)

Executive summary

Germany's science, technology and innovation system must rise to the challenges posed by global shocks and the digital and green transitions

The socio-economic consequences of the COVID-19 pandemic and the impact of Russia's war in Ukraine have revealed vulnerabilities in Germany's export-orientated economic model: an over-reliance on energy from Russia, a continued dependence upon fossil fuels, delayed digitalisation, as well as concentrated supply chains for German industry which are liable to disruption. The result is an increasing awareness in policy and in business that science, technology and innovation (STI) needs to adapt how they innovate and recalibrate the goals of innovation and innovation policy. However, there is a risk that, in attending to the series of crises that has buffeted Germany, insufficient action is taken to address these longer-term issues. Addressing these longer-term issues is essential, as innovation is the cornerstone of the country's socio-economic wellbeing, underpinning employment, investment, and job creation.

The German economy does not operate in a stable, predictable environment, and, just as in many countries around the world, the processes of digitalisation and the green transition are upturning many assumptions about the long-term viability of the German socio-economic model. Digital technologies are changing innovation in terms of what it can produce, how innovation occurs, and providing opportunities for entirely new business models across all sectors of the economy. The emergence of firms such as Tesla in the premium segment of the global automotive industry, long an area dominated by German firms, has demonstrated the disruptive impact of both new business models and digital technologies in areas of strategic importance to Germany. Almost a million people are directly employed in the German automotive industry, with many more employed in the thousands of SMEs that comprise the industry's supply chains – significant disruption to Germany's leadership in these areas would have profound implications for competitiveness as well as socio-economic wellbeing.

The processes of the digital and green transitions, and the structural changes they are engendering in the global economy, are challenging a number of the fundamental pillars upon which German economic competitiveness rests. While German firms and research organisations, and the human capital that powers them, are well-placed to meet these challenges and lead the global response to climate change, doing so will require a new approach to STI policy to raise the resilience of German STI in a context of repeated shocks and better prepare for future transitions.

German policymakers should not lose sight of the importance of how structural economic changes are affecting the pillars of the German economy, and the important role that STI must play in ensuring the future socio-economic wellbeing. Uncertainty will be a recurring theme in STI policymaking in the years ahead, and preserving German STI leadership will invariably involve risk and stepping into unknown areas of science and technology. If Germany is to lead in its core industries – automotive, machinery and chemicals, pharmaceuticals – as well as in new sectors in the future, then the government must adopt a more risk-tolerant and creative approach to STI policy.

The green and digital transitions are actively reshaping Germany's innovative industries

Manufacturing is the locum of the country's innovation system. The dynamics that support innovation are often a virtuous cycle, with success breeding success. Innovation in the German business sector is no different. Investment in education, skills, technology and intangible capital have helped underpin continuous innovative success in a wide range of industries, notably the automotive and machinery industries. This innovation has enabled decades of international competitiveness, which in turn has locked the economy into a self-reinforcing relationship between trade and domestic socio-economic wellbeing. The importance of industry for investment, jobs and innovation has invariably shaped German STI policy, orientating programmes and instruments towards firms that are active in these areas. Yet, while success has historically begot success, past performance is no guarantor of future competitiveness, particularly in a context where Germany's innovative industries are undergoing a process of radical change.

Whilst the benefits that Germany's economic model have been clear, it is less clear whether the predominance of extant industries in German STI has come at the expense of capabilities elsewhere, notably in digital technologies, advanced ICTs, and enabling technologies for the green transition. There is a clear lag in firm-level digitalisation in Germany relative to other advanced economies, in part due to a slow roll-out of high-quality broadband infrastructure, relatively low levels of public investment, and difficulties at the firm-level in investing in the intangible capital – firm know-how, software, intellectual property, data and management capacities – necessary to harness the innovative potential of the digital transformation. The result is that the German economy, perhaps one of the greatest sources of industrial data in the world, is under-utilising a key input for innovation. In addition to the challenge of redirecting existing competencies away from mechanical engineering towards digital areas, there is also the difficulty of fostering new types of business models that are based on digital technologies.

Lagging German digitalisation and the development of competencies in key enabling technologies takes place in a context where Germany's most innovative industries and the markets they serve are being reshaped. This creates challenges for how Germany innovates, as much as it does for what it innovates, and to what end. The growing importance of technologies such as quantum computing and artificial intelligence, as well as the microelectronics that power such technologies, requires capabilities that differ from those – such as mechanical engineering – where Germany has historically excelled.

In line with Paris Agreement on achieving global carbon neutrality in the second half of the 21st century, Germany is working towards securing greenhouse gas (GHG) neutrality by 2050. Achieving this goal will require radically reducing the GHG footprint of major emitters, such as industry and transport, by moving to more sustainable modes of production; increasing the use of renewable energy for electricity generation; and in some instances – such as with individual mobility – changing the behaviour of society and consumers. Not only do these transformational processes place new demands on how industry and society work, but they also fundamentally change the markets upon which some of Germany's most innovative industries rely.

In addition, the increasing importance of digital technologies and technologies that contribute to greener and less carbon-intensive production and products has implications for a number of Germany's highly internationalised industries. Manufacturing, for example, relies critically on intermediary inputs such as semi-conductors and other microelectronics to meet changing consumer expectations, but at present rely upon a small number of foreign suppliers for these items. Not only does this pose challenges for resilience, as shown during the COVID-19 pandemic, but it raises the question of whether this reliance comes at the expensive of acquiring capacities for innovation in core areas of future value-added for manufacturing.

There is a significant role for public policy to play in guiding this transition, mitigating short- and medium-term adjustment costs, and promoting the breakthrough innovations of markets of the future. There is also a need for policy to address the barriers that have to date led to a relative underdevelopment of German innovative competencies in areas of importance for the digital and green transitions, including issues around financing, risk-taking in public policy, inclusion and diversity in innovation, and the commercialisation of high-impact research to the market. Programmes such as SPRIN-D and the BMWK's From the Idea to the Market initiative are important steps in this direction, but more needs to be done.

There are three major areas where Germany must act to ensure future success

Responding to the challenges that face STI policymakers in Germany requires action in two interlinking areas – the *how* and the *what* of the future of German innovation policy (Figure B).

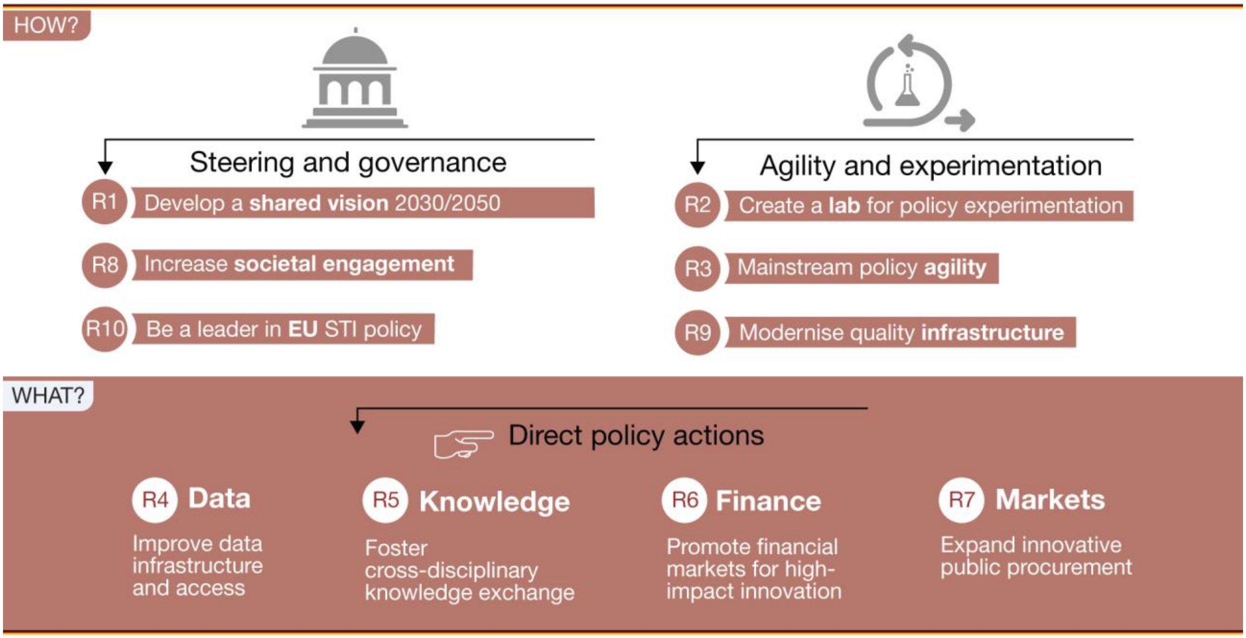
A new approach to STI policy in Germany

- **Steering and governing the German STI system:** Government should establish a clear vision for what success in the digital and green transitions looks like and how the STI system should contribute to this success. A core focus of governance should be to ensure inclusivity with a focus on engaging previously underrepresented groups in STI – for example, women and migrants – and on those who will be affected by the changes ahead. The nature of many core issues requires Germany takes a leading role internationally – at the EU level and beyond – in the governance and development of key technologies for the green transition.
- **Policy agility and experimentation to support private sector innovation:** Success in the transitional context will take place at the frontier of current knowledge and technological capabilities. Going beyond this frontier, and consolidating Germany's global innovative leadership, requires a new level of agility and experimentation, and a willingness from policymakers to creatively provide regulatory certainty to the country's innovators. The policy laboratory proposed by the review could be a key platform for driving policy experimentation and scaling the most promising of approaches.

Key policy actions for supporting innovation in the digital and green transitions

- **Policy levers that can support market creation and breakthrough innovation:** A more risk-tolerant approach from government to supporting breakthrough innovation could accelerate the commercialisation of impactful innovations and support the creation of the markets of tomorrow. Policy also has a role to play in ensuring firms have the data they need to innovate, the necessary skills to use new inputs such as data, the infrastructure necessary for doing so, and that impactful ideas and research can be transferred across sectoral and disciplinary boundaries.

Figure B. Overview of Recommendations



It is normal that in times of crisis, where governments have had to undertake large and unexpected expenditures, that public budgets can come under pressure, with legitimate social concerns taking priority over other support for STI. Importantly, this Review places emphasis on focussing on new processes and approaches that do not claim additional financial resources – the *how* of STI policy – in areas such as experimental and flexible regulation and using public procurement more for innovation. The recommendations are actionable and impactful regardless of uncertainties in the coming years over public budgets.

Part I Overall Assessment and Recommendations

1 Overall assessment and recommendations

The Overall Assessment and Recommendations (OAR) of the Review of Innovation Policy of Germany shows that while Germany has one of the most powerful science, technology and innovation (STI) systems in the world, the country faces a number of innovation-related challenges for competitiveness and sustainability in the years ahead. The OAR introduces recommendations that respond to these challenges in two important ways. The first is to improve the fundamentals of the STI system and the STI policy that supports it, ensuring that it is more efficient, effective and inclusive. The second is to ensure that STI policy prepares for the challenges of tomorrow, with an emphasis on new capabilities, approaches to policy, and governance.

Summary of recommendations

Recommendation 1: Develop a shared vision “Germany 2030 and 2050”

The government should create a cross-ministerial, federal-state, cross-institutional and cross-sectoral forum to steer the process of developing a shared vision, founded on the identified key priority areas for action.

Recommendation 2: Create a public-private laboratory for innovation-policy experimentation

Such a laboratory would support the experimentation, implementation and monitoring of innovation policy, and would promote the forum’s vision. It would support policy agility, and advocate for change and experimentation where needed.

Recommendation 3: Broaden and mainstream the use of agile policy tools to support innovation efforts by SMEs, and achieve the digital and green transitions

Reducing bureaucratic and administrative barriers affecting *Mittelstand* – a German classification of small- and medium-sized enterprises – firms and start-ups that engage in innovation, and continuing efforts to digitalise government-to-business services should be a priority. Regulatory sandboxes should be expanded.

Recommendation 4: Improve data infrastructure and data access, especially for industry

The government should improve data infrastructure and raise firms’ digital absorption capacities so that they can use industrial data for innovation. It should also promote open innovation platforms, and networks for data-based and collaborative innovation.

Recommendation 5: Improve cross-disciplinary and cross-sectoral knowledge transfer and collaboration

To improve knowledge transfer, the government should enhance university engagement with industry, including by encouraging the development of funds for academic spin-offs. It should also support multidisciplinary and entrepreneurship training across the education system.

Recommendation 6: Promote financial markets that are conducive to scaling up breakthrough innovations

Germany should support greater institutional investment in start-ups and higher risk tolerance. It should address regulatory barriers in start-up finance, to increase Germany’s attractiveness as a destination where high-potential start-ups can grow.

Recommendation 7: Strengthen the use of public procurement as a driver of innovation

The government should increase procurement officials’ ability to undertake procurement for innovation, strengthen risk tolerance in procurement, and expand the use of pre-commercial procurement to accelerate the diffusion of new technologies and solutions across the economy.

Recommendation 8: Increase the involvement of key civil-society stakeholders in science, technology and innovation (STI) policy targeting the transitions

The government should expand the engagement of civil society in the STI policy-making process and broaden the diversity of those engaged in innovation, particularly to further its twin transition agenda.

Recommendation 9: Digitalise, modernise and strategically use quality infrastructure

The government should digitalise and modernise its quality infrastructure – such as standards and norms – systems to advance Germany's global position as a standard-setter and rule-maker. Quality infrastructure should be used more strategically.

Recommendation 10: Take a leadership role in shaping EU and global innovation policies

Germany should take a more active role in shaping innovation policies at the EU level, so that policy caters to the current and future innovation requirements of both Germany and the broader European Union.

Introduction

Germany entered 2022 in the wake of nearly two years of disruption caused by the COVID-19 global pandemic. The Russian invasion of Ukraine in February 2022 instigated another shock. Restrictions on mobility affected domestic business operations and consumption, while supply-chain disruptions had a major impact on many of Germany's most competitive industries. Russia's war against Ukraine profoundly affected trade in energy and raw materials. The renewed policy discussions resulting from these events have covered issues such as energy diversification and innovation for renewables and decarbonisation, as well as technological "sovereignty" in the design and production of key intermediary products used as inputs in German industry. The newly constituted government set an ambitious reform agenda to respond to these challenges and address structural goals, notably accelerating the digitalisation of the German economy and the modernisation of the German administration and transitioning towards a more sustainable socio-economic future. The German innovation ecosystem is key to achieving these objectives.

Two major transformational processes present opportunities and challenges for Germany's future socio-economic well-being. The first is the digital transformation, which has implications for both the types of goods German manufacturers will produce – for example, the digital component in vehicles or the use of advanced information and communication technologies (ICTs) to unlock new frontiers in pharmaceuticals and health care. Similarly, firms will need to step up their operations, thanks to data and other digital tools that can transform and radically improve business processes. The second transformational process is Germany's transition to a greener and more sustainable economy. In line with the commitment of the Paris Agreement to achieving global carbon neutrality in the second half of the 21st century, Germany is working towards securing greenhouse gas (GHG) neutrality by 2050. Achieving this goal will require radically reducing the GHG footprint of major emitters, such as industry and transport, by moving to more sustainable modes of production; increasing the use of renewable energy for electricity generation; and in some instances – such as with individual mobility – changing the behaviour of society and consumers. These transformational processes are complex, and will rely on STI to ensure they become opportunities rather than only challenges. Examples include challenges to Germany's dominant global market position in automobiles, as the importance of digital value added increases, or in industry, where demands for more environmentally sustainable development will increase the cost of traditional production modes.

The experience of the COVID-19 crisis and Russia's war against Ukraine has demonstrated the importance of building resilience in global value chains. Disruptions to German industry's productive capacities, including supply-chain problems with intermediate goods caused by continued lockdowns in China, or the implications of the war on global energy flows, also affect the innovative capacities of German firms in fundamental ways. In addition, an undiversified range of suppliers for critical minerals and other inputs necessary for technologies that support the green transition add an additional level of complexity to the question of supply chain resilience. These questions of building robust value chain linkages in which German industry holds central positions of key value added thus becomes an area of systemic importance.

This review provides insights and options related to key questions for the German innovation system from the perspective of innovation-policy design. In the coming years, policy makers in Germany will need to answer a number of questions raised by this survey. For example, what is the right policy approach to supporting the innovation ecosystem in the context of the complex digital and sustainability transitions? What are the implications of the different conditions for participation in innovation activities across *Mittelstand* and large firms, and how can these best be addressed? What is the right innovation-policy mix to meet current and future demands on the innovation system, particularly where those demands may require greater systemic agility? How can regulations, standards and infrastructure support innovation, and what does this imply for policy? What conditions should be provided to support the creation and growth of start-ups, and how can start-ups help meet the transformational challenges mentioned above? What efforts are needed to develop core technologies necessary for future competitiveness and transitions? How can the conditions for knowledge, technology and the successful transfer to the market of inventions developed in the "lab" be improved? What governance arrangements, including co-creation approaches involving the public, are needed for greater agility in the innovation system? And what tools and approaches can support the public sector in its contributions to the innovation system?

German economic strength is underpinned by one of the world's most advanced innovation systems. The country is an international leader in both public and private investment in innovation, with strong linkages between research and industry supporting international competitiveness and domestic socio-economic well-being. The impact of this strong STI ecosystem on the economy is clear, with German firms – from some of the largest vehicle manufacturers in the world to the "hidden champions" of the *Mittelstand* – consistently featuring among the most innovation-intensive in the world. The government's long-standing commitment to supporting research and innovation in the private sector, particularly the *Mittelstand*, has contributed to this success. Another benefit of German policy support for strong innovation intensity is that the economy retains a significant manufacturing sector and remains strongly export-oriented.

Despite these strengths, Germany faces challenges to its global leadership position in innovation. The current STI system suffers from weak innovative business-creation dynamics; difficulties in transferring new ideas and results from public research into new technological solutions and innovation (i.e. new products or services); slow adoption of digital technologies; and unexploited potential of diversity, such as a wider participation of women.

Preparing for the upcoming major transformations will require a new approach to innovation policy. Germany's traditional STI strengths are heavily intertwined with the needs of its existing industry. Responding to future needs requires developing the necessary capacities for innovative success in the context of the twin transitions of environmental sustainability and digitalisation, as well as improving the resilience of inputs – from energy to digital components – necessary for innovation success in these contexts. Addressing these challenges will require policy makers to build on the strong foundations of the STI system, but chart a new approach to designing and implementing STI policy. This approach will be more risk-tolerant, agile and sometimes directional. It will value entrants as much as incumbents. It will focus on the capabilities necessary in tomorrow's context, rather than yesterday's.

This chapter introduces the overall assessment and recommendations of the Innovation Policy Review of Germany. Section 1 provides a background for the analysis. Section 2 presents the main characteristics of the German innovation system. Section 3 considers the system's strengths, weaknesses, opportunities and threats (SWOT). Section 4 examines its structural strengths and weaknesses. Section 5 discusses its preparedness for future challenges. Section 6 concludes with recommendations for the Federal Government of Germany, based on the analysis in this review.

1.1. Overview of Germany's innovation system

In 2021, Germany was the largest economy in Europe and the fifth-largest economy in the world in terms of gross domestic product (GDP), also ranking among the top-performing OECD countries in terms of headline well-being indicators (OECD, 2020[1]; IMF, 2022[2]).[1] Within the OECD, Germany has the lowest number of people (5.9% of the population) who report struggling to make ends meet and is in the top-tier nations (fifth) in terms of household income. Germany also has a well-educated and highly skilled population, with high scores in the OECD Survey of Adult Skills (PIAAC) in 2018 compared to the OECD average (OECD, 2019[3]). Of those aged 25-35 in Germany, 35% hold a tertiary degree, lower than the OECD average of 45% (OECD, 2021[4]).

In part this reflects the country's strong vocational education system (2018), which is a key strength of the country's innovation system and economy more broadly. The government has a diverse and well-resourced range of programmes and instruments in support of innovation policy, with a particular focus on technology transfer for SMEs. The Federal Government's approach to STI policy has several central components. One has been the "Transfer initiative", developed by the Federal Ministry for Economic Affairs and Climate Action's (BMWK, then BMWI) to respond to the challenges of technology transfer between research and the private sector. Another is the "From Idea to Market Success*"* approach, which covers the different stages of the innovation process and aims to accelerate the transfer of technology to the market. Much of German innovation policy for SMEs is administered by the "Central Innovation Programme for SMEs" (ZIM), which mainly supports inter-firm collaboration in different areas of market-oriented and high-risk innovation. The government has also taken steps to allow the public sector to be a more direct driver of technology diffusion and the commercialisation of new ideas. A key example of this is the development of the Competence Centre for Innovative Procurement (Kompetenzzentrum Innovative Beschaffung [KOINNO]), which, among other areas, establishes mechanisms to support pre-commercial procurement, thereby accelerating the transfer of high-potential ideas to the marketplace. Reflecting the growing policy attention to "breakthrough" innovation, the Federal Government established the Federal Agency for Disruptive Innovation *(*Agentur für Sprunginnovationen [SPRIND]) in 2021.

Targeted grant funding is one of the main policy instruments supporting SME innovation. With more than 3 000 new projects every year and EUR 555 million (euros) in funding administered in 2020, ZIM is the largest and most widely used programme. IM mainly supports inter-firm collaboration in different areas of market-oriented and high-risk innovation, and has supported many first-time applicants to innovation-support initiatives. According to a 2019 evaluation, the share of first-time applicants receiving support was 42%, nearly a decade after the programme started (Kaufmann et al., 2019[5]). Attracting new, young firms to apply is an important focus for the programme, as well as supporting the Mittelstand in the digital and green transition process. Other programmes include the new "Innovation Programme for Business Models and Pioneering Solutions" (IGP), which targets close-to-market non-technical innovations (with funding of EUR 35 million in the pilot phase), the "Co-operative Industrial Research" (IGF) programme for pre-market research collaboration (annual funding of EUR 169 million) and (as mentioned above) the "INNO-KOM" transfer programme, which also supports firms in weaker regions (EUR 71 million in annual funding). Several additional thematic programmes focus on funding innovation in specific technology domains (e.g. energy technologies, biotechnology and materials), and developing research partnerships between industrial and scientific partners.

Manufacturing and technological innovation underpin Germany's international competitiveness and support socio-economic well-being. Germany has economic, productive and innovative strengths across a range of vibrant industries, with the machinery and electronics, automotive, and chemical and pharmaceutical sectors posting the highest level of value added and gross output in the euro area.

Generally high levels of investment support the German business sector and STI system, but the country faces a number of investment gaps that could dampen innovation output. The productive base is being supported by the highest level of gross fixed capital formation and of gross capital stocks in the Euro area at the aggregate level as well as in key industries and sectors of the economy, with leading positions in medium- and high-level research and development (R&D) intensity activities (1st) and industry [including manufacturing] (1st) (OECD, 2020[6]).[2] Annual growth of gross fixed capital formation (GFCF) has been relatively low for a number of years, the shocks caused by COVID-19 notwithstanding. In 2019, growth of GFCF in Germany was 1.8%, down from 3.4% in 2018 and behind the United States (3.3%) and France (4%) (OECD, 2022[7]).

Nevertheless, productivity growth in the decade after the Global Financial Crisis of 2008-9 was markedly lower than in the previous decade. This has been attributed a number of investment-related issues. For example, as noted in the 2020 OECD Economic Survey of Germany, public investment – particularly in digital and physical infrastructure – has lagged over the past decade, with the country currently facing a public investment backlog of around EUR 450 billion (OECD, 2020[8]). Similarly, Germany's investment in intangible assets remains low at 9.2% of value added over 2000-15, below the EU average (Roth, 2020[9]). It is also notable that Germany has the lowest share of ICT investment as a share of total GFCF in the G7, with 7.1 % in 2020, the latest year available (OECD, 2022[10]). By contrast, the share of ICT investment to total GFCF in France was 18.4% and 17.1% in the United States. A similar if less dramatic difference is visible in the contribution of intellectual property to total GFCF in Germany, which stood at 18.1% in 2020, the latest year for which data are available. In the United States, the figure for 2020 was 29.4%, in France it was 25.4%, in the United Kingdom it was 22.3%, and in Japan it was 21.6% (Ibid.).

Germany is an international leader in R&D investment. In 2020, Germany had the sixth-highest gross expenditure on R&D (GERD) as a percentage of GDP (3.14% GDP, USD 110 billion) in the world and has surpassed the target set in 2000 by the European Council in Barcelona to raise GERD to 3% of GDP in EU member states, with a domestic target of 3.5% GDP by 2025. In 2019, Germany's GERD amounted to 3.19% of GDP (EUR 110 billion), the fourth-highest level in the world in both relative and nominal terms, behind the United States, the People's Republic of China (hereafter China) and Japan (OECD, 2021[11]). In 2020, business expenditure on research and development (BERD) amounted to USD 91 billion (United States dollars) (EUR 78 billion), the third-highest in in the OECD in nominal terms, and reached at USD 91 billion (EUR 78 billion) and eighth highest relative to GDP at 2.2% of GDP, the ninth-highest level in the world (OECD, 2021[12]). Higher education expenditure on research and development in Germany amounts to 0.6% of GDP (EUR 22.2 billion) – the third-highest level in the world in nominal terms, behind the United States and China. Government expenditure on research and development (GOVERD) of EUR 17.4 billion also places the country in third position, second only to Korea relative to GDP (0.4%).

High levels of R&D expenditure have delivered strong innovation output, with Germany having a large global footprint in patents.[3] Wherever possible, the present review will use additional indicators to this end, such as trademarks and licensing. In 2020, Germany accounted for 30% of all Patent Cooperation Treaty (PCT) applications in Europe and 6.7% globally, and was the second-largest applicant to the European Patent Office (EPO), behind the United States. Indeed, German firms holds a higher share of high-value patents than of all other patents. In 2016 (the latest year for which data are available), Germany accounted for 9.2% of the world's IP5 patent applications, closely behind Korea (9.9%) and China (10.6%); the United States (19.2%) and Japan (28.5%) had the largest shares (OECD, 2021[13]).[4] Within triadic patent families[5], Germany's global share for the last year with comparable data (2016) was slightly lower (7.8%), although it is the third-largest share behind Japan (34.7%) and the United States (26%). Germany also has a globally significant share of triadic patents in frontier areas such as environmental management (10%), climate-mitigation technologies (10%), pharmaceuticals (5.6%) and biotechnologies (5.6%) (OECD, 2021[13]). Germany's strong performance in international patenting comparisons also reflects many of its leading industries' propensity for patenting.

Germany's innovation system is significantly internationalised and competitive, with large innovative companies leading in numerous sectors. Its open and trade-intensive economy features strong and well-developed links to global value chains, and relies heavily on input imports for its production and foreign demand to sell its products. Innovation has allowed Germany to maintain its position at the cutting edge of global industry, with the export of high-quality and high-value added goods driven by strong external demand, primarily from other European countries. Within Germany, the top 2020 PCT applicants were Robert Bosch (4 033 applications), Schaeffler Technologies(1 907) and BMW (1 874) (DPMA, 2020[14]). That same year, 3 of the top 25 largest applicants to the EPO were German – Robert Bosch (seventh), BASF (tenth) and Continental (twenty-fourth), the largest single share in the EU28, with Robert Bosch (1 516), Siemens (1 416) and BASF (1 188) the country's largest applicants to the EPO (EPO, 2021[15]). With 124 firms in the top 2 500 R&D investors globally (2019 data, to be updated), almost 1 in 4 of Europe's most innovative firms is German. Globally, the country has the fourth-largest cohort of top innovating firms, behind the United States (775), China (536) and Japan (309) (European Commission, 2020[16]).

The *Mittelstand*, which represents the vast majority of firms and accounts for half of the economy's output, plays an important role in driving innovation in the country. While large firms are among the most significant business-sector players in innovation, they are in the minority: over 99% of German firms have fewer than 500 employees, a size category referred to in Germany as the *Mittelstand*. This category – which comprises both the OECD definition of SMEs as enterprises employing fewer than 250 employees, and firms numbering 250-500 employees – is highly heterogeneous in terms of size, employment and its contribution to innovation: 64% have fewer than 9 employees and account for only 4.3% employment in the business sector, while 28% have 10-249 employees and account for 34% of employment (OECD, 2021[17]). Roughly 6.5% of German firms number 250-499 employees and are included in the German definition of the *Mittelstand*.

Germany's "hidden champions" are particularly important for innovation in the *Mittelstand*. According to BMWK, Germany has an estimated 1 300 hidden champions – firms that are considered global market leaders, with particularly well-developed competencies in specialised technology areas (BMWi, 2020[18]).[6] While they account for only 1.8% of *Mittelstand* firms with 10-500 employees, their engagement in innovation is higher relative to other firms with similar characteristics. A recent study suggested that hidden champions – classified as firms that have an export share over 50% and sales beyond Europe, rank among the top three sellers in their market, and whose market growth exceeds the industry average by 10% – outperformed competitors in terms of their innovation activities. For example, hidden champions accounted for significantly higher stock of patents over 20 years (91 patents per hidden champion versus 55 for the comparison group of firms), with significant differences in training expenditure per employee and wage levels (Rammer and Spielkamp, 2019[19]).[7]

However, innovation success is unevenly distributed along gender lines and socio-economic groups. Fewer than one in ten German PCT applications published in 2020 came from female inventors, likely reflecting that women remain under-represented in some of Germany's key innovative sectors, such as transport (9.1% female PCT applicants globally in 2020), chemical engineering (15.1%) and electrical machinery (11.7%) (WIPO, 2021[20]). This sectoral divide is due in part to the persistently low inclusion of women in science, technology, engineering and mathematics (STEM) subjects: in 2018, female STEM graduates numbered 11.8 per 1 000 population, compared to 27.8 per 1 000 for men (OECD, 2021[21]). Migrants and disadvantaged social groups in Germany face similar inclusion challenges, which may contribute to missed contribution to innovation by large sections of the population.

While there exist regional divergences in patenting activity, the geographical concentration of patent applications at the city level in Germany is less pronounced than in other OECD countries. Germany has a lower geographical concentration in patenting among the top 10%, 5% and 1% of cities compared to key comparator economies such as Japan, the United States, the United Kingdom and France (Paunov et al., 2019[22]). The concentration is more pronounced for some technology areas than others, likely due to the localised concentration of specialised knowledge around a small number of research institutions and industrial actors. For example, patenting in digital technologies and biotechnology is the most concentrated in the country, with the top 10% of cities accounting for around 41% (digital) and 45% (biotechnology) patenting in 2010-14, higher than the average across all technology fields over the same period. On a per capita basis, applications per 100 000 habitants numbered 123, 97 and 36 in the top 3 regions, compared to 12, 7 and 7 for Brandenburg, Mecklenburg-Vorpommern and Sachsen-Anhalt (Paunov et al., 2019[22]). The regional concentration of patenting activity – and of innovation activities more broadly – is not necessarily a sign of strength or weakness, but it does have implications at the level of local socio-economic well-being and growth, particularly in a context of structural change that may affect some regions.

Some divergences within the business sector suggest that innovation activities from certain firms remain below their potential. Between 2003 and 2018, BERD by large firms (over 500 employees) increased by 53%, compared to only 17% for small firms (up to 250 employees) (OECD, 2021[12]) and 43% for medium-sized firms (250-500 employees), which the German government classifies as part of the *Mittelstand*.

1.2. SWOT diagram of Germany's innovation system

Table 1.1 provides a synthetic SWOT diagram of Germany's innovation system, discussed in further detail in sections 1.3 and 1.4.

Table 1.1. SWOT diagram of the German innovation system

Strengths	Weaknesses
• A highly innovative export-oriented manufacturing sector, especially in automotive, machinery and electronics, chemicals and pharmaceuticals • Large leading and standard-setting firms with well-established value chains in Germany and abroad • Well-established internationally leading research and applied research institutions supporting industry and government • Strong linkages between science, academia and industry, and strong track record in commercialising research • Strong framework conditions for business innovation, including strong education system providing a qualified technical workforce, especially in engineering, and good innovation-funding options, including for *Mittelstand* firms • High political recognition of the importance of innovation for Germany • Strong and effective STI policy-support infrastructure, with large public funding and institutional support mechanisms	• Shortcomings in digital infrastructure, and weak uptake of frontier digital tools among small firms and the public sector • Shortage of certain key workforce skills such as STEM and digital competencies, particularly for *Mittelstand* firms, exacerbated by the impacts of population ageing • Limited business dynamism and limited opportunities for start-ups to scale, also as a result of low levels of venture and growth capital compared to the US market • Limited leverage of diversity in innovation activities, including the contributions of women, minorities and different generations • Limited strengths in knowledge-intensive services and collaborations across sectors and institutions, including research institutions' collaborations with the *Mittelstand*, critical to the sustainability and digital transformations • Limited use by the public sector of new and digital tools and approaches to deal with disruptive change and transitions and improve STI policy, including through public consultation, policy experimentation, and advanced data-analytics tools exploiting large data from the STI system • Complex regulatory frameworks for the implementation of innovative investment (including infrastructure), digital tools and data-sharing practices

Opportunities	Threats
• Advanced and innovative large firms and innovative *Mittelstand* firms are well placed to become world leaders in the sustainability transition and future developments of the digital transition • Huge public purchasing power through procurement and public investment allows stimulating demand for innovations, particularly in markets of the future • Exploiting connections between industry and research institutions, as well as highly successful intermediaries, to bring together diverse interdisciplinary expertise as needed for more disruptive innovation and digital innovation, including more strategic partnerships between industry and science • Industrial and research base are well-positioned to move into new technologies and adapt existing manufactured products to lead in markets of the future (e.g. quantum, batteries, sustainable energy) • Promote a more entrepreneurial culture at universities by rewarding students and research staff for engaging with industry, including SMEs, to support transformation processes • Utilise widespread societal agreement on the needed sustainability transition to build cross-societal partnership missions that steer innovation systems in support of objectives • Transform distributed responsibilities for research and innovation at the federal and state levels into an asset by actively adopting a lead-actor model of the transitions across states • Exploit leadership position within the European Union and globally to set standards and quality infrastructures supporting the German, European and global economy, as well as to develop the desired better socio-economic futures that take advantage of technical opportunities and curb challenges	• US and Chinese leadership in digital tools – including artificial intelligence (AI) – and services and intensive global efforts to lead in other core emerging technology fields may challenge Germany's global competitiveness, including in its core sectors of leadership (e.g. automotive, machinery and electronics, chemicals and pharmaceuticals) • Sustainability transition may transform markets in ways that challenge Germany's leadership, notably due to changing mobility patterns' impact on the automotive sector • New and often disruptive technological paradigms may increase German dependence on foreign expertise in several key future fields (e.g. gene editing, genetically modified food and big-data analytics) • Population ageing and lack of inclusivity reduce the available workforce for the STI system, making it necessary to optimise lifelong learning and exploit the diversity of the system • Global uncertainty in the evolution of international trade creates uncertainties affecting the resilience of the STI system, including future global supply chains

1.3. Strengths and structural weaknesses of the German innovation system

The business sector has sustained Germany's international competitiveness for several decades

The business sector continues to be the main driver of innovation expenditure in the German economy. After falling for the first five years after reunification, BERD has risen steadily, from 1.42% of GDP in 1994 to 2.1% of GDP in 2020 (OECD, 2021[11]). The vast majority of GERD originates in the business sector, which accounted for 69% of GERD in 2019, roughly the same level as before the 2008-09 Global Financial Crisis. The share of BERD by firms with over 500 employees has remained steady since the early 2000s (89% of total BERD in 2018 versus 88% in 2003). Given Germany's innovation success, the concentration of R&D within large firms partly reflects the industrial structure of its economy. Nevertheless, the country may be missing out on contributions to innovation from smaller-sized firms, which could enhance the overall system and expand opportunities for more inclusive growth. Such growth is particularly relevant in innovation-intensive service sectors, where evidence from other countries suggests that SMEs and start-ups – defined here as firms that has been active for two years or less – have particular innovation strengths. However, the contributions of smaller-sized firms will depend on the sector in which they operate. For example, sectors where platforms and networks have gained importance thanks to the digital transformation may present different opportunities than traditional manufacturing sectors.

Manufacturing contributes significantly to Germany's innovation expenditures, driven in large part by the automotive sector. Manufacturing sector makes a substantial contribution to BERD in Germany, accounting for 85% of all intramural R&D – a substantially higher share than in comparable economies like the United States (64%) and France (49%). In 2018, the German automotive industry accounted for 37% of domestic BERD and 24% of global automotive BERD. No other large industrialised country has a comparable level of sectoral concentration of innovation funding and capacity in any single sector. Of the world's leading automotive companies in terms of global R&D expenditure, four of the top ten – Volkswagen (first), Daimler (second), BMW (sixth) and Bosch (seventh) – are located in Germany (European Commission, 2020[16]). Thanks to Germany's private-sector leaders (comprising both large corporations and "hidden champions"), the private sector plays a key role at regional, national and even global levels.

Electronics, machinery, chemicals and pharmaceuticals are also important contributors to innovation in Germany. In addition to their globally leading investment positions, these sectors accounted for 11.4% (electronics), 9.9% (machinery), 7.2% (chemicals) and 5.8% (pharmaceuticals) of total BERD in 2018, the last year for which comparable data are available (OECD, 2021[12]). While these figures are low relative to the automotive sector's contributions, they are significant in nominal terms (with electronics accounting for EUR 8.3 billion, machinery EUR 7.1 billion, chemicals EUR 5.2 billion and pharmaceuticals EUR 4.1 billion) and substantially higher than BERD in the same sectors in other leading innovative nations, such as France and Italy. In addition, Germany has a number of global leaders in these sectors, including Siemens (second globally for R&D in the electronics industry), Bayer (eighth for pharmaceuticals) and BASF (first for chemicals) (European Commission, 2020[16]).

High-quality and international research is a hallmark of German business innovation. In addition to the IP5 patent applications mentioned in Section 2, Germany's high level of BERD has also supported a significant number of high-quality inventions, as demonstrated by the global share of triadic patent families attributed to German inventors.[8] Germany also demonstrates a strong level of research internationalisation, evidencing the global nature of domestic firms' R&D activities. In 2018, for example, co-patents accounted for 16% of total patenting – a share which, although behind the United Kingdom and France, is ahead of major competitors such as Japan and Korea (OECD, 2021[23]). In terms of high-quality research output, Germany has the fourth-highest contribution (4.4%) to the top 10% of top-cited scientific publications in the world's top 10% most-cited scientific journals, behind only China (20.7%), the United States (20.5%) and the United Kingdom (5.2%).

High-quality public research organisations have supported a skilled workforce and research for innovation, underpinned by well-established knowledge-transfer mechanisms

Public research organisations and universities generate strong scientific inputs and ideas that support business innovation. Between 2001 and 2017, the share of researchers per 1 000 employed increased by 43%, from 6.6 per 1,000 to 9.9 per 1,000, the third-highest level in the world, behind only Korea (13.4, 56% increase) and Japan (10, no real change) (OECD, 2021[12]). This research basis has led to a strong output, with Germany accounting for 4.4% of the world's top 10% most-cited scientific publications and 3.7% of the world's total scientific publications, the fourth and fifth highest levels globally (OECD, 2021[24]). Leading public research organisations, such as Max Plank Society, are widely recognised for their high-quality basic research.

A long and sustained process of institutionalisation has created a differentiated institutional ecosystem for knowledge transfer. Whereas institutionalised knowledge transfer in many OECD countries has often emerged as part of special policy programmes (for example, *pôles de compétitivité* in France, established in 2004, or the "Catapult" programme in the United Kingdom, launched by the government in 2011), similar institutions in Germany – such as the Fraunhofer Society or industrial co-operative research institutions (*Arbeitgemeinschaft industrieller Forschungsvereinigungen*) – have evolved over many decades. Thanks to the system's strong linkages with German industry, these knowledge-transfer institutions have evolved in such a way that their output and orientation has been naturally beneficial to German competitiveness, whereas initiatives in other countries are often more top-down and government-directed. In addition to the well-known knowledge-transfer institutions, several thematical programmes are also available to support industrial and business commercialisation of science research in a range of areas, from energy and biotechnology to construction. At the same time, open technology programmes, such as ZIM, have strengthened inter-firm collaboration in different areas of market-oriented and high-risk innovation.

Germany has a well-functioning higher education system, with mature and institutionalised public-private co-ordination and co-operation supplying skills suited to the needs of the innovation system. The Humboldtian university model, which has historically emphasised research, knowledge generation and intellectual inquiry, together with the country's well-regarded technical universities, which focus on engineering and applied sciences, have contributed to Germany's rich supply of well-educated labour-market entrants. Tertiary-level attainment is high, with 1.6% of 25-64 year-olds (eighth-highest level worldwide) and 2.1% of individuals under 35 (third-highest level) graduating from a doctoral or equivalent programme (OECD, 2021[25]). Thanks to the close collaboration between industry and academia, Germany's educational institutions have ensured that the skills of individuals entering the industrial sectors are suited to innovation and practical application. Germany also has a very well-developed and widely respected vocational education training (VET) system, with a strong dual component integrating learning in schools and workplace training. The VET system has extensive coverage. In 2019, 50.7% of adults aged 25 to 64 years old (the third-highest share in the OECD) and 43.8% of 25-34 year-olds (second-highest) had received a vocational upper-secondary or post-secondary qualification in Germany. The VET system has played an important role in supporting the workforce's capacities to absorb innovation.

Germany has a well-established and decentralised policy framework for innovation, supported by a rich policy mix

At the federal level, innovation and research are steered by BMWK and the Ministry of Education and Research (BMBF). As of 2021, there were 14 federal ministries. BMWK and BMBF have the most important roles for innovation, in co-operation with other federal ministries (such as health, transport and the environment) in areas where innovation intersects with other policy areas. Implementation is generally delegated to agencies, such as the Federal Institute of Material Research and Testing (*Bundesanstalt für Materialforschung und -prüfung*) and the National Metrology Institute (*Physikalisch-Technische Bundesanstalt*). BMBF focuses on policy areas that are implemented through higher education and publicly funded research institutions. BMWK generally focuses on areas where innovation policy and applied research can support the business sector, as well as environmentally sustainable industrial development.

A consistent theme in the BMWK approach to innovation policy is the importance of "technology openness" – a sector-agnostic approach to supporting innovation. As part of its broad "Transfer initiative", BMWK reformulated its technology-neutral approach in the 2021 "From Idea to Market Success" funding programmes, which emphasise a bottom-up selection of innovation and technology investment, particularly for the country's SMEs (BMWi, 2021[26]). The "open technology" approach has been a highly successful hallmark of German innovation policy for many years. It is underpinned by the understanding that a degree of non-directionality allows policy to support both technology push and pull, stimulating innovation from both the demand and supply sides. The suitability of a technologically neutral approach to address transitional challenges may require adjustments to advance transitions. For example, the networking and co-ordination dimensions of the digital and sustainability transitions, and efforts by the government to build more resilience in the STI system, may require more co-ordination and guidance from government. The Federal Government does have several more directional tools for stimulating demand and creating markets. One approach is public procurement, which demonstrates that a co-ordinated effort by the federal and state (Länder) governments can stimulate innovation at the firm level. Public procurement – particularly “innovative procurement” – are policy levers in the Federal Government’s “INNO-KOM” transfer programme.

The government has designed robust strategies to help the German innovation system respond to future transformation opportunities and challenges. To co-ordinate some of the technology- and sector-specific strategic plans, it also developed a High-Tech Strategy (HTS), whose fourth edition was issued in 2020. A monitoring and consulting body, the High-Tech Forum, comprising members from industry, science and civil society, supports the implementation of the HTS. Several more granular strategic documents underpin the HTS, including for many frontier areas of science and innovation, such as the Artificial Intelligence Strategy (2018-20), the Autonomous and Connected Driving Strategy (2015) and the National Hydrogen Strategy (2020). These strategies reflect the importance of developing domestically key enabling technologies that will ensure Germany’s future competitiveness and socio-economic resilience. Although most also emphasise creating framework conditions for innovation, they offer few direct inducements or incentives for undertaking innovation activities. The Federal Agency for Disruptive Innovation (SPRIND) is creating – like the Defense Advanced Research Projects Agency in the United States – spaces for innovators where they can take risks and think radically different.

Federal financing of R&D is administered by several ministries, with BMBF, BMWK and the Federal Ministry of Defence (BMVg) the largest contributors. In each ministry, federal funding is distributed either through project-based financing for R&D – directly through the targeted development of specific technologies or indirectly through support for the diffusion of certain technologies – or through institutional funding. The largest share (58.4%) comes from BMBF, because its budget covers federal institutional funding for public research agencies (around 45% of total federal R&D financing). Beyond direct institutional financing, BMBF also funds thematic research in areas ranging from health and environmental sustainability to material science and technologies, such as AI, microelectronics, high-performance computing, quantum technologies and photonics, production technologies and batteries. BMWK is the second-largest federal funding body (22.8%), with resources primarily allocated to project-based programmes, including ZIM and some thematic programmes in areas such as digitalisation, the automotive sector, energy, aviation and transport. BMVg is the third-largest R&D-funding federal institution, allocating its resources primarily to large defence R&D projects and procurement.

The Federal Government’s direct financing of R&D is a cornerstone of German innovation policy. GOVERD is the third-highest in the world at EUR 17.4 billion, and the second-highest (after Korea) relative to GDP (0.44%) (OECD, 2021[12]). Most direct government funding of firm-level innovation is administered through grants for R&D projects from major federal programmes, as well as state-level R&D programmes. Programmes such as ZIM, INNO-KOM and IGF are important drivers of technology transfer between research and the country’s SMEs, and are crucial to ensuring that the private sector is able to absorb innovative ideas and technologies. In 2020, the Federal Government also expanded its use of indirect financing for R&D with the introduction of the Forschungszulage, which grants a 25% tax credit to SMEs on their in-house R&D personnel costs and a 15% credit on their extramural R&D costs for research contractors located in the European Economic Area. The thematic focus of government R&D financing is generally tied to strategic policy documents, such as the HTS. The government has also introduced several thematic finance and policy instruments in support of innovation, such as the “Kopa 35c” programme, which finances sustainable innovation in the automotive sector, and the Industrie 4.0 strategy, which supports the digital transformation of manufacturing.

The government has numerous policy programmes that support start-ups in Germany, and developing venture capital (VC) markets for high-potential entrepreneurship is a policy priority. Through programmes such as the *High-Tech Gründer Fonds* (Venture Capital for High-Tech Founders), EXIST and INVEST, the Federal Government has developed a relatively robust policy-support framework for start-up growth in Germany. In 2021 it also launched the Future Fund (Zukunftsfonds), a EUR 10 billion equity fund managed by KfW bank, which will support start-ups in the growth phase. Nevertheless, despite the importance of VC for innovative start-ups, financing levels remain low compared to other technologically advanced economies, such as the United States and the United Kingdom. In the absence of sufficiently developed domestic VC markets, many high-tech German start-ups have sought growth finance from foreign (mainly US) investors.

The decentralised governance of Germany's innovation ecosystem has a number of advantages. First, the high level of decentralisation and regional autonomy helps focus policy interventions on local socio-economic needs, including at the industry level. In practice, this allows regional policy makers to tailor innovation policy (or indeed other policy inducements for innovation, such as tax incentives) to local business and industry needs, as the Länder are free to make localised fiscal interventions (including through income taxes) to create inducements for innovation at the sub-national level. In addition, education policy (including for universities) is devolved to the Länder. Similarly, public research organisations and universities enjoy a high level of autonomy, and are free to set their own research priorities independent of government directives. This has helped create linkages between public research organisations, local government and industry, and is an example of successful bottom-up innovation activities.

The high degree of regional autonomy in the STI system help policy makers design and implement more effective STI policy. Greater regional autonomy enables policy makers to focus on regional competitiveness issues, respond with more agility to local policy interventions, and better target the actors and sectors they will support. German policy makers must fully exploit these clear regional-level advantages, while at the same time developing a more co-ordinated and coherent national approach towards horizontal innovation challenges, such as the sustainability and digital transformations.

Germany's federated system of governance also creates challenges for the STI system. The high degree of autonomy enjoyed by regional actors in the STI system means that attention is given to local priorities, which can hinder both the implementation of federal government-level objectives, and the coherence of cross-country and cross-government ambitions. Moreover, fragmented approaches to digitalisation – including data sharing, technology transfer at the university level and within the education system more broadly – can make it more difficult to create more suitable conditions for innovation.

Germany has one of the world's most advanced and well-respected quality and certification systems (or "quality infrastructure"), which has supported international competitiveness. The country has a strong tradition of addressing issues of standardisation, certification and regulation from the perspective of creating competition-neutral instruments that support the public good. The prominence of German manufacturing – and the innovation that powers it – means that its regulatory standards have become internationalised, as German industry is intricately woven into global value chains and has high market shares in several manufacturing sectors (particularly automobiles and machinery). This ability to shape the regulatory environment and standards beyond its borders is a key strength of German industry. Indeed, being a "rule-maker" rather than a "rule-taker" can underpin Germany's innovation leadership ambition. This position, however, is challenged by its lack of international leadership in some key areas central to future economic competitiveness, notably digital and advanced technology fields such as AI, robotics, batteries and quantum computing.

Given the export-oriented nature of the German economy, innovation policy has an important international component. Germany engages closely with the European Union in several areas of innovation policy. International co-operation tends to have a higher level of directionality, particularly in supporting key enabling technologies (such as semiconductors, hydrogen and batteries) and data infrastructure. In such cases, a critical mass of technological competency at the supra-national level would have benefits for all EU Member States, both from an innovation perspective and potentially within the context of ongoing debates on technological sovereignty. The direction of innovation within the German business sector, which is highly integrated into numerous global value chains, also has systemic implications for the European Union. The German Federal Government has been working to establish an Important Project of Common European Interest on Next Generation Cloud Infrastructure and Services (IPCEI-CIS) at the EU level, having committed EUR 750 million to the project (BMWi, 2021[27]). At the same time, EU-level co-operation reflects difficulties in adopting a more directional approach at the national level in many of the same fields, with a risk that authorities may fall foul of EU state-aid rules. Moreover, quality infrastructure has an implicitly international component as it supports free trade, which is vital to Germany's export-oriented economy.

Despite clear strengths, Germany's innovation system has several structural weaknesses

Given the significant public support measures for SMEs in innovation, as well as the size and industrial composition of the German economy, the contribution of SMEs, start-ups and young firms to innovation is lower than it could be. As in all other leading R&D-investing countries, large firms represent the bulk of Germany's BERD. However, the relative decline in the *Mittelstand'*s contribution to innovation activities in previous decades is a concern. It began in the late 1990s, but has accelerated since the 2008-09 Global Financial Crisis, with the volume of innovation expenditure by SMEs in 2019 accounting for just 29% of that invested by the country's large firms, compared with 73% in 1995. The government is aware of this challenge and is particularly intent on improving the access of SMEs to research institutions. The BMWK's "From Idea to Market Success" programme aims to counter this trend.

Expanding the engagement in innovation of SMEs and start-ups will strengthen inclusivity. Since SMEs account for 99% of the country's firms and 56% of total employment, an increasing divergence between SMEs and large firms would result in a growing concentration of productivity gains within a relatively small section of the working population (Destatis, 2020[28]). While many of Germany's innovation programmes do accept applications from first-time innovators, knowledge-transfer initiatives have historically been oriented towards firms that already perform innovation activities. Many smaller firms, including start-ups, have therefore been ineligible for publicly backed research and innovation support. It is encouraging that an increasing number of participating firms in government-backed innovation programmes are first-time applicants, although the cumbersome processes involved in applying for support may nevertheless lower the reach of these programmes.

Young firms contribute very little to innovation in Germany. Firms that have been active for less than five years represent a very small fraction of total R&D and innovation expenditure in the German enterprise sector. This may partly reflect the low share of start-ups in the business population, with Germany's share of firms that have been active for two years or less the second-lowest in the OECD (OECD, 2021[29]). Furthermore, innovative entrepreneurship has been weak for many years, albeit more dynamic in recent years. Germany does not have same level of new – often disruptive – innovative firms as other countries, such as the United States and the United Kingdom. In 2020 and within the group of European Union (EU27) countries and the United Kingdom, for example, Germany accounted for 14% of investment in AI start-ups, after the United Kingdom (55%). Linkages between AI firms and SMEs or larger firms in industry is also low, and diffusion of AI in firms for activities such as data analytics, natural-language processing, image recognition and automation remains at an early stage. These dynamics may affect the German economy's innovative capacities, to the extent that existing firms cannot reinvent themselves or adapt to a changing economic environment.

Germany's innovation system needs to opt more for disruptive and radical innovations as the success of the current incremental innovation model will not secure leadership in the future. The major paradigm shifts under way in the global economy of sustainable development and digitalisation require investing in more disruptive and radical innovations for future leadership. These investments are riskier than more incremental innovations and are less obvious in a context where the current innovation model is still highly successful in securing revenues to respective industries. This is illustrated by the continued export success of German cars. Particularly for *Mittelstand* and young firms pushing for disruptive and radical innovations will not be straightforward, with access to human capital and knowledge providers in research institutions being critical. The Federal Government's decision to establish SPRIND in 2021 demonstrates a growing policy appreciation of the need to support breakthrough and disruptive innovation, acknowledging requires a different – more risk-tolerant and ambitious – approach to STI policy support.

Challenges in financing start-ups and innovation create risks that high-potential firms will flee and others will miss out on innovation opportunities. The German VC market remains small in both international comparison and relative to the economy's size. One of the main challenges to financing innovation in Germany is the ability of firms to access growth and late-stage capital, where investment needs are generally higher. The lack of such funds has led high-potential German start-ups to turn to foreign capital markets to launch initial public offerings or obtain later-stage venture financing. The lack of institutional investment hinders the development of this type of financing in Germany. German pension funds, insurance companies and public financing organisations provide very little risk capital, yet are among the only sources of finance that could provide the levels of capital necessary to scale the most promising innovators.

The German economy in general, and its innovation system in particular, suffer from a gender imbalance. Women remain a minority in management positions. According to the latest OECD data, only 13% of German technology start-ups in 2015 were led by women, which is likely to have an impact on the future competitiveness of the German economy, as well as inclusivity (OECD, 2020[8]). Women's participation in innovation and innovative entrepreneurship may be hindered by the same factors that hinder women's full-time employment more generally, notably the high tax burden on second earners and the insufficient supply of full-day childcare and full-day schooling (Yashiro and Lehmann, 2018[30]). The under-representation of women in innovative activities is also partly a result of the large proportion of BERD undertaken in industries where the inclusion of women has historically been low, also owing to the gender gap in STEM studies: in 2018, two out of three tertiary STEM graduates were men, perpetuating female under-representation in key sectors. It is therefore necessary to improve women's inclusion in STEM – as well as future innovators' skills – to meet the needs of increasingly data- and digital-driven innovation (OECD, 2020[8]).

Germany is confronted with skill shortages in several fields that are critical to innovation, including the provision of more cross-disciplinary training. The 2020 skilled labour monitor (*Fachkräftemonitoring*) of the Federal Ministry for Labour and Social Affairs found that labour bottlenecks are most pronounced in occupations that require a high degree of ICT skills, as well as in health care professions, skilled trades, and occupations related to mechatronics and automation technology (BMAS, 2021[31]). Germany does have a good supply of STEM skills from an international perspective, although it may not be sufficient to meet the growing needs of its industrial sectors (OECD, 2021[32]). Skill shortages are most acute in high-skilled occupations, with more than 7 in 10 experiencing shortages of highly skilled personnel, one of the highest rates in the OECD (OECD, 2021[33]). Beside technical skills, soft and social science skills are also important to advance transformative changes in the economy (for example, service-related innovations are a key vector of the digital economy, with a focus on mobility services rather than car purchases). The historical orientation of the German labour force is clear when observing the specialisations of tertiary graduates in the domestic labour market. For example, Germany has the joint-lowest share of social science graduates (24%) in the EU labour force, but the joint-highest share of engineering graduates (25%) (Paunov, Planes-Satorra and Moriguchi, 2017[34]). Promoting more cross-disciplinary training for engineering and social science graduates could enhance their future contributions to the economy.

Germany's demographic outlook, particularly its ageing population, presents a challenge for both its innovation system and broader socio-economic well-being. Germany's population is ageing at a faster rate than in most other OECD countries. The country's dependency ratio – which measures the number of people over the age of 67 per 100 people of working age (taken by the German government to range from 20 to 66) – is the third-highest in the OECD and set to double in the next 35 years (German Federal Statistic Service, 2021[35]). Germany's changing demographics impacts German economic competitiveness in two important ways. First, lower levels of labour replacement (new workers replacing retiring workers) mean that labour shortages in certain areas of the economy are likely to increase (OECD, 2021[32]). Second, Germany has seen decreasing firm-entry rates at the same time as the demographic group most likely to start a business (30-50 years) has been shrinking, a trend that will accelerate in the coming years (OECD, 2020[8]). These challenges are significant, particularly in a context where start-ups can play an important role in developing the innovations necessary to remain internationally competitive in emerging technologies and digital services. If structural barriers hamper innovation, the implications for innovation at the aggregate level could be significant. The demographic context also requires offering opportunities for migrants to participate in the country's innovation system. In addition to individuals already residing in the country, this involves attracting people who possess the skills and experience demanded by Germany's innovating firms. Germany should therefore continue to ease the conditions for attracting foreign talent and facilitating start-up creation by highly skilled foreign-born professionals and scientists (see the BioNTech case below).

Mittelstand and start-ups face well-known challenges in accessing diverse research knowledge and expertise. According to the 2018 Mannheim Innovation Survey, about 38% of innovating large firms in 2018 actively engaged in collaborative research with higher education institutions or public research organisations, compared to only 17.5% of innovating SMEs; the local and regional dispersion of knowledge represented a particular constraint on collaboration (ZEW, 2018[36]). The BMWK's "Transfer initiative" was conceived specifically to increase the number of SMEs that bring a new idea to market (BMWi, 2021[37]). Research institutions also suffer from long-standing issues related to unfavourable career paths, inflexible working conditions, roadblocks to mobility and a lack of incentives for engaging with *Mittelstand* and start-up firms, minimising the potential contribution of publicly financed research institutions to economic innovation.

1.4. The German innovation system and its preparedness for future challenges

The STI system is mature and functions well, but is being challenged by structural changes

The STI system must prepare for future transformations, including by building its capacity to provide breakthrough or disruptive innovations. The German STI system has very successfully supported leadership in key sectors – automotive, chemicals and machinery – that characterised the second industrial revolution. It has provided the conditions for continuously improving innovation within those technology areas, building on technical, scientific, institutional and policy competencies. But the future is set to bring broader and more complex change, embodied by: i) advances in digital technologies that may prove disruptive to existing sectors; ii) societal demand for building environmentally sustainable futures; and iii) a global context characterised by uncertainties and increased risk of crises, as illustrated recently by the 2008-09 Global Financial Crisis and the COVID-19 pandemic. In this complex and changeable context, STI policy requires heightened agility, allowing policy makers and firms to respond to unexpected circumstances and events while maintaining the incremental innovations that have underpinned domestic competitiveness for decades.

Business innovation, research priorities and knowledge-transfer activities are heavily influenced by industry incumbents. This orientation of the STI system may impeded the emergence of disruptive and breakthrough innovation, and consequently the German economy's ability to maintain its status as a global industrial innovator. Industrial and manufacturing firms, particularly in the *Mittelstand*, have focused less on innovation activities that support technologies that support transitions (whether digital technologies and ICT, or environmental mitigation technologies), yet are particularly vulnerable to the impact of these transitions on their products and markets. The low entry of new innovative firms may further slow change in this context. A major issue with digitalisation is whether "winner-takes-most" markets characterised by a few dominant firms will affect opportunities for *Mittelstand* firms to compete, with implications for the future innovation economy's inclusivity (Autor et al., 2020[38]).

An STI policy system that supports change will help prepare for future challenges by introducing more flexible structures and open innovation tools, as well as engaging more with civil society. Greater engagement with civil society can both improve the quality of STI policy – by harnessing a greater number of inputs – and mitigate the asymmetrical socio-economic impacts of STI policy interventions. From a policy design perspective, this could entail a broader use of strategic foresight approaches (such as the BMBF-Foresight "Vorausschau") in STI; building powerful data analytics and visualisation infrastructures at a granular level in the STI system to help design more impactful STI policies, and improve their evaluation and monitoring; and employing experimental policy tools (such as sandboxes) to facilitate implementation. Engaging with society is also important in a context where technological developments affect society, and consequently the uptake of tools resulting from those technologies (Paunov and Planes-Satorra, 2021[39]). New digital tools offer better ways of capturing societal perspectives, including through public forums. From a policy instrument perspective, using regulatory sandboxes and introducing flexibility in regulations can support experimentation, which could drive future success. Adequate tools to address barriers to breakthrough innovations, such as skill shortages and research capabilities in key enabling technologies, are also important.

Germany lags behind in the digital innovation field

Limited digital connectivity may hold back innovation. Germany has a relatively low level of digital connectivity, particularly in terms of fixed high-speed broadband networks and the penetration of high-speed long-term evolution mobile data networks. Levels of fibre-optic broadband connections are substantially below the OECD average: in 2019, 1.72% of total fixed broadband subscriptions were for fibre, compared to 8.91% on average in the OECD (OECD, 2020[8]). Only 36.9% of firms in small and rural municipalities of Germany had access to broadband with download speeds greater than 30 megabits per second, compared to 52.3% in cities (OECD, 2020[8]). The government recognises the importance of closing the connectivity divide and has undertaken a number of initiatives to support the expansion of better-quality digital infrastructure. For example, it established the Mobile Communications Infrastructure Company, which aims to close almost 5 000 "blackspots" in the country's 4G network. Although there is no agreed method for benchmarking 5G rollout, progress in Germany so far has been relatively slow. The private sector is also set to make a significant investment in the country's broadband infrastructure, with the telecommunication association BREKO estimating that some EUR 43 billion will be spent by 2026 to roll out high-quality fibre broadband (Fibre Systems, 2021[40]).

Poor connectivity has already had an impact on German firms' ability to maximise opportunities from digital technology. The slow diffusion of ICT and digital tools is a particular challenge for the innovative competitiveness of Germany's *Mittelstand*, and consequently their preparedness for a more digitally driven economy. Data already suggest that Germany has fallen behind in the uptake of certain key digital technologies. For example, the country significantly lags the OECD best performers in cloud computing, high-speed broadband and big-data analysis (OECD, 2020[8]). Low levels of advanced ICT adoption may partly explain Germany's similarly low processing of data from firms' sensors and devices compared to the best-performing nations, a crucial component of Industry 4.0 which requires investing in high-quality connectivity infrastructure. Other issues – such as outdated data regulations, concerns over cyber security, limited access to finance for corporate digitalisation programmes, limited digital sandboxes, and low levels of investment in the type of knowledge-based capital necessary to create more value from data and digital technologies – contribute to holding back the innovative potential of many German firms.

The slow diffusion of digital technologies and ICT in the public and private sectors may also stem from a lack of skills. As mentioned above, the limited supply of STEM graduates, ICT professionals and data specialists may slow the adoption of new technologies, hampering innovation (OECD, 2020[8]). For example, employment of ICT specialists is strongly associated with firms' adoption of new ICT tools and activities supporting data-driven innovation. Neither the public nor the private sector is currently able to take full advantage of the opportunities presented by digitalisation. Government services continue to be very analogue-based compared to other OECD countries. Germany ranks twenty-sixth in the OECD Digital Government Index, denoting factors such as low digitalisation in the public sector, limited use and interoperability of data, and the limited digitalisation of government services (OECD, 2020[41]).

Germany's international competitiveness has been closely tied to its status as a world-leading innovator in key industries, but the frontier of digital innovation that drives changes across the economy lies elsewhere. In contrast to Germany, the United States, Japan, Korea and China dominate the global share of ICT patents. This is true for both general ICT patenting and more advanced applications, including important general-purpose technologies like AI and nanotechnology. In 2017, Germany accounted for 146 AI-related IP5 patent applications, compared to 1 065 applications from the United States and 1 115 from Japan. In terms of publications, only 2 of the top 50 corporations publishing on AI were from Germany in 2014-16 (OECD, 2019[42]). A similar dynamic applies to nanotechnology, which is a crucial input for the types of semiconductors necessary for the next generation of autonomous driving, as well as a range of other advanced applications: in 2017, Germany accounted for just 17 IP5 patent applications in nanotechnology, far behind the United States (140) and Japan (112). In practical terms, this means that unlike in the past, when German inventions wielded significant influence over manufacturing and industrial processes around the world, German firms will rely increasingly on innovations – and the standards that determine their use – originating beyond its borders. The divide is reflected in German digital firms' lack of global prominence compared to other leading nations in digital innovation, with only 3 firms among the top 100 digital corporations by market capitalisation headquartered in Germany, compared to 13 in China and 59 in the United States (PwC, 2021[43]).

Beyond strictly digital sectors, Germany's position as a global leader in manufacturing will come under pressure as value added derives increasingly from products' digital component. Germany's automotive sector is a strong innovation performer, accounting for some 43% of global patents in "electrical digital-data processing". The digitalisation of the automotive sector will have implications for German manufacturers in several other areas, including the valorisation of digitally embedded services in products, the acceleration of innovation cycles, the opportunity for greater collaboration in digital innovation and firm-level investment in digital solutions to reorganise internal processes. In the German automotive sector in particular, core value added may shift to digital components as the importance of internal combustion engines – a key source of value added in the sector – wanes.

The digital transition will have uneven distributional effects. According to the latest projections of the Federal Ministry for Labour and Social Affairs, approximately 5.3 million jobs will disappear in the next 20 years (until 2040), while 3.6 million new jobs will be created (BMAS, 2021[31]). While accounting for a broader range of issues beyond digitalisation, these findings are in line with OECD observations on the impact of technological transformations on the labour market. For example, Germany is likely to see significant labour displacement due to automation, compounding labour-market and demographic challenges. A 2018 OECD analysis estimated that a large number of jobs across the OECD could be displaced due to automation (Nedelkoska and Quintini, 2018[44]). At the same time, the increasingly digital and knowledge-intensive nature of German firms may aggravate the existing regional divide in terms of productivity, investment and infrastructure quality, especially if there is limited public investment to address some of these issues. Ensuring that displaced workers are equipped with the necessary skills to remain in the labour market, and considering digital technologies (such as high-quality internet connections) as a public good that is necessary to ensure firms' competitiveness, will be a key challenge for policy makers in the years ahead.

The impact of COVID-19 also highlighted the need for a better digital infrastructure. As workers were required to operate from home owing to pandemic-related restrictions, and businesses sought ways to keep lines of communication and collaboration open, the importance of digitalisation to the future of work became increasingly obvious. Deficiencies in the digital infrastructure (such as inadequate bandwidth to support video conferencing or cloud-based collaborative working), as well as skill-related issues, highlighted the different levels of preparedness of different actors across the German economy. The crisis also underscored the importance – and potential – of advanced real-time reporting, which made it possible to integrate detailed and frequent updates on the public health situation into policy making, although this was somewhat impeded by the limited digitalisation of different actors within the public administration.

The sustainability transition affects the core of Germany's innovation strengths and provides an opportunity for leadership

Meeting Germany's reduction targets as part of the Paris Agreement will require fundamental changes within German industry. The example of Germany's automotive industry is particularly edifying in terms of the innovation challenges facing the country's economy and future competitiveness. On the one hand, demand for internal combustion vehicles should continue to fall owing to changing mobility habits and the international shift toward decarbonisation, although the transport sector will remain a major source of carbon emissions in Germany. The country's high-value vehicle exports will likely face lower demand at a time when high-priced product strategies – such as those pursued by the country's automotive manufacturers – are becoming increasingly vulnerable to disruptive innovation.

The automotive sector is a clear example of the interconnectedness of technological competencies for sustainable transitions and key sectors of the German economy. For example, the share of electric vehicles in global car sales continues to grow every year as electric vehicles become more advanced and more cost-competitive against vehicles equipped with internal combustion engines. EU legislation to ban the sale of new internal combustion engines from 2035 may accelerate this trend, an indication that climate-related legislation will fundamentally change consumer preferences in the years ahead. Beyond the automotive sector, STI will contribute to a range of technological solutions to environmental challenges, such as carbon storage and capture, a greater contribution of clean energy to the electricity mix and improved energy efficiency. In the absence of stringent carbon pricing – and given that the government has maintained a number of industrial energy subsidies – German industry has so far not faced significant financial pressure to undertake transformational change, but these pressures are likely to grow in the years ahead.

Just as with the digital transformation, decarbonisation can have an uneven distributional effect, which could aggravate existing inequalities if left unaddressed. Policy makers need to think about distributional implications. For example, coal mining is concentrated in a small number of regions such as Lausitz and Rheinland, which have higher levels of unemployment and lower levels of entrepreneurship relative to the national average (OECD, 2020[8]). The phasing out of coal as part of the country's energy mix is therefore likely to create unequal labour displacement, with a risk of increasing inter-regional inequality. The indirect consequences of decarbonisation – for example, in the automotive sector – are therefore likely to affect the German labour market far more profoundly.

Improving sustainability and supporting decarbonisation are also economic opportunities. Germany has already shown that it can use innovation to create new products and markets supporting decarbonisation. For example, the development of feed-in tariffs as part of its Renewable Energy Sources Act – a cost-based pricing mechanism for electricity production that creates incentives for private investment in renewable sources – shows that public policy, when underpinned by STI, can advance structural transformation. These successes, combined with Germany's innovative potential, augur well for the country's ability to meet its decarbonisation targets in carbon-intensive sectors such as transport and industry. Still, political ambition and astute industrial leadership will be necessary to exploit these opportunities. With an ageing public infrastructure in need of significant investment, the government has an opportunity to target subsidies, investment and public procurement to support the creation of new markets underpinning sustainability and decarbonisation.

Germany's Energy Transition Strategy (Energiewende) outlined a committed plan for transitioning to renewable energy. The strategy, which became official policy after the nuclear accident of Fukushima in 2010, included shutting down Germany's nuclear power plants. It also emphasised the role of innovation in energy technologies, the need for smart energy policies and the export opportunities for climate technologies. It also formulated ambitious targets for a number of sub-aspects, such as reducing carbon emissions. Recent innovation indicators show an increase in R&D spending and the number of patents for energy- and mobility-related innovations compared to other environmental technologies (Walz et al., 2019[45]; Gehrke, Ingwersen and Schasse, 2019[46]). However, the strategy has been more cautious about supporting disruptive innovation strategies that would require new consumption patterns to achieve targets. The challenge here is also global. While technological solutions (such as carbon capture and storage, or the use of hydrogen in industrial processes) are gaining in technological feasibility, several more years will elapse before they can be scaled more widely and become competitive. In the context of Russia's war against Ukraine and the ensuing impetus to German energy diversification, a greater contribution of renewables to total energy consumption will require accelerated innovation, combined with greater levels of investment and policy support. Going forward, the question is whether Germany has the right innovation-policy mix to encourage both the diffusion of available low-carbon technologies and the development of breakthrough technologies.

The shocks of COVID-19 and Russia's war in Ukraine have highlighted structural issues in the German STI system

Strong external demand for Germany's manufactured goods in the decade prior to the COVID-19 pandemic helped underpin a decade-long economic expansion. In the last pre-pandemic year (2019), exports reached USD 1.4 trillion, making Germany the third-largest exporter in the world, behind only the United States and China. While European markets continue to account for the majority of German exports, rising demand from China and the United States for German automobiles and electrical components over the past decade has considerably heightened their importance for German firms. Not only has Germany so far mitigated some of the more drastic labour displacement effects seen in other manufacturing nations, but the spillover into the wider economy remains significant, with 1.2 jobs created for every person employed in manufacturing (Legler et al., 2009[47]).

The shocks caused by the COVID-19 pandemic and Russia's war against Ukraine have highlighted structural vulnerabilities in Germany's export-oriented economy. While these events are very different, both shed light on vulnerabilities in global supply chains, including i) the economy's reliance on trade for both inputs (of intermediary goods and raw materials, including energy) and outputs; ii) the need for the STI system to be resilient and responsive to future shocks, including to the value chains upon which it relies and to which it contributes; and iii) the need for agility in policy design, to avoid damages to innovation and the economy in periods of crisis.

Interruptions to the supply of key intermediary goods for the German economy have particular implications for the country's STI system and the private sector it supports. As border closures disrupted the flow of goods, Germany industries faced a number of shortages, refocusing policy attention on issues of technological and production sovereignty. China's continued "zero-COVID" policy into 2022 has perpetuated these disruptions, with implications for German output. It is precisely owing to supply-chain disruptions that German GDP growth dropped so dramatically. Demand generally remained strong throughout the pandemic, but the fragility of the global supply chains – from raw materials and energy to high-tech intermediate components – meant that industry could not produce the output required.

The crisis also highlighted the importance of having innovative and technological reserves to bolster socio-economic resilience. This was starkly demonstrated by the success of the German biotechnology company BioNTech, in collaboration with the American pharmaceutical company Pfizer, in developing the first COVID-19 vaccine approved for use by a stringent regulatory authority. Germany's pharmaceutical sector is a major investor in R&D, and (as with other areas of the economy) its motivations are understandably commercial. The experience illustrates the importance of building and maintaining technological and innovative capacities in a range of areas, which can be activated in times of crisis or in the face of complex challenges. The contribution of STI to addressing the COVID-19 challenge may be a harbinger of its potential contribution to other complex areas where science and innovation intersect with socio-economic challenges, and where supporting innovative competencies in a range of areas can underpin domestic resilience.

Agile policy making during the COVID-19 pandemic helped the German economy and society emerge relatively unscathed. Quick and well-designed policy interventions saved German lives and mitigated the pandemic's impact on businesses. Sizable public intervention, supported by expansionary fiscal policy throughout 2020, helped protect jobs and firms. A discretionary stimulus package amounting to 4.5% of GDP supported loans, guarantees, grants and equity injections to maintain firm liquidity, preventing the unnecessary market exit of viable firms and long-standing economic scarring. Nevertheless, the challenges outlined above are indicative of several structural issues facing the German economy and its innovation system.

1.5. Recommendations

Context for the policy recommendations

The policy recommendations provided here focus on strengthening the current STI system and preparing for its future. Complex transformative processes, such as digitalisation and the societal push for environmental sustainability, will lead to significant changes for Germany's key manufactured and industrial goods and markets. Given the rich and well-functioning German innovation-policy system, the recommendations focus on the framework conditions for innovation, governance of STI policy, demand-side policies for innovation and policy agility. The rich diversity of policy instruments in support of innovation at the federal and state levels remains essential to future success and must be maintained.

The policy recommendations reflect Germany's ambition of global leadership and are therefore set at a high level for Germany's innovation ecosystem and policies. In the context of the sustainability and digital transformations, Germany's innovation ecosystem must promote high-impact and more disruptive innovation lead. Among the key challenges it considers is how the STI system can engage in breakthrough innovation activities, including to ensure that SMEs are equipped with the skills and technical capacities to engage in cutting-edge technological research, and that this research can be scaled and commercialised. The review also expounds the importance of promoting key enabling technologies.

The review focuses on applied R&D rather than basic research. While questions around the conduct of basic research fall outside the scope of this review, they nevertheless remain essential to the functioning and future competitiveness of the German STI system. The high level of government and business expenditure in these areas is welcome. It is clearly a source of strength for Germany's innovation system, and the review recommends maintaining this strong commitment.

Recommendation 1: Develop a shared vision “Germany 2030 and 2050”

Overview and detailed recommendations:

Most transformational challenges posed by the transition to sustainability and digitalisation challenge Germany’s existing innovation governance system. This has resulted in important experiments, notably within the strategy for research and innovation (R&I) (see Chapter 5), to devise new governance arrangements for STI. This recommendation foresees the establishment of a whole-of-system “forum” to steer Germany’ STI system towards specific goals and ambitions described in a strategic vision. The proposal offers a time-bound and collaboratively developed vision for Germany. For its implementation, this recommendation complements Recommendation 2 on the creation of a public-private laboratory for innovation policy experimentation.

R1.1 **The government should create a cross-ministerial, federal-state, cross-institutional and cross-sectoral forum to steer the process of developing a shared vision founded on identified key priority areas for action**. The purpose of this forum would be to ensure broad engagement in policy making and identification of priorities, both to promote the type of horizontality and multidisciplinary approaches implicit in the challenges posed by transitions, and to secure the social and political legitimacy of the proposed actions. The forum would also provide an environment where all areas of policy (such as digital policy, social policy, education, environmental and health policies) can be discussed as they interact with STI. Although these issues fall outside traditional STI policy portfolios, they invariably affect the effectiveness of policy interventions.

R1.2 **The forum should develop pathways for innovation to realise the desired vision for Germany in 2030 and 2050, as well as define approaches to deal with future risks and inclusivity issues in orienting innovation policies.** All countries will face important socio-economic transitions resulting from the digital transformation and the ambition to develop environmentally sustainable development pathways, as well as the increased risks – including health threats (such as the COVID-19 pandemic), geopolitical conflicts and climate change – arising from the interconnectedness of the global economy. Defining a shared vision can underpin steadier and more and strategic action, rather than addressing challenges in an ad hoc and reactive manner. The debate on inclusivity should also address the question of potential trade-offs of innovation excellence and inclusivity, and how to best approach these challenges.

R1.3 **The vision and its forum must be recognised as central at the highest level of government, as well as by key industry stakeholders and society, to effectively promote an agenda of change in the STI system**. The forum should receive high-level political support to allow it to engage government ministries and institutions at both the federal and state levels, as well as STI stakeholders more broadly.

R1.4 **Effective implementation requires establishing a public-private budgeted strategic plan for the realisation of the “Germany 2030 and 2050” vision. The plan should focus on key thematic areas for action and the monitoring of progress made at different stages. Core themes will be achieving the digital and environmental sustainability transitions, and the role of innovation and STI more generally in that regard.** Other related topics include preparedness for future disruptions (e.g. supply-chain preparedness), key enabling technologies, the industrial transformation and diversity in the innovation system (gender, age, ethnicity and socio-economic background). More granular topics could be developed, depending on which key priorities are identified for the “Germany 2030 and 2050” vision.

R1.5 **Importantly, implementation defined along key missions should not be top-down, but rather bottom-up and market-driven.** Bottom-up approaches can help accelerate implementing pathways for realising the “Germany 2030 and 2050” vision. Adopting actor-driven approaches, in particular, can hasten transition efforts that "reward" lead actors in specific states, regions, sectors, cities and policy fields that undertake innovative actions for change. Market-driven dynamics are also a key aspect of the vision's implementation plan, which should identify and agree on transition pathways and partnerships with industry partners. In this manner, both government and industry commit to investments and other contributions or initiatives (such as "fossil-fuel free Sweden'", with its industry roadmaps negotiated between industry and government) that will drive transitions. The "transformation dialogue for the automotive industry" (*Transformationsdialog Automobilindustrie*") is a first attempt in this direction.

R1.6 **Important goals of the forum, and the "Germany 2030 and 2050" vision, would be to draw upon systemic capacities for STI and better co-ordination in mission-oriented approaches.** Germany has developed a number of mission-oriented approaches for STI, but they are not always sufficiently "transformative" and suffer from a lack of coherence and co-ordination among missions.

Recommendation 2: Create a public-private laboratory for innovation-policy experimentation

Overview and detailed recommendations:

The pace of technological change and the nature of the transformative challenges facing Germany's socio-economic future require more agility and experimentation in policy making. STI policy approaches require foresight strategies, co-creation of policies with civil-society actors and digital tools to inform innovation-policy approaches, such as semantic and big-data analyses to gather and interpret data relevant to the STI system. More agile STI policy could enhance the effectiveness of mission-oriented interventions, help scale the most effective policy approaches and allow recalibrating the chosen course of action more quickly. This is essential if Germany wants to take the lead in introducing new disruptive innovations and associated business models. The proposed public-private policy laboratory would introduce policy agility in key areas linked to the proposed "Germany 2030 and 2050" vision of keeping up with the global pace of change needed to lead in the transitions (see R1).

R2.1 **The laboratory should act as the forum's institutional arm (see R1) to support policy agility, increased and accelerated responsiveness, experimentation and learning, and the major changes needed to achieve the "Germany 2030 and 2050" vision**. To this end, the laboratory would have a mandate to support champions – those who engage in experiments – and promising innovations across the STI system, including public bodies undertaking regulatory experimentation (R3) and innovative public procurement (R7), as well as city initiatives and other bottom-up efforts supporting transitions. This would include promoting lead-actor mechanisms across Germany's *Länder* to experiment with core missions – such as the digitalisation of the public sector – and new approaches to innovative procurement across all levels (including municipalities). The laboratory would also have a mandate to mitigate co-ordination failures across line ministries and public institutions, industry and civil society. It would exploit regional competencies and priorities to hasten the development and scaling of the most promising regulatory and policy approaches to innovation challenges. Importantly, the laboratory would look for ways to promote responsiveness and learning from policy experiments, as well as (where needed) facilitate fundamental policy changes.

R2.2 **The laboratory would promote implementation and monitoring, and the "Germany 2030 and 2050" vision (see R1).** Concretely, it could implement a strategic foresight exercise that will produce the "Germany 2030 and 2050" vision, as well as monitor developments and co-ordination challenges that may impede the transitions. This means considering the full innovation chain, from idea generation to market introduction, driving transfers across different actors. The laboratory would also support agents of change – notably through prizes, competitions, etc. – that help markets and different actors of the STI system to achieve the vision. For example, it would support the development and implementation of regulatory sandboxes and other forms of regulatory simplification (as detailed under R3), and could similarly support innovative public procurement (R6). It would also promote demand-side mechanisms for stimulating innovation, such as innovative procurement, and promote framework conditions conducive to innovation. Finally and importantly, the laboratory would support breakthrough innovation by promoting the activities of SPRIND and, more broadly, risk-taking entrepreneurship.

R2.3 **The laboratory would have the autonomy and means to recruit staff with different profiles through more flexible employment options, as well as to engage flexibly with innovation actors.** This would promote a greater level of industrial engagement through secondments or temporary positions, ensuring that policy making in frontier and complex areas of science and technology is underpinned by technical and entrepreneurial experience, and practical knowledge. To avoid adding further complexity to an already extensive set of STI policy actors, the laboratory would fulfil a temporary role, designed to set in motion a new agenda of change for future transitions.

Recommendation 3: Broaden and mainstream the use of agile policy tools to support innovation efforts by SMEs, and achieve the digital and green transitions

Overview and detailed recommendations:

The Federal Government should consider mainstreaming policy tools (such as regulatory sandboxes) to maximise their potential for change, normalise the use of such methods in the context of its approach to STI and generate more data for policy evaluation. Regulatory sandboxes (*Reallabore*) refer to a limited form of regulatory waiver or flexibility that enables firms to test innovative technologies, products or services which are not yet fully compliant with the existing regulatory framework. At the same time, the government should build greater flexibility into existing areas of regulation and policy, and adopt a more risk-taking and experimental approach to policy making in a context of important transformations.

R3.1 **Reduce bureaucratic and administrative barriers affecting SMEs and start-ups.** The government should both rationalise the processes required for certain government-to-business services, as well as the administrative steps required for firms to receive STI policy-support measures (such as innovation grants). Some SMEs and start-ups will shy away from applying for support schemes because the application procedures are not easily accessible or straightforward. Where legal barriers impede the simplification and flexibility of support measures, the government should undertake a review of the changes required to streamline access conditions. Programmes such as ZIM (BMWK) and KMU-innovative (BMBF) have demonstrated good practices and the feasibility of increasing the rate of firms participating for the first time in initiatives supporting research and innovation.

R3.2 **The government should pursue a programme of digitalising government policy, services and processes.** The digitalisation of government services should proceed after the rationalisation of existing regulations and procedures. Pivoting to digital delivery would consolidate all interactions between firms – particularly SMEs and start-ups – in a single location, preferably a digital “one-stop shop”. More than digitising existing analogue processes, this requires improving them (by reducing the number of intermediary steps), and collecting and analysing data from interaction with digital services to further improve and inform policy making. The integration of new tools, such as machine learning and semantic analysis, could both improve the quality of government policy and regulation, and enable the government to take an active lead in the digital transformation of the public and private sectors.

R3.3 **Expand the use of regulatory sandboxes**. Germany's adoption of the Regulatory Sandbox Strategy (as discussed in Chapter 15 on policy agility and the corresponding R2 on the establishment of a policy laboratory) has been a decisive step in the use of regulatory sandboxes, but additional focus should be placed on the following:

- Strengthening regulatory co-operation across various federal regulators – as well as among municipal, state and federal authorities – when implementing regulatory sandboxes: this is particularly important because emerging innovative areas often cut across traditional industrial sectors, and thus the mandates of regulatory authorities and federal ministries.
- Targeting SMEs and start-ups to ensure they have access to regulatory sandboxes and that the eligibility criteria do not exclude younger or smaller firms: the government should continue to organise awareness-raising activities (such as competitions) on the opportunities and possibilities of sandboxes, with a particular focus on SMEs and citizens. Establishing regulatory sandboxes also requires avoiding possible regulatory capture by participating firms.

R3.4 **Support an easy-to-use digital one-stop-shop for STI policy engagement.** Germany currently provides the private sector with a wealth of policy instruments to support innovation, but their overall effectiveness could be increased. To this end, the public administration should consider improving communication about these instruments, which currently includes a centrally co-ordinated platform listing the instruments (*Förderfinder des Bundes)* and individual consultation activities to allow firms to find offers matching their specific needs (*Förderberatung Forschung und Innovation des Bundes)*. Complementing these services with a full-fledged digital one-stop-shop for STI policy engagement of SMEs, start-ups and individual entrepreneurs would improve access and use of the support schemes. This digital one-stop-shop should also allow any firm (both domestic and international) to easily check its eligibility for different innovation-support instruments. It would also integrate the existing consultation activities by centralising and digitising the back-office application processes for these instruments. The platform could also serve as a vessel for goal- and challenge-oriented innovation, increasing firm-level awareness of and participation in innovation programmes supporting socio-economic policy objectives.

Recommendation 4: Improve data infrastructure and data access, especially for industry

Overview and detailed recommendations:

This recommendation highlights the particular importance of data as a necessary input for all other areas of this review, from supporting greater agility in policy making and more innovative use of procurement, to processing data at the firm level to enhance research and efficiency.

Improving the coherence and interoperability of the data infrastructure for future digital innovation should be a government policy priority. Effective collaboration between research institutions and firms for purposes of innovation also depends on the presence of an accessible and well-designed data infrastructure.

From the perspective of Germany's innovation strengths and international comparative advantages, the strategic use of more industrial data for innovation should be a priority for the public and private sectors, with a focus on the innovation-intensive automotive, machinery, chemical and pharmaceutical industries. This requires top-down and framework-related approaches, complemented by policies to improve the bottom-up uptake of data-producing and data-dependent technologies at the firm level. Open innovation platforms and collaborations to exploit those data are necessary to help activate this potential.

R4.1 **The government should support a programme to improve the country's data infrastructure, and increase the public and private sectors' absorptive capacity of both infrastructure and human capital**. This programme should have a clearly defined mission, with a strong focus on the use of data produced by the business sector and during research to support STI. The programme would be responsible for rationalising and eliminating the soft and hard infrastructure issues constraining the development of better data infrastructure and data access.

R4.2 **The government should consider the data generated by the business sector as a strategic dividend that can strengthen German innovation and competitiveness**. Having recognised the centrality of data for innovation in the Data Strategy of the Federal German Government (BKAmt, 2021[48]), Germany could exploit its position as Europe's largest economy to ensure that high-quality, interoperable and accessible industrial data become an additional strength of its innovation system and economy. From an infrastructure perspective, the GAIA-X and Important Projects of Common European Interest (IPCEI)-CIS programmes – both of which aim to support European-based cloud infrastructure services – are first steps in this direction. The same is true, to a greater extent, for the ongoing efforts to digitalise the automotive sector's value chain through initiatives such as the CATENA-X platform. While these initiatives are important, they must be scaled, the scope broadened, and the speed with which they are rolled out increased. A whole-of-industry strategy will require a coherent and systemic approach to leverage industrial data effectively for innovation, and should be pursued with the relevant actors at both the national and transnational levels.

R4.3 **To promote data-driven innovation, the German Federal Government should address barriers to SMEs' use of the data they produce and enhance SMEs' access to data produced across the economy**. Specifically, the Federal Government should support rationalising regulatory differences across the *Länder* and provide support for implementing the General Data Protection Regulation. It should increase legal certainty and, where appropriate, promote flexibility in using data for innovative processes, encouraging businesses to make the necessary intangible investments to produce, store and process data for innovative purposes. At the same time, the government should recognise the urgency of ensuring that firms are equipped with the necessary connectivity infrastructure to support data-driven innovation and production in the context of the digital transformation, including fibre-optic broadband and the 5G connections required to convey the massive volumes of data inherent to Industry 4.0 processes.

R4.4 **Promote open innovation platforms and approaches. Producing data is a necessary but insufficient condition for innovation.** To succeed in the digital era, firms must have access to data they do not produce, and be equipped with the skills and technological competencies to process and use them. In addition, while some firms may not have the internal capacity to derive value or insights from the data they do (or could) produce, other firms may be able to unlock such insights. This highlights the importance of supporting an open innovation approach – which the Federal Government has begun pursuing through its 2021 Data Strategy – and creating platforms that involve other innovation actors in producing innovations based on private-sector and industrial data. An important benefit of such open innovation platforms is that they allow more collaboration between firms as well as with PROs and universities.

Recommendation 5: Improve cross-disciplinary and cross-sectoral knowledge transfer and collaboration

Overview and detailed recommendations:

Extensive and inclusive knowledge exchange and collaboration across institutions, disciplines and sectors, as well as multidisciplinary open innovation approaches, should become cornerstones of German STI policy. Success in this area would have other positive spillover effects on inclusivity in STI, such as engaging in innovation activities a wider share of the population with skills beyond STEM. Germany's traditional innovative strengths have generally been intra-sectoral, so that knowledge is created, and technology transferred and applied, within a particular cluster and industry. In a digital world, however, knowledge and technology transfer increasingly occurs at the intersection of digital technologies and "analogue" sectors. In addition, the type of innovation necessary to succeed in the sustainable development challenge is – and will continue to be – disruptive. This requires significant breakthroughs, which are achieved through effective knowledge transfer and industry-science collaborations, and based on open innovation approaches and industry-science collaborations across all sectors of the economy. The support for knowledge transfer and collaboration should transcend traditional innovative sectors. The success of the government's recent pilot phase of the Innovation Program for Business Models and Pioneering Solutions (IGP) programme (see Section 2 of this chapter) also demonstrated the potential of government-supported programmes to promote non-technical and multidisciplinary innovation in areas ranging from digital platform design to social impact.

R5.1 **Improve universities' engagement with industry and support research institutions in playing a leading role in the transitions required to achieve the "Germany 2030 and 2050" vision.** Part of the vision should consist in reframing the relationship between research institutions and industry, so that it supports knowledge transfer and innovation collaboration in areas of future importance, as well as an "ecosystem" approach to innovation. In this light, ensuring that innovation actors contribute to knowledge transfer and collaboration could become a formal pillar of German research organisations' responsibilities, with a training and information campaign accompanying this change. This strategy would benefit from incorporating these objectives into performance-based funding and developing a set of metrics, including qualitative measures, to improve the visibility of related programmes. The "Germany 2030 and 2050" vision could also establish a formal mechanism, encompassing the forum proposed in R1, the policy laboratory and the higher education system, to engage research institutions in Germany's transformational processes, including by contributing to environmental development objectives.

R5.2 **Encourage and facilitate the development of university proof-of-concept funds to support academic spin-offs and start-ups.** Through its direct funding of higher education R&D, the government should encourage the establishment of proof-of-concept funds within universities, which could be complemented by industrial contributions. These funds would help accelerate technology transfer commercialisation. The government should explore regulatory channels that would allow (and make it simpler for) universities to engage directly with external finance actors, such as VC firms and the banking system more broadly, as happens in Belgium, Denmark and the United Kingdom. Moreover, the government should take a long-term approach to monitoring and assessing the development of proof-of-concept programmes within higher education – a luxury that the private sector (particularly SMEs) cannot afford.

R5.3 **Reinforce incentives for academics to engage in innovation.** Policy makers and universities need to improve incentives for academics to pursue innovation activities, and address relevant barriers. Establishing clear performance evaluations that take into account knowledge transfer and collaboration at the institutional and researcher levels will be important in this regard. This entails raising entrepreneurial awareness and knowledge among students and faculty, encouraging academic staff to support students who approach them with ideas, or indeed to develop and pursue their own ideas. Academics should be encouraged to avail themselves of industry secondments. At the same time, the government and the higher education system should address financial incentives (such as equity participation and licensing revenues) or barriers to university-based start-ups.

R5.4 **Support multidisciplinary and entrepreneurship training across the entire education system to promote entrepreneurialism, as well as spin-offs and spin-ons.** Training efforts should also be inclusive and involve groups throughout society. The government should encourage under-represented groups, such as women and migrants, to engage in innovation activities, from participating in academic spin-offs to contributing to knowledge transfer and collaboration. Academic "spin-ons", which connect researchers with entrepreneurs, can be an effective way to exploit complementary skills to drive innovation, rather than attempting to transform all researchers into savvy entrepreneurs.

R5.5 **Enhance accountability and develop a framework for performance metrics.** The government should promote the creation of a core set of knowledge-transfer metrics and consistent reporting mechanisms, conducted on an annual basis. This requires strengthening measurement at the institutional level, by establishing reporting cultures and related processes, as well as collecting more holistic metrics, including qualitative measures (e.g. pathways and examples) and new approaches to evaluate the impact of knowledge transfer.

R5.6 **Increase opportunities for open innovation and co-creation.** German SMEs could benefit from further open innovation and co-creation initiatives. These include joint innovation labs (and joint/shared infrastructure and equipment); digital innovation hubs; open innovation platforms; open fab-labs; and testing/demonstration platforms, living labs and hackathons. Co-creation and innovation labs can take the form of digital platforms and virtual laboratories allowing research and data sharing, as well as the co-design and co-creation of solutions, and their piloting and testing. This pooling of diverse competencies would significantly reduce infrastructure and research costs, and accelerate development.

Recommendation 6: Promote financial markets that are conducive to scaling up breakthrough innovations

Overview and detailed recommendations:

Although German firms generally have good access to finance, providing young and small firms with the capital needed to scale remains challenging. This reflects in part the comparative underdevelopment of the venture and growth capital markets in Germany and the European Union as a whole.

R6.1 **Revisit the legal framework for German capital-collecting institutions to encourage investment in risky innovation**. The Federal Government should consider requiring institutional funds to allocate a percentage to VC or private equity funds for innovative firms. For example, German pension funds, insurance companies and public financing organisations provide very little risk capital, even though they are among the only sources that could provide the levels of funding (including investments in private companies through VC funds and investments in listed companies) that are necessary to scale the most promising innovations. Another approach might be to facilitate employee stock-ownership plans. Overall, the German tax framework for equity ownership and awards has been largely unattractive compared to international benchmarks.

R6.2 **Expand tax incentives, especially those that allow private investors to offset capital losses against other income, or to exempt future profits when investing in the VC asset class**. Such incentives should apply to both the VC segment (pre-initial public offerings) and investment through the stock market (development and growth financing). The United Kingdom and France, for example, each have six different tax-incentives to improve the supply of private capital for VC markets.

R6.3 **The Federal Government should support the development of financial instruments at the EU level that would help scale and retain innovative firms**. The volume of finance necessary to scale some of the most promising firms is often available neither in Germany nor within the European Union, meaning that firms regularly move to countries where finance is more easily available, such as the United States or the United Kingdom. The German government should advocate the establishment of EU-level private equity development for investment in pre-public technology and digital innovators. The Federal Agency for Disruptive Innovation, SPRIND, could play a more prominent role in developing a domestic VC market for higher-risk investments.

Recommendation 7: Strengthen the use of public procurement as a driver of innovation

Overview and detailed recommendations:

The public sector has enormous potential to promote innovation through procurement, which it could also use to better support the climate and digital transitions. The market-creating aspect of public procurement can also accelerate the transition of an idea to market by shortening the time required for commercialisation. Start-ups and *Mittelstand* firms in particular will be more inclined to engage in innovation efforts, as the government represents a reliable and high-profile client. A number of barriers, ranging from the low attractiveness of careers in public procurement to its fragmented and un-coordinated approach, currently prevent Germany from fulfilling the potential of public procurement as an instrument of innovative change. As discussed at Recommendation 10, using public procurement as a driver of innovation may require engagement with EU state-aid rules.

R7.1 **Commit to innovation procurement by taking legislative action and creating co-ordinated innovation procurement programmes within public agencies at the federal, state, community and city levels.** One line of action would be to require public agencies to allocate a dedicated amount or percentage to procurement of pre-competitive innovative research. Co-ordinating the different levels of public procurement (federal, state and municipal) will mitigate any potential fragmentation arising from this targeting. These efforts can support the overall "Germany 2030 and 2050" vision if it is linked to strategic projects emphasising innovation procurement, such as in sustainability, health and digitalisation.

R7.2 **Invest in building capacity and incentives for implementing innovative public procurement.** Acting on this commitment would entail a programme focusing on (i) the formulation of innovation agendas (roadmaps/challenges), as well as preparatory tasks for the definition and launch of innovation procurement programmes; (ii) capacity-building and training of staff in charge of public procurement; and (iii) offering incentives for public agencies in charge of procurement to reward innovative procurement (including through prizes). This would benefit from the support of the proposed laboratory on experimentation (see R2 in Chapter 15).

R7.3 **Direct some of the public seed funds for technology commercialisation programmes to pre-commercial procurement programmes**. This can take the form of staged-funding programmes, in the spirit of pre-commercial procurement programmes. The purpose of this approach is to add conditionality or challenges to publicly backed seed funds.

R7.4 **Create incentives for SMEs and start-ups to engage in innovative procurement.** This involves raising awareness of procurement opportunities and rationalising administrative barriers to the participation of SMEs and start-ups, such as clauses requiring past financial statements which start-ups cannot provide. Smaller and younger firms may currently be excluded from procurement tenders, limiting the ability of high-potential firms to scale and commercialise innovative solutions. The government could also create a platform that allows public authorities to issue challenge-oriented procurement tenders, which would draw smaller, high-potential firms. Such a platform would promote stronger innovative business creation through public procurement.

Recommendation 8: Increase the involvement of civil society and key stakeholders in STI policy to achieve the transitions

Overview and detailed recommendations:

Many of the economic and technological challenges facing Germany have asymmetrical, often significant consequences, with societal impacts . The debates around ethics in the use of artificial intelligence (AI) tools and gene editing illustrate such impacts. STI policy making, therefore, should further include civil society in STI, ensuring that government policy and direction reflect the concerns and ideas of a broad range of actors. Broader civil-society engagement would also increase the *supply* of policy ideas and provide testbeds for experimentation, including especially at the city or municipal level. Participation of diverse social groups in innovation activities will also promote wider societal involvement, aside from helping to introduce transitions. Moreover, engaging civil society and STI stakeholders in a dialogue on the best ways to design STI policy programmes targeting or impacting themcan improve diversity in participation and boost programme quality by incorporating the potential difficulties the intended beneficiaries may experience in engaging with those programmes.

R8.1 **Create citizen councils to debate innovation and innovation policy**. These councils could be formally linked to the forum proposed in R1, thereby providing structured input into STI policy making and direction. The citizen councils' discussions could centre on the same thematic agenda as the forum's. Testing policies and defining innovation challenges could also be elements of such exchanges.

R8.2 **Develop "city innovation laboratories"**. The government should consider developing of city laboratories where municipal authorities would have the autonomy to test new approaches to innovation policy. These approaches could take the form of public-private partnerships; partnerships with research institutions or start-ups; and procurement from innovative firms to address local issues linked to transitional challenges, such as electric mobility. City laboratories could provide real-world testbeds for bottom-up and entrepreneurial-driven innovation targeting a range of complex challenges, and serve as a springboard for scaling successful approaches at the state or national level. As an additional advantage, they would provide a more direct and responsive line of communication between STI policy makers at the national and local levels, which could significantly improve policy responsiveness and agility.

R8.3 **Create a policy programme that allows cities or municipalities to apply for special status that grants regulatory flexibility for innovative experimentation**. Allowing local authorities to apply for special status would streamline and accelerate bottom-up innovation as they could create more responsively the conditions conducive to innovation for local firms and better utilise these innovative capacities to solve place-specific challenges. Such localised approaches could encourage the emergence of regional leaders in a range of areas, including policy agility and co-ordination, public-sector digitalisation, innovative procurement, innovation for sustainability, innovation missions, citizen science and innovation, and social innovation.

R8.4 **Use co-creation programmes for innovation at the city and regional levels.** Local co-creation could be especially useful in encouraging innovative public procurement and open innovation systems, such as living labs, regulatory testbeds, and hackathons. Sustainable mobility activities in cities are an important example of where innovation activities could benefit from local co-creation. Co-creation between the public and private sectors in particular could help de-risk innovation investment in emerging areas of technology for both parties.

R8.5 **Boost diversity in the innovation system.** Engaging a more diverse set of actors will support diversity and inclusion, but it can also help improve the quality of innovation. In the context of an ageing society, attracting and involving skilled migrants, women, minorities and individuals from disadvantaged socio-economic backgrounds in innovation training and careers will be essential to ensure the innovation system has the talent it needs to succeed. Unequal representation of women, minorities and individuals from disadvantaged socio-economic backgrounds at senior levels of management could therefore be a source of weakness for the German private sector. The need for new skills – soft as well as technical –for success in the context of the sustainable and digital transitions also means that STEM skills that predominate in corporate boardrooms and leading innovation may pose a challenge for the future and also reduce inclusivity. Women tend to be more represented in these fields than STEM fields, and therefore supporting more those innovations could both bring more women into the innovation system in addition to improving Germany's innovative output in an area where it is comparably weaker. Widening the support for innovation could potentially also increase diversity beyond gender. Importantly, boosting about diversity needs to be also about diversity in the management and steering of innovation activities and not only about participation. Supporting citizen science and innovation activities are also important, as is involving civil society in collaborative innovation activities, that deal with issues important to civil society.

Recommendation 9: Digitalise, modernise and strategically use quality infrastructure

Overview and detailed recommendations:

Quality infrastructure – the standards and norms that shape and inform manufacturing and services – Germany's competitiveness in the manufacturing of certain goods implicitly granted it global leadership in standard-setting. In a world where output has a higher digital intensity, and a greater degree of interconnectedness exists across products, services and sectors, standard-setting is more complicated. The much faster speed of change in the current period of transitions also requires new approaches and more strategic uses of the standards and quality infrastructure.

R9.1 **Enhance digitalisation and develop state-of-the-art capabilities in both the standard-setting process and quality infrastructure**. The institutions in charge of standards and quality infrastructure have not completed their digitalisation, despite urgent needs in capacity and infrastructure investment. The digital connectivity across institutions at the federal and state levels also requires attention. Germany's advanced metrology institutions must be strengthened and modernised to deal with the complexity and interconnectedness of the new technologies they must measure, such as autonomous driving or the application of AI in the medical and pharmaceutical sectors. Developing the quality and standards infrastructure also critically depends on supporting investments in human capital, including by promoting the attractiveness of working in this field.

R9.2 **Use the quality infrastructure as a strategic instrument for innovation and competitiveness**. Germany's leadership in many areas of manufacturing and industry, combined with the high quality of the current metrology system, have conferred on its economy an implicit leadership position in standardisation. This leadership confers competitive and innovative advantages, as it orients global manufacturers towards norms set by German firms. The government should thus adopt a systemic approach to standardisation and the quality infrastructure as integral components of international innovation and competitiveness, explicitly determining their contribution to achieving the "Germany 2030 and 2050" vision.

Recommendation 10: Take a leadership role in shaping EU and global innovation policies

Overview and detailed recommendations:

The ability to effectively address many of these recommendations requires leveraging the scale of EU and international co-ordination. Beyond Germany, efforts are needed at the EU and transnational levels to ensure success, including by (i) developing competencies in key enabling technologies for more resilient value chains; (ii) exploiting efficient digital-data infrastructures (R4); (iii) developing a sufficiently large financial market to scale disruptive, high-potential innovations (R6); (iv) defining the desired standards and quality-control procedures (R9); and (v) boosting innovation to promote environmentally sustainable development. To this end, the German government needs to take active leadership in shaping innovation policies at the EU and global levels.

R10.1 **Better align domestic STI policies and the EU internal market**. As detailed in R9.1, the impact of domestic STI priorities and policies could benefit from a multiplier effect if they were better aligned with the EU and the internal market. The example of data infrastructure is telling, with projects such as GAIA-X able to reach a larger scale than any equivalent national project, as it targets the vast array of industrial and commercial data inputs from across the EU internal market. A similar approach could be taken in other areas of STI, such as the development of specific enabling technologies, the digitalisation and strengthening of industrial supply chains, and the scaling of pre-commercial or pre-public solutions through the internal market in areas such as climate-management technologies. As advocated in R2 (policy laboratory) and R7 (innovative public procurement), Germany could take a leadership role in promoting policies that stimulate demand-side dynamics for innovative solutions at the EU level.

R10.2 **Identify potential IPCEI to support enabling technologies**. Supply shortages during the COVID-19 challenge highlighted Germany's dependence on a few global supplies. Germany could take a more direct role in garnering support for IPCEI targeting the development of certain technology fields. This could have multiple benefits for the German economy and the broader European Union, by (i) enabling the development of key technologies within the European Union and key EU partner economies, to increase supply-chain resilience; and (ii) developing key technological competencies that will be sources of competitiveness for the future.

R10.3 **Take a leadership role in promoting standards and quality-control procedures at the EU level.** Building on the items outlined in R9, and reflecting the multiplier effect of aligning domestic STI policy with EU policy and the internal market, Germany should take the leadership in promoting EU-wide standardisation and quality infrastructure to support the broader competitiveness and innovative strengths of the European Union and its Member States. This would help align the approaches taken by EU economies, and consequently strengthen the position of the internal market in the context of international and systemic competition.

R10.4 **Maximise international co-operation to navigate uncertainties and address the complexities of transitional challenges.** As with other world economies, the nature of the challenges facing the Germany economy is such that no single government or actor possesses all the answers. While there may be no panacea for the complexity of the sustainability and digital transition, there are nevertheless numerous instances where German policy makers can learn from the experiences and efforts of other countries to navigate these complex challenges, from commercialising decarbonisation technologies to digitalising the public sector within a federal state. As part of the "Germany 2030 and 2050" vision, the government should actively seek international collaboration in priority areas identified by the forum, both within the European Union and beyond.

R10.5 **Take a key role internationally in strengthening the global and national innovation ecosystem.** This involves shaping the global innovation agenda and the main targets set for key innovation agendas globally, such /as in AI and biotechnology. Another important component here is connecting effectively to global innovation efforts, attracting talent and engaging in effective collaborations to support the national innovation ecosystem.

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Endnotes

[1] These indicators are taken from the OECD How's Life? (2020) report and cover the following areas: household adjusted disposable income, household median wealth, housing affordability, employment rate, life expectancy, student skills in science, life satisfaction, homicide rate, time off, social interactions and voter turnout.

[2] In many of these areas, Germany has more than twice the total level of capital stock than the second-ranked country. This high level of investment is indicative of globally leading levels of knowledge and productive capacity. All values are given for the latest year available, ranging from 2016 to 2019.

[3] While patents do not give an indication of market readiness or demand for innovative output and are therefore an incomplete measurement of the innovation system's performance, they nevertheless provide an important – and internationally comparable – indication of innovation intensity.

[4] IP5 patent families are patents filed in at least two offices worldwide, including one of the five largest IP offices: the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the United States Patent and Trademark Office (USPTO), and the China National Intellectual Property Administration (CNIPA).

[5] A triadic patent family is defined as a set of patents registered in various countries (i.e. patent offices) to protect the same invention. Triadic patent families are a set of patents filed at three of these major patent offices: the European Patent Office (EPO), the Japan Patent Office (JPO) and the United States Patent and Trademark Office (USPTO). Triadic patent family counts are attributed to the country of residence of the inventor and to the date when the patent was first registered. This indicator is measured as a number.

[6] There exists no fixed definition for "hidden champions" in terms of employee numbers, and some have over 1 000 employees. However, according to the findings of a recent paper, the vast majority have fewer than 250 employees (Rammer and Spielkamp, 2019[19]).

[7] Firms such as Grammer (which specialises in seating and vehicle components), Marquardt Group (electronic and electromechanical switching systems) and Rosenberger Group (high-frequency and high-voltage connectors) are global leaders in their fields, demonstrating the breadth of expertise present in German SMEs (Handelsblatt, 2019[49]).

Part II The German innovation system in international context: performance, capacities and policy

2 The socio-economic context for innovation

This chapter introduces the socio-economic context for Germany's innovation system. Germany's export-orientated and highly industrialised economy has supported a high level of socio-economic wellbeing. Germany also navigated the COVID-19 pandemic relatively well and has committed to making environmental sustainability a key pillar. An ageing population and the long-standing commitment to limiting annual federal borrowing provide for a challenging context in which to develop Germany's innovation system for the future.

Introduction

German economic growth continues to be driven by its highly innovative industries, particularly the manufacturing sector. The global competitiveness of Germany's many export-orientated firms plays a significant role in supporting a generally high level of socio-economic wellbeing. An important plan for the future the new coalition government that came to power in December 2021 has committed to is building greener transitions.

This chapter introduces recent trends in and key structural determinants of Germany's economy as they relate to innovation. The purpose of the chapter is to frame the broader discussion of the innovation system in this Review.

This chapter proceeds with a brief overview of the items outlined above. Section 2.1 introduces the broad structural context for innovation in Germany, before Section 2.2 presents an overview of the impact of COVID-19 on the German economy. Section 2.3 introduces the sustainability goals of the German government, before Section 2.4 concludes with a discussion on public investment.

2.1. Structural context

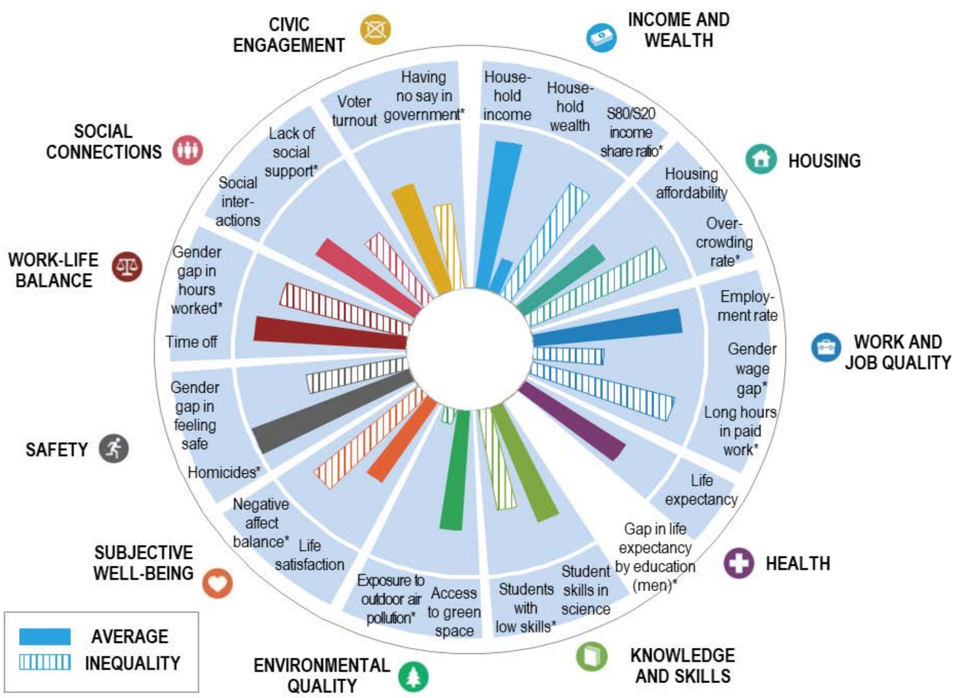
Germany's highly innovative manufacturing and industrial sectors are the cornerstone of its internationalisation and competitiveness. In the euro area, Germany has the highest level of value added and gross output in sectors ranging from chemicals and pharmaceuticals to the automotive and machinery industries. It also has the highest level of fixed capital formation and gross capital stock, both at the aggregate level and in each of these sectors. Investment in medium- and high-level research and development (R&D)-intensive activities, as well as in industry (including manufacturing), is the highest in the European Union (OECD, 2020[1]).

Over the past two decades, the strengths and weaknesses of Germany's export-oriented economy have come to light. In 2019, Germany was the most open G7 economy: its ratio of total trade to GDP stood at 87.8%. Between 1980 and 2019, exports grew by 5.3% per year on average (BMWi, 2021[2]). It is precisely the export-oriented nature of the economy that allowed Germany to recover so rapidly following the global financial crisis, maintaining consumption despite low domestic spending and investment in 2020, and a 9.3% drop in exports (BMWi, 2021[2]). Yet at the same time, the interconnectedness of its value chains was disrupted during the global pandemic. The supply chain disruptions that resulted from the Russian invasion of Ukraine, which exposed the country's strong reliance on raw materials from Russia, shed light on a key structural challenge for the German economy and its innovation ecosystem (see Chapter 9 for a discussion of these questions).

Robust economic performance has underpinned high living standards and well-being. Germany ranks among the leading OECD countries in a range of *OECD Better Life Index* indicators, including in categories such as education, skills and self-reported levels of personal satisfaction (Figure 2.1). Around 75% of people in the 25-64 age group are employed, and the country's labour-force participation rate of 84.4% is among the highest in the OECD. Similarly, 87% of adults in the same age group have completed upper-secondary education, more than the OECD average (78%), although only 35% of 25-34 year-olds have completed tertiary education, lower than the OECD average (45.6%) (OECD, 2020[3]). This relatively low level of tertiary graduates likely reflects Germany's strong competencies in vocational education and training, which is a particular asset for the country's innovation system. In addition to higher educational attainment, Germany has a highly skilled work force, with Germany scoring significantly above the OECD average in literacy, numeracy and problem solving in technology-rich environments as measured in the OECD Survey of Adult Skills (PIAAC) (OECD, 2019[4]).

Figure 2.1. Well-being in Germany: The OECD Better Life Index (2020)

Germany performs above the average in a range of categories



Note: This chart shows Germany's relative strengths and weaknesses in well-being compared to other OECD countries. Longer bars always indicate better outcomes (i.e. higher well-being), whereas shorter bars always indicate worse outcomes (lower well-being) – including for negative indicators, marked with an *, which have been reverse-scored. Inequalities (gaps between top and bottom, differences between groups, people falling under a deprivation threshold) are shaded with stripes, and missing data shaded in white.
Source: OECD (2020[3]), "How's Life in Germany?", in *How's Life? 2020: Measuring Well-being*, https://doi.org/10.1787/fe07a6b7-en, https://www.oecd.org/statistics/Better-Life-Initiative-country-note-Germany.pdf.

Like other advanced economies, Germany faces age-related demographic pressures, accentuating the productivity challenge. The country's old-age dependency ratio (the ratio of people older than 64 to those aged 15-64) is 35%, already among the highest in Europe and forecasted to grow to 47.3% by 2030. With a shrinking working-age population, Germany will face growing pressures on growth and inclusion, as well as on the services and finances of public health and social care institutions. As with other aspects of socio-economic well-being in Germany, demographic challenges due to ageing have a marked regional dimension, with some regions likely to be more affected than others (Eurostat, 2021[5]). Demographic pressure also affects the future availability of skilled workers for innovation, raising questions about how to deal effectively with skilled migration (this is discussed in chapter 6 of this Review).

Germany has a highly federated system of governance, with subnational units enjoying significant levels of autonomy in many areas related to science, technology and innovation (STI). Governing responsibilities are distributed across 16 *Länder* (states), the largest being Bavaria, the wealthiest Baden-Württemberg and the most populous North Rhine-Westphalia. These three *Länder* also account for a high proportion of the country's most innovative and commercially successful enterprises. In 2019, the Federal Government accounted for only 29.3% of tax receipts, the lowest share of the eight federal OECD countries; the majority of tax revenues were redistributed to regional and local governments, which possess significant autonomy and discretion in spending and redistribution (OECD, 2021[6]).

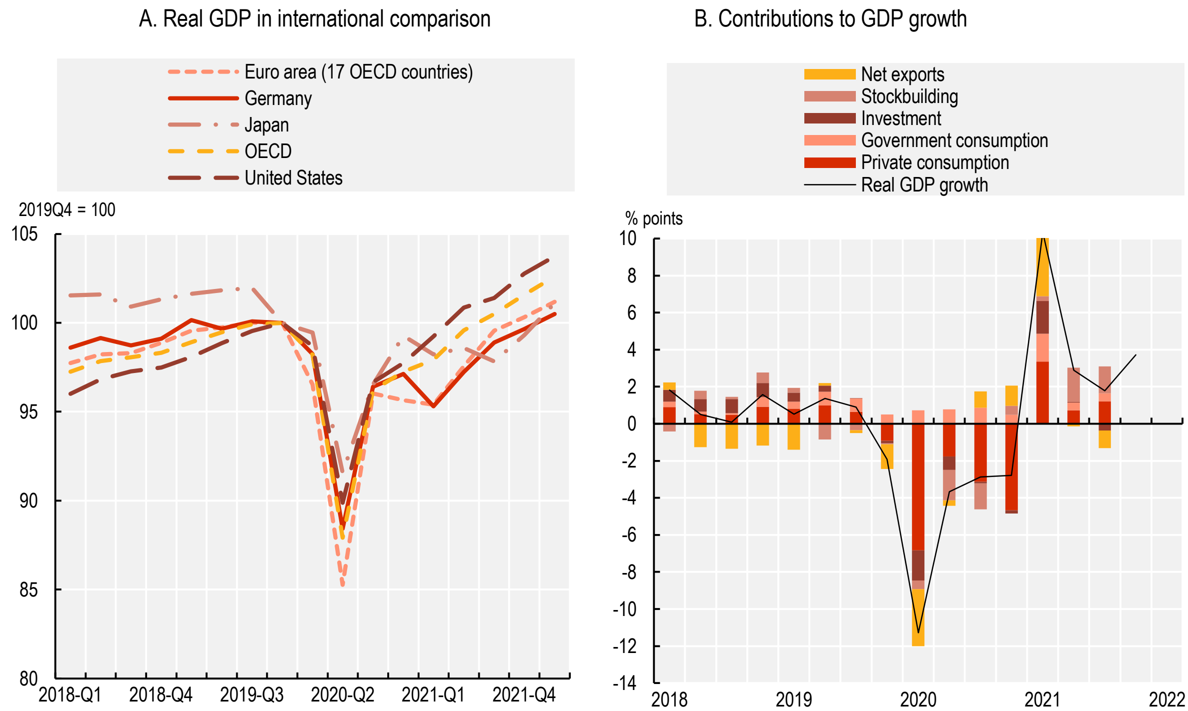
2.2. Recent trends with the COVID-19 crisis

Real GDP growth in Germany has largely tracked the OECD average. After 2000, the country experienced several years of low – and at times negative – growth, but had reached 3-4% growth in the two years preceding the 2008-09 global financial crisis (GFC). As with other developed economies, the GFC induced a sharp recession in the German economy, which contracted by almost 6% in 2009 – a deeper recession than the OECD average (3.3%) – before rebounding to 4.2% in 2010, outpacing the OECD average. Annual growth has somewhat decelerated since then, remaining however relatively stable before contracting significantly (4.6%) in 2020 owing to the COVID-19 crisis (OECD, 2022[7]). Germany's economic recovery in 2021 (2.9%) was already hampered by shortages in key manufacturing inputs, global economic uncertainty and supply-chain problems. These issues will likely be exacerbated by the 2022 war in Ukraine, furthering delaying recovery, with growth likely to fall short of the December 2021 projection of 4.1% for 2022 (OECD, 2022[8]).

COVID-19 affected some demand – but mostly supply – for Germany's industry. Although the impact of the COVID-19 crisis on the German economy was substantial, it was also relatively short-lived (Figure 2.2). While exports were affected during the pandemic due to falling external demand, demand quickly rebounded. The more severe impact of the crisis on Germany's economy stemmed from supply-chain issues, which severely limited the manufacturing sector's production capacities. A survey conducted by the Ifo Institute for Economic Research found that 45% of firms are facing bottlenecks in supply, the highest value since 1991 and higher than the 7.5% reported in October 2020 (Ifo, 2021[9]). The most severely impacted firms are manufacturers of rubber and plastic goods (71.2%), which have struggled to source raw materials, and vehicle (64.7%) and computer (63.3%) manufacturers.

In terms of R&D expenditure, the pandemic had a diversified effect: pharmaceuticals companies, especially biotechnology firms, strongly increased their expenditure in 2020 (+20%); others, such as information and communication technology services (+6%), could not match the growth of previous years; yet other firms in the chemical (-2%), automotive (-5%) and machinery industries (-9%), other manufacturing industries (-7%) and all other industries (-7%) experienced declining R&D expenditure. A relatively high exposure to the supply-chain issues described above, as well as demand effects and other negative economic impacts of the pandemic, were particularly relevant for the typically R&D-intensive machinery and automotive sectors. Overall, firms' innovation activities during the pandemic varied widely. A survey conducted in April 2021 found that firms which continuously or occasionally invested in R&D before the pandemic had tended to prolong the running time of their innovation activities, with some even launching new innovation activities. However, firms which had pursued mainly non-R&D innovation activities before the pandemic, had rather not prolonged their activities or started new ones. Across the board, the second most common response was that firms cut back on innovation projects owing to a lack of innovative ideas or impulses. Strategically, many firms set out to increase their internal level digitalisation, along with digitalising their offers and distribution channels. While these measures tended to be permanent, others, such as further reducing the internal costs of production/service delivery, were more temporary.

Figure 2.2. COVID-19 resulted in a consumption-fuelled economic contraction in Germany



Note: Contribution to GDP growth relative to the same quarter of the previous year. Projection from December 2021
Source: OECD (2022[10]), Real GDP forecast (indicator). https://doi.org/10.1787/4537dc58-en (Accessed on 05 April 2022)

2.3. Germany's sustainability goals

The new coalition government (December 2021) has made environmental sustainability a key pillar of its agenda. In 2016, Germany was one of the original signatories to the Paris Agreement on Climate Change, which committed the signatories to achieving global carbon neutrality by 2050. In 2021, the German Federal Government amended the country's Climate Change Act (CCA), increasing key emission-reduction goals over the medium- and long-term. In its Intergenerational Contract for the Climate, the government now aims to achieve 65% lower carbon dioxide (CO_2) emissions than 1990 levels by 2030, up from the previous target of 55%; the target is now 88% less CO_2 by 2040 and climate neutrality by 2045 (Bundesregierung, 2021[11]).

Successive governments have set out to simultaneously decarbonise energy supply and use in Germany and shut down nuclear electricity production. Thanks to a co-ordinated multilevel governance effort, different energy programmes have fed into Germany's *Energiewende* ("energy transformation"). While its legal basis was set in 2000 through the Renewable Energy Act and strengthened in the Energy Concept of 2010, the policy is also guided by periodic developments within the Conference of the Parties, such as Germany's obligations under the Paris Agreement on Climate Change. More detail on this policy is provided elsewhere in the review.

Despite its strong commitments to environmental sustainability, Germany needs to step up the implementation and performance of its carbon-reduction and sustainability policy agenda if is to meet its ambitions. The contrast of Germany's good socio-economic performance in the OECD Better Life Index with the poorer results achieved in areas related to environmental-related quality illustrates some of the complex challenges, and often countervailing forces, facing the country. The social impact is significant, with over 90% of the German population exposed to small particle air pollution above the World Health

Organization (WHO)-recommended threshold of 10 micrograms per cubic metre, considerably more than the 59% OECD average (OECD, 2020[12]). The public health impact of this pollution is estimated at around 53 800 premature deaths per year (European Environment Agency, 2021[13]).

Moreover, key sectors of the economy including manufacturing and those that are leading innovation performance, are highly polluting (IEA, 2020[14]). While greenhouse gas emissions per capita are below the OECD average, they are higher than in most EU countries, and the reduction in carbon intensity since 2000 has lagged behind the OECD average.

As regards renewable energies, Germany retains a significant proportion of fossil fuels in its energy mix used for electricity production. Sector-specific transition plans, such as those laid out in Germany's initial Climate Action Plan 2050, amended by the CCA in 2021, must contend with the unsustainably high levels of fossil fuels in energy and electricity production – particularly in the absence of commercially viable alternative energy production for industry and manufacturing. High levels of fossil fuels also result in very high reliance on imports from Russia (see discussion in Chapter 9). Consequently, Germany has set ambitious goals to expand renewable energies and has a number of national strategies – including the *Energiewende* and technologically specific strategies, such as on hydrogen – to expedite the development and commercialisation of technologies that could help to decarbonise the energy sector and, by extension, the industries that depend upon it.

2.4. Public debt and investment

The direction of public finance and investment has several implications when it comes to supporting innovation in Germany. Germany has the third-highest level of government support for research and innovation (R&I): government-financed gross domestic expenditure on research and development (GERD) represented 0.88% of GDP in 2019, the latest year for which data are available (OECD, 2022[15]). Yet within this vast and well-resourced innovation system, policy makers must ask whether programmes and support sufficiently target the needs of the future economy, rather than those of previous years and decades. Germany is a country where the vast majority of innovation expenditure originates in the business sector, with enterprise R&D underpinning decades of strong innovative performance. Yet whether the current orientation and trajectories of German industry can generate the types of innovation necessary for a more *sustainable* German economy remains to be determined, nor is it clear whether Germany can maintain its international competitiveness in a global context where decarbonisation and advanced digitalisation are prerequisites for success. Given that many of Germany's leading incumbent firms operate in carbon-intensive sectors, which may be more prone to disruption, policy makers must reckon with whether – and to what extent – the public sector should invest more to shift the country's innovation system in a direction that more explicitly supports sustainability. Lastly, innovation requires high-quality infrastructure, both public and private. This is particularly salient in Germany, where a significant public investment backlog may have a negative externalities for the country's innovative – and potentially innovative – firms (see also the discussion in Chapter 6) (OECD, 2020[12]).

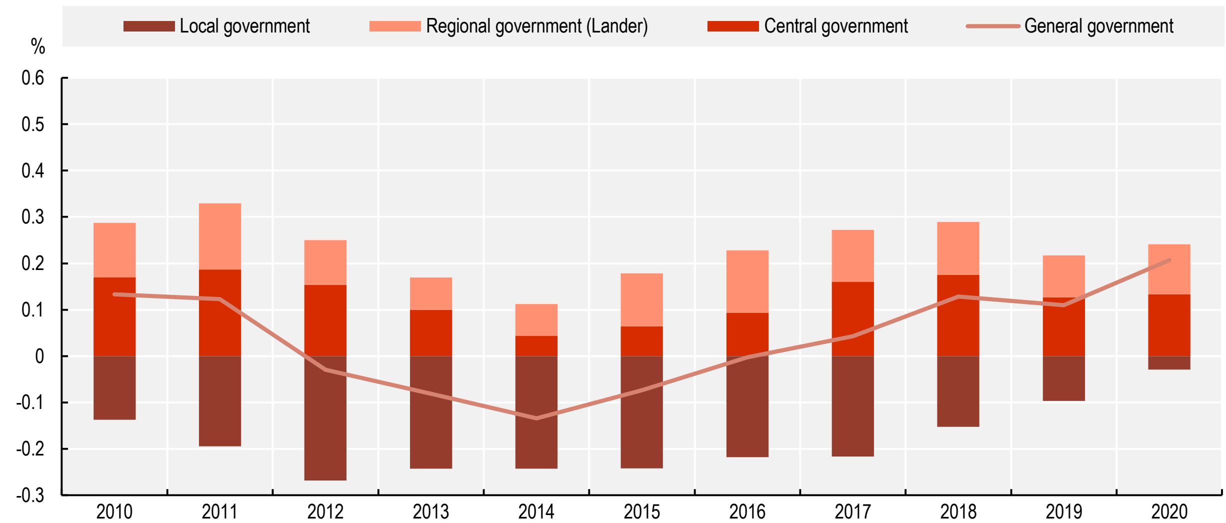
Policy debates around innovation support are taking place in the context of Germany's long-standing and constitutionally binding commitment to limiting annual federal borrowing to 0.35% of GDP, with Germany's pre-pandemic (2019) gross government debt (68% of GDP) the lowest in the G7 (OECD, 2020[12]). This "debt brake" was codified in the German constitution in 2009 and sets stricter limits on the federal states, which are required to run balanced budgets from 2020 onward. These national commitments occur within the context of the EU Fiscal Compact, where ratifying countries, including Germany, have committed to a medium-term structural deficit limit of 0.5% of GDP. Deviation from the 0.35% federal rule is directed to a control account, with consolidation measures implemented during upswings if the control account exceeds a negative balance of 1% of GDP. The COVID-19 pandemic and the resulting fiscal recovery package enacted by the Federal Government, one of the largest in the world at 6% of Germany's GDP, marked a significant departure from previous years' relatively conservative approach to borrowing. This level of borrowing was made possible by a clause that allows structural borrowing in excess of 0.35% in emergency situations, such as that declared by the government in 2020.

In recent years, public investment, both at the national and EU levels, has increasingly focused on achieving sustainability goals, demonstrating a political recognition of the need to support society and the economy in moving towards a sustainable future. The COVID-19 recovery stimulus package introduced by the Federal Government will inject EUR 50 billion into the economy in the form of direct public investment and incentives for private investment. Complementing these funds are additional investments disbursed through the EU Recovery and Resilience Facility (RRF), which at EUR 806.9 billion is the largest stimulus package in EU history. The funding priorities in Germany's RRF applications are indicative of the direction in which policy makers wish to take the country's economy. In addition to providing short-term support to SMEs and the private sector, the RRF also supports reforms and investments targeting the digital and green transitions, and economic resilience and inclusivity more broadly. Projects financed by the RRF must fall under six categories ("pillars"): green transition; digital transformation; smart, sustainable and inclusive growth; social and territorial cohesion; health, and economic, social and institutional resilience; and policies for the next generation. As part of the RRF, the Federal Government requested EUR 27.9 billion for 50 items across all 6 mission areas within the pillars defined by the European Commission. The six mission areas outlined by the European Commission are: Climate change and energy transition; Digitalisation of the economy and infrastructure; Digitalisation of education; Strengthening social inclusion, and; Strengthening a pandemic-resilient healthcare system; Modern administration and reducing barriers to investment. In Germany, the largest amount of financing targeted projects within the "climate policy and the energy transition" mission (40.3% of total funds) and "digitisation of the economy and infrastructure" mission (21.1%). Given that a major component of financing through the RRF will go towards R&I, the concentration of planning and funding in these two areas is indicative of the STI challenges the government anticipates in the context of transition and resilience.

Although public investment has increased since 2015, there remain significant demands, particularly for schools, transportation, and green and digital infrastructures (Figure 2.3). This is particularly true at the municipal level, where net public investment remains negative. A recent joint paper by the German Economic Institute and the Institute for Macroeconomics and Business Cycle Research estimated that EUR 450 billion in public investment will be needed over the next ten years to overcome the existing backlog, expand early education and schooling, decarbonise and modernise transport networks (Bardt et al., 2020[16]). Since 2003, the net municipal capital stock has declined by around EUR 80 billion, contributing to an estimated local backlog of EUR 147 billion, with a particular need for investment in schools and transport (OECD, 2021[17]).

Figure 2.3. Public investment has increased, but net municipal investment remains negative

Net public investment by level of government (% of GDP)



Note: Net public investment = public gross fixed capital formation less depreciation.
Source: OECD National Accounts Database (2020[12]), https://doi.org/10.1787/888934200717.

In a number of cases, the government has made funds available for public investment, but local administrative hurdles hold up disbursement. Challenges in receiving funds, rather than their allocation itself, were a common theme during interviews with several public- and private-sector stakeholders. Delays in disbursement are particularly problematic given the time-sensitive nature of the digital transition. This applies to investments not only in digital infrastructure, but also in sectors (such as transport) with high levels of emissions. It is therefore important that continued and increased transfers to local municipalities go hand in hand with efforts to reduce constraints in local planning, construction and policy implementation. Investment in Germany's connectivity infrastructure in particular would benefit from streamlined administrative approvals for new initiatives, such as infrastructure sharing.

Indeed, better infrastructure – and infrastructure governance – could have a significant positive impact on firm productivity and innovation. The recent *OECD Economic Survey of Germany* highlighted three ways in which better infrastructure governance could benefit firm-level productivity (OECD, 2020[12]). First, strategic planning could be used more systematically to ensure the selection of the highest quality projects, with the OECD Recommendation on the Governance of Infrastructure emphasising the importance of long-term strategic vision for infrastructure, taking into account synergies across sectors. In the transition period of decarbonisation and digitalisation, ensuring a co-ordinated approach to infrastructure planning is particularly important. Second, policy makers should seek to streamline local planning processes as overly onerous and regionally specific procedures delay investment, sometimes causing local authorities to block projects that were committed at the national level. Third, Germany could better leverage data to improve value for money in procurement practices, as a continued lack of federal co-ordination undermines the potential for inter-municipal learning.

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3 Benchmarking German innovation performance

This chapter describes the key characteristics of the German innovation system in international comparison. It shows how Germany performs with regard to key indicators of innovation performance. The data presented in the chapter show Germany is an innovative global leader in a number of technologies and industries. However, some caveats exist, such as decreasing returns on business research and development spending, and persistently low investment in both intangible capital and information and communication technology.

Introduction

Measuring the innovative performance of an economy involves considering a large number of data and indicators, many of which act as proxies for the innovative output of the country's firms and research base. The purpose of this exercise is to place Germany in relation to international peers.

As discussed in Chapter 1, Germany has a well-resourced and established science, technology and innovation (STI) system. Benchmarking the output of this system in an international context clearly demonstrates that Germany has one of the most innovatively productive and powerful economies in the world. In terms of patenting, trademarking and scientific publications, Germany features among the leading global economies, both in terms of established areas of technological expertise (such as engineering) and in many other disciplines that are important to the environmental sustainability and digital transitions.

The innovative output of the German STI system is driven by consistently high levels of capital stock and investment, where Germany is positioned by far as the leading economy in Europe and among the most significant globally. At the same time, investment in intangible capital and information and communication technology (ICT) is relatively low, with a potentially negative impact on firms' ability to capitalise on new opportunities for innovation in the twin transitions.

This chapter is structured in two parts. Section 3.1 introduces Germany's innovation performance at a macro level, looking at key indicators of performance – inputs, intermediate indicators and outputs – at an economy-wide level. Section 3.2 then examines the sectoral, regional and social dimensions of German innovation performance.

3.1. Germany's innovation performance

This section introduces key evidence on the performance of Germany's innovation system, using standard input, intermediary output and output measures (Box.3.1).

Box.3.1. Measuring innovation: Input, intermediate indicators and output

The OECD Oslo Manual defines innovation as "a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)" (OECD, 2018[1]). That being said, assessing innovation capacities and the performance of the innovation system internationally is not straightforward. Several standard indicators are traditionally used to compare and track trends over time. All the indicators for STI have both strengths and shortcomings when it comes to measuring innovation itself and in cross-country comparisons. Consequently, the current discussion presents three types of such indicators, together with the relevant contextualisation.

1. **Indicators of innovation inputs**

Indicators of innovation input measure how much the STI ecosystem has spent to generate innovations. The main downside of this group of measures is that those inputs may not necessarily turn into successful innovations.

Measures such as gross fixed capital formation and research and development (R&D) expenditure can give an indication of the resources available to current or potential actors undertaking innovation activities. One advantage is that the Frascati Manual provides international standards for gathering these data for comparison.

At the same, R&D may not capture all investment that is relevant to innovation. This has led to efforts to gather information on intangible investments, defined broadly as investments in computerised information (databases and software), acquisition of innovative property (such as scientific and non-scientific R&D, copyrights, designs and trademarks), and economic competencies (such as brand equity, firm-specific human capital, networks, organisational know-how and marketing) (OECD, 2011[2]). An increasing body of literature indicates that intangible investments are also an important determinant of both innovative capacity and productivity, since firms with higher intangible investments are more likely to have higher productivity than those that do not (Criscuolo et al., 2021[3]; Haskel and Westlake, 2018[4]; Kaus, Slavtchev and Zimmermann, 2020[5]). Investment in intangibles is an important tool for ensuring that both the public and private sectors can adopt and apply digital technologies to support innovation.

Indicators on research personnel provide a further measure of the human-resource effort in innovation and are also gathered internationally.

2. Indicators of intermediary outputs

Patents and publications are intermediary indicators, insofar as they are pre-commercial discoveries of innovation processes and investments Only a small share will result in successful innovations.

Patent data have the merit that some metrics – notably comparing Patent Cooperation Treaty (PCT) applications[1] and applications to the world's five largest patent offices (IP5), namely the European Patent Office (EPO), Japan Patent Office (JPO), United States Patent and Trademark Office (USPTO), Korean Intellectual Property Office (KIPO) and China National Intellectual Property Administration (CNIPA) – allow international comparisons. IP5 patents are protected in at least two intellectual property offices worldwide, one of which must be a member of IP5.

There are additional caveats to patents: although patent data are widely used, they are known to be relevant in some sectors of the economy – such as pharmaceuticals, chemistry and machinery – but not all. Notably, they play a less important role in the digital economy, where software, artificial intelligence and service innovations are more preponderant. Because of their stronger relevance to manufacturing, patents favour countries that more active in those sectors and will probably shed a more favourable light on the German economy.

Academic publications are another intermediary indicator of innovation performance. They are often used as a measurement of research performance – especially in the natural and applied sciences, where they are an important means of disseminating new knowledge. Academic publications generally fall into three categories: journal articles, which are published to disseminate new knowledge; review articles, which aggregate and summarise research findings published in a given field; and conference papers, which summarise the findings of presentations at conferences. This indicator is also useful because of its metadata, with publications providing a range of details on their authors and institutions that allow researchers to develop insights into collaboration and other indicators (such as patents) linked to these actors (European Commission, 2021[6]).

3. Indicators of innovation output and quality

Innovation output data have been gathered through innovation surveys that ask firms to indicate whether they introduced an innovation, and its degree of novelty (OECD, 2018[1]). While these indicators are the most direct measure of innovation, they have proven more challenging to use in international comparisons, owing to the different criteria applied by the surveyed firms.

A useful indirect measure of innovation output are trademarks. Rather than capture innovations directly, trademarks reflect the first step in their commercialisation. A firm or actor that commercialises a trademark implicitly places a value on the innovation – technological or non-technological – to which it is related. These data are also rich in text and are easily processed. As with patents, their metadata can provide additional insights into issues such as regional and socio-economic inclusion in innovation, as well as research collaboration and internationalisation; they also allow tracking the commercialisation of emerging technologies. Trademarks are particularly important in the service sectors, where innovations are often non-technological.

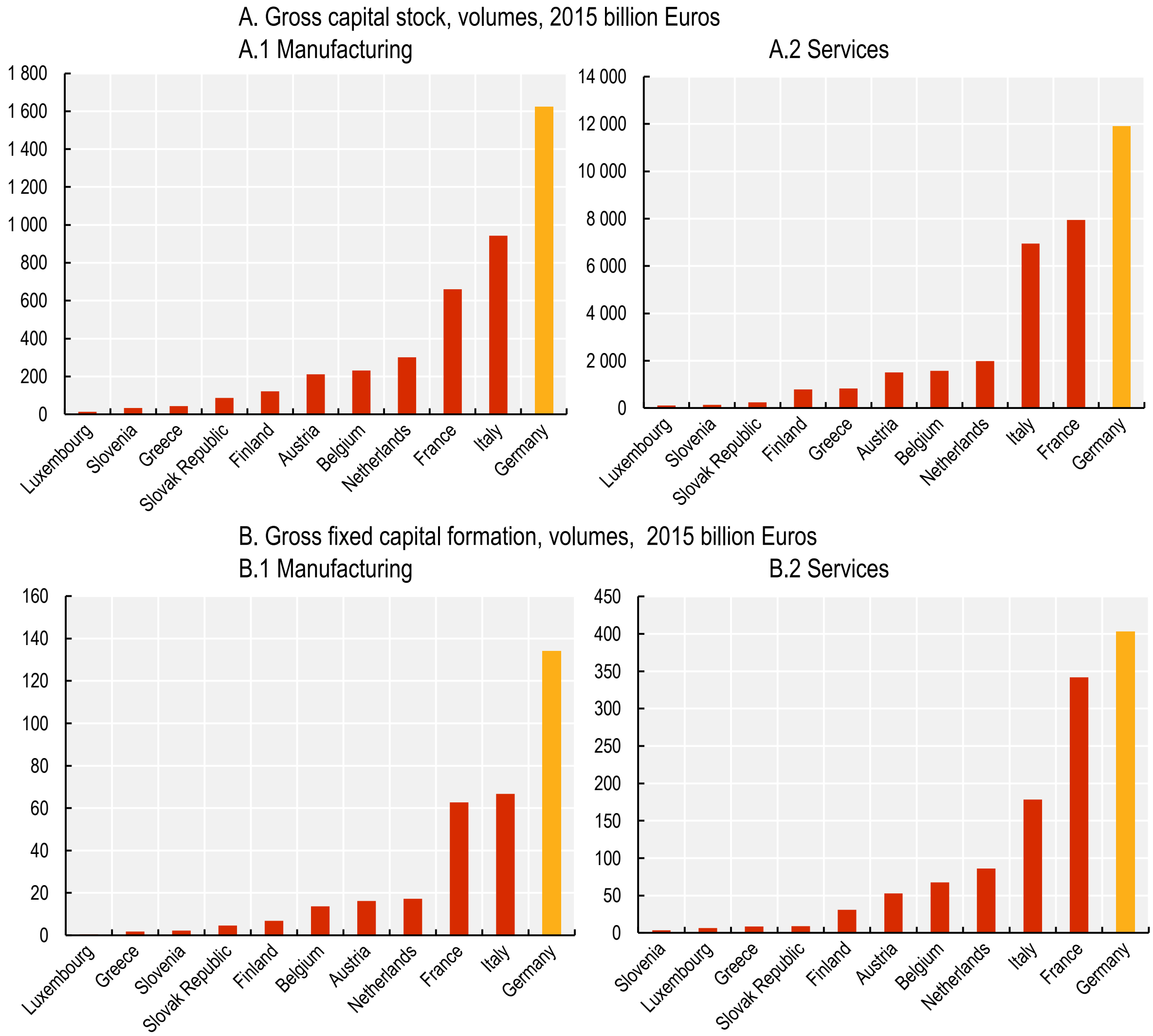
Additional indirect evidence on the quality of innovation may be gathered from assessments of the quality and complexity of export products (Atkin, Khandelwal and Osman, 2017[7]). A higher quality of one country's exported products compared to another country, evaluated assessed using a variety of assessment techniques, is ultimately a reflection of underlying innovation efforts.

3.2. Inputs to innovation: R&D, intangible and other investments in support of innovation

3.2.1 Investment and R&D

In 2018, Germany has the highest levels of annual industrial and manufacturing gross fixed capital formation and gross capital stocks in the European Union (Figure 3.1). In several manufacturing sectors, such as chemicals and machinery, Germany has more than twice the level of capital stock than the second-ranked country (Italy), thereby supporting globally leading knowledge reserves and productive capacity.

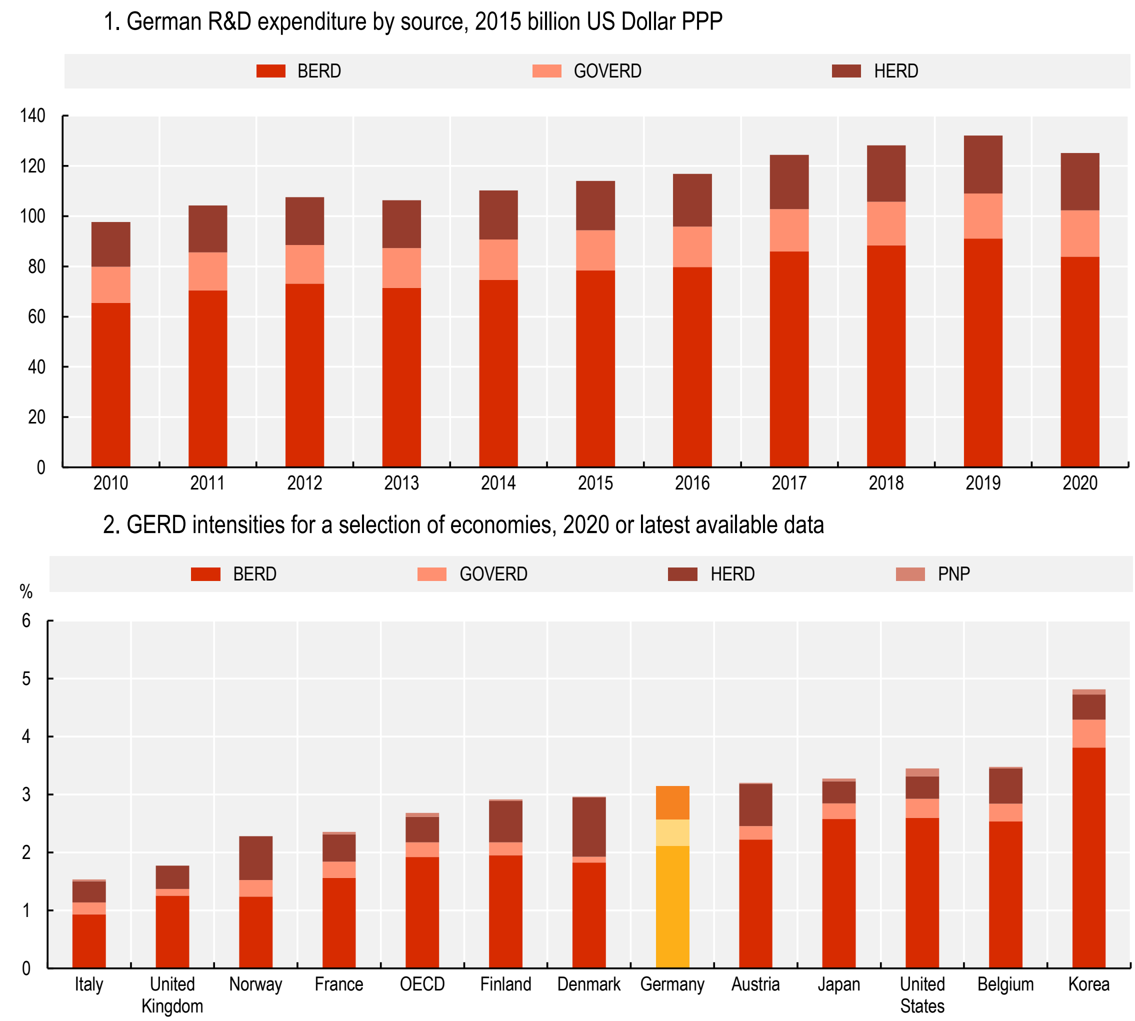
Figure 3.1. Gross fixed capital stock and flows in the euro area (2018)



Source: OECD (2022[8]), "STAN Bilateral trade database by industry and end-use category, ISIC Rev. 4", *STAN: OECD Structural Analysis Statistics* (database), https://doi.org/10.1787/data-00691-en (accessed on 22 April 2022).

In 2019, gross expenditure on research and development (GERD) amounted to 3.19% of gross domestic product (GDP) (EUR 110 billion) – the fourth-highest level in the world in both relative and nominal terms, behind the United States, the People's Republic of China (hereafter China), and Japan (Figure 3.2) (OECD, 2021[9]). In that same year, the German government set a goal of 3.5% GERD by 2025. (BReg, 2019[10])[2] In 2019, business expenditure on research and development (BERD) amounted to USD 91 billion (United States dollars) (EUR 78 billion), the fourth-highest level in nominal terms, reaching 2.2% of GDP – the ninth-highest level in the world (OECD, 2021[11]). The vast majority of GERD (69%) originates in the business sector, growing from 1.42% of GDP in 1994 to 2.2% GDP in 2019 (OECD, 2021[9]). German higher education expenditure on R&D (HERD) amounts to 0.56% of GDP or EUR 22.2 billion – the third-highest level in the world, behind the United States and China. Government expenditure on R&D (GOVERD) amounts to EUR 17.4 billion – the third-highest position globally – and 0.44% of GDP, the second-highest level after Korea.

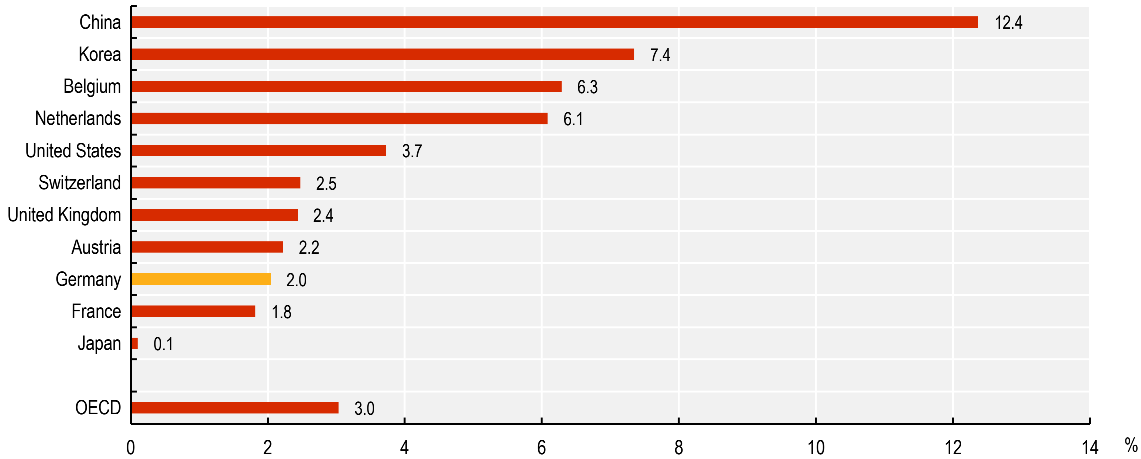
Figure 3.2. Absolute and relative levels of R&D in the OECD



Note: Data for the United Kingdom correspond to 2019.
Source: OECD (2022), "Main Science and Technology Indicators", *OECD Science, Technology and R&D Statistics* (database), https://doi.org/10.1787/data-00182-en (accessed on 22 April 2022).

Germany's compound annual growth rate (CAGR) of industry BERD between 2008 and 2020 was 2.0%. Most other large countries showed a higher rate (12.4% for China, 3.7% for the United States and 2.4% for the United Kingdom). Conversely, France (1.8%) and Japan (0.1%) reported a lower expansion of BERD (see Figure 3.3).

Figure 3.3. CAGR of industry BERD (2008-20)

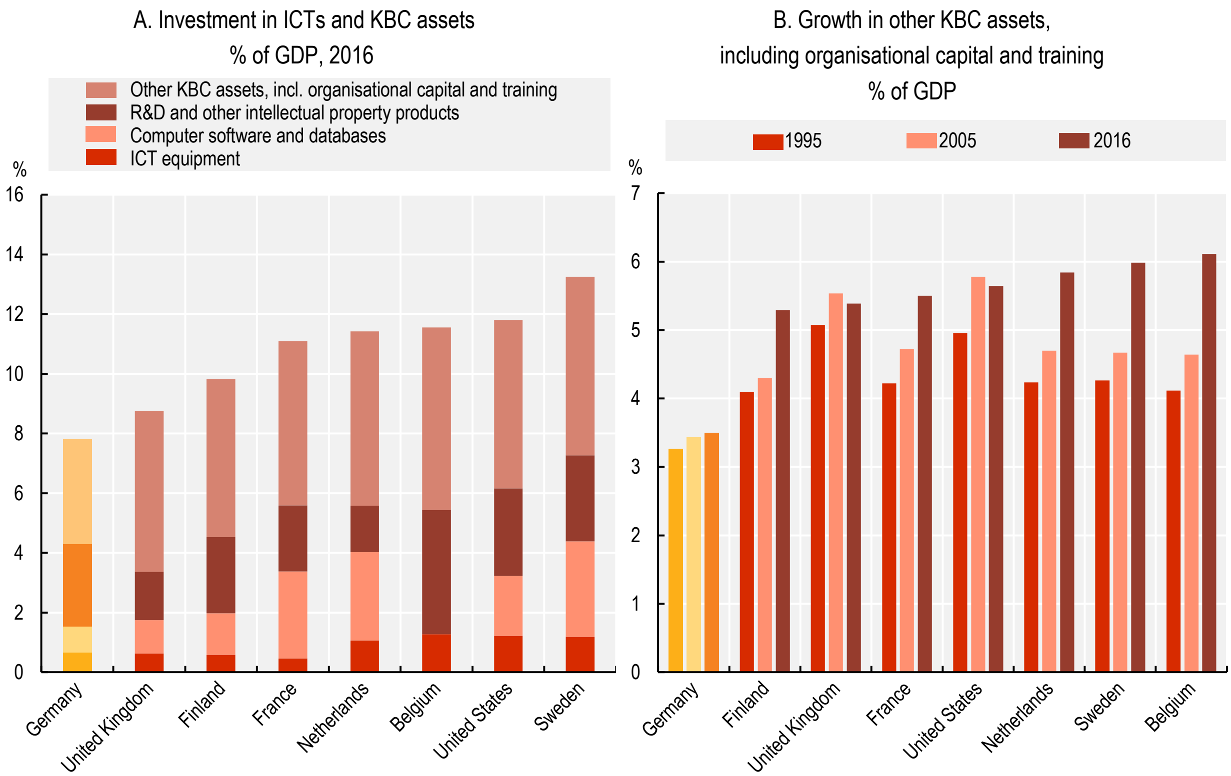


Note: Data for Switzerland correspond to the period of 2008-19
Source: OECD (2022[12]), "Main Science and Technology Indicators", *OECD Science, Technology and R&D Statistics* (database), https://doi.org/10.1787/data-00182-en (accessed on 22 April 2022).

3.2.2 Intangibles and knowledge-based capital in Germany

Investment in ICT is a related aggregate measure of innovation. At 1.63% of GDP (in 2017), German ICT investment is the fourth-lowest in the OECD relative to the economy's size (OECD, 2021[13]). More broadly, the contribution of ICT capital to growth in Germany is half that of the United States, and has been falling steadily since the early 2000s. The data reflect the lower diffusion of ICT in the German economy compared to other leading innovative countries. This is confirmed by the available evidence on the updating of ICT by businesses, as discussed in detail in Chapter 10.

Figure 3.4. Investment in ICT and knowledge-based capital is low



Note: KBC: knowledge-based capital. For Belgium, no breakdowns of intellectual property products are available. Other KBC assets are estimated on the basis of INTAN-Invest data and cover all industries excluding real estate activities, public administration, education, health and households.

Source: OECD (2020[14]), *OECD Economic Surveys: Germany 2020*, https://doi.org/10.1787/91973c69-en, based on *OECD National Accounts Statistics* database, https://www.oecd-ilibrary.org/economics/data/oecd-national-accounts-statistics_na-data-en and INTAN-Invest data, http://www.intaninvest.net/.

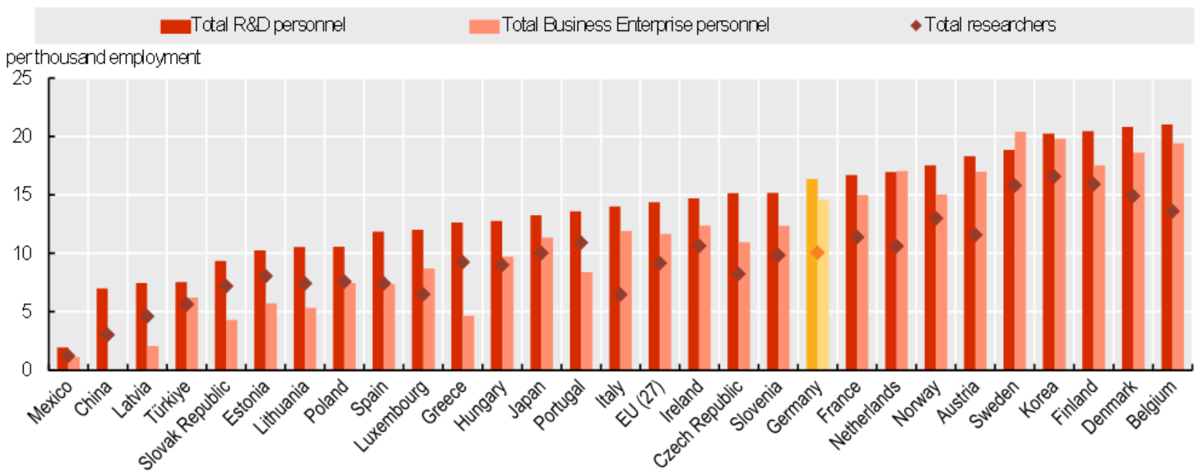
As Figure 3.4 shows, investment in knowledge-based assets, such as organisational capital and training, have remained low in Germany for three decades, particularly when compared to the best-performing countries. Similarly, investment in software and databases is less than two-thirds of the OECD average, partly reflecting Germany's stronger focus on R&D and capital investments in the manufacturing sector.

3.2.3 Human resources for innovation

With 450 700 researchers in full-time employment (FTE), Germany has one of the highest levels of permanent research capacity in the world, behind only China, the United States and Japan. Within the European Union, Germany has by far the highest level, ahead of France (314 100 FTE researchers) and Italy (160 800). Relative to the labour force in countries with populations of over 50 million, Germany ranks tenth in total R&D personnel, similarly to France, but behind Korea. As in other advanced OECD countries, the vast majority of FTE researchers (61%) work in the business sector (OECD average: 64%); 24% work in the higher education sector – slightly lower than the OECD average (30%) – and 13% are employed in the government sector – slightly higher than the OECD average (6.5%).

Figure 3.5. Key indicators for R&D personnel capacity relative to industry (2019)

Per thousand total employment

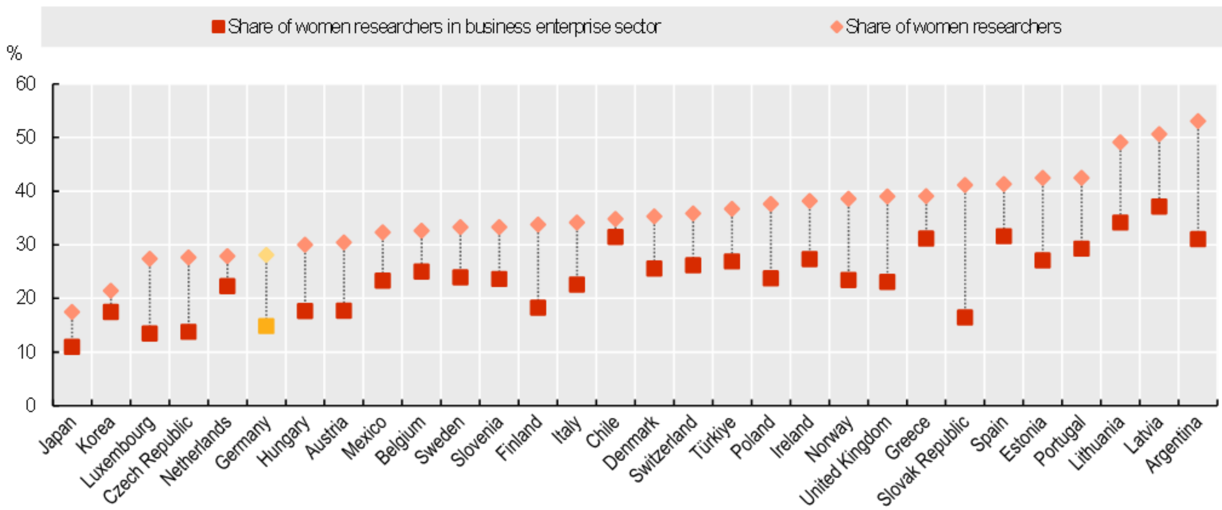


Source: OECD (2022[12]), "Main Science and Technology Indicators", *OECD Science, Technology and R&D Statistics* (database), https://doi.org/10.1787/data-00182-en (accessed on 22 April 2022).

Given the importance of the private sector to German innovation, it is perhaps not surprising that Germany has the fifth-highest number of FTE researchers in business enterprises (262 000), behind only China, the United States, Japan and Korea and ahead of France (189 000) and Italy (78 000). German business-sector researchers account for 27% of total FTE business-sector researchers in the European Union. The proportion of researchers in the working population (9.7%) is broadly similar to countries such as France (10.9%) and Japan (9.9%), though lower than in certain Asian and Northern European economies such as Korea (15.2%), Sweden (14.7%) and Finland (14.4%) (Figure 3.5).

Inclusivity in research face several challenges, including for women. The challenge is visible both at the aggregate level – where women account for only 28% of total FET researchers – and within the business sector (15%) (Figure 3.6). Notably, of all the large and industrial economies in the OECD, only Korea and Japan – two countries with a similar innovation focus on science, technology, engineering and mathematics (STEM) – have lower levels of female researchers than Germany.

Figure 3.6. Women are under-represented in the German research community (2019 or latest year available)



Note: Headcount-based; 2020 data for Japan, Korea, Mexico, Portugal, Slovak Republic and Turkey.
Source: OECD (2022[12]), "Main Science and Technology Indicators", *OECD Science, Technology and R&D Statistics* (database), https://doi.org/10.1787/data-00182-en (accessed on 06 April 2022).

3.2.4 Business dynamics and start-ups

Business dynamism – the number of newly founded and closing companies – has been weakening in Germany. Contrary to a positive trend in other OECD countries, German company entry rates, exits and bankruptcies have been declining over recent decades. Growth potential for German start-ups and smaller firms is hampered by relatively weak domestic financing conditions. Although venture-capital financing has starkly increased in recent years, it only ranks sixth in overall volume in the OECD region, significantly below other economies such as Korea and the United Kingdom (see the detailed discussion in Chapter 7). Public policy initiatives such as the *Zukunftsfond* ("Future Fund") explicitly address this lack of funding, especially in the under-developed second and third growth phases (see Chapter 5 for an overview of policy programmes for business innovation). Moreover, the targeted use of public procurement at the national and regional levels can support innovation capacities among small and medium-sized enterprises and start-ups, as discussed in more detail in Chapter 11.

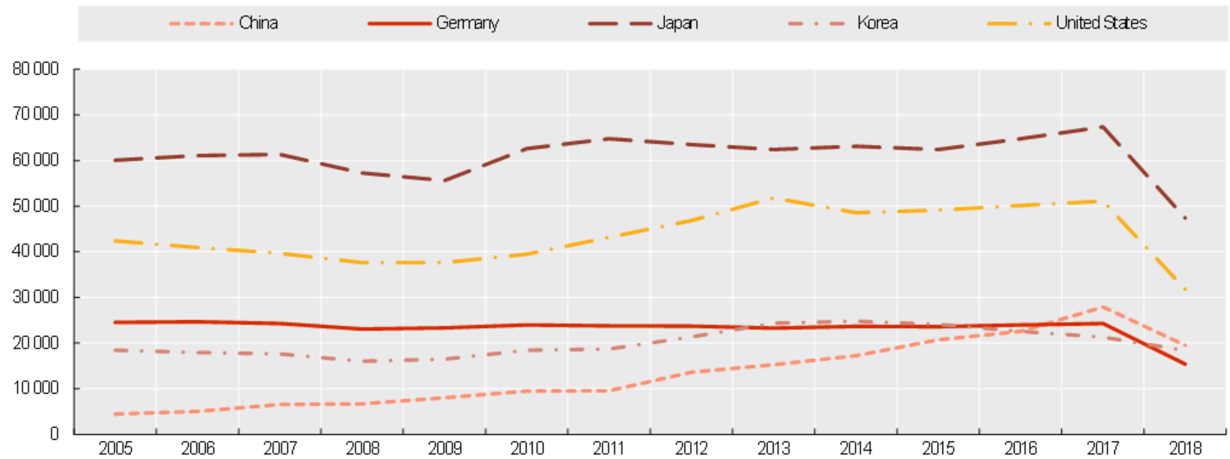
3.3. Intermediary outputs of innovation: Patents, trademarks and publications

3.3.1. German patenting in an international context

In 2020, Germany filed 30% of all PCT applications in Europe and 6.7% globally. In 2018, the last year for which comparable data are available, Germany accounted for the fifth-largest global share of IP5 applications[3], down from third-largest in 2005. This is not due to a decline in the absolute number of German applications, but to the stronger performance of China and Korea.

Figure 3.7. Total of top five IP5 patent applications (2005-18)

By priority date



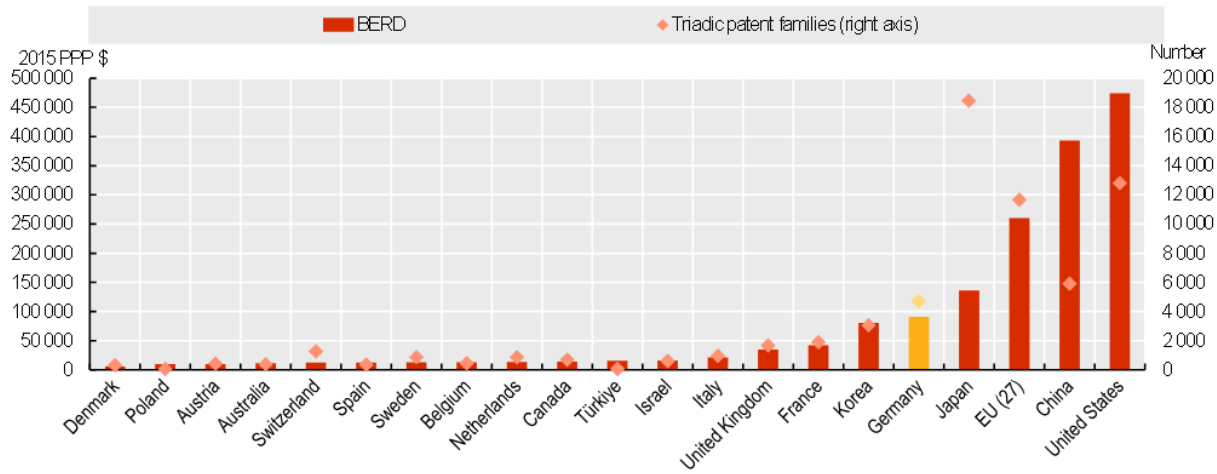
Source: OECD (2022[15]), Patents by main technology and by International Patent Classification (IPC)", *OECD Patent Statistics* (database), https://doi.org/10.1787/data-00508-en (accessed on 22 April 2022).

Interestingly, Germany has a strong level of research internationalisation, demonstrating the global nature of German firms' R&D activities. In 2018, for example, co-patents represented 16% of total patenting – a figure which, although behind the United Kingdom and France, is ahead of major competitors such as Japan and Korea (OECD, 2021[16]). The United States and China also have lower shares – which, however, relate to the bigger size of those economies. Nevertheless, collaboration at a domestic level is lower than in other OECD countries. For example, only 20% of the innovative business population engaged in some form of collaborative innovation, the fourth-lowest share in the OECD, although this may partly reflect the strong degree of internal research capacities among many of Germany's innovation actors. Similarly, with only 8.9% of the German innovative business population engaged in international research collaboration, Germany lags behind other innovation intensive – and large – countries such as the United States (14.6%), France (16.4%) and the United Kingdom (35.9%).

The share of high-value patents held by German firms is higher than the country's global share of all patents. In 2016, the latest year for which data are available, Germany accounted for 9.2% of the world's IP5 patent applications, closely behind Korea (9.9%) and China (10.6%), but far behind the United States (19.2%) and Japan (28.5%) (OECD, 2021[11]). Within triadic patent families[4], Germany's global share for 2016 was slightly lower (7.8%), although still the third-largest share behind Japan (34.7%) and the United States (26%). Germany also has a globally significant share of triadic patents in frontier areas such as environmental management (10%), climate mitigation technologies (10%), pharmaceuticals (5.6%) and biotechnologies (5.6%) (OECD, 2021[17]).Germany's strong patenting performance also benefits from the structural composition of the economy, as the country's dominant industries rely strongly on patents for intellectual property protection.

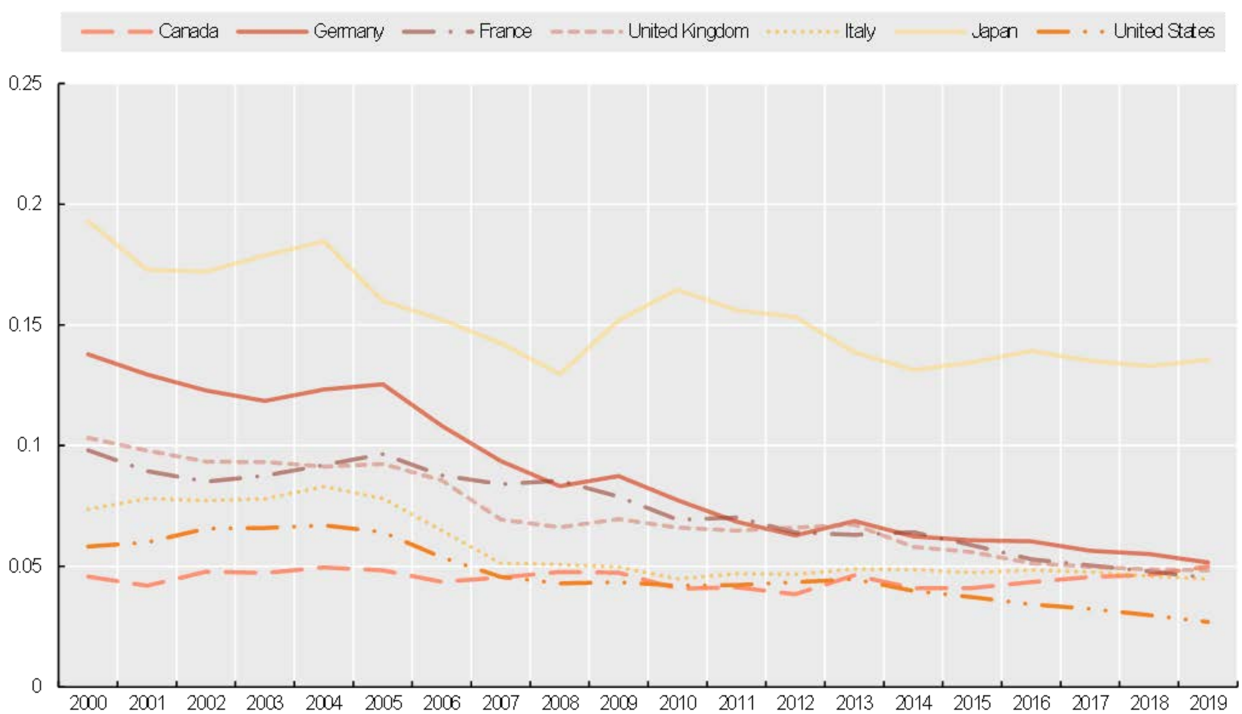
Recent analysis nevertheless shows that Germany's share of "world-class patents", including those that are highly cited and registered in multiple markets, has also declined over the past two decades.

Figure 3.8. BERD and triadic patent applications (2018)



Note: Data refer to priority year.
Source: OECD (2022[12]), "Main Science and Technology Indicators", *Forschung und Entwicklung* (database), https://doi.org/10.1787/data-00182-en (accessed on 22 April 2022).

Figure 3.9. Triadic patents per USD million of BERD (2000-18)



Note: Priority year.
Source: OECD calculations based on OECD (2022[12]), "Main Science and Technology Indicators", OECD Science, Technology and R&D Statistics (database), https://doi.org/10.1787/data-00182-en (accessed on 22 April 2022).

The decreasing trend in triadic patent filing (observable in several leading economies), as well as falling shares in highly cited patents, suggest decreasing technological returns from business R&D. According to a recent study, the contribution of German innovators to the 10% most-cited patents across 58 important technology areas has decreased over the past two decades, although current levels remain high in an international context (Breitinger, Dierks and Rausch, 2020[18]). In 2010, Germany ranked among the top 3 nations in terms of world-class patents (in 47 out of 58 technologies), which had however declined to 22 technologies by 2019. This development also concerns Germany's traditional strength in manufacturing, where highly cited patents are increasingly shifting to East Asian countries. In parallel, technological productivity – as measured by the number of triadic patents per billion dollars of BERD (constant prices) solicited by German applicants – halved over 2000-19.

Despite increasing R&D investments, Germany's capacity to generate high-impact technological innovation has therefore decreased. A similar – but less steep – downward trend occurred in business R&D in the United Kingdom and France. In contrast, Japan and Korea show a more stable evolution, with Japan leading the production of triadic patents per billion dollars of business R&D within these five of comparator countries.

3.3.2. German scientific publications in an international context

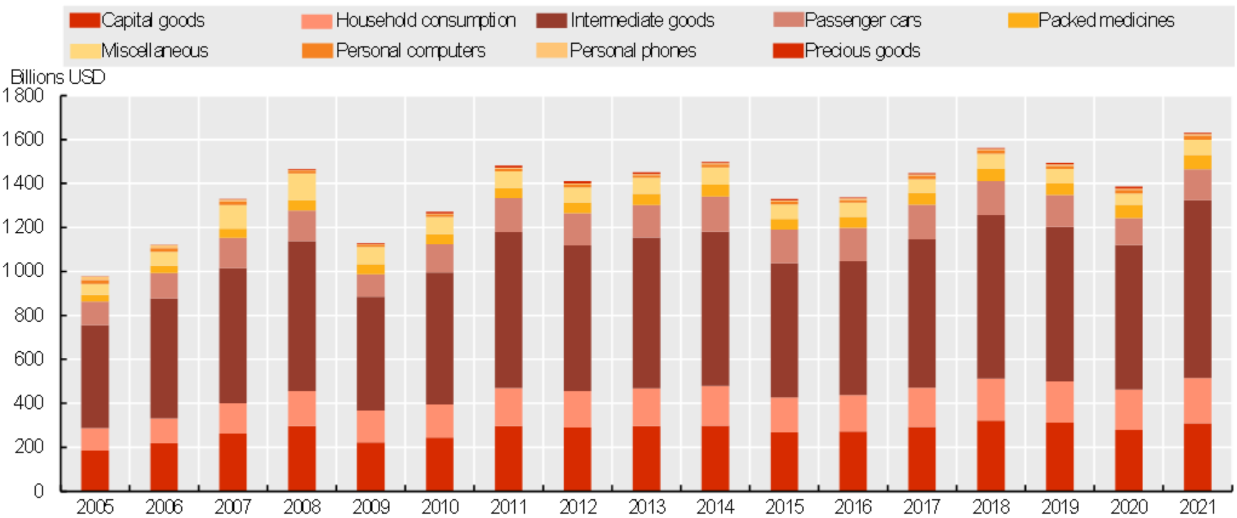
Germany is a major producer of high-quality scientific research and publications. While China (20.7%) and the United States (20.5%) make up the largest share of the 10% top-cited papers in the world's top-cited journals, Germany remains a significant contributor (4.4%), behind the United Kingdom (5.2%). At a high level, the scientific publication output of the German STI system substantiates both the success of the institutions and programmes in place to promote high-quality research, and the vast stock of knowledge available to innovation actors in the economy.

In terms of contributions to high-quality academic literature, Germany performs well in areas that reflect the sectoral strengths of its innovation system, as well as in those that are less ostensibly linked to key sectoral or industrial competencies. Germany features among the top ten contributors to high-quality scientific literature in a range of academic disciplines. It performs well in traditional STEM areas, such as engineering (10.2% – fifth globally), computer science (11.5% – sixth) and material science (9.5% – eighth), but also in the humanities (12.6% – fifth) and social sciences (12.6% – fourth). The broad scope of these combined academic competencies demonstrates the diverse range of scientific knowledge and expertise available to the German innovation system.

3.4. Indicators of innovation outputs and quality based on export performance

Germany's strong innovation performance supports an export-oriented economy, despite significantly higher labour costs than in many developing economies. In absolute terms, Germany has the second-highest level of trade in goods and services within the OECD, behind only the United States. As a percentage of GDP, the level of German exports (47% of GDP) is by far the highest in the Group of Seven (G7) and Group of Twenty (G20), evidencing the exceptional importance of the external sector for a large and industrialised economy such as Germany. Manufactured capital and intermediate goods are a major component of Germany's exports, reflecting the country's importance as a source of finished and intermediary inputs for the global economy (Figure 3.10).

Figure 3.10. German goods exports (2005-20)



Source: OECD (2022[8]), "STAN Bilateral trade database by industry and end-use category, ISIC Rev. 4", *STAN: OECD Structural Analysis Statistics* (database), https://doi.org/10.1787/data-00691-en (accessed on 22 April 2022).

German's high level of manufactured good exports is supported by an innovative and complex export basket, with many German manufacturers producing high-end, technologically advanced products. The complexity of Germany's export basket – as measured by the diversity and sophistication of exports – is indicative of its production competencies, which are ultimately based on innovation capacities. Germany has the second most-complex export basket in the G7, and the fourth most-complex globally, reflecting the broad range of sophisticated innovative products exported by German firms.

Germany's leadership in innovation is also reflected in its share of leading companies among global innovating firms: the country has the fourth-largest cohort of top innovating firms, behind the United States (775), China (536) and Japan (309) (European Commission, 2020[19]). Among the top 2 500 R&D investors globally, 124 firms are German (2020) – almost double the nearest EU country (France, 68), with almost triple the level of expenditure (EUR 89 billion for Germany, EUR 33 billion for France) (European Commission, 2020[19]). Within Europe, nearly one in four of the most innovative firms is German. Four German companies – Siemens (sixth), Robert Bosch (seventh), BASF (tenth) and Continental (twenty-fourth) – featured among the 25 largest applicants to the EPO in 2020, the single largest share in the European Union (EU28) (EPO, 2021[20]). Within Germany, the top applicants to the PCT in 2020 were Robert Bosch (4 033 applications), Schaeffler Technologies (1 907) and BMW (1 874) (DPMA, 2020[21]). Also in 2020, Robert Bosch (1 516 applications), Siemens (1 416) and BASF (1 188) were the country's largest applicants to the EPO.

Despite their success, the attractiveness of German companies on financial markets is somewhat weak compared to successful innovators in several other OECD countries. In 2018, the total market capitalisation of listed domestic companies was 44.1% of GDP, slightly below the euro area average (54.5%), but well below other leading OECD countries, including Korea (82.0%), Japan (105.2%) and the United States (147.7%) (World Bank, 2022[22]). This also applies to the share values of publicly traded companies, where Germany ranked second to last among the G7 in 2018 (OECD, 2022[23]).

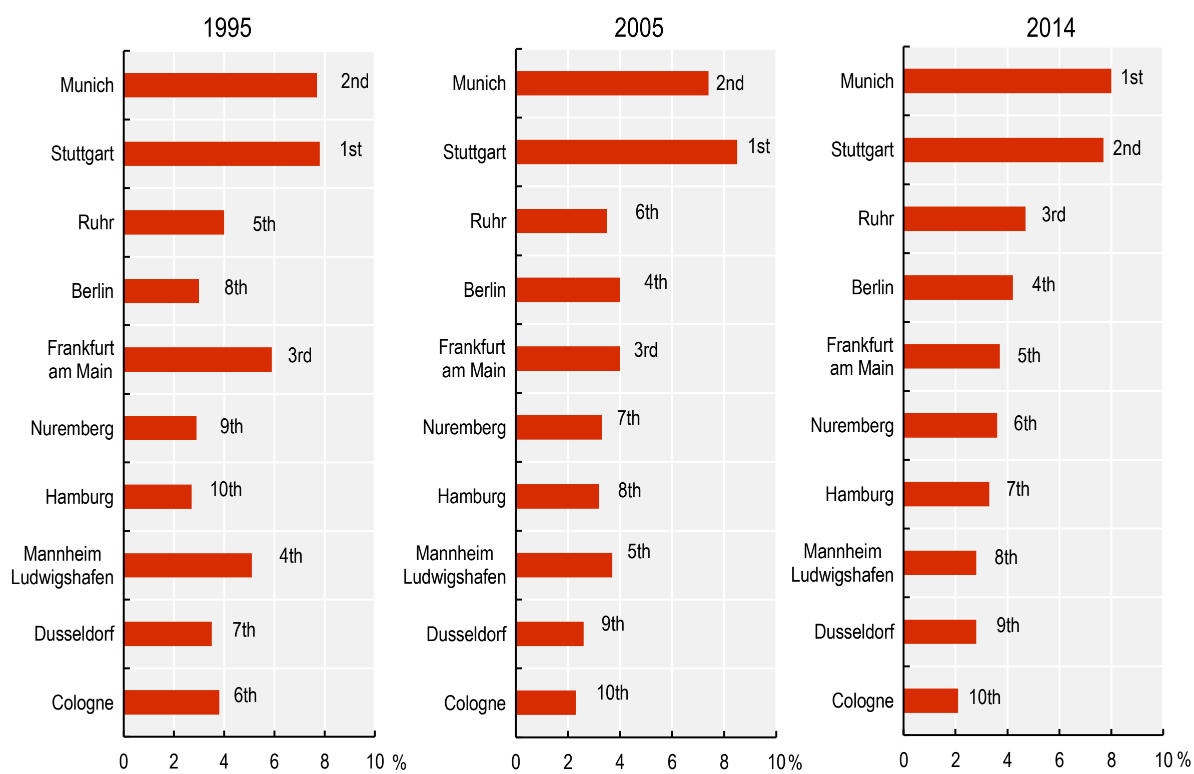
3.5. Regional and sectoral composition of innovation

3.5.1. Regional composition

While there exist regional divergences in patenting activity in Germany, the geographical concentration of patent applications at the city-level is less pronounced than in other OECD countries. As Figure 3.11 shows, Germany has a lower geographical concentration of patenting among the top 10%, 5% and 1% of cities compared to key comparator economies such as Japan, the United States, the United Kingdom and France (Paunov et al., 2019[24]).

Figure 3.11. Ranking and share of top ten cities in patent applications, Germany (1995, 2005 and 2014)

Share of Germany's patent applications



Note: Cities – functional urban areas – selected correspond to the top ten in patent applications in 2014.
Source: Paunov et al. (2019[24]), https://doi.org/10.1787/f184732a-en.

The concentration is more pronounced for some technology areas, likely owing to localised concentrations of specialised knowledge around a small number of research institutions and industrial actors. For example, patenting in digital technologies and biotechnology is the most geographically concentrated. In 2010-14, the top 10% of cities accounted for 41% of digital technology patenting and 45% of biotechnology patenting, higher than the average across all technology fields over the same period (Paunov et al., 2019[24]). On a per capita basis, the top 3 regions registered 122 (Baden-Württemberg), 90 (Bavaria) and 37 (Lower Saxony) applications per 100 000 habitants, whereas the equivalent figures for the bottom 3 regions were 6 (Mecklenburg-West Pomerania), 7 (Saxony-Anhalt) and 14 (Berlin) (DPMA, 2020[21]). Chapter 16 provides more details on the regional distribution of German innovation.

The southern *Länder* are home to Germany's industrial base, with a focus on (automobile) manufacturing and mechanical and electronic engineering. Bavaria hosts companies such as Airbus, Audi and BMW, and Baden-Württemberg is home to Bosch, Daimler and Porsche, alongside many smaller Mittelstand firms. Bavaria also has a well-developed service industry, with global insurance companies Allianz and Munich Re, while Baden-Württemberg is home to one of Germany's few software companies, SAP. Both *Länder* are also research and innovation centres, with 70 institutions of higher learning and multiple Fraunhofer Society and Max Planck institutes in Baden-Württemberg, and almost 40 institutions of higher learning and over 20 research centres in Bavaria (GTAI, 2022[25]). At the border with France and Luxembourg, the Saarland is a logistics and transportation hub featuring over 150 companies; with other clusters, such as information technology (IT) start-ups, currently developing in the region. The home base of companies such as Opel, Rolls-Royce, Jenoptik, Bosch and Zeiss, Thuringia hosts expertise in lens manufacturing, medical and biotechnology, photovoltaic production and software engineering. Rhineland-Palatinate – which is characterised by medium-sized business and "hidden champions", but is also home to BASF – has strengths in the chemical, pharmaceutical, automotive, metal, machinery and equipment, and food industries. Hessen draws in foreign investment and is internationally connected through Frankfurt Airport, but also focuses on digitalisation and data in both the private sector and research: the COVID-19 vaccine manufacturer BioNTech, in the city of Mainz, has recently been a major driver of growth. North Rhine-Westphalia is Germany's most populous state, and a common destination for foreign investment. Its 70 universities and universities of applied sciences, 110 technology centres and non-university research institutes form the densest research network in Europe (Ibid.).

Northern Germany's industrial strengths are often connected to the North and Baltic Seas, with important shipbuilding and harbour industries, maritime trade and international freight transportation in Mecklenburg Western-Pomerania, Schleswig-Holstein, Lower Saxony and Hamburg. Lower Saxony also has a strong local base in the automotive industry (with Volkswagen and Continental), as well as travel and tourism (TUI Group); it is also active in freight transportation through its 35 harbours, in shipbuilding, international trade fairsand hosts over 30 institutions of higher learning. Schleswig-Holstein is experiencing strong growth in renewable energies; it hosts the Fraunhofer Institute for Silicon Technology and the IZET Innovation Centre, as well as leading companies in the medical industry, such as Dräger and Johnson & Johnson Medical. Hamburg is Europe's second-largest port and a logistical hub; it is also a centre for aviation and has a diversified service industry in media, marketing, IT and life sciences. Bremen, also a port city, has strengths in the maritime economy, logistics, wind energy, and the food and beverage industries; it also hosts the automotive (Mercedes-Benz) and aerospace (Airbus) industries and serves as a base for the digital and IT service industries, with the German Research Centre for Artificial Intelligence (Ibid.).

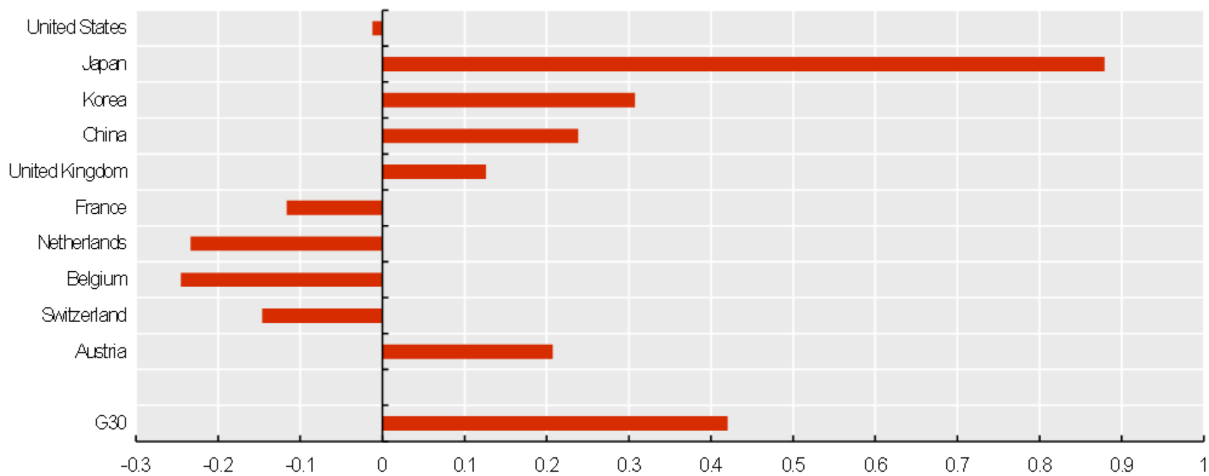
While no longer a centre for industry, Berlin hosts many representations of global and national leading companies as the country's capital. Its own strengths lie mainly in media, fashion, music, services, IT and health care, as well as bio, optical, environmental and medical technologies. Berlin also has a growing start-up community, and hosts 18 higher education institutions and 250 research establishments, including Germany's largest science and technology centre in Adlershof. With its proximity to Berlin and its central location within Europe, Brandenburg acts as a commercial transportation hub. Saxony-Anhalt specialises in chemicals and biotechnology, as well as automotive supplies, and is a centre for polymer production and processing; it hosts 2 universities, 12 colleges and 22 research institutions. In Saxony, research focuses on lightweight construction, energy storage technologies, automation technology and future mobility, while industrial strengths lie in mechanical engineering and microelectronics/ICT; logistics are also a major economic driver (Ibid.).

3.5.2. Sectoral composition

In an international comparison, the sectoral composition of German BERD mostly resembles Japan's, with a 0.88 correlation coefficient between the two countries for the shares of 12 industries (Figure 3.12).

Germany's industry structure of BERD is also somewhat similar to Korea, China and Austria, but is very different from Germany's neighbouring countries in Western Europe (Netherlands, Belgium, France and Switzerland). Germany's 0.42 correlation coefficient with the G30 (see note to Figure 3.12) should be viewed in context with the same figures for China (0.52), Japan (0.72), the United States (0.72) and Korea (0.83), indicating that the sectoral concentration of Germany's BERD is an outlier for a major industrialised economy.

Figure 3.12. International similarity of industrial composition of BERD (2017)

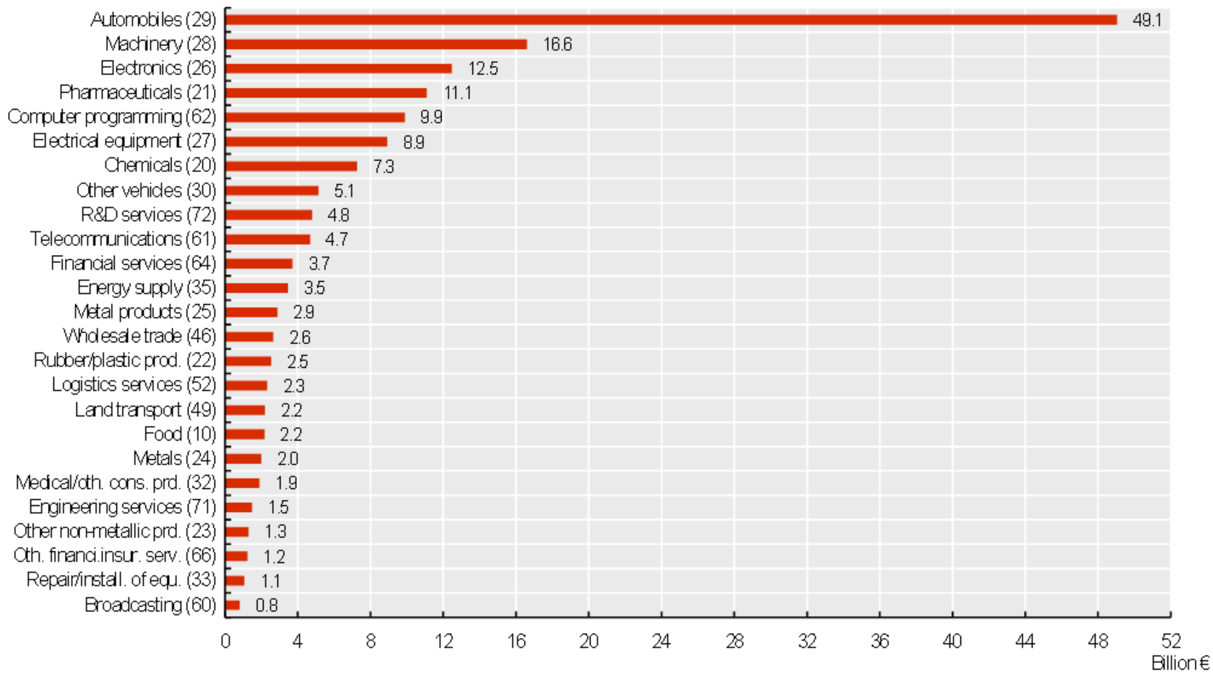


Note: Industries included are automobiles, machinery, business services, electrical equipment, materials, R&D services, pharmaceuticals, electronics, other vehicles, internet and communication services, other manufacturing and all other sectors. Data for Korea are for 2015, data for the United Kingdom are for 2016. G30 is defined here as Germany and 29 important trade partners of Germany and for which a breakdown of BERD by industry is available: Australia, Austria, Belgium, Canada, China, Czech Republic Denmark, Finland, France, Germany, Hungary, Ireland, Israel, Italy, Japan, Korea, Netherlands, Norway, Poland, Portugal, Singapore, Slovakia, Slovenia, Spain, Sweden, Switzerland, Chinese Taipei, Turkey, United Kingdom, United States.
Source: OECD (2022[26]), *OECD Research and Development Expenditure in Industry 2018: ANBERD*, https://doi.org/10.1787/anberd-2018-en (accessed on 22 April 2022).

Germany's BERD tends to be concentrated in a limited number of sectors and industries, with particularly high levels of innovation expenditure in the manufacturing sector. In 2017, the last year for which sectoral data are available, 85% of total intramural BERD occurred in manufacturing, a substantially higher share than in the United States (64%) and European countries such as the United Kingdom (41%), France (49%), the Netherlands (57%) and Switzerland (70%).

National statistics on innovation expenditure include all R&D expenditure (intramural and extramural), as well as expenditure related to the implementation of innovations, such as machinery and equipment purchases, training, marketing and design. From 2017 to 2019, German innovation expenditure was EUR 172 billion for each of the three years. The automobile industry accounted for 28.5% (EUR 49.1 billion), followed by machinery (9.6% or EUR 16.6 billion). Other major industries in terms of innovation expenditure included electronics, pharmaceuticals, computer programming, electrical equipment and chemicals (Figure 3.13).

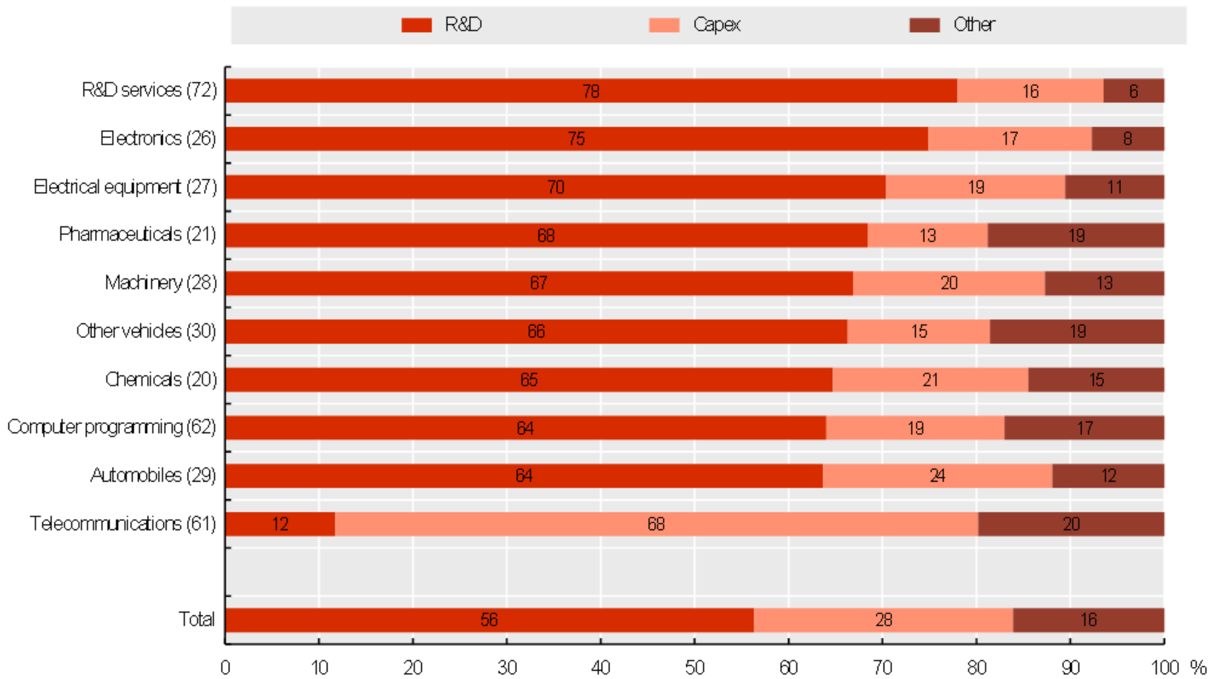
Figure 3.13. The 25 NACE 2-digit industries in Germany with the highest innovation expenditure (2017-19)



Note: NACE: Nomenclature of Economic Activities. NACE classification code in parentheses.
Source: Leibniz Centre for European Economic Research (ZEW) (2020[27]). “Innovation in der deutschen Wirtschaft”. https://ftp.zew.de/pub/zew-docs/mip/20/mip_2020.pdf?v=1616141836 (accessed on 23 April 2022).

The ranking of industries by innovation expenditure closely matches the ranking by R&D expenditure as in most industries with high innovation expenditure, R&D is the main spending category. While on average, 56% of all innovation expenditure in the German business enterprise sector concerns R&D, the top-spending industries spend between 64% and 78% on R&D (Figure 3.14). The only exception is telecommunications, where two-thirds of total innovation expenditure is capital expenditure for tangible or intangible assets. The automobile industry shows a lower share of R&D in total innovation expenditure compared to the other main spending industries, a result of high capital expenditure for innovation (24% or EUR 12 billion per year in 2017-19).

Figure 3.14. Type of innovation expenditure in the ten German industries with highest innovation expenditure (2017-19)



Note: Capex: capital expenditure.
Source: ZEW (2020[27]). "Innovation in der deutschen Wirtschaft". https://ftp.zew.de/pub/zew-docs/mip/20/mip_2020.pdf?v=1616141836

There exist clear sectoral concentrations of BERD within manufacturing. In 2017, for example, the automobile industry performed 37.3% of total BERD, the largest share posted by the automobile industry in any country in the world for which industry-level R&D data are available. The sectoral composition of BERD is strikingly similar to Japan, which has the second-highest concentration of BERD (25.9%) in the automobile industry. This highlights the similarly important role of manufacturing in the Japanese economy, with an almost 90% correlation coefficient of the share of the top 12 industries in BERD between the two economies. Other larger economies with a significant automobile industry show much smaller shares of automotive in total BERD, although some do have high levels of BERD concentration in other industries that are important to the digital transition (such as the electronics sector in Korea). Among OECD countries, the Slovak Republic has the next-closest level of BERD in the automobile sector (35.5%) after Germany.

The automotive sector is the main driver of growth in Germany's innovation expenditure, accounting for more than 40% of the total increase in innovation expenditure between the end of the 2008 Global Financial Crisis and 2019. The three-year rolling average of BERD growth over the previously mentioned period was 1.9%. Over 40% of this total increase can be attributed to the automobile industry, which not only expanded R&D expenditure, but also significantly increased capital expenditure (+2.3% CAGR) and other expenditure (+3.8% CAGR). Other industries that substantially contributed to the increase include pharmaceuticals, computer programming, machinery and electrical equipment. This dynamic of the automotive industry as a significantly larger quantitative source of BERD than other sectors and a key driver of the expansion of BERD in the German economy invariably raises broader political economy challenges for innovation expenditure in the country, due to the sector's linkages with academia and research, and its contributions to growth and employment.

Given the importance of the manufacturing sector – and particularly the automotive sector – to the German economy, it is perhaps unsurprising that it plays a significant role in the country's innovation system. Some

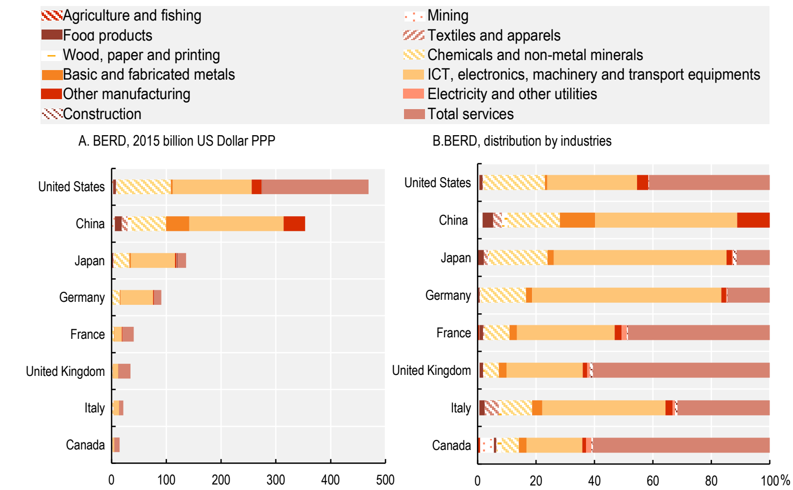
85% of all intramural R&D is undertaken by manufacturing firms, a substantially higher share than in comparable economies such as the United States (64%) and France (49%). In 2019, 53% of German R&D expenditure occurred in the automobile industry – an amount equal to 24% of global automotive BERD. No other large industrialised country had a comparable sectoral concentration of innovation funding and capacity in any one sector (European Commission, 2020[19]). Four of the top ten leading automotive companies in terms of global R&D expenditure – Volkswagen (first), Daimler (second), BMW (sixth) and Bosch (seventh) – are located in Germany (European Commission, 2020[19]).

Yet the automotive sector is far from the only significant manufacturing and industrial player in Germany's innovation system. In 2018, the last year for which comparable data are available, the electronics (11.4%), machinery (9.9%), chemical (7.2%) and pharmaceutical (5.8%) sectors were also major contributors to total BERD (OECD, 2021[11]). While these figures are low relative to the contribution of the automotive sector, they are significant in nominal terms (representing EUR 8.3 billion for electronics, EUR 7.1 billion for machinery, EUR 5.2 billion for chemicals and EUR 4.1 billion for pharmaceuticals). They are also substantially higher than BERD in the same sectors in other leading innovative nations such as France and Italy. Moreover, Germany has a number of globally leading firms in these sectors, including Siemens (second in the world for electronics industry R&D), Bayer (eighth for pharmaceuticals), BASF (first for chemicals) and SAP (eighth for software and computer services) (European Commission, 2020[19]). In addition to their net contributions to R&D in the European Union, five of the top ten companies that contributed to R&D growth in 2019 were from Germany, led by SAP's 18.6% year-on-year growth, the largest contributor to the increase (European Commission, 2020[19]).

Several other industries are also major sources of BERD, both in international comparison (

Figure 3.15) and domestically (Figure 3.16). In 2018, for example, German BERD in the chemical sector totalled USD 5.2 billion. This was the fourth-highest level globally, behind China (USD 23.9 billion), the United States (USD 9 billion) and Japan (USD 8.1 billion), but by far the largest source of sectoral BERD in the European union, ahead of France (USD 4 billion), Belgium (USD 1.2 billion) and Italy (USD 0.7 billion). Similar trends are visible in the machinery industry – where Germany is again the fourth-largest contributor to global sectoral BERD (USD 8.9 billion), behind China (USD 32.6 billion), Japan (USD 12.9 billion) and the United States (USD 12.8 billion) – as well as in R&D-intensive sectors such as electronics (fourth globally, USD 3.4 billion) and pharmaceuticals (fifth, USD 5.8 billion). Taken together, the broad range of sectors in Germany showing high levels of BERD constitute a globally competitive and leading source of private-sector innovation, and a valuable reserve of knowledge and technological expertise.

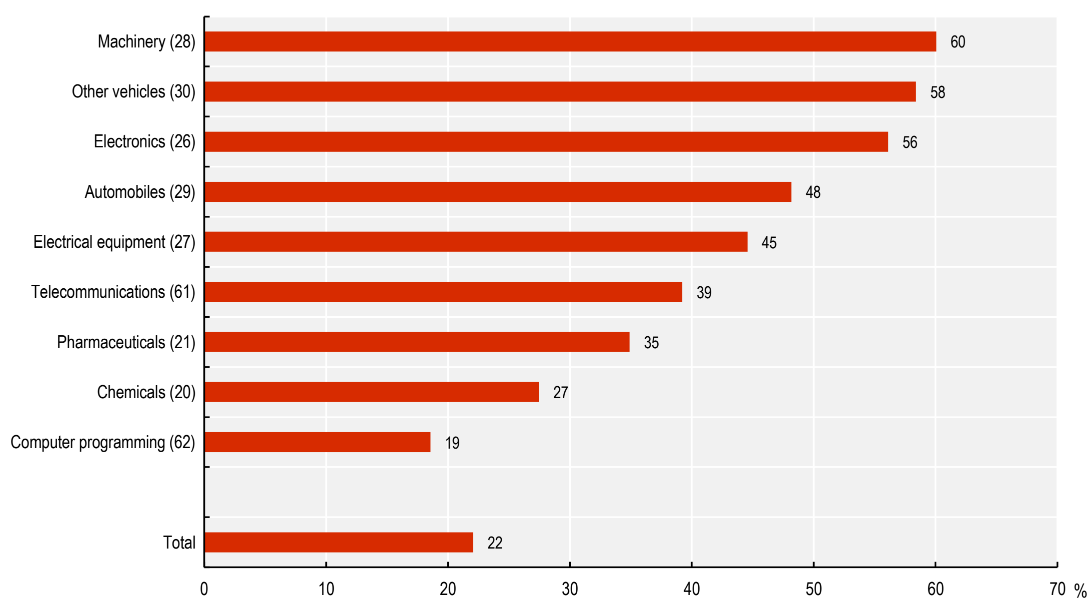
Figure 3.15. Distribution of BERD by industry (2019 or latest available year)



Source: OECD (2022[28]), "STAN R&D: Research and development expenditure in industry - ISIC Rev. 4", *STAN: OECD Structural Analysis Statistics* (database), https://doi.org/10.1787/data-00689-en (accessed on 16 May 2022).

High capital expenditure for innovation is a common feature of many of the industries with high innovation expenditure. Relating the amount of capital expenditure for innovation (additions to property, plant and equipment as well as intangible assets, but excluding R&D expenditure) to the industry's total capital expenditure (also excluding R&D expenditure) as reported in national accounts shows high shares innovative capital expenditure, ranging from 45% (electrical equipment) and 48% (automobiles) to 56-60% (electronics, other vehicles, machinery). The shares are lower in the pharmaceutical (35%) and chemical (27%) industries. For the total economy, just 22% of all capital expenditure targets innovation.

Figure 3.16. Share of capital expenditure for innovation in total capital expenditure* in Germany, by industries with the highest innovation expenditure (2017-19)



Note: Capital expenditure excluding R&D expenditure. Figures are approximations only, as industry classification of innovation expenditure and capital expenditure are based on national accounts.
Source: OECD calculations based on ZEW (2020[27]).

Several other industries in Germany contributed above the average to global R&D growth, including R&D services (accounting for 16.2% of the global increase in R&D expenditure from 2008 to 2017), business services (12.9%) and machinery (10.0%). Across all industries, R&D dynamics were strongly driven by China, which contributed 50% to the total global increase in BERD over the same period. China's contribution to total BERD growth ranged from 33% to more than 100% in the manufacturing industries, and from 11% to 47% in the service industries.

At a sectoral level, Germany's CAGR of BERD exceeded the global rate in three industries (business services, R&D services, other vehicles) and shows a similarly high rate as the G30 (see note to Figure 3.12) for most other industries, including information and communication services, pharmaceuticals and electrical equipment. However, the CAGR of German BERD is clearly lower than the G30 reference value in three industries: electronics, materials and other manufacturing. While the dynamism in materials and manufacturing is dominated by the R&D expansion of the Chinese industry, the growth of R&D in electronics shows a wider geographical pattern, with Korea, Chinese Taipei and the United States also making substantial contributions. The low CAGR of Germany (+1.6%) and its low share in global electronics industry R&D (4.3%) indicate that Germany does not have the same global presence in this sector as other large OECD countries, particularly the economies of East Asia.

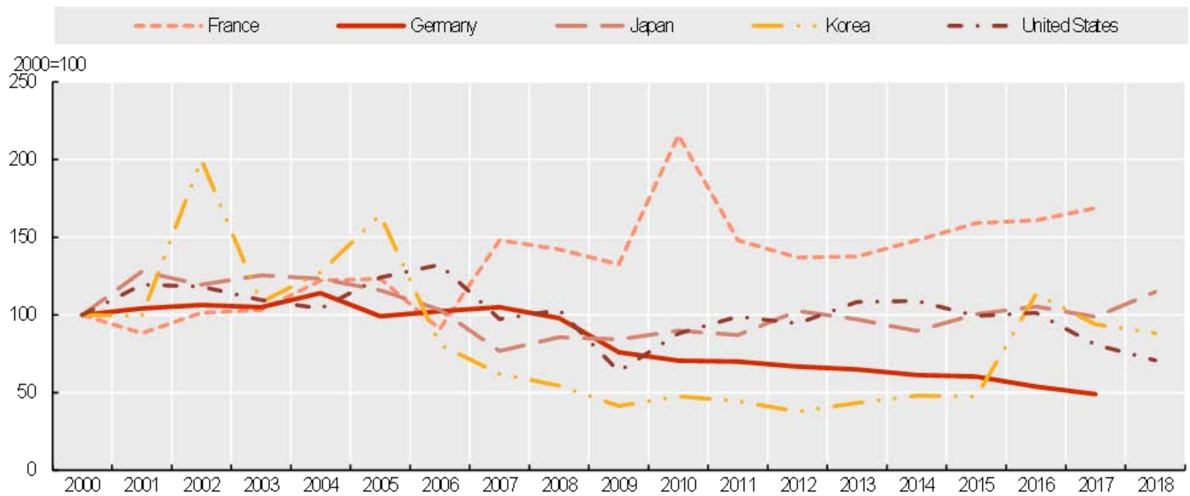
Finally, it is telling that many of the sectors featuring the highest levels of German BERD also make significant contributions to the country’s total exports, further evidencing the relationship between domestic innovation and international competitiveness. For example, the automotive sector, whose innovation expenditure share of industry turnover amounts to 10%, accounted for 37% of global premium car production in 2019, significantly ahead of other producers such as the United States (14%) and China (16%) (GTAI, 2019[29]). Similarly, the strong rankings of research-intensive sectors in Germany as diverse as the aerospace industry (third globally in 2019, 11.8% of the global market share) and pharmaceuticals (first, 14.1%) further attest to the important relationship between successful innovation and international competitiveness for the German economy.

3.6. Innovation productivity: Outputs to investments

Both the United States and Germany have experienced diminishing patenting capacity relative to R&D expenditure since the mid-2000s. Figure 3.17 suggests divergent levels, with the United States posting the biggest decline, while France and Japan have maintained relatively strong or stable returns to BERD since the 2008-09 global downturn.

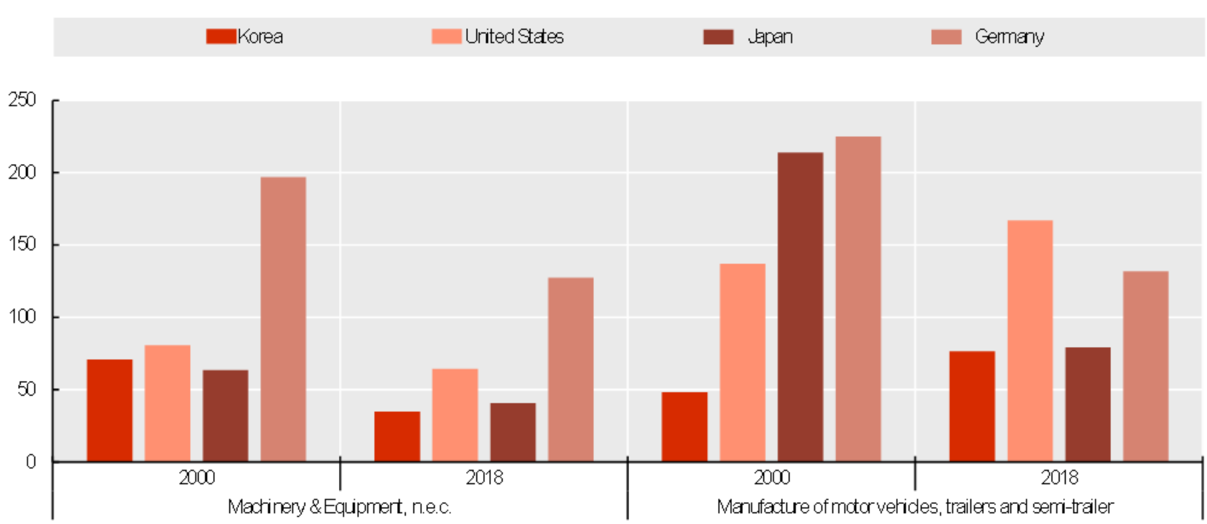
Figure 3.17. Evolution of R&D productivity in manufacturing: Patents per BERD

Industry structure-adjusted average index (normalised to year 2000 =100)



Note: The figure reports the structure-adjusted average (sectors weighted by their share in total manufacturing value added) of EPO-PCT filings per business R&D expenditure in the same year (expenditure and patent filing year). BERD data are expressed in 2015 USD constant prices and PPP. The index reported is normalised to year 2000 (=100). Patenting data were transformed to sector-level patents using the concordance matrix developed by Dorner and Harhoff (2018[30]). The computation of this indicator took into account 18 manufacturing sectors (18 sectors -2 digit ISIC4,[5] reporting BERD data for the whole period; food and beverages and tobacco products are excluded). However, care should be taken in reading this evolution, as data for some low-tech sectors (D13, D14, D15 and D16) are partially covered for the United States and Japan. These sectors, however, represent a minor share in total national manufacturing value added and production. Therefore, this may have only a limited effect on the aggregate for the United States and Japan.
Source: OECD calculations, based on business R&D Statistics from the BERD database (*OECD STAN Database* ISIC-4), and patenting data (EPO patent applications by filing year) consolidated at the sector level.

Figure 3.18. EPO patent applications relative to BERD for selected industries (2000 and 2018)



Source: Source: Own calculations, based on R&D Statistics from BERD database (*OECD STAN Database*) at the ISIC4, 2-digit level, and patenting data (EPO patent applications by filing year) consolidated at the industry level (ISIC4, 2-digit) using fractional allocation.

Additional insights can be derived by applying the same approach at the industry level. In Figure 3.18, for example, this indicator was computed for two of the most important economic sectors in Germany. As largely acknowledged in innovation studies, there exist important cross-sectoral differences in both R&D investment and patenting patterns, with intensive industries being more sensitive to patent protection and experiencing higher rates of technological change, especially in emerging industries. Accordingly, France displays the strongest performance in terms of patenting per R&D dollar, a consistent pattern since around 2007 (Figure 3.17). In contrast, Germany displays deteriorating return of EPO patent applications per BERD dollar in two of its key industries (machinery and equipment, motor vehicles), although the country still had higher innovation performance than France and the United States in 2018 (Figure 3.18).

Both in Germany and globally, research productivity (measured as total factor productivity per number of researchers) has been declining over the past two decades. In the United States, research productivity declined on average by 5.3% per year between 1930 and 2015 (Bloom et al., 2020[31]). This trend was closely mirrored in Germany, where research productivity dropped by 5.2% per year on average between 1992 and 2017 (Boeing and Hünermund, 2020[32]).

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Endnotes

[1] PCT applications are filed with a national patent office of a PCT treaty country. If accepted, the patent can be extended to all signatories of the treaty, making it a de facto "international" patent.

[2] A target has been set to increase R&D spending to 3.5% of GDP by 2025.

[3] Patents that are protected in at least two IP offices worldwide, one of which must be a member of IP5 – namely, the EPO, JPO, USPTO, KIPO and CNIPA.

[4] Triadic patent families are a set of patents filed at the EPO, the JPO and the USPTO for the same invention by the same inventor.

[5] ISIC: International Standard Industrial Classification of All Economic Activities.

4 The German research base for innovation

This chapter introduces key characteristics of the research base for innovation in Germany. The innovation system in Germany is supported by a large, autonomous, and well-resourced network of research organisations and universities. Institutionalised public research is in turn complemented by a highly innovative business sector.

Introduction

The research base – meaning, the strength and competencies of the institutions and personnel dedicated to undertaken research – is an integral pillar of the innovation ecosystem. Both as a provider of expertise and capabilities and a partner in innovation activities, it plays an important role in supporting innovation in firms, particularly *Mittelstand* firms. The importance of the research base will only grow in the transitional context, where firms and research organisations will increasingly require new forms of expertise and a greater level of cross-disciplinary collaboration. Facilitating this collaboration is a central aim of the Federal Ministry for Economic Affairs and Climate Action (BMWK)'s "From the Idea to the market", an umbrella of programme families. These additional requirements are particularly important for the research base to support the types of breakthrough innovation needed to achieve the sustainable transition.

As in other economies, the German research base comprises a range of institutions, each playing a particular role in the science, technology and innovation (STI) system. They include public research organisations (PROs), which undertake different types of research supporting innovation, from basic research to more technologically specific investigation. Higher education institutions (HEIs) are another important component of the research base, as they both undertake research and produce the qualified researchers needed throughout the STI system. In Germany, these institutional groupings are supplemented by the German Research Foundation (Deutsche Forschungsgemeinschaft [DFG]), which provides publicly funded research grants to any researcher affiliated with a German research or educational institution.

This section presents a brief overview of the key characteristics of the research base in Germany. It introduces both the key research actors within the STI system and the research personnel available to them.

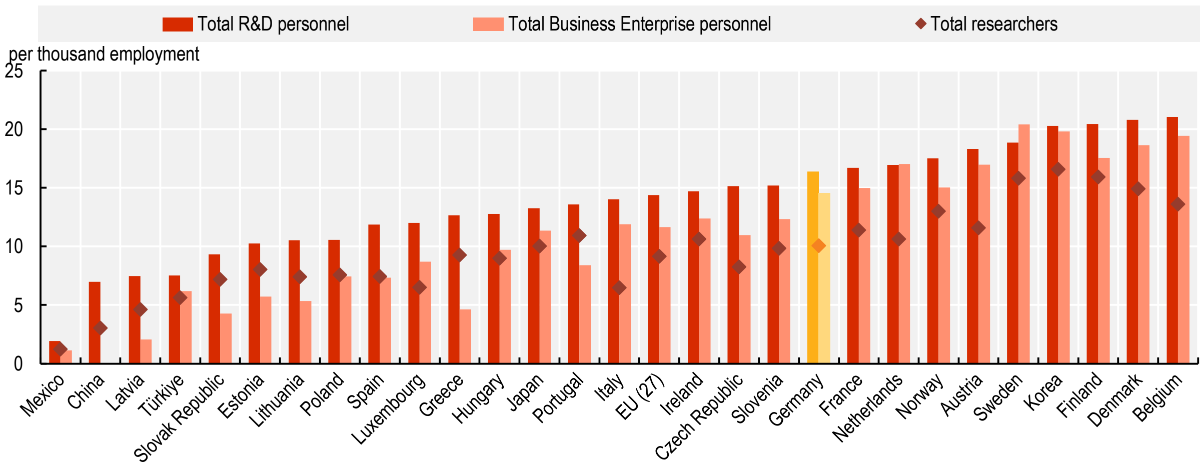
4.1. Research capacity in international comparison

With 450 700 researchers in full-time employment (FTE), Germany has one of the highest levels of permanent research capacity in the world. Only China, the United States and Japan have more FTE researchers. In the European Union, Germany has by far the highest level, ahead of France (314 100) and Italy (160 800).

As in other advanced OECD economies, the vast majority of FTE researchers in Germany are employed in the business sector (61%). The number of FTE researchers (24%) in the higher education sector is slightly lower than the OECD average (30%) and somewhat higher (13%) than the OECD average (6.5%) in the government sector. The number of FTE researchers is slightly lower than the OECD average (30%) in the education sector, and higher than the OECD average (6.5%) in the government sector.

Globally, Germany had the fifth-highest number of FTE researchers in business enterprises (277 000) in 2019, behind China, the United States, Japan and Korea. In the European Union, Germany's 277 000 FTE account for 27% of total private-sector researchers, ahead of France (197 400) and Italy (78 100), the two other largest contributors to FTE private-sector researchers. The share of researchers in the work force (9.7%) is broadly similar to countries such as France (10.9%) and the United States (9.8%), but lower than in certain South Asian and Northern European countries, such as Korea (15.2%), Sweden (14.7%) and Finland (14.4%) (Figure 4.1).

Figure 4.1. Key indicators for R&D personnel capacity relative to industry (2019)



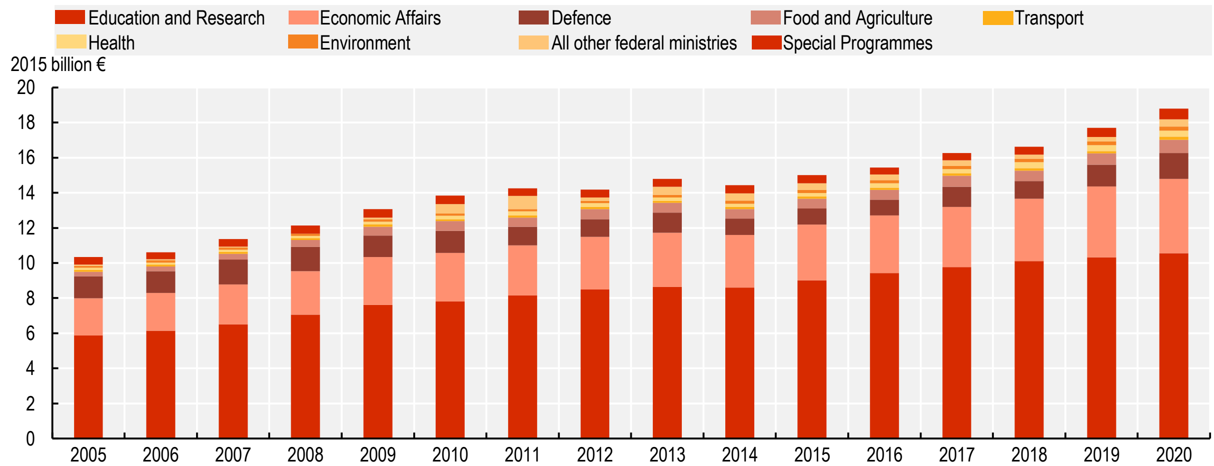
Note: R&D = research and development.

Source: OECD (2022[1]), "Main Science and Technology Indicators", OECD Science, Technology and R&D Statistics (database), https://doi.org/10.1787/data-00182-en (accessed on 22 April 2022).

Germany's strong research capacity masks a significant inclusion challenge, particularly for women. As discussed elsewhere in the review, women are underrepresented in the research system, accounting for only 28% of total FTE researchers at the aggregate level and 15% in the business sector. Gender and other inclusion related challenges in the research base are discussed in Chapter 6).

Moreover, precarious working conditions in academic are also affecting Germany's research institutions. Researchers at universities and other academic institutions often remain on a succession of fixed-term contracts that are capped at six to nine years (in practice often shorter) with limited prospects of advancing in their careers (77% of postdoctoral researchers in higher education institutions and 72% in non-university research institutions) (OECD, 2021[2]) To create better and more stable career paths in science, Germany introduced a (limited) tenure track programme in 2017, also with a view to inducing young researchers to make career choices within or beyond academia earlier in their lives. It should remain a priority for further policy action to ensure that basic and applied research in academia presents an attractive career path for talented graduates from all disciplines and backgrounds, e.g. by promoting inclusive governance schemes at research institutions or by their improving human resource management (ibid).

Figure 4.2. R&D financing by the Federal Government of Germany, by federal ministry (2005-20)



Source: BMBF (2022[3]), Federal Government expenditure on science, research and development, by departments (database), Federal Ministry for Education and Research (BMBF), https://www.datenportal.bmbf.de/portal/en/K1.html (accessed on 1 March 2022).

Federal funding for the research base is important and has grown over the past decades. In 2019, 50.1% of federal R&D financing went to PROs (including government agencies), 10.7% to HEIs, 12.6% to the DFG (which, in turn, funds projects at HEIs), 18.3% to businesses (including a very small share of businesses located outside Germany) and 8.3% to international organisations (BMBF, 2022[3]). Overall, federal R&D funding grew in real terms by around 3.9% per year between 2005 and 2020 (Figure 4.2). R&D financing for HEIs and DFG grew markedly faster (respectively by +5.8 and +6.8% per year in real terms) as a result of the Excellence Initiative. PRO funding grew by 3.5% per year in real terms, but business enterprises (+3.1%), international organisations and programmes, and other recipients abroad experienced slower growth (+2.6%).

4.2. Overview of research-performing organisations

Germany's research base is made up of several components. The country numbers over 1 000 publicly financed research-performing organisations (not including HEIs) spanning fundamental and applied research, and both scientific and innovation-focused work (Figure 4.3) (BMBF, 2022[4]).This figure includes the institutes operated by Germany's four large PROs (Fraunhofer Society, Helmholtz Association, Leibniz Association and Max Planck Society), which have representation throughout the country. Additionally, around 40 federal research institutions and 144 state-level institutions provide scientific information to the federal and regional governments to support policy making (BMBF, 2022[4]).

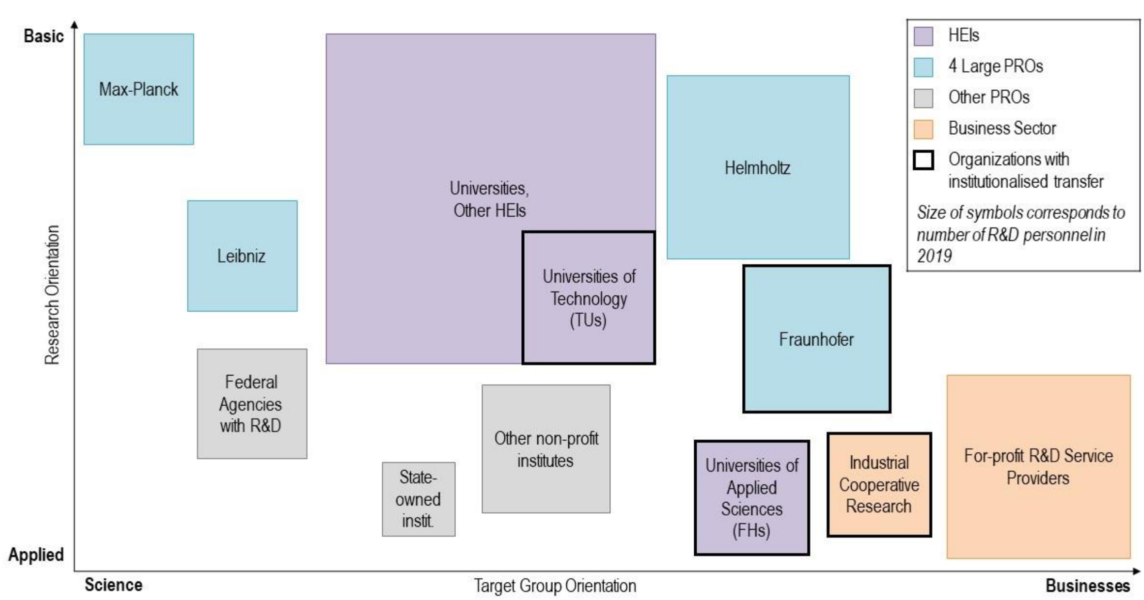
In addition to the 1 000 institutions in the publicly funded network of research organisations, the German research base also comprises over 400 HEIs, including 120 universities (*Universitäten*), over 200 universities of applied sciences (*Fachhochschulen*), and around 60 art and music colleges (BMBF, 2022[5]). In 2020, around 760 000 people worked at HEIs, one-third of whom are considered academic staff (Destatis, 2022[6]). With more than 100 000 employees working in higher education in each of the following *Länder*, North Rhine-Westphalia, Baden-Württemberg and Bavaria lead the 16 *Länder* in terms of higher education personnel. Next to HEIs, over 1 000 non-university PRIs, funded by federal or state governments, complete the research base and are often tightly linked to the innovation system (OECD, 2011[7]). Many research projects at HEIs and PROs are funded by the central research-funding organisation DFG, which is endowed by the federal (69%) and state (30%) governments with an annual budget of around EUR 3 billion, including EU funds and private donations (DFG, 2020[8]).

The German universities and PROs – and indeed the DFG – have organisational and governance structures that insulate them from governmental micromanagement. Unlike their equivalents in many countries, they are not government agencies but rather self-governing associations. Organisations within the state have a high degree of institutional autonomy, above and beyond the international norm that universities should be free to decide what to teach and to research. The *Wissenschaftsfreiheitsgesetz* (Scientific Freedom Law) of 2012 continued the process of increasing universities' independence by granting them a greater level of budgetary autonomy.

Germany has four main PRO networks. The first is the Fraunhofer Society (Fraunhofer-Gesellschaft), which has 76 institutes and research institutions across Germany focused primarily on applied research. The second is the Helmholtz Association of German Research Centres (Helmholtz-Gemeinschaft Deutscher Forschungszentren), whose 18 centres operate research infrastructures for the innovation system, including accelerators, telescopes, research ships and supercomputers. The third is the Leibniz Association (Leibniz-Gemeinschaft), which acts as an umbrella organisation for nearly 100 research institutions investigating scientific problems of societal and international relevance. The fourth is the Max Planck Society (Max-Planck-Gesellschaft), which focuses on advanced basic research. Each of these PROs is highly autonomous, while also benefiting from significant public funding (see Section 4.3).

The DFG, which provides investigator-initiated research funding, is similarly autonomous. All five organisations' governing structures are topped by various forms of general assemblies of members and appoint their own members, removing any opportunity for the government to directly control the organisations or their policies. In practice, these organisations rely on public funding and the government therefore retains a high degree of control, but at an aggregate level that impedes micromanagement.

Figure 4.3. Science-based R&D-performing organisations in Germany, by research orientation and target group orientation



Source: OECD authors' elaboration based on Destatis (2022[6])

4.3. Public research institutions in the German STI system

Germany's particularly large PRO sector stands out in comparison to many other countries. The sector features four main public research organisations with very different missions:

- The Helmholtz Association comprises 18 medium-sized to large independent research centres focusing on big science and infrastructure.
- The Fraunhofer Society operates 105 institutes and centres focusing on applied sciences, engineering and innovation.
- The Max Planck Society runs 82 institutes across all disciplines, focusing on basic research.
- The Leibniz Association comprises 93 independent institutes from a wide variety of disciplines, mostly in the humanities (including museums), arts and social sciences.

The PRO sector also includes R&D-performing federal agencies ("government labs") and R&D institutes operated by state governments (Table 4.1). R&D statistics on PROs include R&D across all disciplines, performed at libraries, museums and numerous publicly co-financed R&D institutes, many of which operate similarly to private non-profit organisations.

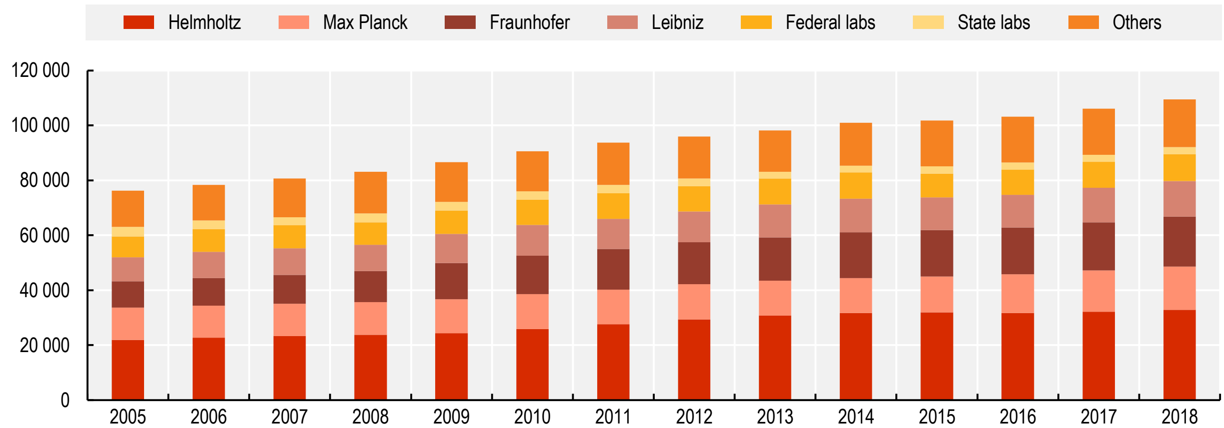
Table 4.1. Public research organisation (PRO) groupings in Germany

PRO grouping	Institutional funding Federal : State	No. of institutes/ centres	No. of personnel (FTE, 2018)		
			Total	Scientists	R&D personnel
Helmholtz	90 : 10	18	32 962	16 685	32 853
Fraunhofer	90 : 10	105	15 736	9 146	15 736
Max Planck	50 : 50	82	18 206	9 207	18 206
Leibniz	50 : 50	93	14 622	7 228	12 946
Federal agencies	100 : 0	38	19 286	9 644	9 747
State R&D institutes	0 : 100	53	5 976	2 937	2 620
Libraries/museums	varying	176	11 128	3 402	3 548
Others	varying	463	17 152	10 078	13 831
TOTAL		1 028	135 066	68 325	109 487

Source: Destatis (2022[9])

The number of FTE personnel in the PROs has grown steadily, from 76 000 in 2005 to 110 000 in 2018 (Figure 4.4), with Fraunhofer growing slightly faster than the others. In contrast to the others, employment at *Länder*-owned institutes ("state labs") fell by about 2% per year over 2005-18.

Figure 4.4. R&D personnel at PROs, by organisation (2005 to 2018)



Source: BMBF (2022[3]). Federal Government expenditure on science, research and development, by departments (database), Federal Ministry for Education and Research (BMBF), https://www.datenportal.bmbf.de/portal/en/K1.html (accessed on 1 March 2022).

The big four PROs have strongly similar governance systems. Each features a self-selecting membership, which directly or indirectly appoints the president, top management and other governing committees. Thus, while federal and *Länder* governments are sometimes represented in these structures, the big four PROs are autonomous.

4.3.1. Helmholtz Association

The Helmholtz Association comprises Germany's 17 ”big science” institutes, which are not only large in employment terms but also tend to rely on large research infrastructures. The association originated in a working group of organisations developing nuclear reactors established in 1958 and comprising the research centres at Karlsruhe and Jülich, along with several university institutes. Throughout the 1960s, other big science centres in areas such as aerospace, high-energy physics, materials and health joined the working group, which in 1970 established the *Arbeitsgemeinschaft der Großforschungseinrichtungen* (Association of major research institutions) to manage their relationship with the state, reduce governmental micromanagement of the centres and increase their autonomy.

In absolute terms, Helmholtz had the largest share of the increase in R&D capacity from 2005 to 2018 (33.1%), with most of the change happening by 2014. Fraunhofer was the next-largest, accounting for 25.9% of the total increase. In terms of scientific disciplines, growth in R&D capacities at PROs was evenly distributed across natural sciences, engineering and medicine, with a CAGR in 2005 of 2.7% to 2.9% in 2018. Most of the absolute increase in R&D capacity took place at PROs doing research in natural sciences (45.8%) and engineering sciences (24.5%); social sciences grew about twice as fast in percentage terms, but from a low base.

4.3.2. Max Planck Society

The Max Planck Society's organisational predecessor was the Kaiser Wilhelm Society for the Advancement of Science (Kaiser-Wilhelm-Gesellschaft zur Förderung der Wissenschaften), founded in 1911, whose institutes conducted a mix of fundamental scientific, applied technical, industrial and defence research. The Allies dissolved the Kaiser Wilhelm Society in 1946, as some of the institutes had been involved in research and technical support to the Holocaust. The Max Planck Society was established in 1948, building on some of its predecessor's physical and manpower, but with a focus on basic research. More than other German institutes, Max Planck still follows the “Harnack Principle”, established by Adolf von Harnack, the first president of the Kaiser Wilhelm Society, which holds that an institute should be established around the capabilities of a leading researcher and should only continue after the researcher's retirement if a suitably prominent successor can be found. Other institute groupings take a more corporate and collective view.

The Max Planck Society is governed by its members, who may include paying, scientific, ex officio or honorary members. The general assembly elects some members of the senate, which also comprises two representatives of the Federal Government and three representatives of *Länder* governments. The senate, in turn, elects the president and executive management, and decides on the opening or closure of individual institutes.

4.3.3. Fraunhofer Society

The Fraunhofer Society (Fraunhofer-Gesellschaft) was originally founded in 1949 by the Bavarian and federal governments and recognised by the then-Federal Ministry for Economy as the third major block in the national research system, after the DFG and the Max Planck Society. Fraunhofer opened its first institutes in 1954 and pursued a mix of industrial and defence research up to 1969, when it had 19 institutes and around 1 200 employees. A commission on the development of the Fraunhofer Society then devised the "Fraunhofer model" of financing, wherein the government provides roughly one-third of Fraunhofer's income in the form of institutional funding. The institutes are expected to win a further third from competitive state sources (now including the EU framework programme) and the remaining third from industry. The federal-state commission for education planning and research funding (Bund-Länder-Kommission für Bildungsplanung und Forschungsförderung [BLK], since 2008 replaced by the Joint Science Conference (Gemeinsame Wissenschaftskonferenz [GWK])) agreed on the new funding model in 1973, and Fraunhofer redeployed its activities on industrial technologies and R&D, with a special focus on small and medium-sized enterprise development, its current role. The Fraunhofer Society took over some of the German Democratic Republic (GDR)'s industrial research institutes after reunification, though many of the GDR's research facilities were also closed. The post-1973 version of the Fraunhofer Society is internationally seen as the leading role model among PROs. However, it deviates from the normal PRO model in that it has a collection of small offices, institutes and collaborations outside Germany, which appear not only to provide international "antennae" and marketing for the Fraunhofer Society, but also to serve as vehicles for German scientific diplomacy. Fraunhofer is a bigger exporter of R&D and technical services than most other PROs.

Fraunhofer is more decentralised than other large PROs, such as the Netherlands Organisation for Applied Scientific Research (TNO) or the VTT Technical Research Centre of Finland. The Fraunhofer model means that in practice, institute directors have high autonomy, provided they satisfy Fraunhofer budget requirements. In the past two decades, top management has succeeded in networking together institutes in related areas, strengthening administrative and management services, and establishing both a technology transfer office and an international division. Nonetheless, Fraunhofer's strategic business units are the individual institutes, which remain fiercely independent. Institute directors are required to be part-time university professors, usually at an adjacent university, cementing links to fundamental research and providing a flow of PhD students working in Fraunhofer-related areas. Fraunhofer aims explicitly to recruit from this group and has a minimum target for labour turnover, on the principle that most PhD graduates should spend a few years honing their skills at one of its institutes and then move on to industry. These arrangements also mean that Fraunhofer institutes work at a more theoretical and fundamental level than technology support and transfer organisations such as the Steinbeis Foundation, the German Federation of Industrial Research Associations (Arbeitsgemeinschaft industrieller Forschungsvereinigungen [AiF]) and Deutsche Industrieforschungsgemeinschaft Konrad Zuse e. V.

The Fraunhofer Society is governed by a general assembly of members. Ordinary membership is open to "natural persons and legal entities, including associations and societies without legal capacity (federations), that wish to support the work of the Organisation" (Fraunhofer, 2015[10]). Official membership is available to members of the senate, the executive board, institute directors and senior managers, and the governing boards.

4.3.4. Leibniz Association

The Leibniz Association originated in a 1949 meeting during which the *Länder* agreed that several existing institutes were too big for any single *Land* to fund and that they should make arrangements to fund them jointly. In 1969, the German Basic Law (the 'constitution') was modified to enable joint funding of research organisations by the federal and *Länder* governments. After intensive negotiations that finally ended in 1977, a list of 46 institutes designated for joint funding was drawn up on a piece of blue paper. In 1990, these Blue List (*Blaue Liste*) institutes established an *Arbeitsgemeinschaft* (consortium). By 1992, following the German reunification, the Blue List had grown to include 81 institutes. The consortium set up a committee to consider the institutes' future, which resulted in the creation of a *Wissenschaftsgemeinschaft* (scientific community) in 1995, whose name was changed in 1997 to Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz, now referred to simply as the Leibniz Association.

The Leibniz Association has five sections, or groups of institutes, specialising in:

- humanities and education research
- economics, social and spatial research
- life sciences
- mathematics, natural sciences and engineering
- environmental sciences.

The Leibniz Association's membership is made up of the institutes, whose top managements appoint the president and vice-presidents and decide on institutes' admission during a general assembly. The executive board comprises both the top management and the heads of the association's five sections. The senate comprises top management, representatives of the five sections and a mix of representatives from the federal and *Länder governments*. Unlike in the other three major PROs, the senate's role is advisory.

4.4. Higher education institutions

Almost all larger general universities are public and receive basic funding from their respective state governments. Many other HEIs have private (usually non-profit) ownership. All public HEIs are governed by state governments, except for a few federal universities. The general universities differ little in research quality and performance: 51 German universities are listed among the top 1 000 universities in the Shanghai Ranking for 2021, and 4 feature among the top 100 (University of Munich is ranked 48th, Technical University (TU) of Munich 52nd, Heidelberg University 57th, and University of Bonn 84th) (Shanghai Ranking, 2021[11]). Around 20 general universities focus on engineering and technical sciences; many of these use the name "'technical university" and traditionally work in close co-operation with industry.

Table 4.2. Germany's HEIs

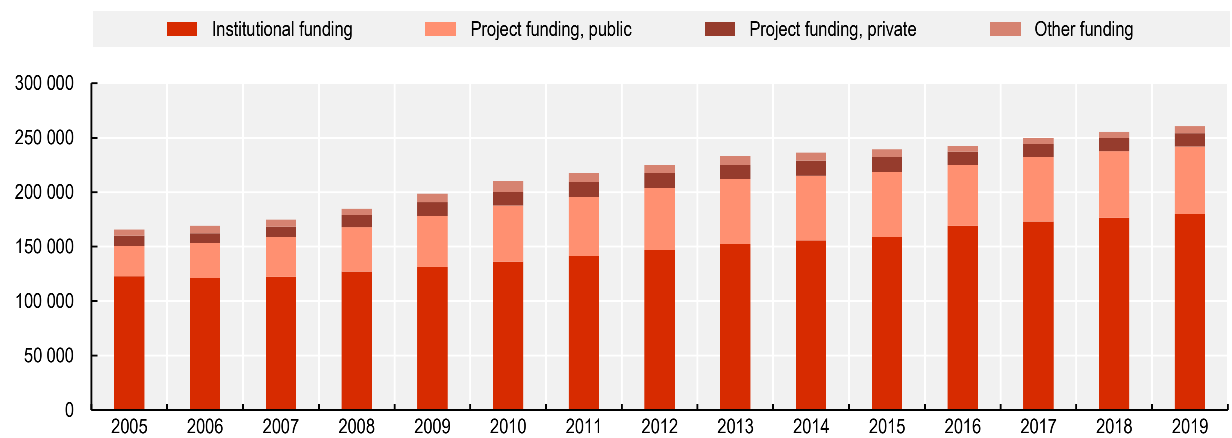
Type of HEI	No. of organi-sations	No. of personnel (headcount, 2019)			No. of students (2019/20)	No. of graduations (2019)	
		Total	Scientists	Professors		Total	PhD
General universities	112	574 545	213 658	24 854	1 749 734	301 961	28 509
(*including TUs*[1])	*20*	*130 797*	*58 806*	*5927*	*478 843*	*86 608*	*7 902*
Universities of applied sciences	236	136 782	38 578	20 234	1 023 146	182 907	0
Colleges[2]	108	26 435	8 375	3 459	118 169	27 417	181

TOTAL	456	737 762	260 611	48 547	2 891 049	512 285	28 690

Note:
1. 20 universities with a large engineering faculty: RWTH Aachen, TU Berlin, Ruhr University Bochum, TU Brunswick, TU Chemnitz, TU Clausthal, TU Cottbus-Senftenberg, TU Darmstadt, TU Dortmund, TU Dresden, University of Erlangen-Nuremberg, TU Freiberg, TU Hamburg, Leibniz University Hannover, TU Ilmenau, TU Kaiserslautern, Karlsruhe IT, TU Munich, University of Stuttgart, University of Wuppertal.
2. Educational colleges, theological colleges, schools or arts, administrative colleges and others.
Source: Destatis (2022[6])

Driven by a policy of increasing student numbers, the university sector has grown substantially, from about 349 000 first-year students in 2005 to 496 000 in 2019 (Table 4.2). The proportion of young people in Germany who begin their first year of university study has risen from one-third to half. The student body is nonetheless rather international: a quarter of first-year students do not have German citizenship. The number of academic personnel has risen correspondingly (Figure 4.5), with the research agendas of the universities likely to be influenced both by students' subject choices (as the universities must hire academics to teach them) and the thematic priorities of external research funders.

Figure 4.5. Number of scientific personnel at HEIs, by source of funding (2005 to 2019)



Note: * including student fees and unknown sources.
Sources: Destatis (2022[6]); ZEW (2021[12])

Universities (especially the TUs) may co-operate with (or even host) one or more '"An-Institute". Although they are formally outside the university structure, An-Institutes are generally located on campus or nearby. Many of them are involved in industrial extension or other forms of technology transfer, sometimes in co-operation with an industrial association or even a single company. An-Institutes may also enable co-operation with other parts of the research sector. Members of the four big PRO networks – especially Fraunhofer and Max Planck – may also be co-located with universities. The directors of these institutes are required to hold part-time university chairs, often located at the neighbouring university.

Changes to the Higher Education Framework Act (*Hochschulrahmengesetz*) in 1998 and 2000 aimed to increase competition within the university sector by reducing regulation and introducing performance-related incentives; restricting ministries' role in university governance; and strengthening internal university leadership, by reducing the relative power of the collegium. The *Länder* have different models for university boards, which were introduced around 2012. At that point, 12 of 15 *Länder* required university councils to be primarily composed of external members (one *Land* did not set rules for university boards) (Stockinger, 2018[13]). University rectors continue to be elected by the university senate and council, but are usually appointed formally by the competent ministry.

While German universities enjoy a high degree of academic freedom, their financial freedom is more limited. Since 2011, they have not been allowed to charge tuition fees. Although they can borrow money (within limits), they may not own buildings. Academics are civil servants and therefore subject to fixed salary scales that prevent universities from hiring "superstar" professors; their civil-servant status means they are also difficult to fire (EUA, 2017[14]).

Starting in 1999, the Bologna Process strengthened the movement to establish fixed-length degrees and promoted regular evaluation of the universities. Combined with the increased use of English in university teaching, this prompted the dramatic growth in the number of foreign students enrolled at German universities.

4.5. Government labs

The Federal Government operates a total of 42 government labs (*Ressortforschungseinrichtungen*) with a combined R&D spending of around EUR 1.2 billion in 2020 (BMBF, 2021[15]). Unlike the PROs, these are ministry agencies. They cover the normal range of functions, including metrology, public health, geology and social policy. As elsewhere, the proportion of research compared to other tasks, such as data collection and more routine technical functions, varies greatly among institutes.

Since 2004, the German Science and Humanities Council (*Wissenschaftsrat*) has been responsible for evaluating the government labs. These labs have been formally organised since 2005 in a working group (*Arbeitsgemeinschaft der Ressortforschungseinrichtungen)*.

In 2007, based in part on evaluations of some of the government labs, BMBF produced quality and management guidelines and a plan for the government labs, which defined their tasks as (BMBF, 2007[16]):

- R&D
- science-based advisory and information services
- science-based services such as testing, certification and licensing.

While the plan recognised the labs as major providers of these services to the government, it acknowledged that universities, PROs and others could also be asked to provide similar services. The plan aimed to increase the labs' financial autonomy, stating they should be free to earn income from third parties in addition to the institutional funding provided by their parent ministries. The plan outlined several measures, such as membership in research networks, personnel placements and exchanges, and participation in collaborative research to support labs' wider participation in the wider scientific community.

Having been asked to develop proposals to improve the government lab system, the German Science and Humanities Council recommended in 2010 that government labs engage more actively in international co-operation, in the ongoing process of rationalisation and re-division among government labs and intensify agenda-setting activities in the EU's Framework Programmes (Wissenschaftsrat, 2010[17]), which would involve better co-ordination at both the national and EU levels. The council further proposed that the labs undergo periodic review and be further integrated into the national research community. It stated that R&D-intensive labs (in practice, almost all of them) should be free to spend at least 15% of turnover on research topics of their own choosing. It also recommended that labs operating significant research infrastructures open them inasmuch as possible to use by other members of the research community.

There appears to have been little further policy development since 2010. Although the German Research Council occasionally evaluates individual labs at the request of their parent ministries, the overall role of the government labs has not been revisited. Many of the *Länder* also maintain their own labs at the regional level, with no national oversight or evaluation.

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5 Strategies and the policy mix for innovation

This chapter reviews public funding for innovation in Germany and presents the main innovation policy strategies and instruments. Germany has an extensive system of policy support for innovation, which was recently supplemented by the introduction of an R&D tax credit. While many public programmes are focussed on SMEs that already innovate, increasing attention is now being paid to raising the contribution of start-ups and previously non-innovation active firms. Guiding policy interventions is a well-developed, if at times fragmented, range of strategic documents, a growing number of which include mission-orientated principles.

Introduction

Germany’s science, technology and innovation (STI) policy is well-resourced, with public expenditure on research and innovation (R&I) among the highest in the world. Relative to gross domestic product (GDP) in 2020, the latest year for which data are available, total government budget allocations for research and development (GBARD) were the fourth-highest in the world at 1.1%, behind only Japan (1.71%), Korea (1.25%) and Norway (1.15%) (OECD, 2022[1]). Still in 2020, German GBARD amounted to USD 50.3 billion PPP (US dollars at current USD purchasing power parity), trailing only the governments of the United States (USD 169.9 billion) and Japan (USD 90.9 billion). The volume of government expenditure on research and development (R&D), which is equivalent to 34.7% of total GBARD in the European Union that same year, illustrates the resources available to policy makers as they seek to promote and steer innovation.

Reflecting the federal system of government in Germany, public support for R&D is split between the federal and state governments through various mechanisms. A major component is project-based government financing, which accounted for 49.5% of GBARD in 2020. Many project-based initiatives are organised under the aegis of national strategies and programmes. These include thematic initiatives, such as the *Energiewende* (“Energy Transformation”) and strategy for research and innovation, and the technology-specific programmes organised therein; and specific programmes targeted at small and medium-sized enterprise (SMEs), such as *Zentrales Innovationsprogramm Mittelstand* (ZIM), which emphasises increasing *Mittelstand* participation in innovative sectors. These approaches have supported a highly successful incrementalism in innovation, allowing German firms to remain at the technological frontier of many internationally competitive industries. Another example is *KMU-innovativ,* which has been running since 2007 to strengthen own research in SMEs and research co-operation with academia in key technologies, totalling more than 2 400 projects.

This section reviews the main national and thematic strategies, and the major direct and indirect public funding for R&D and innovation in Germany. It is structured as follows: Section 1 discusses Germany’s major innovation policy strategies. Section 2 discusses direct and indirect public funding for R&D and innovation. Section 3 describes the policies under the “From the idea to market success” initiative.

5.1. Innovation policy strategies

Like many other countries, Germany is increasingly using national strategies to focus, promote and build on R&I efforts and promote the implementation of wider related changes. These strategies concern a range of thematic and technological areas. For example, the Federal Ministry for Economic Affairs and Climate Action (BMWK)-led *Energiewende* serves as Germany’s national strategy for the sustainable energy transition and has a prominent innovation component (Table 5.1). In addition to high-level guiding strategies, Germany also has a range of other technology-specific initiatives in areas such as artificial intelligence (AI) and hydrogen, reflecting the importance of developing domestic competencies in emerging technologies to maintain international competitiveness as well as achieve transition-related objectives. Other strategies and programmes address specific technologies and topics, notably related to digitalisation, such as photonics, microelectronics, high-performance computing, information technology (IT) security and privacy, future communication technologies and materials, and civil security.

Some strategies fall under the responsibility of a single ministry, while others are cross-ministerial programmes. Typically, strategies are implemented through a mix of new and existing ministry-funded programmes, so that monitoring and evaluation of individual ministry strategies can easily be performed by building on existing evaluation routines. Cross-ministerial strategies are almost always led by a single ministry, but co-ordination between ministries is required for monitoring and evaluation. This has been a particular issue with the R&I strategy, where very little strategy-level evaluation effort was commissioned until the current fourth edition. The High-Tech Strategy 2025 follows 12 missions, and the Fraunhofer Institute for Systems and Innovation Research has been commissioned to perform a real-time evaluation.

Table 5.1. Overview of selected national STI strategies and programmes

Strategy/programme	Start	Lead	Others	Co-ordination mechanism	Scope
Energiewende	2000	BMWK from 2014	4 ministries, Länder, federal agencies, industry, regulators	BMWK	R&I and implementation
Pact for Innovation	2005	BMBF, Länder	-	BMBF, Länder	PROs, DFG
Excellence Initiative	2005	BMBF	WR, DFG	DFG	Universities
High-Tech Strategy	2006	BMBF	All governmental departments	BMBF	R&I
Bioeconomy strategy	2010	BMBF	BMEL	BMBF	R&I
Industry 4.0	2013	BMBF, BMWK	Business, trade associations, Länder, tech transfer network, research council, FhG	Ministry/industry steering committee	R&I, implementation, dissemination
AI	2018	BMBF, BMWK, BMAS	Other ministries	BMBF	R&I
Quantum technologies	2018	BMBF, BMWK, BMVg, BMI		Co-ordination rounds between the ministries involved	R&D
Hydrogen	2020	BMWK	Other ministries	State Secretaries Committee on Hydrogen; National Hydrogen Council	R&I and implementation

Note: DFG = German Research Foundation; BMAS = Federal Ministry of Labour and Social Affairs; BMBF = Federal Ministry of Education and Research; BMI = Federal Ministry of the Interior and Community; BMVg = Federal Ministry of Defence; BMWK = Federal Ministry for Economic Affairs and Climate Action; WR = German Science Council.
Source: Various ministry websites

Many of Germany's key STI policy documents have a strong thematic focus on several areas that are important to the sustainability and digital transitions, even where they are not solely dedicated to these areas. This reflects in part a growing horizontality in German STI policy making, with key strategic documents intended to guide the STI system featuring high cross-referencing to previously disparate technology and knowledge domains. Similarly, many strategies that do focus on a particular technology area are also linked to socio-economic outcomes, such as inclusivity and resilience. For example, an analysis of strategy documents conducted by the OECD leads to a number of observations regarding how policy makers understand the role of different domains of STI in achieving specific socio-economic outcomes (Table 5.2).

Table 5.2. Priorities in Germany's STI policies (2018-22)

Sustainability	*Inclusivity*	*Resilience*	*Competitiveness*	*Digitalisation*
Sustainability is considered a **guiding principle for transitions**, particularly for innovation policy, with commitments to meeting sustainability objectives. Specific sectors, fields and technologies include: hydrogen • electric mobility/battery production • machine learning/AI.	Inclusivity in transitions focuses on **regional equality** as an important component for achieving STI policy goals in specific technology fields like **AI, automotive and other** industries, as well as in regional innovation hubs through bottom-up oriented innovation processes. Social inclusivity focuses on using digitalisation to reduce inequalities in education and public administration. At the same time, R&I policy seeks to strengthen regional innovation ecosystems to reduce inequalities Specific sectors, fields and technologies include: automotive and other industries and their regional suppliers • education • public administration.	Resilience goals during a transition relate to **securing value chains and enforcing disaster prevention**, as well as specific commitments to **strengthen the health care system**, increase the **attractiveness of health care jobs** and promote the **digitalisation** of the health care system. Specific sectors, fields and technologies include: • health care • global value chains • critical infrastructures • disaster prevention and civil defence • business continuity in essential areas.	Competitiveness focuses on improving **resource and energy efficiency**, supporting the **climate agenda** and using **digitalisation** to improve competitiveness in STI. Technological sovereignty is seen as a central pillar of future competitiveness. Commitments include developing **competence centres** and **regional hubs** in AI, quantum technology, hydrogen research, future communication technologies (6G) and cyber security. Specific sectors, fields and technologies include: • energy and climate • machine learning/AI • quantum technology • hydrogen • future communication technologies (6G) • cybersecurity.	Digitalisation is considered a crucial component of Germany's **competitiveness** and vital to addressing inclusivity issues. The government pledges to **digitalise** the **education and health care sectors.** Specific sectors, fields and technologies include: • education • health care.

Source: Einhoff, McGuire and Paunov (Forthcoming[2])

5.1.1. Strategy for research and innovation

One of the most important national strategic documents for STI is the strategy for R&I, which, currently in its fourth edition, is entitled “High-Tech-Strategy 2025” (BMBF, 2021[3]) – a new strategy entitled Future Strategy for Research and Innovation” (Zukunftsstrategie für Forschung und Innovation) is set to be published in the autumn of 2022. The R&I strategy is led and primarily funded by the Federal Ministry of Education and Research (BMBF) but involves co-ordination with and funding from all others, with several areas falling under the remit of BMWK. The R&I strategy has evolved considerably over the more than 15 years since it was established and is now one of the clearest expressions of “mission-oriented” policy in German STI.

The first R&I strategy, entitled “High-Tech Strategy” (HTS), was introduced in 2006 as an umbrella for the existing innovation policies from all departments of the German Federal Government that fund STI. The HTS aimed to provide an “all-of-a-piece R&I policy” by co-ordinating and orchestrating the programmes and policies of the Federal Government. This aim persists across all four releases of the R&I strategy published in each legislative period. The first R&I strategy was still technology-oriented, as it defined 17 technology fields of specific interest under the responsibilities and interests of several ministries. As these technology fields, as well as the policy programmes and actions, were in many ways a continuation of existing policies, observers and analysts criticised the HTS as being “old wine in new skins”. Furthermore, no integration or intersection with innovation policies between the Federal Government and regional governments, or the European level is observed in the HTS.

From today's perspective, however, the R&I strategy has resulted in clear changes to innovation policy and measurable effects. In addition to the overall co-ordination effects across governmental departments and even within a few ministries, several new policy approaches and perspectives have been introduced. For example, additional co-ordination and integration at the lower level of individual policy programmes occurred in the aftermath of the HTS. For instance, earlier SME tools devised by the Ministry for Economic Affairs and Energy (now the Ministry for Economic Affairs and Climate Action, BMWK), like PRO-INNO, NEMO and INNOWATT, were integrated into the new ZIM programme, which became Germany’s most important and effective SME programme and is still one of its largest innovation programmes, with an annual budget of over EUR 500 million. New policy approaches like the Leading-Edge Cluster Competition (renamed Clusters4Future in 2019) and the Excellence Initiative were established during this first edition of the R&I strategy. The HTS led to the Pact for Research and Innovation, which gives budgetary planning responsibility to non-university research organisations, who in exchange agree to co-ordinate better, collaborate more intensively and contribute to overarching policy objectives.

The HTS explicitly set overarching policy aims like the “3% goal” (i.e. spending 3% of GDP on R&D) and the 10% goal (spending 10% of GDP on science, technology and education). While the 10% goal’s public visibility slowly deteriorated and it was not explicitly addressed in later periods, the 3% goal was continuously reached and during the 2018 edition of the HTS was increased to 3.5%. By the end of the first R&I strategy, the number of researchers in the German innovation system had increased by more than 100 000 – in public and private research labs – and the share of GDP spent on R&D had grown from 2.5% in 2006 to 2.9% in 2010, with stronger increasing public budgets in this first period of the HTS owing to the global financial crisis and the delayed leverage effect of public spending. The first R&I strategy definitely put STI higher on the agendas of policy makers and stakeholders, leading to higher visibility and higher budgets.

In 2010, the government adopted an updated and revised HTS. This version emphasised more strongly and concretely global and societal challenges as central to R&I policy and identified five such challenges: climate and energy, health and nutrition, mobility, security and communication (BMBF, 2021[3]). It also introduced the notion of directing R&I policy towards specific missions and suggested several “projects for the future” (*Zukunftsprojekte*), including “the CO^2-neutral, energy efficient and climate-adjusted city”, “treating illnesses better with individualised medicine”, “sustainable mobility” and “Industry 4.0” (BMWi, 2021[4]). Successors of the HTS were introduced in 2014 and 2018, providing the clearest case of mission-oriented policy approaches in Germany.

The analysis of the R&I strategy shows that Germany has been more ambitious than other countries with regard to identifying and propagating missions in key strategy documents (particularly the HTS 2025). However, experience with mission-orientated innovation policy is still limited, and it will be necessary to further explore how best to co-ordinate it in the context of strong ministries.

5.1.2. Pact for Research and Innovation

The Pact for Research and Innovation has run in five-year periods since 2005 (BMBF, 2022[5]). It is an agreement between the federal state (BMBF) and the *Länder* to provide stable and predictable institutional funding increases to the four major public research organisations (PROs) and the DFG. Its original aim is to increase enhance their strength and competitiveness, promote co-operation and co-ordination of research, develop the workforce, identify and enter new research areas, and improve links to the economy through collaboration with existing firms and spinning off new ones. In return, the organisations must meet specific policy-related performance targets:

- Pact I (2005-10) provided 3% per year nominal funding increases;
- Pact II (2011-15) had very similar goals, but offered budget growth of 5% per year;
- Pact III (2016-20) returned to 3% per year budget increases. It largely maintained the existing goals, but added a requirement to make internal procedures more family-friendly and to include a minimum of 30% of women in the beneficiary organisations' senior committees;
- Pact IV (2021-30) runs for ten years, but is subject to review after five. It provides budget increases of 3% per year and hones – rather than changes – most of the existing goals.

Excellence Initiative

The Excellence Initiative was launched in 2005 to create a subset of elite universities capable of competing internationally with global leaders (DFG, 2022[6]). It provided EUR 4.6 billion in additional research funding to higher education institutions (HEIs) from 2006 to 2017 (i.e. about EUR 420 million per year). In parallel, the (teaching-oriented) Higher Education Pact resulted in additional funding of EUR 4.5 billion from 2007 to 2020 (i.e. about EUR 320 million per year).

The Excellence Initiative emerged from a period starting in the 1990s where the performance of German universities was increasingly seen as average (Möller, 2018[7]) and a desire emerged to pursue something more akin to the model of prestigious "excellent" research universities that tended to reach the top of the international university rankings. Like other European countries, Germany adopted this approach to have strong research universities across all the regions with the aim of providing strong, locally accessible higher education for all.

The initiative underwent its first two rounds in 2005/06 and a further round in 2012. The formal aims of the initiative were to:

- support high-quality research in the interest of the economy
- mobilise and retain excellent researchers in the universities and German industry
- support cutting-edge interdisciplinary research to address demographic changes and international competitiveness
- improve the rankings of the best German universities in the face of the strong Anglo-American challenge and the rapid development of high-performing universities in Asia.

The Excellence Initiative was run by the DFG and the Science Council (*Wissenschaftsrat)* on behalf of BMBF. It established 40 graduate schools and funded 30 Clusters of Excellence; universities that won grants in both categories were awarded further development funding and labelled “Excellence Universities” (DFG, 2019[8]). Much of the initiative’s funding went to strong existing universities, especially in Southern Germany. In a context where all universities have been increasing their research productivity (in terms of publications per professor) and number of citations per paper, the effects of the initiative are not clearly discernible. While the productivity differential between Excellence and other universities remained substantial between 2004 and 2011, the citation rates of the non-Excellence universities have caught up with those of the Excellence Universities (Stockinger, 2018[9]). The initiative was replaced by the Excellence Strategy in 2019, which no longer funds graduate schools, but only Excellence Universities and Clusters of Excellence (BMBF, 2019[10]).

The Excellence Initiative appears to have hastened the rate at which beneficiary universities were able to increase their total research expenditure, and the likelihood of winning competitive research funding between 2003 and 2012 was much greater for the beneficiaries than the non-beneficiary universities (Möller, 2018[7]). Bibliometric analysis suggests that the effect of the initiative was to concentrate more highly cited work among the beneficiary universities, but that there was no increase in performance at the level of the German university system as a whole (Möller, Schmidt and Hornbostel, 2016[11]).

5.1.3. Other thematic innovation policy strategies

AI Strategy

The government adopted the National AI Strategy in 2018 and updated it in 2020 (BReg, 2020[12]). The strategy was the result of a nationwide online consultation, expert fora with research and industry, and a short series of consulting studies examining the opportunities in Germany and comparing AI strategies in other countries. The rationale for the strategy was that while Germany had a fairly strong position in AI research, there existed a need to respond to the huge investments being made abroad in AI research and application, especially in light of the sluggish adoption rate in Germany. The strategy is driven by BMBF, BMWK and BMAS, but other ministries also participate in niches, typically related to their sector as a potential adopter of AI.

The AI Strategy focuses on the development of ”weak AI”, in the sense of systems that are essentially supportive, as opposed to systems that aim to achieve levels of intelligent behaviours that imitate or rival human capabilities. This implies a focus on applied R&D rather than fundamental research, with the aim of using AI to support or establish competitive industrial positions. The strategy has three main goals:

- make Germany (and Europe) a leading centre for AI, thereby helping to safeguard Germany’s competitiveness;
- promote responsible development and use of AI that serves the good of society;
- integrate AI in society within ethical, legal, cultural and institutional structures, in the context of a broad societal dialogue and active political measures.

The strategy involves 12 fields of action with specific interventions. These include increasing funding for research and research transfer; expanding bi- and multilateral research collaboration; building up competence centres, application hubs, clusters, testbeds and AI observatories; providing AI-specific SME support, start-up funding and venture capital; improving the data architecture; strengthening AI training and skills; updating guidelines for the use of AI; disseminating information about AI applications in society; and establishing a social dialogue about AI. Funding was originally set at EUR 3 billion and subsequently raised to EUR 5 billion after publication of a progress report on the strategy.

The strategy goes beyond traditional “key technology” programmes in establishing a strong ethical and social responsibility dimension, as well as the early involvement of regulators. Until recently, however, it had no specific and measurable goals. It also involves other stakeholders and the general public only to a limited extent, and is not as strongly connected to demand-side measures or clear about the role of citizens. It is therefore a rather traditional – though wide-ranging and well thought-out R&I strategy that essentially assumes AI will be a ”plug-in” technology within the existing sociotechnical regime.

The energy transformation (Energiewende) and the national hydrogen and bioeconomy strategies

BMWK leads a major national and multidisciplinary strategy, *Energiewende,* targeting the energy aspects of the sustainability transition. Given the importance of developing and commercialising technologies that can both support the decarbonisation of the German economy and underpin the future competitiveness the country's private sector in this decarbonised context, *Energiewende* has significant overlaps with STI policy (European Commission, 2018[13]). Organised jointly under BMBF and the Ministry for Food and Agriculture (BMEL), the 2020 German National Bioeconomy Strategy aims to maximise the potential of the bioeconomy for Germany and strengthen the country's role as a bioeconomy leader (BMBF/BMEL, 2020[14]). A cross-ministerial National Hydrogen Strategy was published in 2020 (BMWi, 2020[15]). Chapter 11 describes these strategies in more detail.

Strategic initiatives in the field of quantum computing

In line with the framework programme “Quantum Technologies – from basic research to market” launched in 2018, the Federal Government is providing EUR 650 million for research into quantum technologies between 2018 and 2022 (BMBF, 2020[16]). In early 2020, the government also announced it was earmarking an additional EUR 300 million for this technology. Finally, the Federal Government's economic stimulus and future package, adopted in mid-2020, pegged an additional EUR 2 billion for quantum technology, including around EUR 1.1 billion allocated to BMBF funding for this research area.

Along these lines, BMBF is funding the development of quantum computer hardware, i.e. quantum computer demonstrators in Germany, within the related call published in 2021 (“Quantum Processors and Technologies for Quantum Computers”). The goal is to fund research on competitive German quantum computers with at least 100 individually controllable quantum bits (qubits) within 5 years, scalable to at least 500 qubits. The most promising technological approaches are being pursued to this end. The systems are based on domestic or European research results and made comprehensively accessible to users, for example through appropriate connection to a cloud. The work is intended to lay the foundation for an error-corrected system to be available in 10 to 15 years that will allow solving a universal class of problems, thereby achieving a broad benefit for the economy and society. Companies in the commercial sector, as well as universities and non-university research institutions, are involved in the funded projects.

These measures are accompanied by the BMBF call "Application Network for Quantum Computing", which funds projects that develop quantum algorithms and software to explore the potential of quantum computing in different application areas, such as energy networks or industrial manufacturing.

5.2. Direct and indirect public funding of R&D and innovation in Germany

Although the business sector is the single largest source of R&D financing in Germany, the government – at both the federal and regional levels – retains an important role in R&I funding. In many ways, the government's funding instruments and approaches – whether it be providing institutional funding for basic research, creating targeted funding programmes for certain actors or technologies, or providing indirect funding through the newly created R&D tax credit – are the most powerful levers available to it to shape and direct the country's innovation system.

5.2.1. Federal and state responsibilities in R&D and innovation

The policy mix in Germany is influenced by the division of responsibilities between the federal and *Länder* levels, and funding programmes are generally directed at the country's manufacturing sector rather than service-based firms. The federal level pays most of the cost of government activities in R&I. However, few programmes fund innovation-related activities other than R&D, and these programmes are themselves relatively small. In practice, innovation policy is mostly made at the level of the *Länder*, which tend to have and execute their own innovation strategies based on their individual characteristics. This also provides opportunities to direct large amounts of European structural funds in the poorer *Länder* at innovation, while taking advantage of the richer *Länder*'s ability to pay for innovation policy in their own territories. The combined effect is to focus the federal policy mix on formal R&D and technology transfer, as opposed to the later stages of the innovation process. The dominant instrument is direct funding of R&D, in the guise of collaborative grants to consortia bringing together actors from public research and industry.

5.2.2. Federal government financing of R&D

The Federal Government finances R&D through a variety of funding mechanisms and federal ministries; the largest contributions are made by BMBF (54.3% of total federal R&D financing in 2019) and BMWK (17.7% of total federal R&D financing in 2020) (BMBF, 2021[17]).

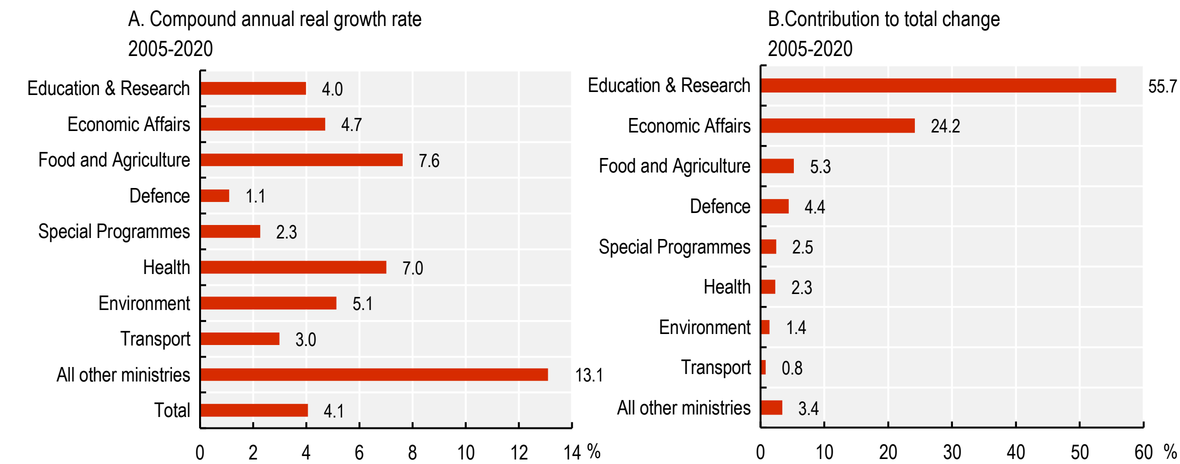
Most of the Federal Government's institutional funding of PROs and research-funding agencies (such as the DFG, which accounts for 45% of total federal R&D financing) is distributed through the BMBF budget. A further priority of R&D financing by BMBF is project-based funding within thematic programmes such as health; environment, climate and sustainability; microelectronics; high-performance computing; information and communication technology (ICT), including future communication technologies; cybersecurity; nanotechnology and new materials; bioeconomy; production technology; photonics; quantum technologies; civil security; and education, humanities and social sciences.

BMWK, for its part, finances R&D mainly through project-based programmes, including ZIM and some thematic research programmes (on energy, aviation and space technologies, transport technologies and some areas of ICT). In 2019, BMVg contributed 7% to total federal R&D financing, mainly by funding large defence R&D projects (including procurement). BMEL runs the fourth-largest R&D budget (3.6% in 2019) within the Federal Government. All other federal ministries contributed 5.3% of total federal R&D financing in 2019; 3.0% of the federal R&D budget is for special programmes that are not allocated to one of the federal ministries. In 2019, this mainly applied to the “Energy and Climate Funds”, which provides R&D financing for certain federal initiatives, including the E-Mobility initiative.

As Figure 5.1 shows, the substantial increase in federal R&D financing from 2005 to 2020, amounting to a +4.1% compound annual real growth rate (CARGR), was distributed unevenly across federal ministries: 55.7% of the increase was allocated to BMBF's budget (+4.0% CARGR), and 24.2% to BMWK (+4.7% CARGR). Above-average growth rates in R&D financing are reported for the federal ministries of food and agriculture (+7.6%), health (+7.0%) and environment (+5.1%), as well as for all ministries with low absolute R&D financing (+13.1%). Below-average growth reports were reported for the federal ministries of transport (+3.0%) and defence (+1.1%), as well as for non-ministerial special programmes (+2.3%).

Figure 5.1. Change in federal R&D financing, by federal ministry (2005 to 2020)

Compound annual real growth rate (CAGRG) (LH) and contribution to total change (RH)



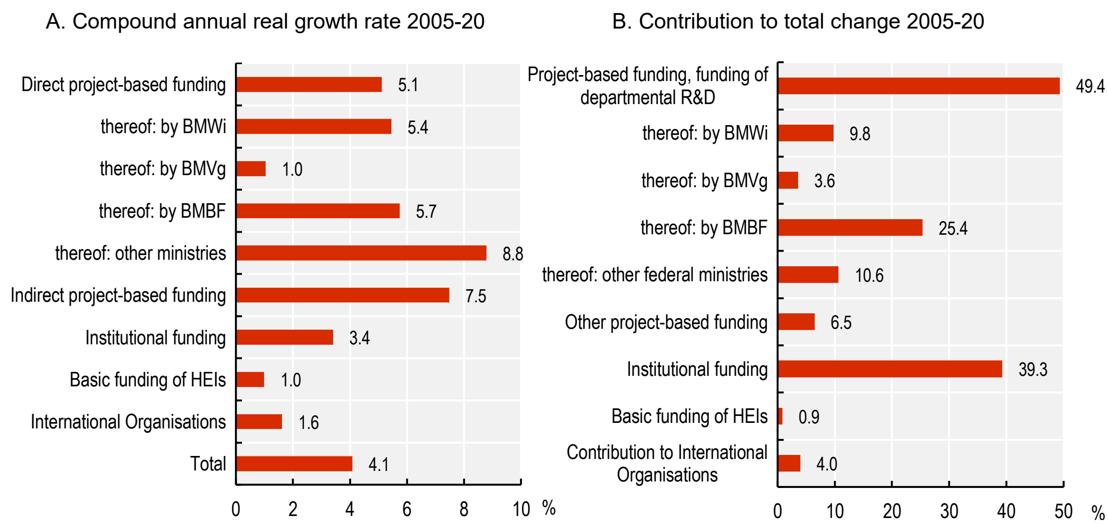
Note: LH = left hand. RH = right hand.
Source: BMBF (2022[18]), Federal Government expenditure on science, research and development, by departments (database), Federal Ministry for Education and Research (BMBF), https://www.datenportal.bmbf.de/portal/en/K1.html (accessed on 1 March 2022).

The Federal Government distributes R&D financing through two main channels: project-based funding for R&D projects (either targeting the development of specific technologies, labelled "direct" funding in many government documents, or targeting the diffusion of technologies, labelled "indirect" funding) and institutional funding of PROs (including the DFG). Project-based funding (including contract research) accounted for 49.5% of total federal R&D financing in 2020. Institutional funding represented 44.5% (including special federal funding programmes for HEIs, mainly for buildings and other fixed investment). The remaining share (6.1%) went to international organisations and international R&D programmes.

Between 2005 and 2020, 55% of the increase in federal R&D financing was distributed through project-based funding and 40% through institutional funding, implying a slight shift towards project-based funding. This is also reflected in the higher CARGR of project-based over institutional funding (Figure 5.2).

Figure 5.2. Change in federal R&D financing, by main instruments (2005 to 2020)

CARGR (LH) and contribution to total change (RH)



Note: LH = left hand; RH = right hand
Source: BMBF (2022[19]) Federal Government expenditure on science, research and development, by types of funding, Federal Ministry for Education and Research (BMBF), https://www.datenportal.bmbf.de/portal/en/K1.html (accessed on 20 April 2022).

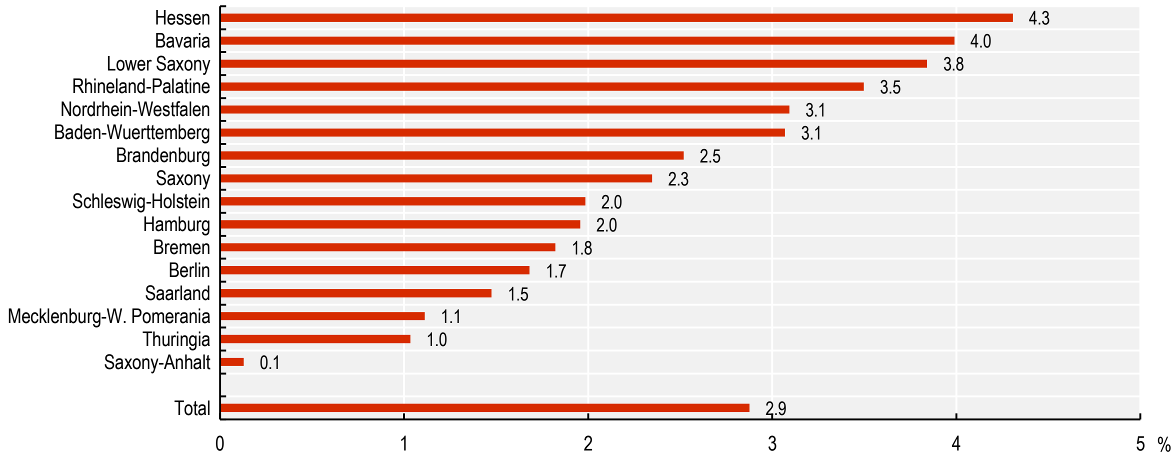
Federal R&D financing targets different groups of recipients. In 2019, 50.1% of total R&D financing went to PROs (including government agencies), 10.7% to HEIs, 12.6% to the DFG (mainly allocated to HEIs), 18.3% to businesses (including a very small share of business located outside Germany) and 8.3% to international organisations. These relationships did not change significantly between 2005 and 2020, although some shifts can be seen. R&D financing for HEIs and the DFG grew markedly faster (respectively by +5.8 and +6.8%), signalling the stronger engagement of the Federal Government in funding university research as part of the "Excellence Initiative". PROs reported a CARGR of 3.5%, slightly below the average CARGR of federal R&D financing (+3.9%). R&D financing for business enterprises (+3.1%), and for international organisations and programmes and other recipients abroad (+2.6%), expanded more slowly.

5.2.3. Regional government financing of R&D

From 2005 to 2017, R&D financing by regional governments grew by 2.9% (CARGR), but this increase was shared unequally across the 16 *Länder* (Figure 5.3). Several regions with strong manufacturing bases, including Hessen, Bavaria, Lower Saxony, Rhineland-Palatinate, North Rhine-Westphalia and Baden-Wuerttemberg, experienced above-average growth rates. At the same time, city-states (Hamburg, Bremen and Berlin) and all five states in Eastern Germany (Brandenburg, Saxony-Anhalt, Mecklenburg-Western Pomerania, Thuringia and Saxony) saw below-average increases in R&D financing.

Figure 5.3. Change in R&D financing of German Länder, by state (2005 to 2017)

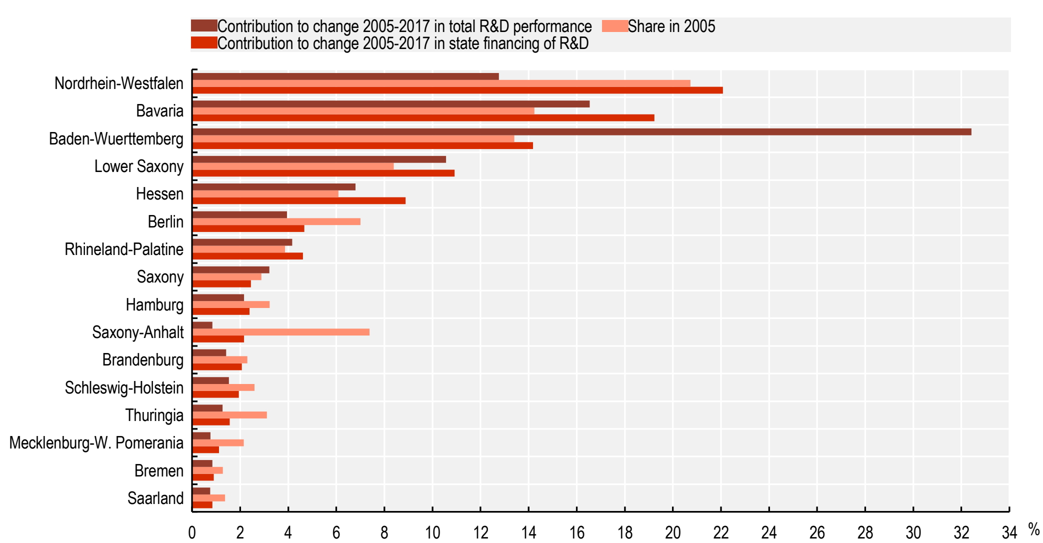
Compound annual real growth rate (%)



Source: BMBF (2022[20]), Regional distribution of R&D expenditure in the Federal Republic of Germany (implementation) and of government R&D expenditure by the Länder (financing), Federal Ministry for Education and Research (BMBF), https://www.datenportal.bmbf.de/portal/en/K1.html (accessed 1 March 2022)

The total increase in R&D financing by states from 2005 to 2017 (roughly EUR 5 billion) was mainly driven by just five *Länder* – North Rhine-Westphalia, Bavaria, Baden-Wuerttemberg, Lower Saxony and Hessen – which together contributed 75% (Figure 5.4). Their contribution in 2017 was significantly higher than at the beginning of the expansion period in 2005 (63%). This means that the expanded R&D by state governments strengthened the position of large western states with a strong innovation system. Both in 2005 and 2017, the share of these five states in total R&D performance (by business enterprises, HEIs and PROs) in Germany amounted to 78%, mainly driven by business expenditure as most of the large R&D-intensive corporations are located in these states.

Figure 5.4. Contribution to total change in R&D financing of German Länder, by state (2005 to 2017)



Source: BMBF (2022[20]), Regional distribution of R&D expenditure in the Federal Republic of Germany (implementation) and of government R&D expenditure by the Länder (financing), Federal Ministry for Education and Research (BMBF), https://www.datenportal.bmbf.de/portal/en/K1.html (accessed 1 March 2022).

The different dynamics of R&D financing by state governments stem from two main factors. First, the fiscal scope of governments is strongly linked to industry structure, GDP per capita and the costs of local social security expenditure. In this respect, large western states have a higher flexibility in providing additional funding for R&D than eastern states or city-states. Second, R&D financing by state governments is closely tied to funding HEIs and PROs. The expansion of R&D in the German science system since 2006 is closely linked to the Excellence Initiative and the Pact for Research and Innovation, both of which are based on bipartisan (federal and state) financing schemes. Hence, state governments with a strong science system are better positioned to attract additional federal funding to further strengthen their HEIs and PROs, either by expanding institutional financing or offering additional project-based funding (such as through the Hessian government's Loewe Programme).

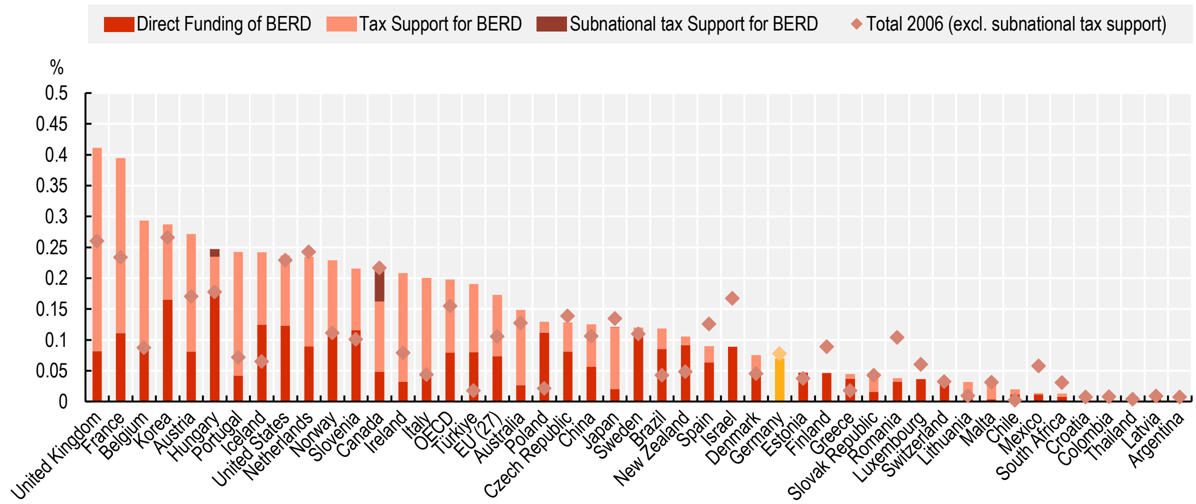
It is important to know that R&D financing is one (of many) mechanisms used to compensate for lower competitiveness of eastern and western states with structural problems (e.g. Saarland, Bremen and Berlin). Financing of the large HEI and PRO sector in these *Länder* serves to increase the regions' attractiveness for private investment, by offering a sufficient supply of a well-educated workforce and a knowledge infrastructure for co-operation among firms. Thus, eastern states as well as Berlin, Bremen and Saarland have the highest state R&D financing per GDP. At the same time, providing equal living conditions as much as possible across all regions of Germany has been a priority, in accordance with the respective article in the German constitution. Funding public science in all regions is a key element in this respect. Consequently, per capita R&D financing by state governments does not differ substantially across states, except for city-states (showing higher figures) and states close to major metropolitan areas (such as Brandenburg and Schleswig-Holstein) showing lower figures, as they are supplied by science institutions in the metropolitan areas (such as Berlin and Hamburg).

5.2.4. Indirect financing of innovation: R&D tax credit

In 2020, Germany introduced an R&D tax credit aiming to create incentives for firms (particularly SMEs) to increase their research expenditure. Expenditure-based R&D tax incentives are common across the OECD region to help address R&D market failures: they accounted for around 55% of total government support for business R&D in the OECD in 2017, up from 30% in 2000 (OECD, 2021[21]). In 2020, Germany introduced such a policy instrument for the first time, with the tax incentive subsidising business expenditure on R&D (BERD) of up to EUR 2 million each year (Figure 5.5). As part of the COVID-19 recovery package, the cap was increased to EUR 4 million per firm until the end of 2025, whereupon it will revert to the lower level. The incentive, known as the "Research allowance", allows firms to claim 25% of total in-house R&D personnel costs and up to 60% of extramural R&D costs for R&D contracts performed by contractors located in the European Economic Area.

Figure 5.5. Direct government funding and government tax support for business R&D (2019 and 2006)

As a percentage of GDP



Source: OECD (2021[21]), *OECD R&D Tax Incentives Database*, http://oe.cd/rdtax, April 2022.

The tax credit is a welcome addition to the policy instruments available to support STI in Germany. Similarly – and reflecting in part broader challenges with bureaucracy – several firms participating in focus groups for this review noted that the process of applying for the R&D tax credit was cumbersome, which could dissuade smaller firms with lower levels of internal administrative capacity.

5.2.5. Funding for thematic programmes

Germany has allocated significant funding for particular technology domains of current and future importance for success in the sustainability and digital transitions. These programmes cover a wide range, including electronics and microelectronics, high-performance computing, advanced ICT (including future communication technologies), cybersecurity, aviation and space technologies, materials, maritime technologies, nanotechnologies, quantum technologies, optical technologies and photonics, production and service technologies, and civil security. Many of these funding programmes have strong industry linkages. Responsibilities and budgets are divided between the two ministries. BMBF runs programmes for strategic, application-oriented basic research (technological-readiness levels 1 to 3) related to health, sustainability, climate protection and energy, mobility, urban and rural development, security, and economy and Work 4.0. BMWK runs applied R&D activities to help commercialise research, for example on industrial biotechnology and lightweight construction. Some other programmes start as thematically open competitions and become thematically focused during the execution phase. Section 5.3 describes funding arrangements for several key programmes.

5.2.6. Programmes with an international perspective

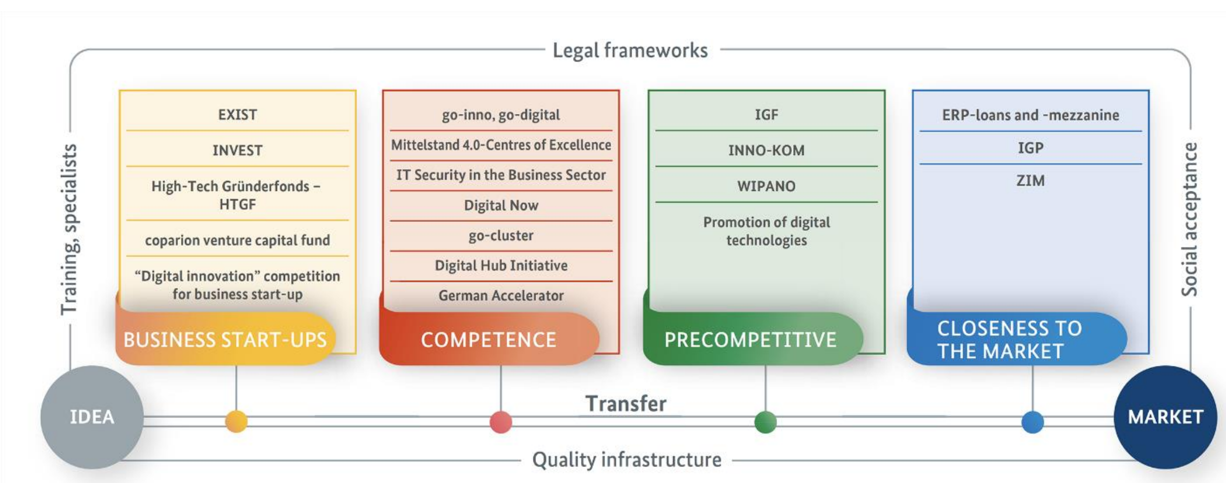
In addition to national participation in the EU framework programme, Eureka and various multilateral research organisations, such as the European Organization for Nuclear Research and the European Molecular Biology Laboratory, both BMBF and BMWK run programmes to help German research performers develop internationalisation strategies and companies establish small R&D partnerships. In 2017, BMBF updated its "Strategy on Internationalisation of Education, Science and Research" (2008) to reflect growing trends and challenges (such as digitalisation). The strategy focuses on global co-operation, developing the European Research Area, international business networking (especially for SMEs), and co-operation on vocational training with emerging or developing countries. The associated funding programme supports both academic institutions and SMEs (BMBF, 2022[22]). BMWK programmes also have specific funding portfolios for international co-operation. For example, the *Existenzgründungen aus der Wissenschaft* ('Start-ups from science') (EXIST)-Potentiale competition awards funds to universities and clusters to support the internationalisation of start-ups. Also, the ZIM programme provides specific funding for international innovation and cooperative R&D networks (BMWK, 2022[23]; BMWi, 2017[24]).

5.3. "From the idea to market success" and related programmes

Many BMWK programmes that support applied R&D are organised under an umbrella initiative, called "From the idea to market success" (BMWi, 2020[25]) Reflecting the importance of the *Mittelstand* to Germany's innovation system and, more broadly, to the country's economic competitiveness, BMWK has an expansive set of policy instruments to support SME innovation.

The "From the idea to market success" programme for an innovative SME sector comprises the major innovation policy instruments of the BMWK (Figure 5.6). Each of its four programme families targets specific challenges facing firms during the innovation process: early product development and funding ("Business start-ups"); competence development ("Competence"); precompetitive aspects of technology transfer ("Precompetitive"); and barriers during market entry ("Closeness to the market"). In addition to direct assistance, the overarching programme aims to promote an innovation-friendly ecosystem, public acceptance of innovation processes, and a functional and high-quality infrastructure.

Figure 5.6. From the idea to market success: Institutions and policies



Source: BMWi (2020[25]).

5.3.1. Business start-up programmes

The first programme family, "Business start-ups", aims to support start-ups in the early phases of the innovation process, especially by remedying the lack of funding for precommercial innovations and business ideas. This includes supporting innovative start-ups through a policy package combining R&D-related measures, financing, stimulating start-ups at HEIs, and consultancy and information services. Three of the main instruments to this end are the EXIST, INVEST and High-Tech Gründerfonds (HTGF) programmes.

Science-based start-ups – Existenzgründungen aus der Wissenschaft (EXIST)

Since the late 1990s, entrepreneurship and spin-off activities at higher education and non-university research organisations have been supported by the EXIST programme, under the auspices of BMWK. EXIST is one of the longest-running innovation programmes (BMWK, 2022[26]). It aims to improve the entrepreneurial culture and environment at universities and research organisations, which at the time was rather underdeveloped but has since improved. The programme helps students, graduates and scientists prepare technology-oriented and knowledge-based start-ups. Starting from five model regions, EXIST has expanded through several phases, substantially supporting the slow but steady rollout of entrepreneurship education across the German university system over the past two decades. The programme offers start-up scholarships to aspiring entrepreneurs of up to EUR 3 000 per month and covers material expenses up to EUR 30 000. In addition, it provides up to EUR 250 000 to participating high-tech start-ups in the funding phase and up to EUR 180 000 after the company is founded. Universities can also receive funding for project-related expenses of up to EUR 100 000 during the early concept phase (six months) and up to EUR 2 million during the following project phase (up to four years).

Zuschuss für Wagniskapital (INVEST)

Since 2013, INVEST has supported young innovative companies seeking venture capital (VC) funding, as well as private investors aspiring to become business angels (BAFA, 2022[27]). The programme has provided more than EUR 900 million in risk capital since its inception. It promotes investments in innovative start-ups through an acquisition grant of up to EUR 500 000 per year; once investors sell their shares, it provides an exit grant. INVEST's acquisition grant can support total investments per company of up to EUR 3 million per year. The tax due on a capital gain can be compensated as a lump sum with an exit grant.

High-Tech Gründerfonds (HTGF)

With the HTGF, the Federal Government set up a powerful platform-based support structure for start-ups – which, while not primarily science-oriented, can be leveraged to support the best and most relevant ideas from science as well (HTGF, 2022[28]). Arguably, the HTGF is the central vehicle of federal support for high-potential innovative start-ups. As a platform with its own investment managers, it combines funding from different public and private sources. Since its establishment in 2005, the HTGF has supported more than 600 investments, and had more than 150 successful exits and initial public offerings, and manages a portfolio of nearly EUR 900 million. In addition to providing capital, the fund provides the necessary support for the management of young start-ups: it extends initial funding of up to EUR 1 million, with a total of up to EUR 3 million usually available per company. In its first phase (up to November 2011), the fund extended a total of EUR 272 million in financing. The follow-up fund (HTGF II) provided EUR 304 million. A third fund, HTGF III, was launched in the third quarter of 2017, with a EUR 319.5 million financing envelope. In addition to support from BMWK and the KfW Capital, 33 private investors – either well-established SMEs or large corporations – have contributed more than 30% of the amount. To be eligible for financing, projects must have shown promising research findings based on innovative technology, and the market situation for the product must be promising. Further support programmes exist under the management of KfW and various local development banks, but their threshold for support is generally much lower. A new generation of the Fund (HTGF IV) with an investment volume of more than EUR 400 million was announced in June 2022 (BMWK, 2022[29]).

Other support measures in the "Business start-up" programme family

Three further initiatives complete this first programme pillar. The EUR 275 million **coparion VC fund** is financed by the European Recovery Programme (ERP) Special Fund, KfW Capital and the European Investment Bank (coparion, 2022[30]). Jointly with private investors, the fund invests in equity capital to support start-ups and SMEs under ten years old that are developing innovative products, processes or services. Via the **ERP Venture Capital Fund Investment programme**, also financed by the ERP Special Fund, KfW Capital can invest a maximum of 19.99% or EUR 25 million in German and European VC and VD funds. A total of EUR 180 million p.a. is available through this programme to strengthen the VC and start-up landscape. The "**Start-up Competition for Digital Innovations"**, held every six months since 2021, aims to attract innovative start-ups in the field of ICT. In each round, up to six start-up ideas will each be awarded EUR 32 000 in seed capital, and up to 15 further ideas will be awarded cash prizes of EUR 7 000. In addition, a special prize of EUR 10 000, thematically based on the Federal Government's Digital Agenda, is awarded during each round of the competition.

5.3.2. Competence programmes

The second programme family, "Competence", provides direct funding and consulting services to firms to improve their (digital) competencies, and also supports innovative clusters and firms, both regionally and abroad. The "go"-programmes and the *Mittelstand 4.0* Centres for Excellence are two of the main instruments in this second family.

Go-inno and go-digital

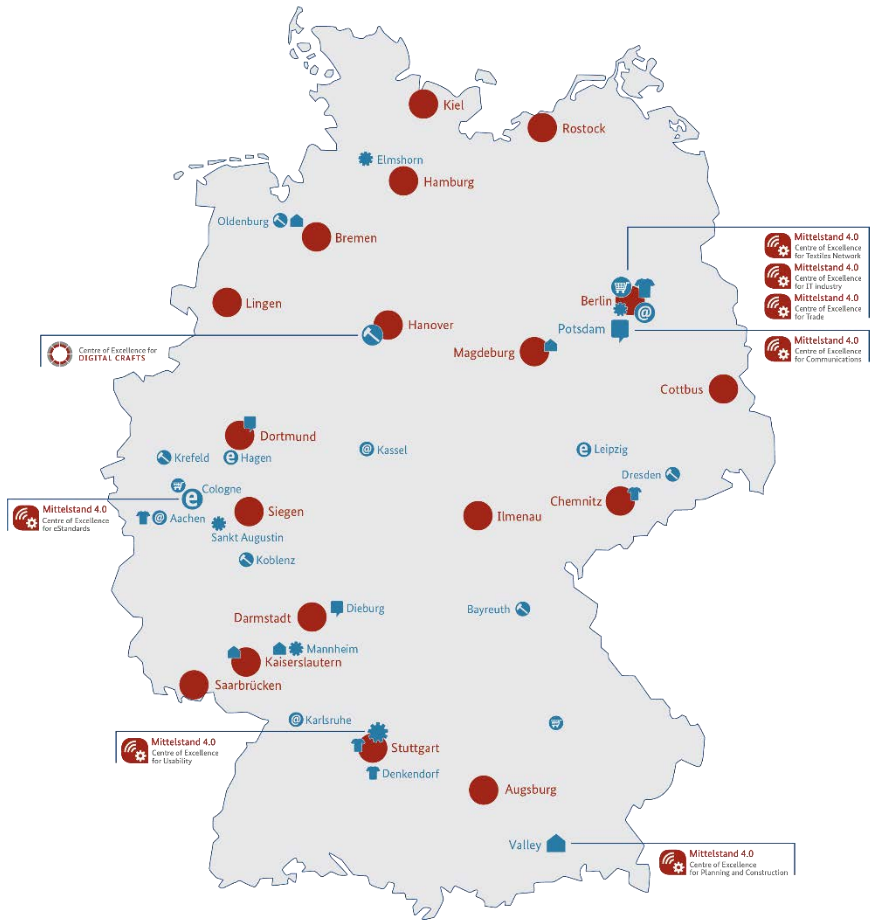
The "go-inno" and "go-digital" programmes fund external management and consulting services related to product and technical process innovations, and digital business processes (BMWK, 2022[31]). Go-inno specifically targets the preparation and implementation of product and technical process innovations, without thematic restrictions to specific technologies, products, sectors or branches of industry. The go-digital programme aims to provide the beneficiary company with expert advice by authorised consulting firms to support the implementation of necessary measures related to digitisation strategy, IT security, digitised business processes, data competence and digital market development. Go-digital and go-inno cover 50% of external consulting services expenses, up to EUR 1 100 per consultancy day.

Mittelstand 4.0 Kompetenzzentren (competence centres)

Since 2015, BMWK has established a total of 26 *Mittelstand 4.0* competence centres as part of the funding announcement "*Mittelstand 4.0*", which are located throughout Germany (Figure 5.7) (BMWi, 2020[32]). These centres act as regional and topic-related contact points for SMEs, and have significantly raised awareness among SMEs of the opportunities and challenges of digitisation. *Mittelstand 4.0* competence centres offer neutral, cost-free information, demonstration, qualification and accompaniment, including workshops, visits of demonstration plants, meetings with experts and practical support for SMEs developing their own digital solution. The *Mittelstand 4.0* competence centres are separate consortia of universities, Fraunhofer institutes and other external partners (like chambers of commerce). Within these consortia, each partner takes on a specific role tied to its area of competence (e.g. 3D printing, flexible manufacturing or new business models). All partners act together to promote the overarching topic of digital transformation. The internal evaluation reports from the *Mittelstand 4.0* competence centres show many positive effects emanating from the centres. SMEs who were involved in concrete development projects with the centres particularly benefitted from the support of the affiliated experts.

The way in which the measure was able to reach SMEs and organise support for their digital projects can be called a success story, especially for SMEs who had at least a basic interest in or affinity with digital technologies. Arguably, the *Mittelstand 4.0* competence centres contribute substantially to speeding up the integration of digital technologies in SMEs (BMWi, 2019[33]). However, as noted in the ministry's report, a more general assessment of the impacts of this measure is methodologically challenging because in addition to the competence centres, several other institutions (e.g. business associations, chambers of commerce and software suppliers) also support the digital transformation efforts of SMEs.

Figure 5.7. Location of Mittelstand 4.0 competence centres (2020)



Note: Red dots indicate the location of 4.0 Competence Centres. Blue dots denote contact points for cross-cutting topics.
Source: BMWi (2020[32]), Förderschwerpunkt Mittelstand-Digital: Die Mittelstand 4.0-Kompetenzzentren, https://www.mittelstand-digital.de/MD/Redaktion/DE/Publikationen/Factsheets/faktenblatt-mittelstand4.0.pdf?__blob=publicationFile&v=5 (accessed 1 March 2022).

Germany is not the only OECD country experimenting with new facilities for demonstrating and testing new technologies. Similar to the German competence centres, Norway's "Catapult Centres" aim to enhance digital technology adoption and diffusion. Similar initiatives from other countries include financial support for digital technology investments and other support services (e.g. the "SMEs Programme for Smart Manufacturing" in Korea and "service design vouchers for manufacturing SMEs" in the Netherlands) and improving access to state-of-the-art facilities and expertise (e.g. through high-performance computing centres in many European countries) (Planes-Satorra and Paunov, 2019[34]).

Other support measures in the "Competence" programme family

The second programme family, "Competence", features a range of other initiatives. **"IT Security in Business"** was initiated in 2011 by BMWK in co-operation with the business community to improve awareness of IT security among SMEs. The initiative primarily supports SMEs with concrete measures and expert assistance to improve their IT security when using ICT systems and implement basic IT security measures. It also aims to facilitate the transfer of knowledge and technology to SMEs, create awareness of IT security, and promote networking with multipliers and other initiatives. A transfer office is accessible through a virtual and mobile (tour bus), as well as through 80 regional showcases at trade association offices (BMWi, 2019[35]).

"**Digital Now – Investment Support for SMEs**" aims to encourage SMEs to invest in digital technologies and know-how across industries and regions in order to strengthen their competitiveness and innovative capacity (BMWi, 2020[25]). The programme funding is structured around two modules. The first covers investments in digital technologies and related processes and implementations, such as data-driven business models, AI, cloud applications, big data, IT security and data protection. The second finances investments in employee qualification measures related to digital technologies, including qualifications or further training in digital transformation, digital strategy, digital technologies, IT security and data protection, digital and agile working, and basic digital skills.

"**Go-cluster"** supports regional innovation clusters in their efforts to build networks and promote exchange with other national and international clusters (BMWi, 2020[25]). The programme offers project-funding grants of up 50% of the total eligible expenditure or a maximum of EUR 100 000 per project across three funding priorities, as follows: 1) support clusters seeking to develop and pilot new concepts for strategic innovation and foresight management; 2) support clusters seeking to identify and develop new fields of action and turn them into a business or revenue model; and 3) provide open-topic funding for the development and piloting of new cluster services without thematic predefinition, as well as cross-cluster project co-operation.

The **Digital Hub Initiative** supports the establishment of digital hubs across Germany connecting German and international start-ups with established companies, researchers and investors in a specific region, following the example of Silicon Valley (BMWi, 2020[25]). The hubs aim to promote networking and co-operation within and between hubs, and are expected to serve as platforms for dialogue with global market leaders and foreign investors. To facilitate such interactions, the initiative developed a joint brand ("*de:hub*") and created a joint "Hub Agency". Efforts are ongoing to develop an international marketing campaign to build the hubs' reputation abroad and attract international start-ups, scientists, companies and investors. Hubs currently exist in 12 cities, each focusing on a particular industry (e.g. the IoT&Fintech hub in Berlin, the Digital Hub in Karlsruhe focusing on AI, and the Digital Chemistry and Digital Health hub in Ludwigshafen/Mannheim) (Planes-Satorra and Paunov, 2019[34]).

The **German Accelerator** was created in 2012 to support German start-ups in their international expansion, with locations in San Francisco, New York, Boston and Singapore, and a number of business angels and mentors (BMWi, 2020[25]). Participating firms receive free office space and access to a global network of partners and investors. More than 240 start-ups have successfully participated in the programme since its launch, receiving funding totalling more than USD 3 billion. The German Accelerator is managed by German Entrepreneurship GmbH and supported by the BMWK.

5.3.3. Precompetitive programmes

The third programme family, "Precompetitive", supports joint R&D projects of SMEs and industrial research institutes as well as the commercialisation of research results. Its most important programmes are "*Industrielle Gemeinschaftsforschung*" (IGF), "INNO-KOM" and "WIPANO – Knowledge and Technology Transfer through Patents and Standards".

Industrielle Gemeinschaftsforschung (IGF)

In 2020, IGF provided EUR 201 million for R&D projects performed by member organisations' research institutes (30% in 2020), HEIs (55%) and PROs (15%), for (mostly co-operative) projects (BMWi, 2020[25]). SMEs do not directly receive funding within such projects but are involved in the definition of R&D projects and can use the project results. In 2020, the German Federation of Industrial Research Associations (AiF) reported that almost 25 000 SMEs were involved in the 1 876 projects funded by IGF in 2020, amounting to about 13 SMEs per project. A subsidiary company of the AiF also serves as a programme agency for the ZIM programme (co-operative projects only).

INNO-KOM

INNO-KOM supports non-profit industrial R&D institutes in eastern – and since 2017, western – Germany regions with structural problems, as defined by the constitutional Joint Task "Improvement of the regional economic structure" (Gemeinschaftsaufgabe Verbesserung der regionalen Wirtschaftsstruktur [GRW]) (BMWi, 2020, p. 17[25]). The programme provides about EUR 75 million per year for R&D projects and R&D-related investments. The R&D projects are usually performed by the institutes without external partners. Knowledge transfer towards industry takes place through contract R&D for SMEs and other firms, based on the knowledge and technologies obtained from publicly funded projects.

WIPANO – Knowledge and Technology Transfer through Patents and Standards

A programme that is key to the commercialisation of public research results through channels other than start-up creation, WIPANO has supported universities and non-university research institutions in identifying, protecting and exploiting economically promising research results since 2016 (BMWi, 2020[25]). Companies (primarily SMEs), universities, universities of applied sciences and non-university, publicly funded research institutions are eligible to apply to one of four funding lines. WIPANO extents about EUR 26 million in funding per year.

5.3.4. Closeness to the market

The fourth programme family, "Closeness to the market", comprises two major innovation policy programmes. Launched in 2019, the Innovation Programme for Business Models and Pioneer Solutions (Innovationsprogramm für Geschäftsmodelle und Pionierlösungen [IGP]) is a new pilot measure that funds non-technical innovations by self-employed persons, start-ups and SMEs, often in digital and service industries. IGP funds different vehicles, including experimental projects and feasibility tests; market tests and pilots; and cross-sectoral innovation networks consisting of at least five SMEs which are supported by a network management institution, and whose actors exchange knowledge on cross-sectoral innovation topics, develop ideas and implement innovations.

Zentrales Innovationsprogramm für den Mittelstand (ZIM)

The major instrument of open support for SMEs' R&D activities is ZIM, which emphasises co-operation and networking activities targeting SMEs' innovation performance in all technologies and sectors (BMWi, 2020[25]). ZIM has been administered by BMWK since 2008, when it was launched as a merger of several predecessor programmes. Since its introduction in July 2008 and up until June 2018 included, ZIM had funded over 28 000 projects by nearly 18 000 companies, of which 47% were first-time applications (Kaufmann et al., 2019[36]). In 2019, ZIM supported more than 3 550 projects with EUR 559 million. With its three programme pillars (individual R&D projects, R&D co-operation projects and networks), ZIM is in terms of volume one of the most important instruments of innovation policy in Germany.

A recent evaluation shows that ZIM has a well-defined position in the national funding portfolio thanks to its bottom-up attributes (no thematic delimitation), focus on experimental development in SMEs, project sizes and funded cost types, as well as the reduced administrative effort for applicants (Kaufmann et al., 2019[36]). The number of applicants who are funded for the first time by ZIM is high, which is a positive indicator of the programme's openness. In the Kaufmann et. al assessment of the ZIM programme, the authors found that participation in the programme had a positive effect on R&D turnover intensity. For a representative company, the effect is estimated at 4 to 6 percentage points – which, based on an average 4.3% R&D turnover intensity, corresponds to around doubling. ZIM has already significantly reduced the administrative requirements and is therefore also suitable for SMEs with little R&D experience.

Compared to BMBF or EU programmes, ZIM mainly targets companies with a less-pronounced R&D inclination. However, the demands on the level of innovation of the applicant projects, and the level of contributions by the companies, favour companies with more R&D experience. One empirical analysis showed that the effect primarily exists at the level of additional R&D in companies that are already active in R&D (Kaufmann et al., 2019[36]). This means that regularly R&D-active companies can maintain their level more easily thanks to the funding, and that previously irregular R&D-performing companies can conduct more follow-up projects. To a much lesser extent, ZIM also appeals to companies that originally performed little or no R&D. ZIM funding guidelines were adjusted in 2020, and now offer better conditions for co-operative innovations and first-time innovators. One of the reasons for these adaptations was the need to ensure higher complementarity of ZIM with the new R&D tax credit.

5.3.5. Related programmes

This section summarises other programmes with objectives related to the “From the idea to market success” initiative.

Support for cluster initiatives

At the federal level, Germany has a respectable history of cluster initiatives dating back to the 1990s. BMBF has traditionally funded ambitious, science-based clusters, such as in biotechnology. More recently, it funded the “Leading-Edge Cluster Competition” (2007-17), which supported 15 Clusters of Excellence and their partners, and is currently running the “Clusters4Future” competition. Since 2012, BMWK has funded the “go-cluster” programme, covering technical services and advice rather than R&D. Multiple regional cluster schemes complement these initiatives. For example, as part of the “Innovation and Structural Change” initiative and previous programmes, BMBF has run a series of regional innovation initiatives in the “New *Länder*” and structurally weak regions in the western part of Germany, with the aim of reducing regional disparities. The Federal Ministry of Education and Research (BMBF), for its part, has supported over 500 regional initiatives since the 1990s to strengthen regional innovation systems.

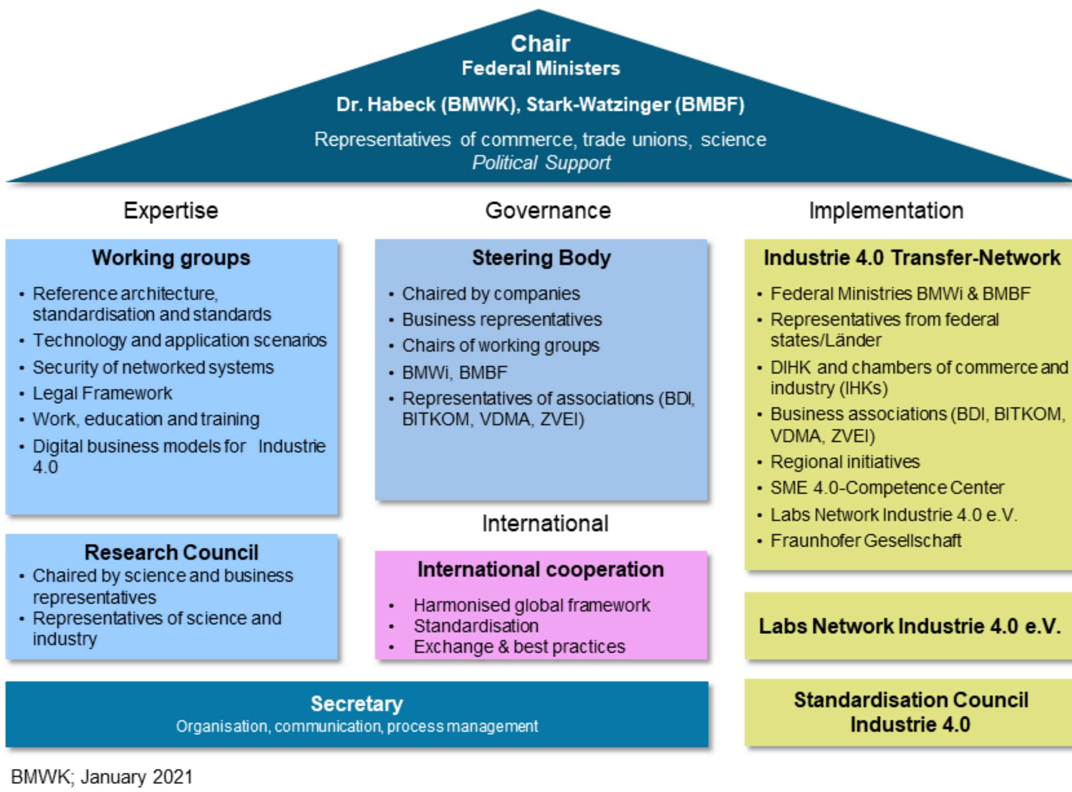
Support for science and technology-based start-ups

BMWK, BMBF and Länder governments provide a wide palette of support for science and technology start-ups. As an early step in the innovation chain, the “Validation of the technological and societal innovation potential of scientific research (VIP+)” and “Research at Universities of Applied Science” programmes administered by BMBF support universities in taking scientific ideas further, by funding both R&D and validation (proof-of-concept) projects. The BMBF initiative “StartUpSecure” supports young companies (particularly start-ups) in developing new ideas for IT security. The BMBF initiative “Enabling Startup – Unternehmensgründungen in den Quantentechnologien und der Photonik“ aims to transfer innovative ideas in quantum technologies and photonics from universities and research institutions to spin-offs for application and commercialisation. To this end, it will particularly fund alliances between individual start-ups and university or research institutions.

Industry 4.0.

Industry 4.0 is a platform engaging about 150 organisations. Its purpose is to encourage, co-ordinate and disseminate information about the opportunities offered by more advanced and systemic digitalisation in manufacturing. Within the two funding programmes "Autonomik für Industrie 4.0" and "Smart Service Welt", the BMWK is providing nearly EUR 100 million for R&D for innovation. (BMWK, 2022[37]). The project was proposed in 2013 by an Acatech working group with wide membership across the manufacturing industry and research (Acatech, 2013[38]). The BMWK and BMBF ministers lead the platform, together with a committee of senior industry and research figures. Key activities include running working groups (listed in Figure 5.8) to define and co-ordinate responses to issues, as well as providing broad information and advice services in the Industry 4.0 Transfer Network (which includes regional centres) as well as the Mittelstand-Digital network, particularly to serve the *Mittelstand*. While the platform funds work to showcase examples of successful projects, it relies on the ministries' ordinary R&I support programmes to fund R&I projects.

Figure 5.8. Organisation of the Industry 4.0 platform (2022)



Source: BMWK (2022[39]). Structure of the Plattform Industrie 4.0, Federal Ministry for Economic Affairs and Climate Action (BMWK), https://www.plattform-i40.de/IP/Redaktion/EN/Bilder/graphic-plattform-4-0.html (accessed 1 August 2022).

Zukunftsfonds (Future Fund)

Jointly managed by BMWK and KfW, the Future Fund aims to expand (both qualitatively and quantitatively) the federal support architecture, particularly the financing options available to start-ups in the capital-intensive scale-up phase (BMWK, 2022[40]). The government has allocated EUR 10 billion have for the fund's investments and costs. The ERP Special Fund also makes financial contributions to several components of the Future Fund.

The concept of the Future Fund, which covers a ten-year funding period, is to increase the available capital stock through successful investments and thus create a greater volume for re-investment without negatively impacting the budget. Several components of the concept are already available, and additional elements are currently being developed and implemented. The various components are closely linked and serve as a toolbox. The instruments will be adjusted, especially as regards the volume of allocation, taking into account the changing market environment and new needs. Further public and private investors are to make funds available for the various components, bearing the related risks of these funds. The following components have already been launched:

- **ERP/Future Fund Growth Facility:** KfW Capital is investing up to EUR 50 million per fund through this facility. Together with its ERP Venture Capital Fund Investment programme, KfW Capital can consequently now invest up to EUR 75 million per fund. KfW Capital will thus contribute to increasing the fund volumes of VC funds in Germany and Europe, facilitating more frequent and larger financing rounds for start-ups. A total of EUR 2.5 billion will be available up to 2030 for the ERP/Future Fund Growth Facility.
- **GFF-European Investment Fund (EIF) Growth Facility:** in line with the existing ERP-EIF Growth Facility, a new growth facility with a volume of up to EUR 3.5 billion was established to invest in growth funds and growth-financing rounds for start-ups. Again, larger fund volumes can facilitate more frequent and larger start-up financing rounds.
- **DeepTech Future Fund:** a new investment fund in the field of deep tech, the DeepTech Future Fund will be financed on a long-term basis by the Future Fund and the ERP Special Fund. Its purpose is to help deep-tech companies with validated business models grow sustainably while remaining independent. To this end, the DeepTech Future Fund always invests together with private investors. The aim is to support deep-tech companies as an anchor investor on their way towards capital-market maturity. The fund will further strengthen Germany as an innovation hub, as it provides a long-term perspective and makes the country more attractive to high-tech companies. Up to EUR 1 billion is expected to be available for the DeepTech Future Fund over the next ten years.

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Part III Sowing seeds, fertile ground: getting the conditions right for innovative entrepreneurship

6 Framework conditions for innovation in Germany

This chapter discusses the key framework conditions necessary for innovation in the German economy. These include the regulatory framework for innovation, digital and data infrastructure, as well as skills, education and labour market conditions. The chapter introduces recommendations on simplifying the operational environment for innovative firms through more effective digitalisation of government services and the adoption of more agile policy approaches. Although regulatory conditions for innovative firms in Germany are generally strong, there is scope for simplification. Similarly, despite Germany's well-educated population, the private sector faces a number of skill shortages and labour market rigidities that may affect its ability to perform innovative activities. With the growing importance of the digital economy and data-driven innovation, it is essential for Germany to invest in better digital and data infrastructures.

Introduction

Companies' ability to invest, experiment and innovate is shaped by framework conditions, including notably a well-functioning regulatory framework, access to capital, and an educated and skilled labour force. Moreover, with the digital transformation, connectivity and a high-quality data infrastructure are paramount.

Easing framework conditions and improving access to science, technology and innovation (STI)-related policy information – such as by reviewing the available support schemes – is particularly relevant for smaller players and start-ups. While framework conditions matter to all firms, smaller companies often have lower internal capacities to deal with business-environment and regulatory challenges, and therefore risk being disproportionately affected by framework conditions. Start-ups are also often at a disadvantage when it comes to accessing STI-related policy information and support programmes, as they lack prior experience.

Although framework conditions are important for incremental innovations, they are even more important to spur wide engagement of innovation actors in the disruptive innovation activities needed to support the green and digital transitions. The digital infrastructure, for instance, is essential to both transitions. Access to finance is necessary to invest in disruptive innovation, and the provision of funding to *Mittelstand* and start-up firms is therefore essential.

This section presents evidence on key framework conditions for innovation in Germany: the broader regulatory framework for business, access to finance for innovative firms, labour-market regulation and performance, skills, education, and the development of a digital and data infrastructure that can support innovation needs.

The chapter is split into five sections. Section 1 begins with a recommendation on improving the agility of policy making to support innovation. Section 2 considers the overall regulatory and legal framework for business. Section 3 reviews the digital and data infrastructure for innovators in Germany. Section 4 looks at labour-market conditions. Section 5 concludes with a discussion on skill capabilities and shortages in the German innovation system.

Recommendation 3: Broaden and mainstream the use of agile policy tools to support innovation efforts by SMEs, and achieve the digital and green transitions

Overview and detailed recommendations

The Federal Government should consider mainstreaming policy tools (such as regulatory sandboxes) to maximise their potential for change, normalise the use of such methods in the context of its approach to STI and generate more data for policy evaluation. Regulatory sandboxes (*Reallabore*) refer to a limited form of regulatory waiver or flexibility that enables firms to test innovative technologies, products or services which are not yet fully compliant with the existing regulatory framework. At the same time, the government should build greater flexibility into existing areas of regulation and policy, and adopt a more risk-taking and experimental approach to policy making in a context of important transformations.

R3.1 **Reduce bureaucratic and administrative barriers affecting SMEs and start-ups.** The government should both rationalise the processes required for certain government-to-business services, as well as the administrative steps required for firms to receive STI policy-support measures (such as innovation grants). Some SMEs and start-ups will shy away from applying for support schemes because the application procedures are not easily accessible or straightforward. Where legal barriers impede the simplification and flexibility of support measures, the government should undertake a review of the changes required to streamline access conditions. Programmes such as ZIM (BMWK) and KMU-innovative (BMBF) have demonstrated good practices and the feasibility of increasing the rate of firms participating for the first time in initiatives supporting research and innovation.

R3.2 **The government should pursue a programme of digitalising government policy, services and processes.** The digitalisation of government services should proceed after the rationalisation of existing regulations and procedures. Pivoting to digital delivery would consolidate all interactions between firms – particularly SMEs and start-ups – in a single location, preferably a digital "one-stop shop". More than digitising existing analogue processes, this requires improving them (by reducing the number of intermediary steps), and collecting and analysing data from interaction with digital services to further improve and inform policy making. The integration of new tools, such as machine learning and semantic analysis, could both improve the quality of government policy and regulation, and enable the government to take an active lead in the digital transformation of the public and private sectors.

R3.3 **Expand the use of regulatory sandboxes**. Germany's adoption of the Regulatory Sandbox Strategy (as discussed in Chapter 15 on policy agility and the corresponding R2 on the establishment of a policy laboratory) has been a decisive step in the use of regulatory sandboxes, but additional focus should be placed on the following:

- Strengthening regulatory co-operation across various federal regulators – as well as among municipal, state and federal authorities – when implementing regulatory sandboxes: this is particularly important because emerging innovative areas often cut across traditional industrial sectors, and thus the mandates of regulatory authorities and federal ministries.
- Targeting SMEs and start-ups to ensure they have access to regulatory sandboxes and that the eligibility criteria do not exclude younger or smaller firms: the government should continue to organise awareness-raising activities (such as competitions) on the opportunities and possibilities of sandboxes, with a particular focus on SMEs and citizens. Establishing regulatory sandboxes also requires avoiding possible regulatory capture by participating firms.

R3.4: **Support an easy-to-use digital one-stop-shop for STI policy engagement.** Germany currently provides the private sector with a wealth of policy instruments to support innovation, but their overall effectiveness could be increased. To this end, the public administration should consider improving communication about these instruments, which currently includes a centrally co-ordinated platform listing the instruments, the Federal Funding Advisory Service (*Förderfinder des Bundes),* and individual consultation activities to allow firms to find offers matching their specific needs, the Federal Funding Advisory Service on Research and Innovation (*Förderberatung Forschung und Innovation des Bundes)*. Complementing these services with a full-fledged digital one-stop-shop for STI policy engagement of SMEs, start-ups and individual entrepreneurs would improve access and use of the support schemes. This digital one-stop-shop should also allow any firm (both domestic and international) to easily check its eligibility for different innovation-support instruments.. It would also integrate the existing consultation activities by centralising and digitising the back-office application processes for these instruments. The platform could also serve as a vessel for goal- and challenge-oriented innovation, increasing firm-level awareness of and participation in innovation programmes supporting socio-economic policy objectives.

Relevant global experience

Regulatory flexibilities

Digitally enabled products and emerging technologies often do not fit easily into existing regulatory frameworks, creating uncertainty for innovative firms. In addition, the pace of technological change, and the complexity of many of these technologies, create further challenges for regulators. Where digitally innovative firms face regulatory uncertainty – or even an absence of regulation – they may be disinclined to innovate, or unable to attract the funding necessary for innovation and business scaling. Recognising this issue, policy makers across the OECD have begun to experiment with their approaches to regulation, several countries moving towards a “test-and-learn” approach to regulating.

One of the most commonly used approaches – including in Germany – is regulatory sandboxes, a limited form of regulatory waiver or flexibility that enables firms to test new business models or products with reduced regulatory requirements. Sandbox approaches are useful for advancing German innovation in key industries (such as autonomous driving for the automotive industry), but also for achieving the green transformation of industry.

Two interesting examples that utilise sandboxes for green transitions are the United Kingdom’s “Innovation Link” and France’s “Experimentation”. The UK energy regulator Ofgem launched a regulatory sandbox called “Innovation Link” for innovators in the energy sector, which enables them to trial innovative business products, services and new business models that could not operate under existing regulatory conditions (Attrey, Lesher and Lomax, 2020[1]). The inspiration for the Ofgem sandbox came from software development, where it is common to test new code in a controlled setting without risking the integrity of the wider programme. The programme involves bespoke guidance for programme participants, and projects included peer-to-peer energy trading and innovative tariff systems. The experience of France’s “Experimentation” also highlighted the potential for sandboxes to support sustainability objectives, with a quarter of the 85 applications to its industrially and technologically agnostic programme focusing on environmental protection (Attrey, Lesher and Lomax, 2020[1]).

Regulatory flexibility also has an important role to play in supporting the digital transformation of the economy (OECD/KDI, 2021[2]). This is particularly true in the context of digital service platforms, which often blur the boundaries between sectors and industries (including banking), creating new regulatory challenges. The question of data regulation, which remains a complicated issue in the German context owing to the decentralised nature of data governance in the country, is particularly salient here. In 2016, the UK Financial Conduct Authority launched a regulatory sandbox programme that allowed businesses of all sizes to test innovative financial products in the market with real consumers. The programme objectives included allowing firms to test potentially disruptive products in a controlled environment, to reduce the time to market of commercially viable products and business models, and to identify consumer protection gaps in existing regulation related to these new products. Similar programmes have since been launched in a number of OECD countries, including Canada, where the Canadian Securities Administrators conducted a programme in 2016-19 to support finance and technology (fintech) firms through time-bound regulatory waivers to gain a better understanding of how innovations could affect financial markets (OECD/KDI, 2021[2]).

While many OECD countries have now begun to address issues of regulatory agility, these approaches remain mostly industry-specific. This is understandable, as many of these programmes are administered by domain-specific regulators. Mainstreaming these approaches in Germany – and monitoring their implementation under, for example, the policy forum suggested in Recommendation 1 or the policy laboratory discussed in Recommendation 2 – would offer the advantage of adding a greater level of directionality to these efforts, guiding them towards whole-of-economy transformational goals.

Agility is also important in the policy-making process itself. A range of new digital tools can enable policy makers to make better-informed decisions more quickly and efficiently. As discussed in the TIP report '*Alternative Tools to Support Innovation Policy: What is Feasible Today'*, a range of digital tools are becoming available to support policymakers and enable them to be more agile in their approaches to policymaking. These tools can support more granular and timely data collection (e.g. pulse surveys or web-scraping), more effective processing of evidence and data (for example, by using semantic analysis on textual data, natural language processing and artificial intelligence), as well as improve societal participation STI and STI policymaking (e.g. online and participatory digital platforms) – the importance of which will continue to grow in the transitional context.

Mission-oriented innovation policies

Mission-oriented policies are defined as a co-ordinated package of policy and regulatory measures tailored specifically to mobilise science, technology and innovation in order to address well-defined objectives related to a societal challenge over a defined period of time (Larrue, 2020[3]). These measures can span different stages of the innovation cycle, from research to demonstration and market deployment, supply-side and demand-side instruments, and cut across different policy fields, sectors and disciplines.

Mission-oriented innovation policies (MOIPs) in France belong to a long tradition of proactive policies to achieve strategic or economic objectives or, more recently, to respond to major societal challenges. These include in particular the Grands Programmes, the 'Thematic research networks' (Réseaux thématiques de recherche) such as PREDIT during fifteen years to support research for the automobile industry since the beginning of the 1990s, as well as the large-scale projects of the Industrial Innovation Agency (Agence de l'innovation industrielle) in the mid-2000s. The initiatives aimed at supporting a more strategic approach and allowing critical mass on national priority areas and projects in a policy landscape largely characterised has fragmented and multi-layered.

The fourth generation of the Future Investment Program (PIA4) launched in 2021 may mark a turning point. It is structured in two main so-called "intervention logics". The "structural logic" provides long-term sustainable funding to key research and innovation institutions. The "directed logic" promotes a more directional approach to support exceptional investments to meet 5 "Grand Challenges" (1. Securing, certification and reliability of artificial intelligence; 2. Improving medical diagnostics through artificial intelligence; 3. Cyber-security: making our systems sustainable resilient to cyber-attacks; 4. Producing high value-added proteins biologically and at a reduced cost; 5. Development of high density energy storage for sustainable mobility.) These challenges were selected by the Innovation Council, created in 2018 to define the main priority orientations of the French innovation policy, define cross-cutting actions and simplify the French research and innovation policy landscape.

The main instruments of the ‘Directed logic’ component are the Acceleration Strategies. In specific challenge areas, these large initiatives aim to identify the main socio-economic transition challenges and to invest to tackle these challenges using a global and systemic approach combining various modes of intervention (research, training, financing, standards and norms, taxation, etc.). The expected added value of Acceleration Strategies is not primarily in the novelty of the supported activities but in their stronger strategic steering and integration along the innovation cycle. While the objectives of the first PIA were politically determined in 2010 in the context of the 2008 financial crisis, the PIA4’s acceleration strategies are co-constructed by all relevant partners. For instance the “Digital Health” acceleration strategy resulted from a public consultation A dedicated working group of the Digital Health Council (CNS) on "economic development of digital health / structuring of the sector” also provided inputs for the preparation of the strategy. Each Strategy also has specific targets.

For instance the carbon-free hydrogen acceleration strategy has set targets for 2030, including the installation of a carbon-free hydrogen production capacity of 6.5 GW by electrolysis, the saving of more than 6 Mt of CO2 and the creation of 50,000 to 150,000 direct and indirect jobs in France. Each strategy has its own structure of governance, with a dedicated interministerial coordinator who report to the Innovation Council. The task of the coordinator is to lead the interministerial coordination and monitoring of all the actions implemented. The Carbon free Hydrogen Acceleration Strategy has a budget of EUR 3.4 billion during the period 2020-2023, and EUR 7 billion are planned until 2030. The Strategy covers all aspects related to the establishment of a hydrogen value chain (filière) from research to production, pipelines and markets. The Acceleration Strategy also aims to develop key technologies and components through pilot projects for different types of usages and markets.

Other countries have set up more integrated and focused missions at a lower level in their innovation systems, notably under the leadership of one or several agencies. In Norway, three agencies have set up ‘Pilot-E’, a joint initiative to serve as a one-stop-shop that provides seamless support from idea to market to various climate emission free and energy saving solutions. Within this cross-agency scheme, the three agencies mobilise their respective instrument portfolio to support jointly selected projects to reach collective goals with the aim to both initiate the necessary energy transition and develop new business activities.

Another type of mission-oriented policy, popular in Nordic countries, mainly relies on ecosystems. These initiatives aim at creating and structuring national or regional innovation ecosystems (bringing together public and private stakeholders from different research and business communities), around a common challenge. This model generally operates in two stages: 1) A call for roadmaps where public authorities provide incentives for the development of roadmaps proposed by ecosystems (established or emergent) to solve societal and economic challenges; 2) selection, engineering (e.g. mergers, reorientations) and support to the implementation of roadmaps, using the underpinning ecosystem to coordinate actions. This is the case of the Strategic Innovation Programme (SIP) led by the Swedish innovation agency Vinnova, the Finnish Growth Engines and the Danish Green Missions. This approach allows stronger directionality and legitimacy by delegating responsibilities related to strategic orientation and coordination to relevant community (ecosystems) of stakeholders in priority or emerging areas.

6.1. The regulatory framework for innovation and access to innovation policy: Information and support programmes

The regulatory framework for business refers to the legal conditions for a firm’s operations and affects all aspects of the business life cycle, including starting and closing a firm, accessing finance and exporting products. The regulatory framework interacts with the innovation system in several ways:

- Regulatory frameworks create legal stability which allows firms (both domestic and international) to make decisions on innovation investments.

- They also add costs to innovation, ranging from costs associated with opening an innovative business to obtaining approval for selling a new product.
- Finally – and particularly salient to innovation in emerging technological areas – the regulatory framework can give clarity, or create a lack of clarity, for innovators working on products and services at the technological frontier.

These aspects of the regulatory framework for firms occur in an environment that is dynamic and interacting with other economies and jurisdictions around the world, particularly the European Union. Consequently, the "ease of doing business" will also affect in which country international innovative activities are taking place.

A key challenge for policy makers and regulators is how to design governance strategies and regulations that prevent or mitigate the unintended and unknown negative consequences of scientific and technological developments, without stifling innovation and while harnessing the opportunities stemming from such advances. Laws and regulations also allow governments to influence the development of innovations and direct them towards the benefit of society, as well as minimising risks.

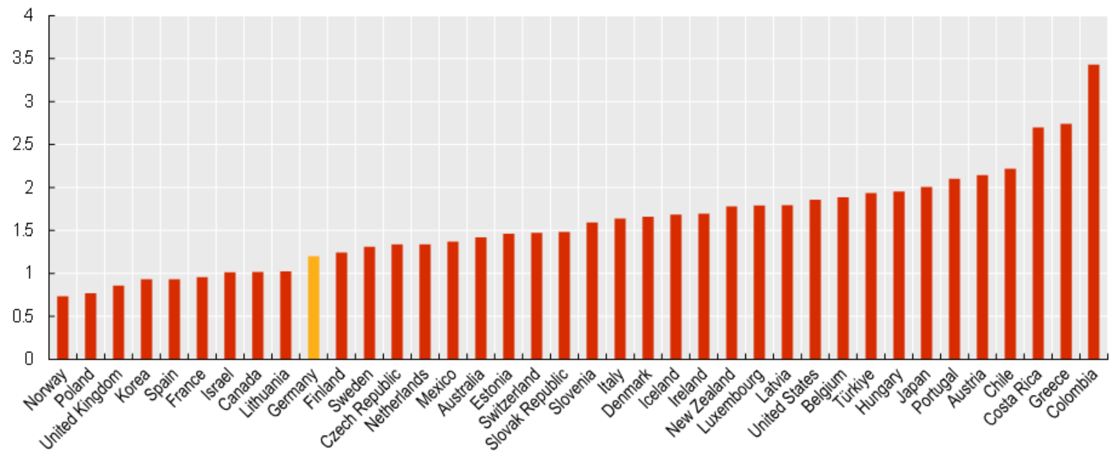
In addition to the general regulatory framework for business in Germany, policy makers face a number of key regulatory questions regarding innovation, particularly in the context of the green and digital transitions. What can be done to facilitate administrative framework conditions and access to policy information and support programmes for stakeholders in the STI ecosystem, particularly *Mittelstand* and start-up firms? How can policy makers advance innovation, reconciling the need for agility and flexibility in innovation regulation with the need for stability and predictability?

6.1.1. The regulatory environment for firms in Germany is generally strong, but a number of issues may weigh on the innovative capacities of firms

The quality of business regulations in Germany is generally high, and administrative barriers to entrepreneurship are low (Figure 6.1). Recent reforms, such as the introduction of a "one-in-one-out" rule for regulation offsetting – whereby regulators must abolish one regulation for every new one introduced within a year of the introduction of the new rule – has helped simply the regulatory environment for business (Trnka and Thuerer, 2019[4]). The third version of the *Bürokratieentlastungsgesetz* (the Law on reducing bureaucracy, introduced in 2015 as part of the "Bureaucracy Reduction and Better Regulation" programme) further lowered regulatory burdens for firms, creating an estimated EUR 1.1 billion (euros) saving for the private sector.

Figure 6.1. OECD Product Market Regulations: Simplification and Evaluation of Regulations (2018)

Germany is among the top OECD performers in terms of the simplification of business regulation



Note: The indicator is on a scale of 0 (least burdensome) to 6 (most burdensome), with the indicator established following a detailed questionnaire issued to the country in question

Source: OECD (2022[5]) "Economy-wide regulation", OECD Product Market Regulation Statistics (database), https://doi.org/10.1787/data-00593-en (accessed on 24 May 2022).

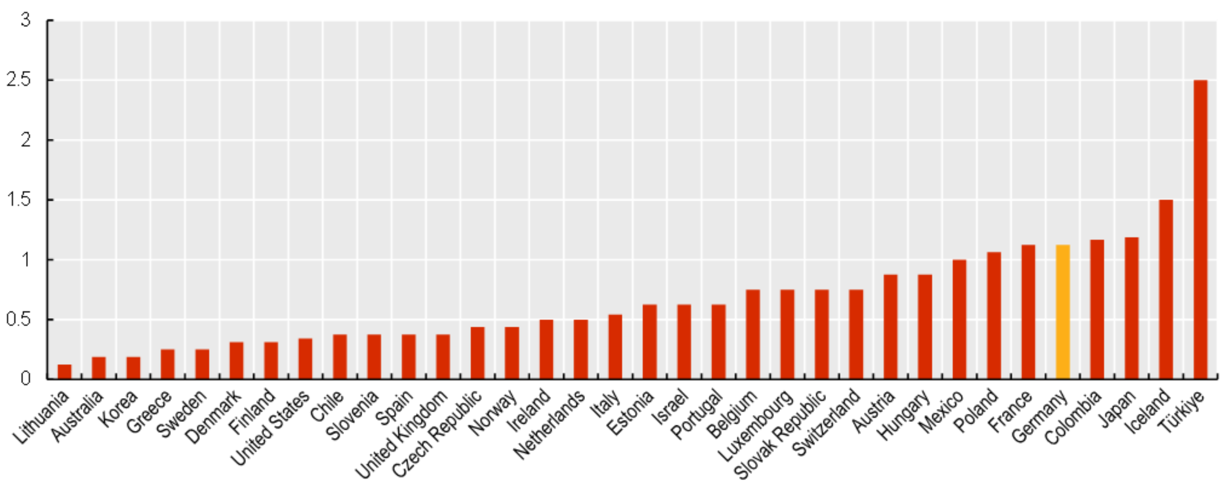
However, there exist opportunities for improvement: starting and closing a business in Germany is more difficult than in other OECD countries owing to lengthy and costly administrative procedures, many of which are only partly digitised. Administrative burdens for start-ups remain markedly above the OECD average (Figure 6.2). For example, starting a business in Germany requires entrepreneurs to make appointments with various administrative bodies, with the associated paperwork often remaining entirely analogue. This lack of digitalisation and consolidation stands in marked contrast to many OECD countries, where digital "one-stop-shops" for enterprise creation have been established.

While extensive information on Germany's many innovation-support instruments is available on the individual programme and institutional websites, identifying the most suitable support poses a challenge for smaller firms and start-ups in particular. Application procedures can also be complex, particularly if the documentation required varies strongly across programmes. In a 2021 survey conducted by BMWK during the COVID-19 pandemic, 89% of participating SMEs agreed that application processes for innovation-support measures should be both reduced and accelerated (BMWi, 2021[6]).

One action that might help reduce the administrative burdens and costs for firms would be to further pursue the digitalisation of public services. According to the OECD Digital Government Index, Germany currently scores the lowest among all OECD countries in the data-driven public-sector dimension. Better data-sharing across public services could significantly reduce the burden on firms using government services as it would limit the need to submit the same information multiple times to different public bodies (OECD, 2021[7]). An important step in this direction is the Online Access Law (*Onlinezugangsgesetz*) introduced in 2017, which requires public authorities at the federal, regional and local levels to make a range of administrative services digitally available by 2022.

Figure 6.2. Administrative burdens for limited liability companies and personally owned enterprises are high

Countries ranked in ascending order, from most (0) to least (6) competition-friendly



Note: For federal countries, where matters are regulated at state level, the values reflect the situation in one selected representative state (listed below).
Source: OECD (2022[5]) , "Economy-wide regulation", OECD Product Market Regulation Statistics (database), https://doi.org/10.1787/data-00593-en (accessed on 24 May 2022).

Identifying where regulatory requirements for firms can be eased without compromising consumer safety will also be important. The 323 new regulations – often related to information technology (IT) – introduced between 2011 and 2019 created over EUR 12 billion in one-off compliance costs for firms; only 51 of these regulations reduced ongoing costs for the economy (NKR, 2019[8]).

6.1.2. Anticipating and preparing for sustainable and digital transition changes: New approaches to regulatory flexibility

The sustainability and digital transitions require disruptive changes and products, while at the same time providing the necessary security to consumers. The regulatory environment for innovators needs to be flexible or future-proofed to keep up with rapid advances in technologies. In the context of digitalisation and emerging technologies, the rate of change often exceeds the speed with which regulators can react, and new technologies and their applications – particularly where previously separate technologies and industries begin to intersect – can lead to a level of uncertainty that is difficult to codify in laws and regulations. The popular regulatory sandboxes permit a degree of legal and regulatory flexibility in certain technology fields or industries, with the aim of developing and commercialising new innovations. These initiatives can be organised at the national, federal or city level, and oriented towards missions or goals. A key aspect of German regulatory sandbox policy is the notion of "experimentation clauses" (*Experimentierklauseln*). These are legal provisions that allow implementing authorities to exercise case-by-case discretion in applying the rules. The clauses generally have one of two objectives: to create opportunities to test innovations where the existing legal framework does not permit the proposed application; or to allow regulators and legislators to learn at an early stage about new technologies, and adapt the legal framework accordingly. BMWK has been implementing a cross-governmental sandbox strategy to ease the regulatory conditions for sandboxes since 2018. It recently proposed a concept for a regulatory sandbox law that would codify standards for experimentation clauses and review existing ones.

The law would be complemented by a “one-stop-shop” for sandboxes as a central entity charged with reviewing experimentation clauses.

The BMWK, and the government more broadly, are open to using flexible and anticipatory regulation to support innovation. As with other areas of innovative public policy, the challenge is mainstreaming these approaches throughout government; supporting their more holistic and strategic use; and ensuring that civil servants and public officials, as well as private-sector counterparts, are aware of the opportunities available to them and are encouraged to utilise these tools. The Federal Government has been making inroads in these areas. As early as 2015, it started establishing sector- and technology-specific programmes, like the Digital Motorway Test Bed for autonomous driving. While these individual programmes are impressive, the different initiatives lack interconnectedness, limiting the ability of these islands of regulatory flexibility to contribute to broader – and strategic – government ambitions.

An important area of regulatory consideration for innovative firms, particularly those engaged in advanced information and communication technology (ICT) and data, is regulation surrounding the use of AI. In Germany, as in other jurisdictions, the suitability of extant regulation and standards, as well as the complexity of processes involved with AI and ML, pose challenges. A key example is the notion of “explainability” in AI processes – i.e. the ability to describe and explain how an AI process reaches a decision – which regulators continue to require regulators at the national and EU levels. Regulators’ attachment to explainability is understandable – particularly in the context of sensitive applications, such as in medicine– but deriving the working processes for decisions and outcomes from the neural networks that underpin more advanced AI is increasingly difficult, if not impossible.

Managing this tension in a regulatory framework is likely to become an increasingly important area for policy makers. Getting it right will be important to ensure that Germany and the European Union are desirable locations for AI-based innovation in the future. To this end, it is notable that the European Union has developed a number of documents exploring the issues of regulation in AI, such as the 2020 *White Paper on Artificial Intelligence* and the Joint Research Council’s *Technical Report on Robustness and Explainability in Artificial Intelligence* (Hamon, Junklewitz and Sanchez, 2020[9]; European Commission, 2020[10]). At a national level, Germany has explored issues of explainability in AI through standardisation institutions such as Deutsches Institut für Normung (DIN), which in 2020 released the *German Standardization Roadmap on Artificial Intelligence* (Wahlster and Winterhalter, 2020[11]). While these endeavours demonstrate advanced thinking on the ways in which AI should – and could – interact with the innovation system, they nevertheless represent an attempt to codify ex ante the limits of a technology that is still at a relatively early stage of development.

6.1.3. Data regulation

Data are another area of German regulation with particular impacts on innovation. The role of data regulation and innovation is complex and multifaceted, with the OECD issuance a Recommendation on Enhancing Access to and Sharing of Data in 2021 reflecting the importance of this issue on the global policy agenda (OECD, 2021[12]; OECD, 2015[13]; Guellec and Paunov, 2018[14]). A number of existing regulatory barriers in the collection and use of data affect the ability of German firms to make the most of opportunities in the context of Industry 4.0, as well as the ability of the German economy to support and grow data-driven firms in the service sectors. Of course, data regulations also have international dimensions: data regulation and compliance may yield market-creating opportunities, but they also impose regulatory hurdles that discourage some firms from engaging in innovation in this field (Casalini, López-González and Nemoto, 2021[15]).

Data-privacy regulations at the national and EU levels also affect the use of private data. Within Germany, compliance with data regulation is complicated by regulatory fragmentation, since the country has 18 separate regional bodies for data regulation. A recent survey of a representative sample of 502 firms conducted by Bitkom (the German industrial association of firms in the digital economy) found that compliance with German data regulation continues to significantly raise costs for firms, and that the quality of support from regulatory bodies was insufficient (Weiß and Streim, 2021[16]). The EU General Data Protection Regulation (GDPR) was introduced by the European Commission in 2018 to harmonise privacy laws across the European Market for all firms operating in the EU market. Respondents to the Bitkom survey reported increased compliance costs since the introduction of the GDPR. Yet there is also evidence that the GDPR has generated opportunities for innovation by providing a more harmonised regulatory framework, facilitating firms' compliance (Martin et al., 2019[17]). In addition, the GDPR has helped mainstream data-privacy considerations, which are an essential element to build consumer trust in data-based business models.

6.2. Broadband and data infrastructure for innovation

Reliable infrastructure – including better-quality broadband or cellular networks, in addition to traditional areas of "hard' infrastructure" – is a prerequisite for innovation and employing innovative approaches to work. At the same time, innovation *in* infrastructure development is just as important, particularly when considering the role of public infrastructure in climate resilience or infrastructure to support industrial decarbonisation (covered in Chapter 11).

Data are an increasingly important input for innovation and play an essential role in three key ways:

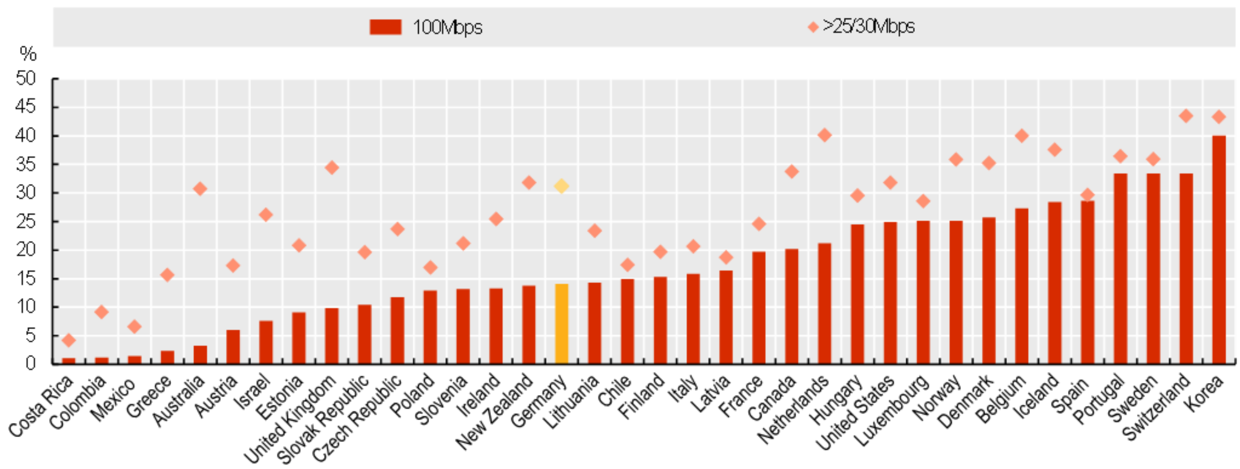
- First, exploiting data from production, logistics and research allows firms to innovate value chains, improve the efficiency of energy use and other inputs. In turn, digitising these processes produces further data that can be used as input for innovations.
- Second, business data can help inform decision-making on smart grid technologies and decarbonisation processes. Data produced through business operations are therefore integral to the sustainability transition.
- Third, the digitalisation of the public sector will allow policy makers to use more powerful tools to design policy interventions, map scenarios and exercise foresight, as well as help boost public services relevant to innovative businesses.

This section considers the state of digital connectivity underpinning the potential roles of data in supporting Germany's innovation system and its transition objectives.

The latest OECD Economic Review of Germany outlined the digital infrastructure challenges Germany faced in expanding access to high-quality broadband infrastructure; such shortcomings affected Germany during the COVID-19 pandemic (OECD, 2020[18]). Relatively low levels of digital connectivity, particularly in terms of fixed high-speed broadband networks (Figure 6.3), limit the economic and innovative potential of digitalisation. They can also deepen inequalities – as in Germany, which is characterised by a significant rural-urban connectivity divide. In 2019, 94% of households in large cities had access to fixed broadband with download speeds of over 100 Megabits per second (Mbps), compared to only 53% of households in rural municipalities (OECD, 2020[18]). The adoption of ICT tools – ranging from simpler processes such as enterprise resource planning and customer relationship management, to more complex applications such as big data analysis, social media and cloud computing – may be affected by limited high-speed broadband (OECD, 2021[19]). These supply-side issues may also have a demand-side impact for new, data-rich and technologically intensive services, as the ability of households and firms to take advantage of such services will be impeded by connectivity barriers. These demand-side barriers are perhaps one explanation for firms' persistently low uptake of data-heavy and advanced ICT tools, as discussed above.

Figure 6.3. Germany has a low share of internet subscriptions in higher-speed tiers (2020)

Fixed broadband subscriptions with contracted speed faster than 25/30 Mbps and 100 Mbps, June 2021

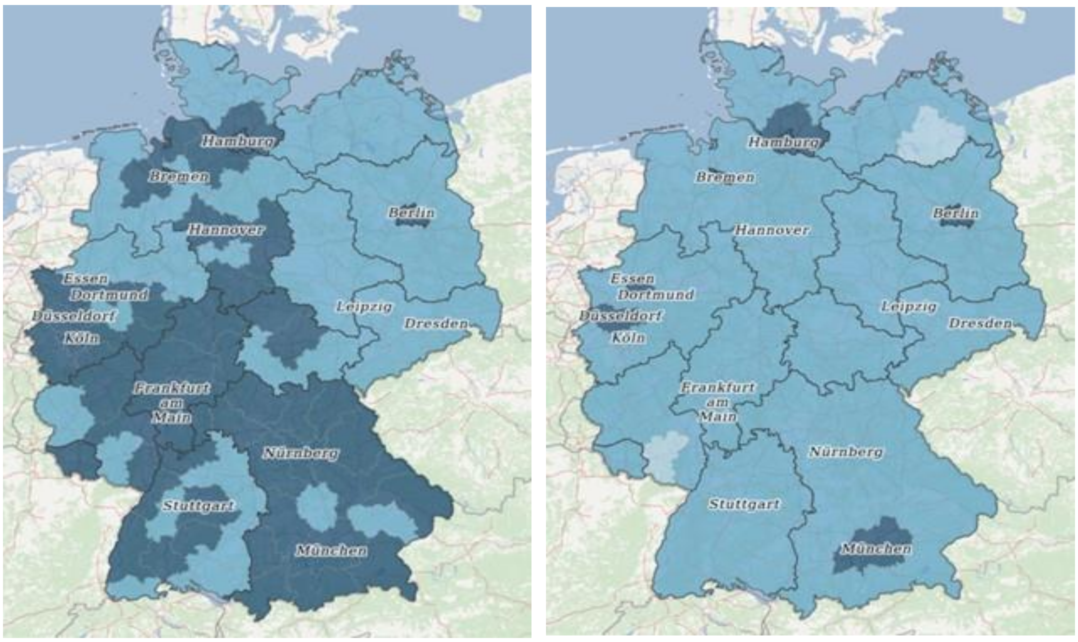


Note: Denmark: Data are temporary OECD estimates, Switzerland: Data are preliminary; Based on 2020 speed tiers.
Source: OECD (2022[20]) Broadband Portal, https://www.oecd.org/sti/broadband/oecdbroadbandportal.htm.

In 2020, Germany numbered 44 fixed broadband subscriptions per 100 inhabitants, higher than the OECD average of 33. However, the share of subscriptions in higher-speed tiers – which are crucial for using key ICT tools, such as cloud computing and data processing – is low. The vast majority of fixed broadband subscriptions are digital subscriber line (DSL) technology, indicative of the low percentage of higher speeds shown in Figure 6.3; fibre optic connections for households account for only 4.1% of the broadband mix, significantly below the OECD average of 28%. Access to high-speed broadband is also heavily region-dependent (Figure 6.4), which may create or exacerbate digital divides between SMEs and entrepreneurs across the country. The regionality of the connectivity divide also highlights the importance of ensuring that municipal authorities can disburse funds set aside at the federal level to upgrade their connectivity infrastructure, an objective that is sometimes hindered more by administrative barriers than by the availability of funds for investment (OECD, 2020[18]). Given that DSL technology, which remains prevalent in many rural areas, was designed for low-speed analogue voice services, these connections suffer from an inherently asymmetrical capacity and are largely unsuitable for many modern ICT and data-intensive activities. The demand for better services is clear, and Germany's firms would likely capitalise on increased access to better-quality connectivity, leading to productivity gains and the opportunity to pursue hitherto impossible innovation activities.

Figure 6.4. Access to high-speed fixed broadband is geographically dependent

A. Coverage > 30Mbps   B. Coverage > 100Mbps



Note: Pale blue – 10-50% of households, blue 50-75%, dark blue 75-95%.
Source: MIG (2021[21]), *Breitbandatlas*, https://netzda-mig.de/breitbandatlas/interaktive-karte (accessed on 1 April 2022).

A key pillar of the German economy's digital transformation is the expansion of 5G in the country. Progress has been made in this area (though there remains a lack of consensus internationally on how to benchmark 5G rollout), with the German Federal Network Agency reporting in December 2021 that 53% of the country's territory – around 80% of the population – is now covered with at least one 5G network provider (BNetzA, 2021[22]). The expansion of the 5G network is an important framework condition for the Industry 4.0 programme of the BMWK, which looks to help the private sector to embed digital and advanced technologies into production processes, with a view to increasing productivity and efficiency. For example, the authors of a 2020 study by the German market intelligence firm International Data Corporation (IDC) found that 59% of the 254 sample firms surveyed across five sectors of the economy intended to implement industrial internet of things projects – a key component of Industry 4.0 – using 5G technology (IDC, 2020[23]). Importantly, fibre optic internet and wifi are equally valid ways of powering IoT.

The example of 5G, and its importance to the digital transformation of the private sector, highlights the need for investing in the infrastructure underpinning these transformations. Beyond the general connectivity infrastructure, this extends into the service-based infrastructures that depend upon it, such as cloud computing and data infrastructures. Cloud-based computing and data storage are important for internet of things applications such as predictive maintenance analysis, yet German firms significantly lag behind the best-performing OECD countries in adopting these applications, as discussed in Chapter 10 of this review.

6.3. Labour market conditions

6.3.1. Employment regulation and the labour market

Labour markets interact with innovation by allowing firms to find and hire workers with the skills necessary for innovation, which in turn supports the diffusion of new technological knowledge through the economy. Germany has a historically strong performance in ensuring labour-market entrants are equipped with the skills and technical knowledge necessary to succeed in some of the country's leading innovative sectors. The challenge in the years ahead will be to ensure that as the types of skill and knowledge required change (owing for example to a greater focus on digital and ICT skills over mechanical ones), the policy programmes and institutions that both train and match workers to companies adapt to new demands.

Employment protection is generally high in Germany, which has the seventh-highest employment protection for individual and collective dismissals in the OECD (OECD, 2019[24]). Skill levels do not generally make a difference in hiring or firing conditions (OECD, 2019[25]). According to a study by Muehlemann and Pfeifer (2016[26]), the cost of hiring skilled workers in Germany is eight weeks of pay on average and increases with firm size. In a 2017 survey of 12 775 business executives (112 from Germany) across 137 countries, Germany ranked 18th in terms of flexibility of hiring and firing conditions – numerically above average, with a score of 4.66 on a scale from 1 (heavily impeded by regulation) to 7 (very flexible). Germany was more flexible than Italy (3), Japan (3.5), Korea (3.54) and France (3.67), but more regulated than the United Kingdom (4.99) and the United States (5.31) (World Economic Forum, 2018[27]).

6.3.2. Labour market performance during the COVID-19 period

The German labour market remained relatively resilient to the COVID-19 pandemic, from its onset in March 2020 to March 2022, with modest employment losses compared to other OECD countries. This partly reflects the strengths of Germany's short-time work (STW) scheme (*Kurzarbeit*), where employers reduce employees' working hours instead of laying them off. Other OECD countries also relied heavily on STW during the COVID-19 crisis. Germany had previously used the STW work scheme for job retention during the global financial crisis, where it was however far more widespread in the manufacturing sector, unlike during the pandemic, where some 80% of STW applications were in services (OECD, 2021[19]).

In May 2021, the seasonally adjusted unemployment rate in Germany was 3.7%, the fourth-lowest in the OECD. This level was only 0.2 percentage points above its value at the beginning of the crisis and 0.4 percentage points below the peak during the pandemic; these increases were significantly lower than in other OECD economies, such as the United States and Canada (OECD, 2021[28]). Germany's level of youth unemployment is higher (8% in May 2021), although still the fourth-lowest in the OECD, and only marginally above the pre-pandemic rate. However, as in other OECD countries, the COVID-19 pandemic has had a multifaceted impact on Germany's labour market, specifically with regards to training opportunities and the reallocation of labour market participants that was challenged during the COVID-19 crisis.

The relatively low level of adoption of digital tools in the workplace and at home also illustrates resilience and agility challenges in the German context. Throughout the pandemic, Germany relied much less on teleworking than comparable OECD countries. This was also true prior to the pandemic, when only 10% of employees in Germany worked from home occasionally, compared to 18% in France, and over 20% in the United Kingdom and the United States. During the crisis, the number of employees working from home tripled (to 31%) in Germany, but nevertheless remained below France (33%), and significantly below the United Kingdom and United States (around 50% each) (OECD, 2021[28]). The uptake of teleworking arrangements in Germany depends strongly on employees' educational attainment. College graduates are twice as likely to have worked from home during the pandemic than employees who did not go beyond secondary education, and are nearly five times more likely to work from home than workers with no high school degree. Workers in the top 25% of the earnings distribution are over 50% more likely to telework than workers in the bottom 25% of the earnings distribution.

6.4. Germany's skill base and capabilities for innovation

6.4.1. Overview of the supply of skills and capabilities for innovation

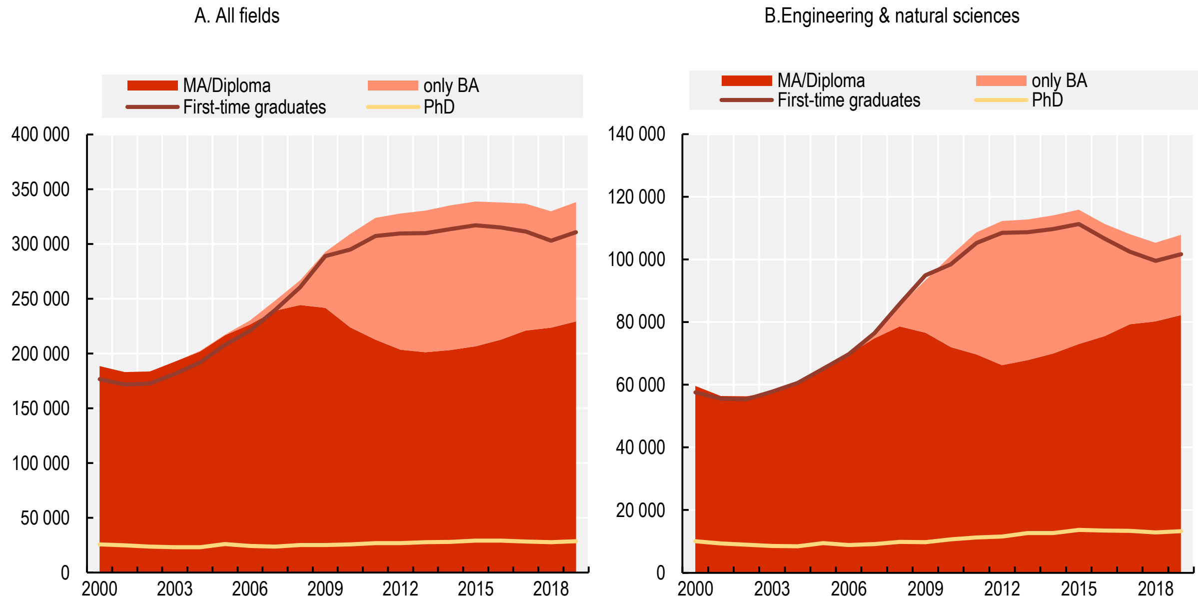
Germany's innovation system is supported by a well-educated and highly skilled workforce, with a strong increase in the share of entrants in tertiary education in the past two decades. Although below the OECD average (44%), 32% of young adults (aged 25-34) in Germany held a tertiary degree in 2018, compared to 24% in 2008. The share of higher education graduates in the total population of the same age expanded from about 17% in the early 2000s to 32% in 2019, and has been continuing at this rate ever since (OECD, 2019[29]).

The increase in the number of higher education graduates in Germany began in 2002 and accelerated after the shift from diploma-based curricula to a Bachelor of Arts (BA)/Master of Arts (MA) system in 2009. The number of first-time graduates was at its lowest in 2001 (172 000). It then grew steadily year by year, peaking at 317 000 in 2015 thanks to the new BA/MA system, which produced a growing number of BAs who did not pursue an MA programme. The number of graduates with a diploma or master's degree peaked in 2008 (244 000) and declined until 2013 (201 000), slightly increasing thereafter (229 000 in 2019).

Evidence from private-sector job openings suggest that most firms are still looking for MA degrees to fill vacancies requiring academic skills. While the federal and state governments initially expected only a fraction of BA graduates to pursue a master's degree, around 90% of BA graduates from the general and technical universities embark on an MA programme. The share is markedly smaller (about 40%) at universities of applied sciences (*Fachhochschulen*) (DIPF, 2020[30]). As a result, the share of graduates with "only" a BA in the total number of graduates is declining, particularly in engineering and natural sciences (including mathematics and computer sciences), which is particularly relevant for suppling high-skilled labour for innovative firms. The number of new PhD graduates also grew in this field, from under 9 000 in 2006 to over 13 000 in 2015.

Graduates in science, technology, engineering and mathematics (STEM) disciplines are particularly relevant to innovation in firms. Over the past two decades, the number of MA and PhD graduates in these fields has increased faster than the total number of graduates (Figure 6.5). The share of MA graduates in STEM fields rose from 30% in 2005 to 36% in 2019. The increase was even more marked for PhD graduates, from 36% in 2005 to 46% in 2019. According to data from the OECD Education Database, the share of university STEM graduates in Germany is higher than in almost all other comparator countries, except Japan (OECD, 2021[31]). Moreover, the number of MA and PhD graduates in STEM fields has been increasing faster than the total number of graduates. STEM graduates are particularly key for addressing new technological and societal challenges, as well as industrial innovation needs.

Figure 6.5. Number of graduates from higher education in Germany (2000-19)



Source: OECD calculations based on data from Destatis (2022[32])

The supply of new graduates with such skills has been quite stable in absolute figures over the past ten years. Every year, Germany numbers about 16 000 first-time graduates in IT-related higher education fields, and between 10 000 and 12 000 graduates having passed exams in vocational training related to IT occupations. Between the early 2000s and 2009, the number of first-time university graduates in IT-related fields grew strongly in response to a significant shortage of related skills during the "new economy boom" in the late 1990s. The pool of IT graduates will likely increase in the coming years, both in higher education and vocational training, as the number of first-year students is growing – probably due to heightened public attention towards digitalisation. With the transition from diplomas to a BA/MA system, the number of graduates with an IT-related diploma or MA significantly decreased, from 14 000 in 2007 to under 8 000 in 2014, particularly because many students at universities of applied sciences did not go on to pursue an MA programme. The figure has increased since then.

Germany also scores high in international rankings in terms of doctorates and the placement of scientists in the business sector. Roughly 29 000 graduate students complete a doctorate in Germany every year, more than half of which are PhDs in natural sciences, mathematics and engineering. These figures are far higher than in any other EU Member State. In total, Germany's share of population with a doctoral degree (1.6% in 2020) is above the OECD average (1.3%) and similar to that of Australia, Norway and the United Kingdom, but lower than the United States (2.0%) and leading countries like Switzerland (3.0%) or Slovenia (5.2%) (OECD, 2021[33]).

The below-average share of university graduates in Germany is compensated by – and likely due to – its highly developed and widely respected vocational education and training (VET) system, which integrates both learning in vocational schools and training in the workplace. More than 50% of adults aged 25-64 and 40.8% of those aged 25-36 received a vocational upper-secondary or post-secondary qualification in 2019. Over the past decades, the VET system has played an important role in expanding the skills and capacities of the German workforce. At the advanced tertiary level, attainment is among the highest in the OECD: 1.6% of 25-64 year-olds have graduated from a doctoral or equivalent programme (eighth-highest rank in the OECD) and 2.1% of adults under 35 (third-highest) (OECD, 2021[34]). However, the supply of workers with VET degrees related to manufacturing, handicraft and professional services has declined by 19% in

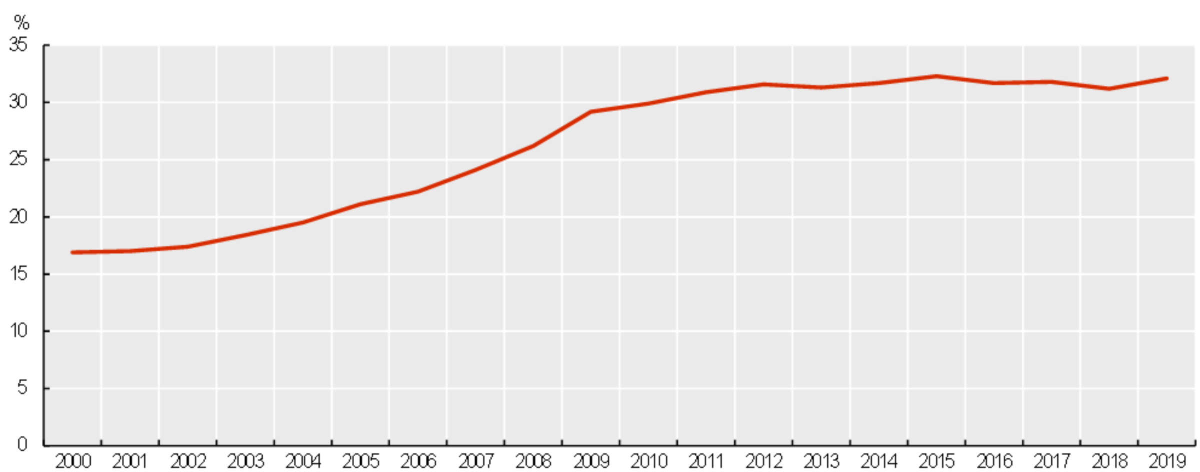
Germany, from 444 000 in 2005 to 359 000 in 2019. By contrast, the number of first-time graduates from higher education rose by 49%, from 208 000 in 2005 to 311 000 in 2019.

Moreover, Germans do well in soft skills by international comparison. German adults perform above the OECD average in key information-processing skills (see the 2018 Survey of Adult Skills [PIAAC]) (OECD, 2019[35]). According to the PIAAC data, Germany performed relatively well in building foundation skills, the average literacy achievement of students at age 15 increased more than the OECD average between 2000 and 2018.

6.4.2. Opportunities and challenges for the skill base and capabilities in Germany

It should be noted that the expansion in the supply of academically trained people in Germany over the past two decades occurred at a time when demographic change caused a decline in the number of young people (Figure 6.6). This implies that the share of higher education graduates in the total population of the same age sharply increased, from about 17% in the early 2000s to 32% in 2019. The increase mainly took place between 2002 and 2012, while little positive dynamics have occurred over the past seven years. This will further complicate the challenge of providing the required skill base.

Figure 6.6. Share of first-time higher education graduates in the total population of the same age in Germany (2000-19)



Source: OECD calculations based on data from Destatis (2022[36])

There exist opportunities to expand Germany's skill and capability base by increasing diversity. Currently, two out of every three tertiary graduates in STEM are men, perpetuating the under-representation of women in key innovation sectors. Attracting and encouraging individuals from under-represented groups, including students from non-academic and minority households, to engage in innovation should be one component of a strategy to address skill shortages, as discussed in Chapter 15 on inclusivity.

Germany's traditional institutional organisation of public-private co-ordination and co-operation, which has supplied skills suited to the needs of its successful innovation system, now needs to be exploited in a new context. The Humboldtian university model, which has historically emphasised research, knowledge generation and intellectual inquiry, together with the focus of Germany's well-regarded technical universities on engineering and applied sciences, have contributed to the rich supply of well-educated labour-market entrants. The close collaboration between industry and academia in German educational institutions has ensured that the skills of individuals entering the industrial sectors are suited to innovation and practical application.

6.4.3. Skill shortages and their consequences for innovation

Despite the good supply of a skilled and capable workforce, Germany's innovation ecosystem faces a limited supply of some core skills, which will likely become a greater challenge in the future owing to population ageing. According to the 2018 Mannheim Innovation Survey, 34% of the respondent firms pointed to lack of skilled labour as the most important barrier to innovation, up from 10% in 2006 (ZEW, 2018[37]). The Mannheim Survey also collected data on the number of job vacancies that could not be filled, filled only with delay, or filled with personnel who did not possess the required skills, complemented by information on the type of skills initially required to fill the vacancies. The survey of 1.1 million job openings advertised by 297 000 participating firms in 2017 showed that 18.2% of all vacancies could not be filled by the time of the survey (second and third quarters of 2018), equal to about 200 000 positions. Additionally, 33% (361 000 positions) could be filled only with delay, or only with personnel who did not have the required skills, 48.7% (534 000 positions) of all vacancies were filled as planned.

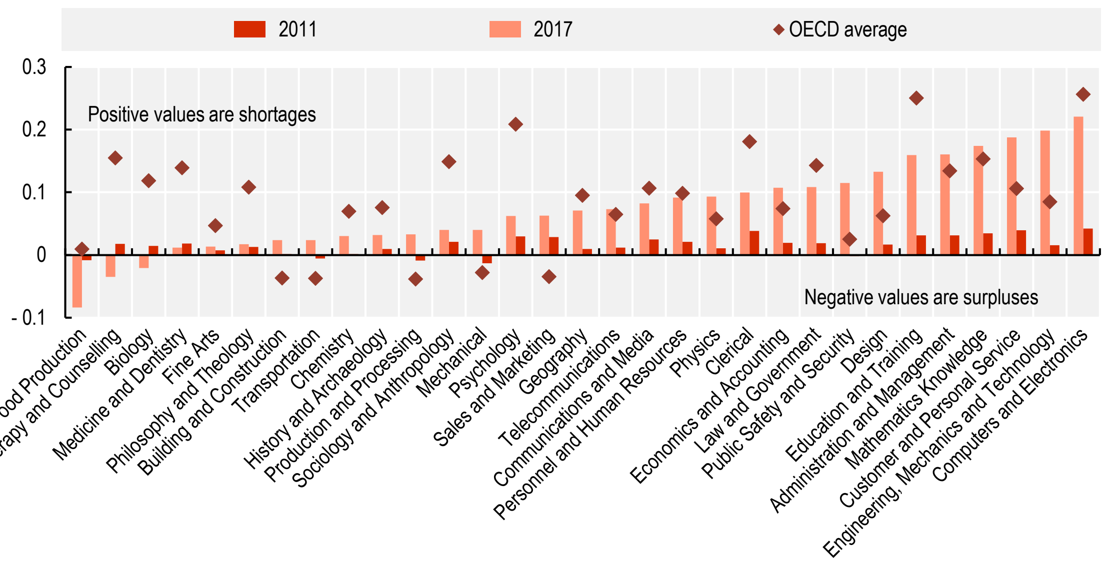
Still according to the Mannheim Survey, 36% of participating firms were seeking new personnel with academic skills in engineering and natural sciences or other academic disciplines, compared to 9% of firms with job openings in computer science, mathematics and statistics. According to some estimates, German firms will need around 700 000 more people with technological skills by 2023 than were available in 2019, particularly skills in complex data analysis and user-centric design (Kirchherr et al., 2020[38]). Moreover, in the future, industries' increasing orientation towards digital services and innovations might require interdisciplinary approaches (Paunov, Planes-Satorra and Moriguchi, 2017[39]).

Seven in ten high-skilled occupations experience skill shortages, one of the highest rates in the OECD (OECD, 2021[40]), particularly in the computer and electronics sectors, engineering and mathematics, and customer and personal services (Figure 6.7). According to the 2019 Skilled Labour Shortage Analysis (*Fachkräfteengpassanalyse*) of the Federal Public Employment Agency, occupational bottlenecks were the largest in medical and care professions, IT, construction and skilled trade (Federal Employment Agency (BA), 2020[41]).

Future labour bottlenecks are likely to be most pronounced in occupations that require a high degree of ICT skills, health care professions, skilled trades, and occupations related to mechatronics and automation technology (BMAS, 2021[42]; Kirchherr et al., 2020[38]; Leifels, 2020[43]). According to a study by the German Economic Institute, in October 2021, there were 276 900 (unfilled) vacancies in STEM roles, which is an increase of 155% on October 2020, but also higher than pre-pandemic figures (October 2019: 263 000). This concerns mainly skilled STEM workers (130 100) and STEM expert roles (103 500) The largest gap was in energy and electronics (81 300), while in 46 400 IT job position could not be filled (Anger, Kohlisch and Plünnecke, 2021[44]). Another report found 96 000 positions for IT specialists to be open in 2021, up by 12% from the previous year, with two thirds of companies reporting shortages (bitkom, 2022[45]).

Figure 6.7. Significant shortages exist in STEM-related knowledge domains

Knowledge domains experiencing shortage or surplus



Note: The *Skills for Jobs* database defines skills as either in shortage or in surplus. These imbalances are measured following a two-step approach. First, an "occupational shortage indicator" is calculated for 33 occupations, based on an analysis of wage growth, employment growth, growth in hours worked, the unemployment rate and the change in under-qualification. For each country, long-run trends are compared to the economy-wide trend. Based on the *O*NET* database, the "occupational shortage indicator" is then used to build indicators of skill shortages and surpluses. Knowledge domains refer to the body of information that makes adequate performance of the job possible (for example, knowledge of mathematics for an economist).
Source: OECD (2020[18]), OECD Economic Surveys: Germany 2020, OECD Publishing, Paris, https://doi.org/10.1787/91973c69-en based on OECD Skills for Jobs database.

An econometric analysis of the data reveals that skill shortages have negative impacts on firms' innovation activities (Horbach and Rammer, 2019[46]). Firms that reported a skill shortage during 2017 (i.e. they could not fill open positions at all, or only with delay, or not with the desired skills) experienced a 11.5% higher probability of abandoning innovation activities (when considering the endogeneity between skill shortage and innovation activities).

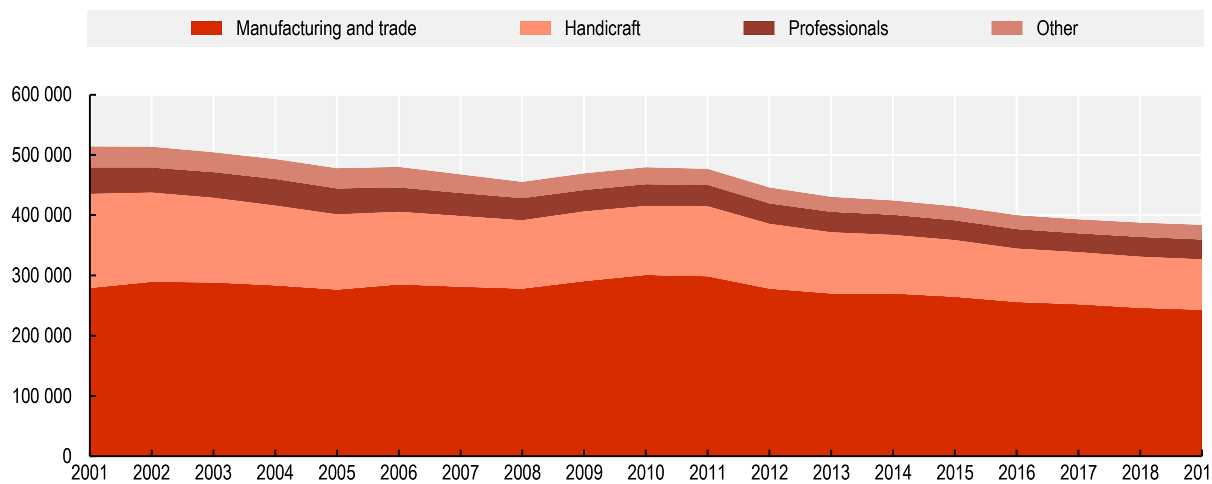
6.4.4. Continued education, vocational training and upskilling

There exist opportunities for continuing education and training (CET) in Germany, but these are used unevenly and not tailored to the more substantive reskilling necessary in light of future transitions. Data from the 2018 German Adult Education Survey suggested that 54% of adults (aged 18-64) in Germany take part in continuing education, a level that is slightly above the EU average of OECD countries (OECD, 2021[40]). However, adults with low skills, low earners and those working for SMEs have particularly low rates of participation (OECD, 2021[47]).

Most CET tends to be rather short and is not aimed at truly transforming workers' skill set and technical competencies, which may be required if existing jobs are displaced and not replaced. Finally, the governance of the CET system is highly fragmented across Germany's states, which may limit a co-ordinated national approach to upskilling and reskilling workers affected by the sustainability and digital transitions. It also generates challenges with regards to accreditation (OECD, 2021[47]).

The growing number of young people embarking on an academic degree in an ageing society, along with the shrinking number of young people in general, implies that the number of graduates from non-tertiary tracks will decrease. This is clearly the case for the most important education programme in Germany, the dual system of vocational training (Figure 6.8), where the total number of exams passed declined from 451 000 in 2011 to 359 000 in 2019. The decline was particularly strong in handicrafts, manufacturing and trade, and less pronounced in the field of professional services (*freie Berufe*), public services, agriculture and domestic services.

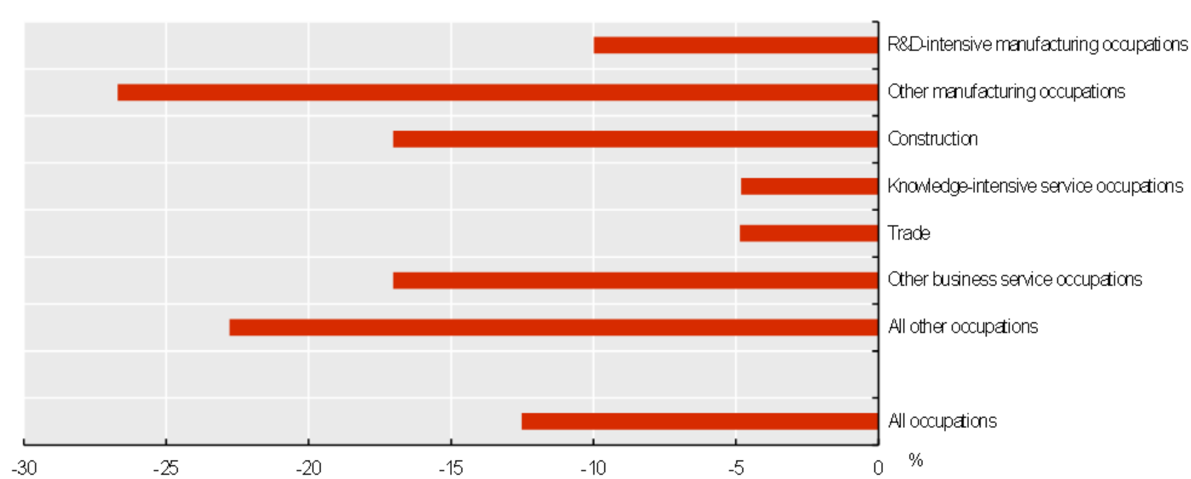
Figure 6.8. Number of passed vocational training exams in Germany, by main area (2001-19)



Source: OECD calculations based on data from Destatis (2022[48])

A closer look at occupations related to different industrial sectors shows a rather moderate decline in passed exams for occupations related to knowledge-intensive services (i.e. ICT; financial and insurance services; and scientific, technical and professional services) and other business services (e.g. transport and storage, and facility management) over 2012-19[1] (Figure 6.9). The number of passed exams declined by 10% in occupations related to R&D-intensive manufacturing and declined more sharply (27%) in other manufacturing occupations.

Figure 6.9. Change in the number of passed vocational training exams in Germany, by related industrial sector (2012-19)



Source: OECD calculations based on data from Destatis (2022[48])

In the context of the socio-economic effects of the digital and climate transitions, it is essential for the adult population to engage in upskilling and reskilling initiatives even later in life to minimise long-term labour displacement and inclusivity challenges. This is particularly important in Germany: according to a 2018 OECD study, around 18% of jobs are at high risk of automation, and an additional 36% of jobs face a significant risk of being displaced (Nedelkoska and Quintini, 2018[49]).

6.4.5. Skilled migration

Germany needs to do more to attract workers from abroad with skill profiles that are in particular demand. According to the 2019 *OECD Indicators of Talent Attractiveness*, Germany is the third most attractive country for international students in the OECD, behind only Switzerland and Norway, and ahead of Finland and the United States. (Chaloff et al., 2019[50]). The student visa system, which allows students to work while studying, combined with low tuition fees, were an advantage for international students. Germany also scored relatively well (sixth) in terms of its attractiveness for migrant entrepreneurs, but in the OECD average in terms of its attractiveness to talented workers.

For companies – particularly smaller firms – facing skill shortages, opting for skilled migration still remains an unusual option. In a 2021 survey of 7 500 companies with more than 10 employees, only 16% said they were recruiting skilled personnel from abroad as a way to prevent skill shortages. Instead, the companies were choosing to offer in-house VET to new employees (47%), make family life and work more compatible (41%), offer further training to existing employees (39%), raise salaries regularly (26%) and offer workplace health management (17%). The 501 responding firms that opted not to recruit foreign skilled workers despite reporting shortages cited language barriers (45%) and uncertainties regarding foreign qualifications (45%) – especially for non-EU workers – as the main reasons for their choice; firms that had actually recruited foreign skilled workers also pointed to language barriers (39%) and foreign qualifications (28%) as major obstacles (39% and 28%, respectively) (Mayer, 2021[51]).

In view of Germany's ageing population, which will affect the future supply of skills, the Federal Government is focusing more on the topic of skilled migration. Issues hindering the success of skilled immigration to Germany include the need to establish formal recognition for foreign qualifications, as well as address the topic of overqualification: only 40% of foreign-born and foreign-educated academics work in a highly skilled occupation, compared to 77% of German academics (OECD, 2020[52]). The skilled-labour migration law (*Fachkräfteeinwanderungsgesetz*), introduced in 2020, aims to ease administrative burdens and contribute to increased inward migration, by increasing and centralising administrative capacities, as well as simplifying requirements for the recognition of qualifications in the ICT sector, where skill shortages are particularly dire (BMWi, 2020[53]). The new government's coalition agreement foresees furthering the issue, including by introducing a point system in which applicants for immigration who have not obtained a job prior to immigrating will be scored according to (among others) their education and language skills (SPD, Bündnis 90/Die Grünen und FDP, 2021[54]; Bayat, 2021[55]). This follows a long-held and widely shared view in Germany of the exemplary character of Canada's immigration system, which also includes point scoring (OECD, 2020[52]).

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Endnote

[1] The period was chosen due to a break in series between 2011 and 2012 stemming from a change in the classification system of VET occupations.

7 Financing innovation in Germany

Germany has a well-functioning banking system that provides financing to innovating companies, including *Mittelstand* firms and start-ups. Much progress has also been made in providing funding for high-risk innovation. However, financial resources to scale those innovations, which may play a critical role in future competitiveness, are below what that available in the US market. This chapter introduces a recommendation on how Germany could raise more investment for innovation, including high-risk and breakthrough innovations, and assesses the prevailing conditions under which German firms access finance.

Introduction

Research, development and innovation (RD&I) begin with investment, whether in physical, human or intangible capital. The manner in which firms finance their investments – and the terms of financing – are therefore major enablers or hindrances to innovation. While a large share of innovation funding worldwide traditionally comes from firms' own resources, access to external finance plays an important role in supporting further innovation. This is particularly true of breakthrough innovations, which require very large investments and consequently would not be accessible to many industry players. As with the regulatory framework, financing constraints do not affect firms equally, and *Mittelstand* and start-up firms often face more difficult financing conditions than larger, more established firms. Increasing the availability of risk and growth capital for highly innovative firms is therefore essential if Germany is to both succeed in the sustainability and digital transitions, and retain its position as a global leader in the next generation of technologies.

Different sources are available for financing innovation, including private equity, bank financing, venture capital and stock markets. German firms – including *Mittelstand* companies – rely primarily on banks, which have been a solid and effective source of financing for investments. They use capital markets less than some other OECD countries, such as the United States. As in other OECD countries, however, German banks are less willing to finance intangible investments, owing to information asymmetries between banks and firms, or to difficulties in collateralising intangible assets; this may limit the ability of firms, particularly small and medium-sized enterprises (SMEs), to make the most of new technologies, including digital instruments, in their innovation activities (OECD, 2021[1]).

Funding opportunities for breakthrough and high-risk innovations – which are more challenging to obtain through banks – have been increasing. However, investments focus on the early stages of firm growth, with significant funding gaps at the middle and later growth stages. As a result, high-potential German innovators face a domestic financing gap that hinders opportunities to scale. The ability of *Mittelstand* and high-potential start-ups to scale and produce breakthrough innovations, and for the German private sector to transition towards knowledge-based activities, will depend on finding solutions to these financing challenges.

This chapter introduces a recommendation on how the Federal Government of Germany could improve the financial markets necessary for developing and scaling firms with high levels of innovative potential. The chapter proceeds with a brief assessment of the current access-to-finance conditions for German firms and concludes with an overview of venture capital (VC) markets in the country.

Recommendation 6: Promote financial markets that are conducive to scaling up breakthrough innovations

Overview and detailed recommendations:

Although German firms generally have good access to finance, providing young and small firms with the capital needed to scale remains challenging. This reflects in part the comparative underdevelopment of the venture and growth capital markets in Germany and the European Union as a whole.

R6.1 **Revisit the legal framework for German capital-collecting institutions to encourage investment in risky innovation**. The Federal Government should consider requiring institutional funds to allocate a percentage to VC or private equity funds for innovative firms. For example, German pension funds, insurance companies and public financing organisations provide very little risk capital, even though they are among the only sources that could provide the levels of funding (including investments in private companies through VC funds and investments in listed companies) that are necessary to scale the most promising innovations. Another approach might be to facilitate employee stock-ownership plans. Overall, the German tax framework for equity ownership and awards has been largely unattractive compared to international benchmarks.

R6.2 **Expand tax incentives, especially those that allow private investors to offset capital losses against other income, or to exempt future profits when investing in the VC asset class**. Such incentives should apply to both the VC segment (pre-initial public offerings) and investment through the stock market (development and growth financing). The United Kingdom and France, for example, each have six different tax-incentives to improve the supply of private capital for VC markets.

R6.3 **The Federal Government should support the development of financial instruments at the EU level that would help scale and retain innovative firms**. The volume of finance necessary to scale some of the most promising firms is often available neither in Germany nor within the European Union, meaning that firms regularly move to countries where finance is more easily available, such as the United States or the United Kingdom. The German government should advocate the establishment of EU-level private equity development for investment in pre-public technology and digital innovators. The Federal Agency for Disruptive Innovation, SPRIND, could play a more prominent role in developing a domestic VC market for higher-risk investments.

Relevant global experience

Many countries throughout the OECD region have taken steps to expand the availability of financing for innovation, including by developing VC markets for high-potential, high-risk innovative start-ups.

Government-backed VC to de-risk investment in early-stage but potentially impactful start-ups has proven successful in a number of countries, such as Israel. When Israel created the Yozma initiative in 1993, around 50% of VC in the country came from public funds; within seven years, the share of public finance had fallen to almost zero. While government VC could crowd out private investment, the Israeli case demonstrated that a properly targeted programme can have the reverse impact, rapidly accelerating a private VC marketplace and supporting a domestic start-up ecosystem. In the Yozma initiative, the government provided a maximum of 40% of the necessary capital, with the private investors having the right to buy the government stake in the five years following investment at a pre-determined price (Apolitical, 2017[2]; Yozma, 2022[3]). The Israeli model of using a government-backed VC institution to develop private capital markets for investment in start-ups is one that could be extended to SPRIND, allowing it to play a bigger role in the development of German VC markets and international co-ordination to support the development of such markets at the EU level.

German firms face major challenges in later rounds of VC financing, where funding volumes tend to be much higher than in earlier investment rounds. More generally, equity financing faces similar challenges, because financing volumes are also high. In the United States, institutional investors such as pension funds increasingly invest in private equity because of the returns such investments have brought them compared to traditional instruments. In 2021, for example, US public pensions funds' private-equity investments reached USD 480 billion (United States dollars) (Gillers, Heather, 2022[4]). It is the sheer scale of the liquidity available to the US VC market that allows the high number of late-stage investment rounds, pointing to the need for greater institutional investment in Germany – and across Europe – if Germany's start-ups are to secure the needed growth finance within the European Union.

In Austria, the government has also taken a combined approach to VC. In May 2019, the Government of Austria and the federal promotional bank, the Austria Wirtschaftsservice (AWS), announced a new start-up package featuring a series of measures aiming to position Austria as a more attractive location for start-ups. At the same time, the AWS Mid-Cap Fund is a complementary instrument managed by the AWS which provides growth financing to medium-sized companies. The combination of the two funds is indicative of the ability of federal governments to provide additional public financing to innovative start-ups and SMEs throughout their development. AWS also runs a seed and early-stage "Founder Fund", which co-invests with private investors on a long-term basis in high-potential firms, with the possibility of multiple funding rounds. The fund targets firms that struggle to raise capital through traditional financing avenues (such as bank loans), focusing on those with significant growth potential (Austria Wirtschaftsservice, 2022[5]).

Mobilising private finance for start-up VC often requires a creative approach to the regulatory environment, beyond merely the financial and banking system. One way to promote greater levels of investment in start-ups is to increase their fiscal attractiveness. In the United Kingdom, the government has implemented a number of tax relief and incentive programmes aimed at encouraging individuals to invest in firms. The Seed Enterprise Investment Scheme (SEIS), for example, offers tax benefits to investors in return for investment in small and early-stage businesses in the United Kingdom (UK Government, 2021[6]). In return for investing in a firm that has been pre-approved by the tax service, the investor is eligible for income tax relief (up to 45% of the initial investment, applicable to the current and previous year's income tax bill); capital gains tax exemption on the shares in the SEIS business for three years after the investment; capital loss relief; and inheritance tax relief. The Enterprise Investment Scheme for later-stage start-ups follows a similar model. Both programmes provide incentives to the investor, while the start-up is able to access VC in exchange for equity where financing might may not have been possible through a traditional bank loan.

7.1. Banking finance for innovation in Germany

The banking sector in Germany is a major source of financing for the country's *Mittelstand*. Domestic credit to the private sector provided by banks amounted to 85.2% of the country's gross domestic product (GDP) in 2020 (World Bank, 2020[7]). While bank credit is slightly higher than the OECD average (84.7%), total domestic credit to the German private sector (85.7% of GDP) was significantly lower than the OECD average (161.9%), and lower still than the United States (216.3%), Japan (194.6%) and Korea (165.5%). Furthermore, although the German banking system is the largest in the European Union by absolute numbers of banks, it is characterised by a high level of fragmentation across private, state and co-operative credit institutions (Hufner, 2010[8]). This did confer privileged positions to the regional savings banks (*Sparkassen*), playing an important role in Germany's *Mittelstand* funding as lending is based on trusted relations with those institutions.

As evidenced by several survey results, access to finance by SMEs in Germany is generally good: the latest (2020) survey of 11 007 firms, including 1 337 German firms, identified access to finance as much less of a barrier in Germany than in other European countries (ECB, 2021[9]). The low interest rates that have characterised the German banking sector for several years (with the central bank rate at 0% since 2016) continue to provide favourable conditions for bank finance, which remains the most important source of private-sector financing for German SMEs. As in other countries, however, the use of private finance for research and product development is relatively low, at around 25% in Germany against 20% for the EU average (ECB, 2021[9]). Bank finance, which offers relatively sound conditions in Germany, is only one of several financial means of obtaining necessary financing for firms performing RD&I.

As in other OECD countries, German firms face challenges in accessing bank finance for investments in intangible capital. Intangible assets are ones that lack physical substance. They can allow the commercialisation of knowledge and are widely acknowledged as the main source of future growth, particularly as knowledge-based activities become more important than traditional activities, such as manufacturing. Such investments can relate to R&D, patents, software, databases, managerial skills and a range of other assets that share characteristics such as uncertain returns, non-rivalry, large synergies and low re-deployability (OECD, 2021[1]). The resulting information asymmetries (meaning that the firm or innovator has a much better understanding of the value of the investment than the bank) leads to difficulties in using such assets as collateral, and a lack of willingness from the banking sector to provide the necessary finance. As in other areas of access to finance, the effects are uneven across the private sector, affecting SMEs and start-ups more than larger firms. Consequently, firms rely increasingly on private equity and retained earnings to invest in intangible assets (Cecchetti and Schoenholtz, 2017[10]).

These financing issues have existed for a long time, but are increasingly important in a context where economies are transitioning towards knowledge-based growth models and complementary investments in intangible capital are necessary to fully exploit new (particularly digital) technologies. In Germany, financing constraints to investment in intangible capital may lower the ability of existing and new firms to contribute to innovation, limiting the innovation contribution of the German science, technology and innovation system.

7.2. Venture capital funding and other funding for high-risk innovation

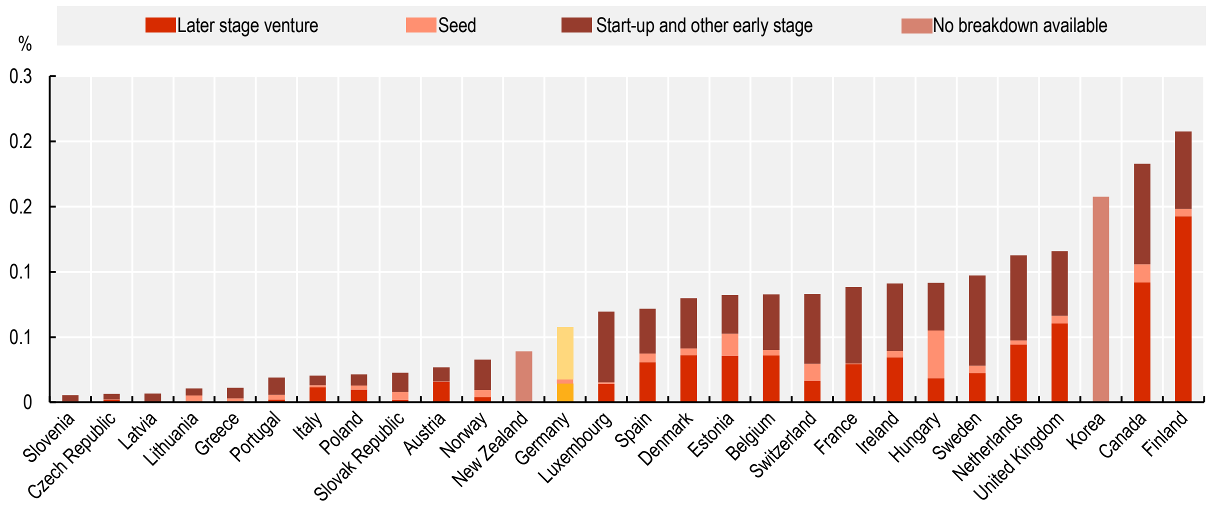
7.2.1. VC funding

Venture capital[1] (VC), which has funded high-risk innovation in countries such as the United Kingdom, the United States and Israel, is an important source of finance for high-risk and potentially breakthrough innovations in Germany. Traditional bank finance, which often requires asset collateralisation that is not easily secured with the intangible and knowledge-based assets of young firms, is less attractive than VC when it comes to investing in riskier innovation.

While VC is increasingly popular in Germany, having experienced 160% growth in 2019 over 2009. However, German VC levels of EUR 2.4 billion (euros) are only the sixth-highest in the OECD region (Figure 7.1). In 2019, VC in Germany amounted to Germany amounted to 0.056% of GDP, significantly less than in other economies such as Korea and the United Kingdom, although ahead of Japan. Although VC relative to GDP is low in most OECD countries, there exist some notable exceptions. In Israel, which is widely noted as a “start-up nation”, with one of the world’s most developed networks of VC funds, VC investments totalled 2.2% of GDP in 2020 (Figure 7.1).

Figure 7.1. Seed and later-stage VC investment is underdeveloped in Germany

VC as % GDP (2020)

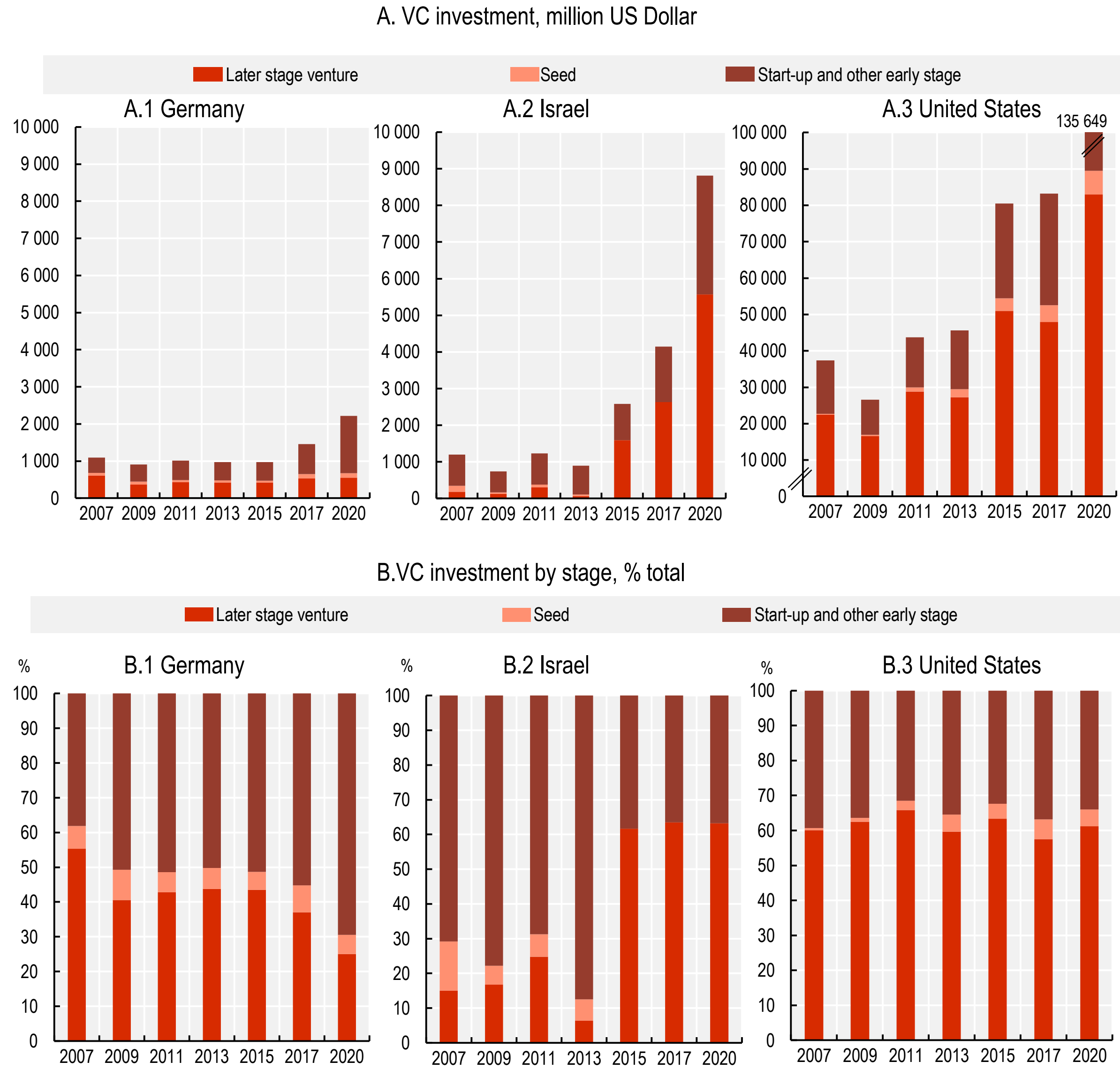


Note: For Korea and New Zealand, no breakdowns of VC by stage are available.
Source: OECD (2022[11]), "Venture capital investments", Structural and Demographic Business Statistics (database), https://doi.org/10.1787/60395228-en (accessed on 24 May 2022).

While the VC market in Germany has increased over the past decade, it remains underdeveloped in the second and third growth phases, where financing volumes amount to EUR 50-150 million. In 2021, Germany numbered over 150 VC firms, but 78% of the capital was raised by the first two funding rounds, Seed and Series A, which target start-ups at an early stage of their development. Yet 83% of fundraising is late-stage. This means that although there exists a well-developed VC market for early-stage start-ups – which receive extensive public support (through programmes such as EXIST and *Zukunftsfonds*, described in Chapter 3) in addition to private investment – it is the more advanced firms that are in greater need of financing. As noted by SPRIND, there are almost no mid- or late-phase VC funds in Germany that can provide the capital necessary for IPOs of mid-cap technology firms (those with EUR 10-100 million in revenue and less than EUR 1 billion in market capitalisation) (SPRIND, 2022[12]).

Trends in the development of VC markets in Germany possess several notable characteristics. As shown in Figure 7.2, the absolute levels of VC across all stages are significantly lower than in the leading economy (the United States), but also behind much smaller economies (e.g. Israel). As previously mentioned, the bulk of German VC investment tends to happen at the seed and earlier stages of investment, whereas in the United States and Israel, VC investment occurs in the later stages, often involving much higher levels of financing. In Germany, 40% of VC in 2019 targeted late-stage investment rounds, compared to 60% in the United States and 70% in Israel. Notably, Israel's VC market, including for later-stage investment, has only really developed over the last decade or so: in 2011, total late-stage VC investments in Israel totalled USD 80 million, compared to USD 432 million in Germany. By 2019, late-stage VC investment in Israel had grown by 6 000% (to USD 4.9 billion). Growth in Germany was significant, but a nevertheless more modest 127% (USD 981 million).

Figure 7.2. VC at different investment phases: Germany, United States, Israel



Source: OECD (2022[11]), "Venture capital investments", Structural and Demographic Business Statistics (database), https://doi.org/10.1787/60395228-en (accessed on 24 May 2022).

A lack of well-developed VC markets for start-ups at the middle and later stages of development may create challenges for the growth prospects of new and innovative German firms, such as those formed through academic spin-offs. Yet in a global financial market, German firms that cannot secure domestic VC can – and do – turn to markets in countries with some of the world's most developed VC markets, such as the United Kingdom and the United States. The example of artificial intelligence (AI), a technology that is crucial to applications such as autonomous driving and pharmaceutical research, is telling. In 2020, German AI start-ups received USD 1.5 billion in VC investment, including USD 331 million from German investors and USD 1.2 billion from international investors, the largest two being the United Kingdom and the United States. As a point of comparison, that same year, AI start-ups in the United States secured USD 45.2 billion in VC investment, USD 26.5 billion of which came from the domestic VC market – almost USD 8 billion more than secured abroad (Dealroom.co, 2020[13]).

The health of domestic VC markets therefore has both economic and strategic importance for German innovation. On the one hand, the undoubtedly lower levels of domestic VC available to German firms may make it harder for promising firms to obtain the financing they need to grow. On the other hand, although funding may be available externally, this has implications for the localisation of intellectual property attached to these firms. This is perhaps less of an issue for the start-up itself and a greater concern for governments, which may believe it in their strategic national interest to ensure that knowledge and technological competencies crucial to their key industries remain domiciled within their country. This is particularly true in the context of a more digitalised global economy, where the value added in key exports may shift increasingly towards such technological competencies. At present, late-stage financing mostly relies on foreign investors (mainly the United States and Asia), with foreign investment growing twice as fast as domestic investment (Dealroom.co, 2020[13]).

Attracting funding is particularly difficult for pre-commercial projects and firms that work on emerging technologies at an early stage of development. Such projects often lack the necessary infrastructure and business case, increasing the risk involved. This is often the case for so-called spin-offs – start-ups founded by academic researchers – despite their being potential drivers of radical innovation that are urgently needed to develop and diffuse new technologies among larger firms. The federal-level EXIST programmes are the most prominent public instrument for promoting such entrepreneurship among academics. They support up to 240 projects each year through monthly stipends and mentoring, as well as covering up to EUR 250 000 in personnel and material expenses in the early funding phases. A second policy initiative that focuses specifically on promising pre-seed, pre-market projects is the Federal Agency for Disruptive Innovation (SPRIND), established by the Federal Government in 2019 and funded with EUR 1 billion. Based in Leipzig, SPRIND funds pre-market projects selected through regular innovation challenges. Notably, the new coalition government intends to ease oversight mechanisms to allow the agency to support promising higher-risk projects that could result in disruptive and commercially successful innovations. Chapter 3 provides further information on policy programmes that support high-risk and potentially breakthrough innovation through investment and acceleration measures.

7.2.2. Financing green innovation

Germany has a broad array of public and private initiatives that can contribute to innovation for the green transition. Reflecting the importance of innovation in support of more sustainable industry, many such initiatives stem from the industrial sector. For example, BASF has operated a VC fund for green entrepreneurship since 2011 and Siemens since 2016, while Volkswagen announced in 2021 that it would establish a EUR 300 million VC fund to invest in de-carbonisation start-ups (OECD, 2022[14]). The policy and private-sector impetus towards green innovation has supported the development of a vibrant green start-up ecosystem: Germany is home to 276 climate-related technology start-ups, compared to 180 in the United Kingdom, 103 in France and 44 in Denmark. Such start-ups play a significant role in developing technology that can support the sustainable transition, with the German start-ups active in green hydrogen and energy storage featuring among the most competitive in the world.

Green innovation is an area where public funding plays a vital role. The German Federal Environmental Foundation (Deutsche Bundesstiftung Umwelt DBU), for example, supports green start-ups through its dedicated "Green Start-up Programme", which provides up to EUR 125 000 in non-repayable grants to selected projects. In 2021, the programme had a 7% approval rate, with 14 start-ups selected for funding. Other projects include the Green Start-Up Investment Alliance, co-ordinated by the Borderstep Institute for Innovation and Sustainability, which aims to support business angels and other early-stage investors involved in green start-ups.

The Federal Government also finances the Future Fund, a major equity fund co-ordinated by KfW Capital that invests in VC for future technologies. While the fund does not explicitly focus on green technologies, it can nevertheless be a significant source of funding for related projects. In 2021, the Federal Government promised an additional EUR 10 billion to the Future Fund, anticipating that it would provide over EUR 50 billion in public-private VC for start-ups. The fund has three important components:

- **DeepTech Future Fund (DTFF):** this new fund co-invests with private investors in high-tech German companies during their rapid-growth phase. DTFF has a budget of EUR 1 billion to be allocated over the next decade. It is managed by the High-Tech Growth Fund and focuses on industries related to green entrepreneurship, including e-mobility and energy.
- **European Recovery Programme/Future Fund Growth Facility:** around EUR 2.5 billion in EU funds have been made available for KfW to invest in German and European VC funds, with a view to enabling larger and more regular financing rounds for start-ups.
- **German Future Fund/European Investment Fund Growth Facility:** backed by the European Investment Fund, this facility has a budget of EUR 3.5 billion to be invested over the next decade in growth funds and growth financing rounds for start-ups.

7.2.3. Increasing the contribution of institutional investors to risk-related finance

Providing the financing necessary to high-potential German innovators necessarily entails increasing the amount of investment by institutional investors in start-ups and innovative firms through VC and private equity. Pension funds have a particular role to play in this regard as they are often the only institutions outside the banking sector with the capital necessary to invest in fast-growing or more established innovative firms, where funding volumes are generally higher than for early-stage VC. Yet these funds are often risk-averse and preferring investments with lower yields but also lower risks, such as government bonds. The result is that a vast reservoir of capital at both the national and EU levels remains untapped for investment in innovation.

The experience of Nordic pension funds, which have accounted for 16% of total VC raised in the region since 2013, is indicative of the important role institutional investors can play in the VC market (Atomico, 2018[15]). In the United States, pension funds are among the largest domestic VC investors, making up two-thirds of all capital in VC funds. In contrast, pension funds in Germany, Switzerland and Austria have only accounted for 2% of total VC funds raised since 2013 (Atomico, 2018[15]). Nordic countries have also introduced incentives for pension funds to invest in VC; in 2018, the Swedish government issued a directive that allowed private pension schemes to increase their share of alternative investments from 5% to 40%. The Danish fund-of-funds model also shows how insurance companies can make significant investments in VC. Thus, the Nordic system of loss-prevention guarantees for pension funds investing in VC contributed to the creation of a vibrant financing ecosystem, with very little cost to the government. In France, the government also succeeded in convincing institutional investors to extend growth finance to high-tech start-ups.

7.2.4. Regulatory and taxation considerations for financing innovative start-ups

Though not strictly a financing instrument, employee stock-ownership option plans (ESOPs) can play an important role in a start-up’s growth phase. ESOPs are options – not obligations – given by the start-up to an employee to purchase the firm’s stock at a set price for a limited period of time, essentially locking in a potentially below-market rate for a quantity of a firm’s shares before it goes public. Issuing ESOPs allows start-ups to align the motivations and ambitions of employees or cofounders with the firm’s vision.

The limited development of ESOP regulation to date in Germany not only reduces possibilities for start-up to attract talent, but also stifles the possibility for investment-cascade effects (e.g. when cashing in stock options). ESOPs are prohibitively difficult under German law and impose a major tax burden. As of 2020, fewer than 30% of German start-ups used ESOPs. A study by VC firm Index Venture ranked Germany second to last in an international comparison of 22 North American and European countries in terms of the regulatory and cultural environment for stock options (Richter, Maximilian, 2020[16]).

The implications for the talent pool are also significant. The regulatory difficulties in issuing ESOPs may negatively affect the ability of promising start-ups to attract and retain staff, since cash-flow constraints in the early stage of start-up development limit the ability to pay salaries. A future stake in the company's growth can therefore provide an attractive alternative. Generally speaking, the German tax framework for equity ownership and awards has been largely uncompetitive in international comparison. Furthermore, the workaround is twice as expensive as setting up such a scheme in other locations, such as the United Kingdom, Israel or the United States. Instead, start-ups issue virtual stock options, which can be very expensive for firms and are not equally attractive for employees.[2]

Five European countries (Latvia, Lithuania, Estonia, France and the United Kingdom), [1] in addition to Canada and Israel, have improved the terms of ESOP regulation and now offer more favourable stock option rules than the United States. In Germany, a 2021 draft law (*Fondsstandortgesetz*) aiming to tackle these issues has fallen short in terms of reforms and incentives. For example, tax relief is only available to employees of companies created less than ten years ago. In addition, despite its increase, the amount of the tax allowance is still modest compared to other European jurisdictions.

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Endnotes

[1] VC refers to financing of a firm not listed on the stock market by private investors, often together with management or founders, with a view to commercialising a promising business idea or innovation. This financing is either secured at the pre-seed or seed phase, where the start-up is yet to commercialise, at an early or middle phase, where the start-up is entering a market, or at a later stage, where the start-up is looking to scale and expand.

[2] Under a virtual stock option plan, employees receive a cash equivalent when the business goes public or is taken over. Yet such schemes are often prohibitively expensive for the company. They also tend to be disadvantageous for employees because payments are taxed like income, not capital gains.

8 Quality infrastructure for innovation in Germany

This chapter assesses the quality infrastructure in Germany, and the extent to which it can support or constrain innovation. Norms and standards by quality-infrastructure institutions play a crucial role in the innovation system, setting the rules of the game and creating path dependencies in global value chains. Germany has traditionally played an important role in the international quality-infrastructure architecture, but the shift towards digital and other new advanced technologies creates a systemic challenge to the country's leadership position and requires policy attention to modernising the quality infrastructure.

Introduction

Norms and standards – ranging from the size of paper to interfaces for human-machine interactions in Industry 4.0 – are key to companies' ability to innovate and market new products and services. By providing common rules, standard-setting institutions give the legal and financial clarity necessary to invest in innovation. Norms and standards also help secure the legitimacy of the "rules of the game" for public and private economic actors. They can support social welfare by improving product safety and quality, building trust among market participants and reducing transaction costs, especially in cross-border trade. Moreover, well-devised standards spur innovation by codifying accumulated knowledge and forming a baseline from which new technologies emerge, whereas outdated standards increase resistance to change by codifying inefficient or obsolete technology (Allen and Sriram, 2000[1]; Blind, 2022[2]).

In Germany, norms and standards are developed and overseen by a network of highly specialised institutions that make up the quality infrastructure, which refers to the public and private institutional framework needed to support and enhance not just standard setting but the general quality, safety and environmental soundness of goods, services and processes. Organisations in the quality infrastructure system are responsible for the implementation of standardisation, accreditation and conformity assessment services such as inspection, testing, laboratory and product certification. Key bodies include the German Institute for Standardisation (DIN), the National Metrology Institute of Germany and the German Accreditation Body. Emerging digital technologies such as artificial intelligence (AI), robotics, batteries and quantum computing pose new challenges and entail novel processes and expertise, requiring an upgrading of the infrastructure.

In practice, the prominence of German industry in the international economy means that German standards and norms are often global. Innovation in the German economy therefore has the ability to shape the regulatory environment and standards beyond its borders, which is a key strategic strength of German industry. The practical – and, as these standards become codified in different legal environments – internationalisation of Germany's quality infrastructure is particularly important for some of its most successful industries, such as machinery and automotive manufacturing. Being a "rule-maker" as opposed to a "rule taker" can underpin Germany's ambition for global innovation leadership, but the digital and sustainable transitions, where Germany is not as successful as in other technology fields, could challenge its position.

This chapter is organised into five parts. The first section begins with an overview of recommendations related to Germany's quality infrastructure. Section 8.1 reviews the key stakeholders in Germany's science, technology and innovation (STI) quality infrastructure. Section 8.2 deals with German quality infrastructure in an international and EU context while section 8.3 addresses the role of quality infrastructure in the context of the digital and green transitions. Section 8.4 concludes with a discussion of the use of quality infrastructure as a strategic instrument for competitiveness.

Recommendation 9: Digitalise, modernise and strategically use quality infrastructure

Overview and detailed recommendations

Quality infrastructure – the standards and norms that shape and inform manufacturing and services – Germany's competitiveness in the manufacturing of certain goods implicitly granted it global leadership in standard-setting. In a world where output has a higher digital intensity, and a greater degree of interconnectedness exists across products, services and sectors, standard-setting is more complicated. The much faster speed of change in the current period of transitions also requires new approaches and more strategic uses of the standards and quality infrastructure.

R9.1 **Enhance digitalisation and develop state-of-the-art capabilities in both the standard-setting process and quality infrastructure**. The institutions in charge of standards and quality infrastructure have not completed their digitalisation, despite urgent needs in capacity and infrastructure investment. The digital connectivity across institutions at the federal and state levels also requires attention. Germany's advanced metrology institutions must be strengthened and modernised to deal with the complexity and interconnectedness of the new technologies they must measure, such as autonomous driving or the application of AI in the medical and pharmaceutical sectors. Developing the quality and standards infrastructure also critically depends on supporting investments in human capital, including by promoting the attractiveness of working in this field.

R9.2 **Use the quality infrastructure as a strategic instrument for innovation and competitiveness**. Germany's leadership in many areas of manufacturing and industry, combined with the high quality of the current metrology system, have conferred on its economy an implicit leadership position in standardisation. This leadership confers competitive and innovative advantages, as it orients global manufacturers towards norms set by German firms. The government should thus adopt a systemic approach to standardisation and the quality infrastructure as integral components of international innovation and competitiveness, explicitly determining their contribution to achieving the "Germany 2030 and 2050" vision.

Relevant global experience

Although Germany's quality infrastructure is generally highly advanced, international best practices can provide helpful guidance. Leading global institutions, such as the American National Standards Institute (ANSI) and the Korean Agency for Technology and Standards (KATS), explicitly address the strategic importance of standards for trade and innovation in their strategies. Two aspects are particularly important. First, as mentioned in the strategic report of ANSI, standards and their application should be continuously monitored and updated to ensure they do not become trade barriers to products and services. Second, international outreach programmes beyond national borders are crucial facilitators of better trade relations and the success of a country's own standards (ANSI, 2021[3]).

As discussed in Recommendation 9.1, improving institutional operations and engagement with producers and users of new innovations, as well as the wider public, is important for quality infrastructure institutions. This includes capacity and skill development in some key technologies, particularly AI and data-driven digital applications, that affect several important sectors of the German economy and raise new questions on privacy and security. To deal with those developments, ANSI has established "standardisation collaboratives" – forums where stakeholders and experts can advise the Federal Government on how to proceed with standardisation in emerging technology fields that both require technical expertise and affect society (ANSI, 2022[4]). KATS publishes annual reports on its ongoing activities, providing quantitative data on the benefits and challenges of standardisation that support evidence-based policy making. Both KATS and KSA are active in public schools and universities, by offering certificates and training on the basics of standardisation and quality assessment, or organising regular educational events (KSA, 2022[5]). In its 2020 strategy, ANSI also addresses the importance of promoting a standards-literate workforce by building awareness of standards and overall competence (ANSI, 2021[3]).

8.1. Overview of Germany's quality infrastructure

This section describes the formal institutions that comprise Germany's quality infrastructure for standard-setting, metrology, research and testing, conformity assessment and accreditation, and market surveillance. In addition to these institutions, several informal forums and consortia draft sectoral and industry-wide standards that often become standards in practice.

Since the introduction of the Standards Agreement in 1975, two institutions have acted as the main national standard-setting bodies on behalf of the German Federal Government: DIN and the German Commission for Electrical, Electronic & Information Technologies (DKE).

DIN is a public-private partnership whose primary task is to develop consensus-based standards that meet market requirements. At DIN, work is co-ordinated by the standardisation department, focusing on five key areas: construction; research and transfer; living and environment (relates to health, life sciences and sustainability); industry and information technology (IT); and water, air, technology and resources. In addition, DIN set up several thematic commissions that co-ordinate its activities within a specific area of standardisation, currently health care and small businesses. The main standard-setting work, however, is carried out by its working committees, which bring together technical experts from industry and research to develop standards in specific fields. These committees are either permanent (for example, the construction or information and communication technology [ICT] committees) or appointed for a limited period. to work, and are partly not located within DIN, but rather within industry associations.

DKE, a division of the Association for Electrical, Electronics & Information Technologies (VDE), is responsible for the development of standards and safety specifications in the areas of electrical engineering, electronics and IT. Both are non-profit organisations that finance themselves in large part through the sale of standards (representing 63% of funding for DIN and 95% of funding for DKE in 2019) (BMWK, 2021[6]).

With regard to the process described in Figure 8.1, anyone can submit a proposal, and all those interested in a specific topic related to standard can participate in the standard-setting process and contribute their expertise. Firms that introduce new products and services are most likely to participate in standard-setting, hence the importance of this process for innovative firms and the competitive advantage of being a first mover (Blind, Lorenz and Rauber, 2021[7]). Before a standard is officially adopted, the standard-setting institution publishes a draft and solicits public comments, allowing experts to reach an agreement on the standard's content. Moreover, standards are regularly reviewed by experts at least every five years to ensure they reflect current best practice (Hallscheidt et al., 2016[8]).

Figure 8.1. The standard-setting process in Germany

Other than norms, standards do not require a full consensus of all stakeholders involved in the process

Source: BMWK (2021[6]), United in Quality and Safety: An introduction to quality infrastructure in Germany and the European Union for policymakers and trade partners. https://www.bmwk.de/Redaktion/EN/Publikationen/united-in-quality-and-safety.pdf

8.1.1. Metrology and conformity assessment

Metrology – the science of measurement and the development of measurement units – is a key component of the quality infrastructure. It is vital to the innovation system, as it provides the basis for product development, quality assurance and regulation, and fair and reliable market transactions. The crucial role of metrology is confirmed by studies that find large benefits for productivity and economic growth, especially in IT (Link, 2021[9]; Robertson and Swanepoel, 2015[10]).

Economic incentives for market actors to develop measurement units are limited and under-investment is likely, owing to the public-good character and high positive externalities of measurement units, making private provision unviable. Measurement development has high fixed costs, while marginal costs (and benefits) are relatively, low so that the government usually becomes the effective provider of metrology services (Robertson and Swanepoel, 2015[10]). Public policy must therefore play an active role in supporting metrology.

In Germany, two main institutions perform metrology, as well as related research and testing. The National Metrology Institute of Germany (Physikalisch-Technische Bundesanstalt [PTB]) is responsible for developing and disseminating measurement units in the service of science, society and the economy. It derives its legal mandate and activities through 23 laws and ordinances, particularly the German Units and Time Act of 1978, which regulates the legal time in Germany and entrusts PTB with disseminating legal time to the public. PTB is a the highest federal authority under the Federal Ministry for Economic Affairs and Climate Action (BMWK).

While PTB is in charge of metrology, the Federal Institute for Materials Research and Testing (Bundesanstalt für Materialforschung und -prüfung [BAM]) conducts research and testing to guarantee the technical safety of products and processes in order to protect people, the environment and material goods. Its working areas include materials science, materials engineering and chemistry. BAM is a senior scientific and technical federal institute overseen by the Federal Ministry for Economic Affairs and Climate Action (BMWK).

8.1.2. Accreditation

The main function of accreditation is to assess the competence of organisations conducting conformity assessment, supporting trust in the quality infrastructure. Accreditation contributes to the effective operation of markets, so that buyers and sellers can trust in the reliability and competence of their (trading) partners, and in the properties of the goods and services on offer (Frenz and Lambert, 2014[11]). For instance, as accreditation increases the credibility of test reports and certificates, producers can gain greater commercial benefits from the products and services offered. This is particularly true for innovative products and services, creating incentives for further innovation-related investment.

The German Accreditation Body (Deutsche Akkreditierungsstelle [DAkkS]) is the sole provider of accreditations in Germany, and operates in the public interest on the basis of both EU and Germany regulations. DAkkS was established as a limited liability company operating on a non-profit basis. It is owned equally (one-third each) by the Federal Government, the federal states and the Federation of German Industries (Bund der Deutschen Industrie [BDI]).

8.1.3. Market surveillance

Identifying market actors and products that do not comply with German and EU regulations is the main function of market surveillance institutions. Thus, market surveillance not only protects consumers from potentially dangerous products but also promotes fair competition among businesses, based on the same rules for all. In Germany, two main institutions are in charge of market surveillance at the federal level.

The Central Authority of the Federal States for Safety Engineering (Zentralstelle der Länder für Sicherheitstechnik [ZLS]) is in charge of monitoring product markets and co-ordinates the market surveillance activities at the level of the German states. In case of a suspected problem, it delegates authority to respective conformity assessment bodies, which carry out product inspections. ZLS received its mandate through from an agreement of the 16 *Länder* in 1993, but is in fact a higher state authority that operates within the Bavarian State Ministry responsible for technical labour and consumer protection.

In the markets and infrastructures linked to energy, telecommunications, post and railways, market surveillance is delegated to the Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway (Bundesnetzagentur [BNetzA]). BNetzA is an independent higher federal authority overseen by BMWK and the Federal Ministry for Digital and Transport. It seeks to promote well-functioning markets through deregulation and liberalisation, while ensuring compliance with the German Telecommunications Act, the Postal Act and the Energy Act.

8.2. Germany's quality infrastructure in European and international standard-setting

This section discusses Germany's position in European and global standardisation, which plays an important role in trade, competitiveness and innovation performance. It also discusses current initiatives to strengthen standardisation at the EU and international levels. It highlights areas for improvement, notably missing empirical evidence and the lack of awareness among businesses and policy makers on the impact of standardisation on German businesses and the economy as a whole.

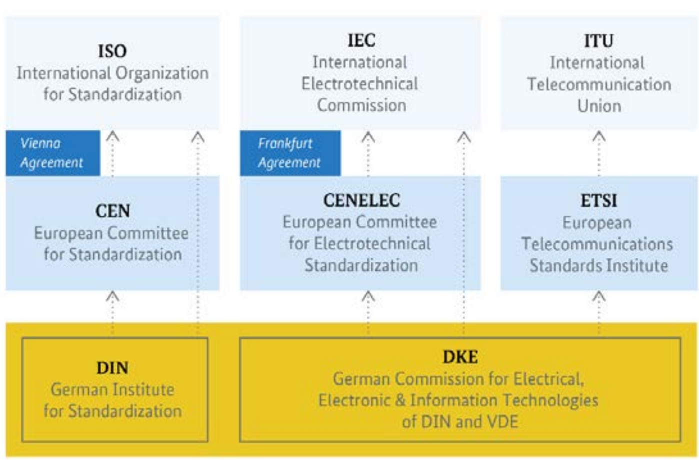
As a major trading country, Germany has a central position in European and international standard-setting. Today, roughly 85% of all national standards projects were originally European or international, which generates significant benefits for the German economy (DIN, 2022[12]). Economic research shows that standards that are shared by more than one country drastically decrease transaction costs, thereby reducing barriers to the international trade on which Germany depends. By contrast, relying solely on national standards in certain product areas, which foreign market actors may struggle to comply with, may hamper cross-border trade. In particular, the combination of national and international standards is known to facilitate international co-operation and generate higher gains from trade, especially in Europe (Blind et al., 2017[13]).

However, as at the national level (discussed above), the international standardisation process faces new challenges from the diversification of business models, the increasing role of ICT and the growing importance of services in global value chains. In addition, as the need for communication between market participants grows, owing to the increasing number of production stages in global value chains, standards gain in importance as means of reducing information asymmetries (Blind et al., 2017[13]). It is therefore crucial for both German companies and policy makers to secure and expand Germany's influence on standardisation beyond the national level. Germany should continue to act as an initiator for international standardisation projects and the regional harmonisation of standards, especially in Europe. This implies the active participation of German companies, especially small and medium-sized enterprises (SMEs), in filling seats on European or international standardisation bodies. Businesses and policy makers in general should see standardisation as a strategic tool for improving Germany's competitiveness. This requires raising awareness of international standardisation, as well as further empirical investigations on the benefits of standardisation for both individual companies and the overall economy in order to guide effective policy.

Germany's main bodies in charge of standard-setting, DIN and DKE, are embedded in a larger network of European and international standardisation organisations. Generally, international standards are set by the European institutes CEN, the European Committee for Standardization (for non-electrotechnical standardisation), CENELEC, the European Committee for Electrotechnical Standardization (for electrotechnical standardisation) and the European Telecommunications Standards Institute (ETSI), as well as by three international organisations: International Organization for Standardization (ISO), International Electrotechnical Commission (IEC) (for electrotechnical standardisation) and International Telecommunication Union (ITU) (for standards in telecommunication). By agreement with the Federal Government, DIN is acknowledged as the national body representing German interests in European and international standards organisations, with DKE closely supporting DIN in line with the German Standardisation Strategy (DIN, 2017[14]). In addition, DIN can transfer standards established by the consortia into national, European or international standards, and works on harmonising national and international standards to reduce trade barriers.

Figure 8.2. Standard-setting across German, European and international levels

German standard-setting institutions are embedded in a network of European and international actors



Source: BMWi (2021[6]), *United in Quality and Safety: An introduction to quality infrastructure in Germany and the European Union for policymakers and trade partners*. https://www.bmwk.de/Redaktion/EN/Publikationen/united-in-quality-and-safety.pdf

At the European level, the importance of standards has been explicitly recognised by the European Commission's Joint initiative on Standardisation, which was established through the 2015 Digital Single Market strategy. The joint initiative aims to advance the EU standardisation system in co-operation with industry, standardisation organisations and the wider standardisation community (European Commission, 2016[15]) It prioritises (1) improving awareness, education and understanding about the European Standardisation System; (2) promoting co-ordination, co-operation, transparency and inclusiveness in standard-setting; and (3) supporting competitiveness in international trade. In line with the Digital Single Market strategy, EU-level efforts have focused specifically on ICT technologies and reviewing the European interoperability framework. However, there remains significant untapped potential in the development and use of voluntary European service standards, which currently account for only a small fraction of EU standards.

In early 2022, the Commission presented an updated Standardisation Strategy that shifts the focus explicitly on standards as a strategic tool for competitiveness and for supporting member states and the European Single Market as a whole (European Commission, 2022[16]). In five key areas for action, the strategy recognises the EU's need to be assertive and strategic at international level and seeks to address standardisation issues arising from the green and digital transformation of the EU's industrial ecosystem. A central goal is to prioritise standardisation in strategic areas, especially in medicine production, critical raw materials recycling, clean hydrogen value chains, low-carbon cement, chips certification and data standards ("1. Anticipate, prioritise and address standardisation needs in strategic areas."). This includes setting up a high-level forum to anticipate and inform future standardisation priorities, a new Chief Standardisation Officer function to ensure high-level guidance across the Commission on standardisation activities as well as an EU excellence hub on standards.

The strategy also outlines several actions for improving the governance and integrity of the European standardisation system ("2. Improve the governance and integrity of the European standardisation system."). To avoid undue influence of outside actors on the development of standards for key areas, like cybersecurity or hydrogen standards, standardisation mandates at the request of the Commission should in the future be handled by national standardisation bodies. Further, the Commission will launch a peer review process to support the modernization of national standard organisations, particularly with regards to the inclusiveness for civil society, users as well as SMEs-friendly conditions for standardisation.

On a global level, the Commission aims to strengthen the EU's leadership position by establishing a new mechanism with member states and national standardisation bodies to share information, coordinate and strengthen European approach to international standardisation ("3. Enhance European leadership in global standards."). Moreover, standardisation will be linked closer to EU-funded research programmes, for instance by supporting researchers under Horizon 2020 in testing the relevance of their results for standardisation as well as through a new Code of Practice for standardization in a research context ("4. Support innovation."). Lastly, the new strategy outlines the Commission's goal of promoting standardisation expertise and awareness of standards among academic researchers ("5. Enable the next generation of standardisation experts.").

At the international level, ISO – which numbers more than 160 member countries – is the most important forum for German influence on standardisation. German interests at ISO are represented by DIN, which sends expert delegations to ISO working bodies, who then vote on standardisation decisions. In addition, DIN holds a large number of secretariats of ISO committees and working groups. Participation in these committees and working groups offers companies and research institutions the opportunity to place their research results at the international level and promote their own technical specifications as international standards. As of 2022, Germany is one of the most important members of ISO and participates in 700 ISO technical committees (Blind and von Laer, 2021[17]), positioning Germany at the third place worldwide behind France and China. DIN, as a permanent member of ISO steering committees and the ISO Council, as well as through its regular participation in the annual ISO General Assembly, can also actively shape the strategic direction of international standardisation. As technological development accelerates and moves away from the traditionally strong sectors of the German economy, DIN should step up its efforts to represent German interests.

Beyond formal co-operation across the European and international levels, German institutions regularly engage in international partnerships to develop a more coherent and uniform body of standards and specifications, and promote trade and product safety. An important platform for collaboration is the Global Project Quality Infrastructure (GPQI), which was established in 2017 by BMWi (now BMWK), jointly with important trading partners including Brazil, China, India, Indonesia, Mexico, Canada, the Eurasian Economic Union and the United States. The goal of GPQI is to support the international harmonisation of quality infrastructures among participating countries. It is set up as a multi-stakeholder platform that brings together governments and experts from the public and private sectors. Similarly to national standard-setting, GPQI initiates and implements political and technical dialogues where each stakeholder can propose topics. These topics often concern co-operation on specific sectors (e.g. chemistry or transport) or the harmonisation of activities and procedures (e.g. in metrology).

8.3. Digitalisation and the green transition create new demands on Germany's quality infrastructure

Accelerated technological developments pose new challenges to Germany's quality infrastructure, notably by requiring institutions to improve their speed of work. Quality infrastructures were traditionally developed to deal with linear innovation processes, but today's technological developments tend to be much more dynamic, creating a greater degree of interconnectedness across products, services and sectors. Standard-setting bodies need to find new ways of processing and keeping up with these fast-paced technological developments, particularly in areas like autonomous driving, or the use of AI in critical fields such as medicine and pharmacy.

Developed in 2016 by representatives from all the institutions involved in standard-setting, the German Standardisation Strategy was an important first step towards future-proofing Germany's standard-setting capacities and role as a global rule-maker (DIN, 2017[14]). The strategy sets out six specific goals for the future development of DIN and DKE.

- Goal 1 emphasises the role of standardisation for international – and especially European – trade. It pledges to promote the adoption of international standard agreements in Germany while ensuring high transparency of standard-setting in the country.
- Goal 2 stipulates that standardisation should also be employed as an instrument for deregulation allowing participating actors to achieve independent and consensus-based agreements that do not require detailed legislative action.
- Goal 3 recommends new processes and open platforms for co-ordination in standard-setting. This is particularly relevant to future-oriented topics, such as "smart cities", Industry 4.0 and the energy transition, which require much broader stakeholder involvement. The digitalisation of standard-setting, and utilisation of open-source methods and technologies in standardisation, will support this goal.
- Goal 4 recommends reducing standard-setting costs, and promoting the active involvement of industry and SME associations, as well as actors from society as a whole.
- Goal 5 recognises standard-setting as a strategic instrument allowing companies to promote their own (or favourable) standards in global competition. However, this means that standardisation should be transparent and easily accessible, and that corporate management considers participation in standardisation committees as both beneficial and effective.

- Finally, Goal 6 recommends improving public recognition of standardisation thanks to transparent and efficient standard-setting procedures, and by promoting the role of standard-setting in ensuring quality, safety and innovation.

Table 8.1. Impacts of standardisation on innovation

The positive impacts of standards on innovation outnumber the negative impacts

General functions of standards	*Positive impacts on innovation*	*Negative impacts on innovation*
Information	• Provide codified knowledge relevant to innovation • Co-ordinate collaborative innovation activities	• Generate cost for standard screening • Allow unintended knowledge spillovers to competitors by implementing standards
Variety reduction	• Allow exploiting economies of scale through standards • Support critical mass through standards in emerging technologies and industries • Create incentives for incremental innovation based on standards	• Reduce choice • Support market concentration • Push premature selection of technologies • Limit incentives for radical innovation
Minimum quality	• Create trust in innovative technologies and products on the demand side	• Promote market concentration
Compatibility	• Increase the variety of system products • Promote positive network externalities • Avoid lock-in into old technologies	• Push monopoly power • Promote lock-in into old technologies in case of strong network externalities
Insurance	• Serve as insurance against failure of radical innovation	• Create incentives for incremental rather than radical innovation

Source: Blind (2022[2]), *Standard and innovation – What does research say?*, https://www.iso.org/files/live/sites/isoorg/files/store/en/PUB100466.pdf.

Further steps towards modernising standard-setting in Germany are being developed by QI Digital, a consortium established in 2021 by BAM, DAkkS, DIN, DKE and PTB, and supported by BMWK. The goal of QI Digital is to develop ways for quality infrastructure institutions to exploit new developments in digital technologies and internationalise the standardisation process. To identify and illustrate practical implications of emerging technologies for Germany's quality infrastructure, the consortium has compiled use cases for a number of fields. This includes new products and production technologies, where additive manufacturing such as 3D printing drastically reduces requirements for production chains and allows manufacturing very small batch sizes of new products (e.g. in aerospace, energy and medical technology). In such cases, conventional conformity assessment methods are often inadequate, requiring new procedures for process-integrated quality assurance, non-destructive testing, and digital evaluation of process and measurement data. This is also the case for digitally connected networks of hydrogen filling stations, for example, where more complex hardware and software interfaces, and interactions between producers, suppliers and customers (e.g. through distributed ledger systems on a blockchain) require new approaches to digital systems and data security in quality infrastructures.

AI is another key technology where quality infrastructure institutions must assess whether existing standards and specifications are still suitable, and find new ways to evaluate autonomous and self-learning systems (Wahlster and Winterhalter, 2020[18]). The rapid development and wide applicability of AI poses a particular challenge to the quality infrastructure, notably with regard to ethical considerations, quality, conformity assessment and certification, and IT security. To improve Germany's capacities in this field, specifically in standard-setting, DIN and DKE jointly developed the *German Standardization Roadmap on Artificial Intelligence*, which was published in 2020 (Wahlster and Winterhalter, 2020[18]). The roadmap aims to provide a framework that guides standardisation efforts in AI to support German industry in international competition, as well as promote an innovation-friendly environment for AI research and development (particularly at the European and international levels). The roadmap's six recommendations focus on the implementation of data reference models that ensure the interoperability of AI systems, the creation of security standards, and the initiation and promotion of standards for reliable and "trusted" applications of AI.

In addition to investments in digital capacities, developing Germany's quality infrastructure depends critically on investments in human capital. This includes promoting the attractiveness of working in the various quality infrastructure institutions, and creating university chairs and programmes that both produce scientific knowledge and educate future experts in advanced technologies and their regulation.

8.4. Using Germany's quality infrastructure as a strategic instrument to promote innovation and international competitiveness

8.4.1. Standard-setting for global leadership

Standard-setting should be an international effort if it is to reduce transaction costs in cross-border trade and promote the compatibility of new inventions with existing ones in world markets. In Germany, these efforts have been largely driven by export-oriented companies, which actively promoted their product standards among global manufacturers and took a leadership position in standard-setting for many areas of manufacturing and industry. In the context of the digital and sustainable development transitions, many new standards will need to be set for fundamentally different projects where setting the standards can yield a competitive advantage. However, such strategic uses of Germany's quality infrastructure rely critically on business innovation being at the frontier, since (as has always been the case) leadership in innovation supports building international standards.

Policy makers should recognise and support standardisation as an integral part of international innovation and competitiveness. The German Standardisation Strategy (Goal 5) has already highlighted the need to support businesses in using standardisation as a strategic tool (DIN, 2017[14]). Government support for standardisation, both in the form of resource allocation and indirect promotion of standards (e.g. through public procurement), can crucially support the innovation system. This includes active involvement in international standard-setting bodies, where Germany had a strong position in the past, but which increasingly require engagement, expertise and funding to keep up with accelerated technological developments beyond Germany's traditional core industries (e.g. software and AI). The central contribution of standard-setting – and the quality infrastructure more broadly – to realising the vision for Germany 2030 and 2050 should also be discussed by participants of the forum (see R1.1).

8.4.2. Engaging firms in quality standards

Companies benefit from actively participating in standards projects. By interacting with specialists in other areas, they can gain a knowledge lead, introduce their own technologies and help shape the content of standards. Furthermore, innovations that have been guided by standardisation processes from the initial idea to the market launch have a better chance of penetrating the market. Clearly, standardisation is an important strategic instrument in a company's technology and innovation management portfolio. Participating in the development of standards is a valuable alternative to – or can supplement – the patenting process, which can be cost-intensive and often only touches on a limited topical aspect (DIN, 2017[14]).

At the same time, technical experts are aware of the benefits of standardisation for their companies. Their technical know-how and experience are indispensable to the success of standard-setting work. However, companies can only unlock this potential when they integrate standardisation in their overall strategy. It is essential that management recognise and value employees' commitment to their work in standards committees, for example by securing the financing allowing them to attend committee meetings. Companies' participation in standard-setting should be further promoted by easing and digitising access to the standard-setting process and committee meetings, particularly for corporate management and technical experts.

In addition to efforts by DIN, DKE and other quality infrastructure institutions, BMWK promotes firms' participation in standard-setting with EUR 26 million (euros) annually through the "WIPANO – Knowledge and Technology Transfer through Patents and Standards" programme. Since 2016, WIPANO has supported firms in identifying, protecting and exploiting economically promising research results through expert advice on patenting and standard-setting procedures.

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Part IV Unbundling the international factor in domestic German innovation

9 The international dimension of Germany's innovation ecosystem

This chapter discusses the implications of Germany's highly internationalised economy on its innovation system. The chapter introduces the interlinking questions of how foreign demand supports domestic investment in innovation, the role of the German economy in many technologically advanced global value chains, and the challenges of supply chain resilience for the green and digital transformation of the German economy. The chapter also introduces a recommendation concerning the importance of Germany's international leadership in meeting many of the challenges outlined in this Review.

Introduction

The export-orientation of the German private sector has significant implications for innovation in the country and for Europe more broadly. The importance of foreign demand for domestic German innovation and research means that domestic STI is closely linked with the external performance and competitiveness of the German economy. At the same time, the extent of integration of the German economy with global value chains (GVCs) in many strategic industries means that the way German business responds to changes in those industries can have systemic implications, domestically and abroad.

This chapter unpacks a number of these implications, and looks at how the internationalisation of the German economy interacts with innovation performance, competitiveness, and the green transition. There are, broadly speaking, four ways in which 'the international component' of the German economy affects innovation capacities and output, interlinked by the question of competitiveness and resilience:

1. Germany relies heavily upon foreign demand to maintain innovation activities in its export-orientated industries. This in part is a reflection of relatively weak increments in domestic demand – also affected by the COVID-19 shock - and high savings rates fuelled by uncertainties as to future developments, including in the context of the Ukraine war. The export-orientated German business sector underpins the country's competitiveness, since it provides revenues that can be reinvested into research and innovation.
2. German manufacturing – and to a lesser extent, services – play a key role in a number of important global value chains (GVCs), as is the case for the automotive industry. German firms' prominent positions in these GVCs reflects the innovative leadership of German firms in a broad range of technologies. The German private sector imports a wide range of intermediate goods for use in its most innovative industries. As the value added in manufacturing is increasingly derived from digital or other enabling technologies that Germany imports, there is a risk that the contribution of German firms to value added in manufacturing, and therefore competitiveness, lessens.
3. The reliance on imported primary and intermediary goods can also lead to bottlenecks. During the COVID-19 pandemic a shortage of semiconductors had significant consequences for the automotive industry. An undiversified range of suppliers for certain primary goods, such as rare earths and metals, and intermediary goods, such as semiconductors, has a particular importance in the context of the digital and sustainable transitions, where these materials have important applications.
4. Like many OECD countries, the German government is currently assessing the issue of energy imports and issues linked to dependence upon a narrow range of suppliers. Following the Russian invasion of Ukraine in February 2022, the importance of this issue has risen on the policy agenda. Higher energy costs has significant implications for domestic and international consumption as well as for the competitiveness of industry, which in Germany is a major consumer of electricity and heat produced by oil and gas imported from Russia.

Addressing the challenges the complexities that come with external linkages of the German innovation system requires setting policies within the context of the EU and beyond. The latter is also essential in the context of addressing global challenges, such as the green transition, and provide opportunities to scale up innovations in Europe and avoid their migrating to the United States and offer the advantages of a large unified European market to innovators against large markets in the United States and China.

This chapter begins with a recommendation concerning German leadership in international STI governance and policymaking. This recommendation links to a number of key themes discussed in this Review – particularly those such as strategic European autonomy in key emerging technologies, public and private investment and regulation to accelerate the sustainable transition, and managing greater international uncertainty domestically and in international co-operation – where solutions are unlikely to be found within the confines of any one national boundary. Germany is in a unique position to offer leadership to a coordinated response to these internationally important STI challenges owing to the deep technological expertise of its private sector and research base, as well as the systemic implications for Germany's success in navigating these challenges, both domestically and in the broader European context.

The Chapter is structured as follows. The Chapter begins with a recommendation on Germany taking a leadership role in EU and global policies with regards to innovation, reflecting the international aspect of many of the challenges discussed in this Review. The Chapter then proceeds in Section 1 with an analytical discussion of the importance of foreign demand for the sustainability of German manufacturing and industry, and by extension the STI systems they support. Section 2 discusses the role of global value chains and the implications for the German business sector and its research base and orientation. The Chapter concludes in Section 3 with a discussion of a number of highly important and interlinking questions concerning the interaction of Germany's supply chain challenges for the digital and green transitions.

Recommendation 10: Take a leadership role in shaping EU and global policies with regards to innovation

Overview and detailed recommendations

The ability to effectively address many of these recommendations requires leveraging the scale of EU and international co-ordination. Beyond Germany, efforts are needed at the EU and transnational levels to ensure success, including by (i) developing competencies in key enabling technologies for more resilient value chains; (ii) exploiting efficient digital-data infrastructures (R4); (iii) developing a sufficiently large financial market to scale disruptive, high-potential innovations (R6); (iv) defining the desired standards and quality-control procedures (R9); and (v) boosting innovation to promote environmentally sustainable development. To this end, the German government needs to take active leadership in shaping innovation policies at the EU and global levels.

R10.1 **Better align domestic STI policies and the EU internal market**. As detailed in R9.1, the impact of domestic STI priorities and policies could benefit from a multiplier effect if they were better aligned with the EU and the internal market. The example of data infrastructure is telling, with projects such as GAIA-X able to reach a larger scale than any equivalent national project, as it targets the vast array of industrial and commercial data inputs from across the EU internal market. A similar approach could be taken in other areas of STI, such as the development of specific enabling technologies, the digitalisation and strengthening of industrial supply chains, and the scaling of pre-commercial or pre-public solutions through the internal market in areas such as climate-management technologies. As advocated in R2 (policy laboratory) and R7 (innovative public procurement), Germany could take a leadership role in promoting policies that stimulate demand-side dynamics for innovative solutions at the EU level.

R10.2 **Identify potential IPCEI to support enabling technologies**. Supply shortages during the COVID-19 challenge highlighted Germany's dependence on a few global supplies. Germany could take a more direct role in garnering support for IPCEI targeting the development of certain technology fields. This could have multiple benefits for the German economy and the broader European Union, by (i) enabling the development of key technologies within the European Union and key EU partner economies, to increase supply-chain resilience; and (ii) developing key technological competencies that will be sources of competitiveness for the future.

R10.3 **Take a leadership role in promoting standards and quality-control procedures at the EU level.** Building on the items outlined in R9, and reflecting the multiplier effect of aligning domestic STI policy with EU policy and the internal market, Germany should take the leadership in promoting EU-wide standardisation and quality infrastructure to support the broader competitiveness and innovative strengths of the European Union and its Member States. This would help align the approaches taken by EU economies, and consequently strengthen the position of the internal market in the context of international and systemic competition.

R10.4 **Maximise international co-operation to navigate uncertainties and address the complexities of transitional challenges.** As with other world economies, the nature of the challenges facing the Germany economy is such that no single government or actor possesses all the answers. While there may be no panacea for the complexity of the sustainability and digital transition, there are nevertheless numerous instances where German policy makers can learn from the experiences and efforts of other countries to navigate these complex challenges, from commercialising decarbonisation technologies to digitalising the public sector within a federal state. As part of the "Germany 2030 and 2050" vision, the government should actively seek international collaboration in priority areas identified by the forum, both within the European Union and beyond.

R10.5 **Take a key role internationally in strengthening the global and national innovation ecosystem.** This involves shaping the global innovation agenda and the main targets set for key innovation agendas globally, such as in AI and biotechnology. Another important component here is connecting effectively to global innovation efforts, attracting talent and engaging in effective collaborations to support the national innovation ecosystem.

9.1. Export characteristics

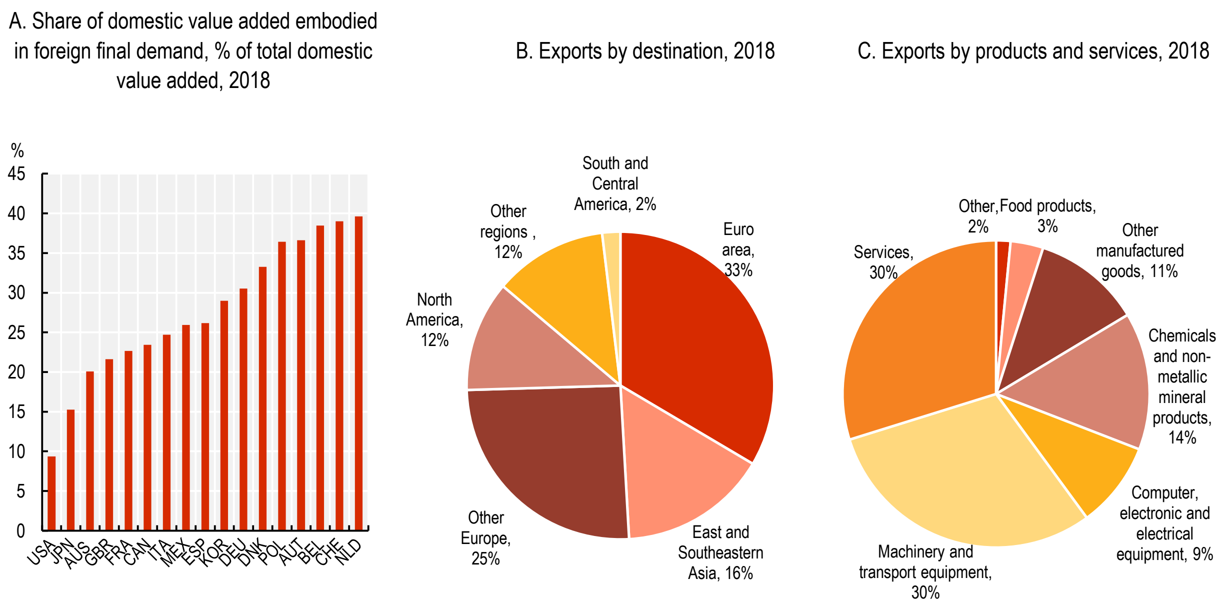
Germany is the most important trading country in the EU, and is the third largest trading nation in the world behind China and the USA, accounting for 7.8% of global exports and 6.6% of global imports. In 2021, German exports amounted to almost 47.3% of GDP, the highest in the G20, and significantly higher than all other G7 nations (OECD, 2022[1]). The significance of exports for German growth is notable given the large size of the country's economy, with domestic consumption within larger economies having a downward influence on the importance of exports. The importance of exports for the German economy, and by extension the innovative private sector that powers the economy, makes Germany's international position somewhat unique among other large and industrialised economies. A consequence of Germany's net international trading position combined with high domestic saving has contributed to a significant current account surplus.

Germany's exports, particularly high-value manufactured and capital goods, are sustained by foreign demand. Given the size of the German economy, the importance of value added in foreign demand is particularly high – as with exports more generally, larger economies generally have a lower share of domestic value added in foreign demand due to larger domestic markets – and this speaks to the specialisation of German firms in the production of high-value and technologically advanced capital goods as final or intermediary products in GVCs (Figure 9.1).

Capital goods dominate German exports, with road vehicles, machinery and other transport goods accounting for 40% of all exports, followed by other manufactured goods (19%), services (18%) and chemicals (13%). Between 2008 and 2018, the export orientation of most German industries increased, with 60% of value added in the German manufacturing sector driven by foreign demand in 2018, and more than 70% in the *basic metals, chemicals and pharmaceuticals, ICT, and other transport equipment* industries (OECD, 2022[2]).[1]

Germany's most important trading partners are other European and OECD countries, in part due to the location of key manufacturers in the value chains that support and are supplied by German firms. In 2021, the OECD accounted for 78.5% of German goods exports and 72.1% of imports, with the EU27 share being 53.1% and 51.9% (BMWK, 2022[3]). In both these cases, the share is slightly lower than the equivalent in 2006, reflecting the growing importance of Asian markets, particularly China. While the OECD and EU collectively continue to account for the bulk of German trade, the importance of China for German exports and imports has grown significantly in recent decades. In 2021, China's share of German goods exports was 7.5% and 11.8% of imports, up from 3.1% and 6.8% in 2006. Whilst this reorientation towards China has not dislodged the importance of Germany's traditional markets, it nevertheless reflects a significant development for the country's trade-orientated private sector.

Figure 9.1. Germany's export-orientated industries rely heavily on foreign demand



Note: Panel C: "Other" includes Agriculture, hunting forestry and fishing, mining and quarrying Electricity, gas, water supply, sewerage, waste and remediation activities and construction. "Other manufacturing goods" includes textiles wearing apparel leather and related product, wood and paper products and printing basic metals and fabricated metal products and Manufacturing nec; repair and installation of machinery and equipment.
Source: OECD (2022[2]), "Trade in value added", OECD Statistics on Trade in Value Added (database), https://doi.org/10.1787/data-00648-en (accessed on 16 May 2022).

The question of foreign demand for domestic value added has several important implications for the German STI system and the economy more broadly. For example, and as discussed above, Germany's export-orientated sectors are a key driver of domestic GDP growth. Germany's export-orientated private sector has major implications for domestic – and regional – employment. Within Germany, 27.1% of domestic employment is embodied in final demand – e.g. in export-orientated activities – with the share rising to 39% when considering only the business sector (OECD, 2022[4]; OECD, 2022[5]). These figures are significant, and are all the more so when one considers the linkages between foreign demand for German goods and the regional supply chains within Europe that support German firms. The 39% figure falls within the generally observed share in Europe, where the share of business sector employment embodied in final demand is between 30% and 50% (OECD, 2022[6])

There are differences at an industry level, with 64.3% of employment in the German automotive industry, for example, driven by foreign final demand. The equivalent figures for other European countries with large automotive industries, such as the Slovak Republic and Czech Republic are higher (93.8% and 88.7%), but the total number of persons employed in each of these countries within this industry varies significantly, with direct automotive manufacturing employment in Germany accounting for 920 000 jobs, compared to 82 000 in the Slovak Republic and 182 000 in the Czech Republic (European Automobile Manufacturers' Association, 2022[7]). The interaction between foreign final demand and business sector innovation is particularly stark in Germany when one considers that 1 in 4 private sector R&D positions are in the automotive industry (GTAI, 2021[8]).

9.1.1. Exports and innovation performance

What defines Germany's export-orientated economy is the sophistication of the products that it exports. This is directly linked to innovation and by extension competitiveness, since for Germany's exported products to be internationally competitive their production must be either more efficient than other exporting nations – including through lower labour cost – or of higher quality. A key characteristic of the German economy, and of its manufacturing sector in particular, has therefore been to use cutting-edge technology to innovate in mature products and to improve the efficiency of production of those products. The recent policy focus on Industry 4.0 is yet another example of Germany's private sector integrating – and indeed developing – the most advanced digital technologies and ICTs to remain globally competitive.

Germany's focus on product quality has therefore allowed the economy to remain competitive internationally despite higher costs of domestic production, and by extension, to retain manufacturing as a key pillar of socio-economic well-being and growth. Germany is an outlier in this respect among other advanced and industrialised nations, but the approach has been successful. For example, in contrast to the fate of manufacturing as a source of employment in other several OECD countries, the share of manufacturing jobs in Germany in total employment has increased over the past 15 years.

Germany's international position, and the domestic and regional jobs and investment which such a position supports, will rely on how firms perform in the context of the twin transitions of digitalisation and environmental sustainability. From a technological and product perspective, the challenge is that the value added in many exported goods will shift from areas where Germany has traditionally had leading competencies to those – such as in digital technologies – where the private sector's international leadership is clear-cut. Similarly, the way in which the industrial sector operates will be profoundly affected by the sustainability transition.

The sophistication of Germany's manufacturing sector is observable through the products the economy exports. For example, Germany has the second most 'complex' export basket in the G7, and the fourth most complex globally, owing to the broad range of sophisticated, innovative products exported by German firms.2 Anecdotally the sophistication of German manufacturing is observable through the leading export-orientated companies, such as BMW and Mercedes in automotive manufacturing, which generally compete in premium product categories. Future competitiveness of the German economy therefore implies continued sophistication and quality in German manufacturing output that is at least equal to if not better than the equivalent output of other export-orientated manufacturing economies.

9.2. Trade and value chain linkages in the German business sector

Another important international factor for Germany's economy beyond the reliance on export markets are the global production linkages that involve the sourcing of key inputs of diverse types (machinery, intermediaries and primary goods) for Germany's production of intermediary or final products.

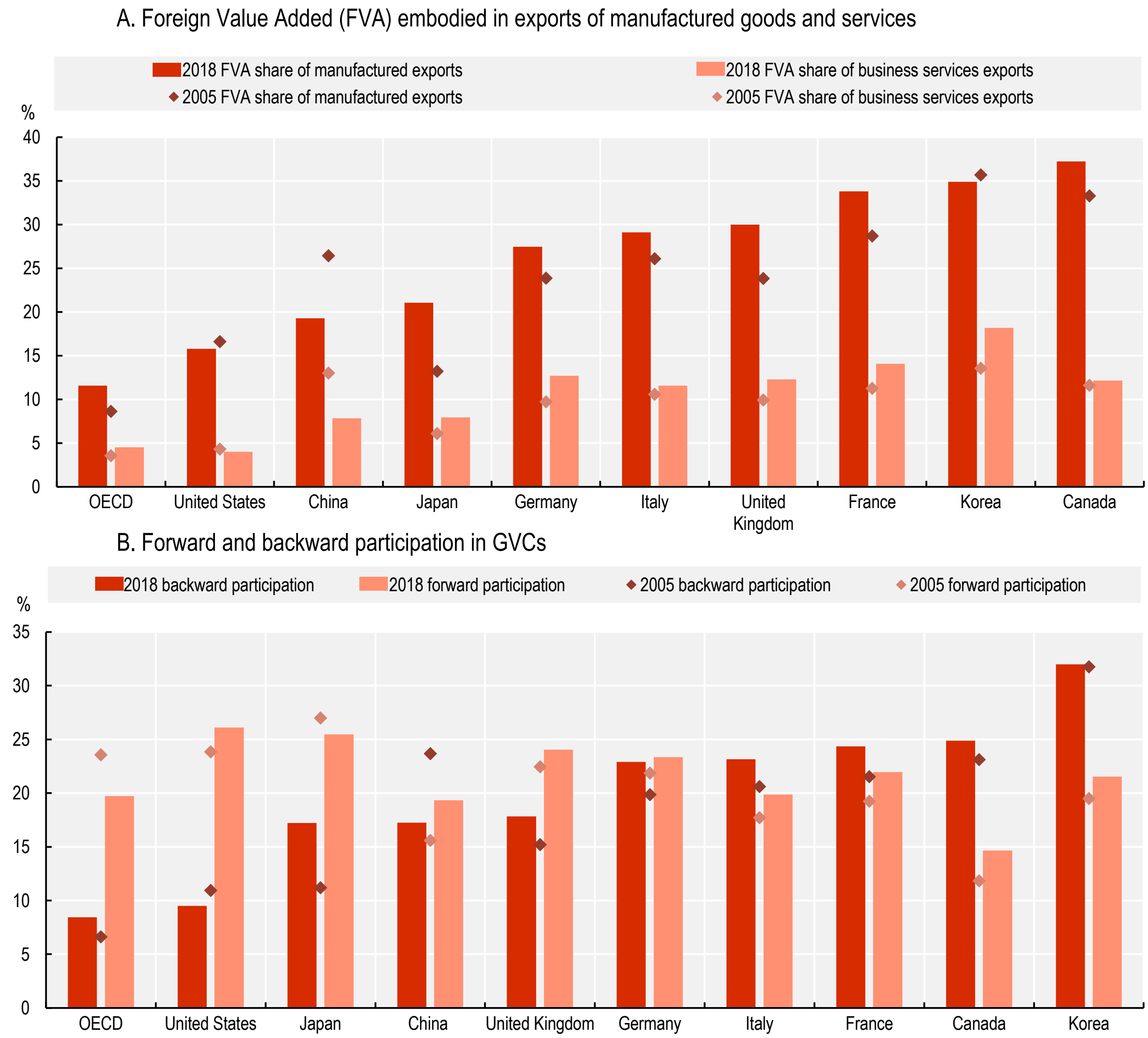
9.2.1. Dynamics and characteristics of Germany's value chain linkages

Many of the most innovative German firms are highly integrated in GVCs. German firms source inputs from abroad as well as providing intermediary inputs to firms in other countries. These GVC linkages can happen within firms – e.g., within multi-national enterprises that have globalised activities – or across firms. This integration also allows firms, within Germany as elsewhere, to outsource less complex activities whilst focussing on ones that create more value added, such as R&D. The foreign added value content in Germany's gross exports – an indication of the significance of value chains outside of Germany – accounted for 22.9% in 2018, the most recently available.

Unlike other OECD economies, Germany's integration within GVCs – measured in terms of foreign value added (FVA) embodied in exports of goods and services and forward and backward participation in GVCs – has increased since 2005 (Figure 9.2 panel A). For example, the FVA share of manufactured German exports was 27.5% in 2018, the latest year for which data are available, indicating a growing importance of foreign inputs for domestic export-orientated industries. A similar dynamic is observable with OECD computations of Germany's 'forward' (the degree of reliance of exports of a given country on demand from foreign countries) and 'backward' (the degree of FVA from foreign suppliers of input) participation in GVCs, where Germany's global position has remained relatively stable since 2005 (Figure 9.2 panel B). In Germany, the increase in GVC participation and specialisation in medium-intensive and high technology intensive industries over the period 2005-2015 have been accompanied by employment growth and social outcomes (i.e. reduction of income inequality) well above the OECD average (OECD, 2017[9]).

Figure 9.2. GVC integration: Germany in international comparison

Share of gross exports

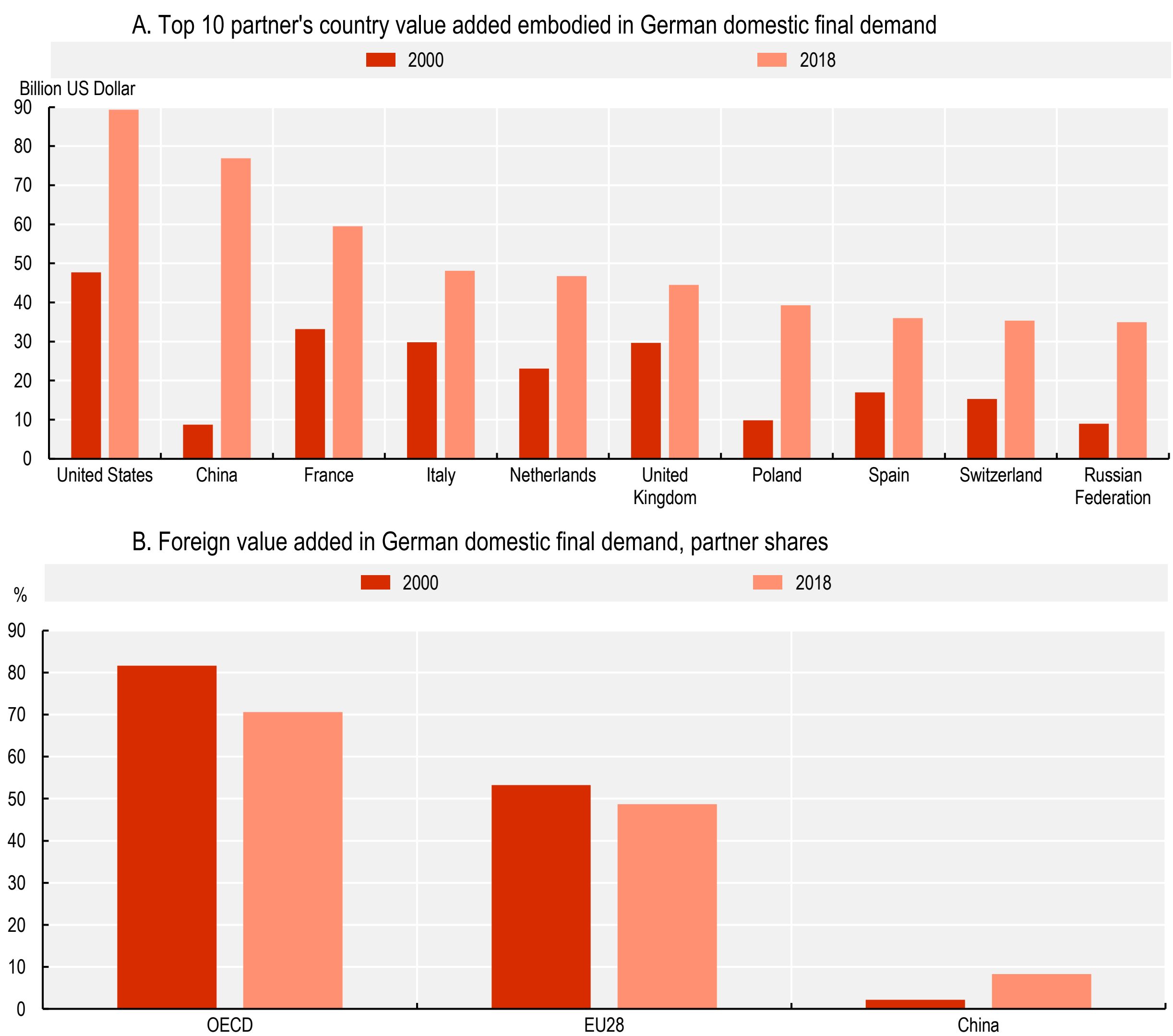


Source: OECD (2022[2]), "Trade in value added", *OECD Statistics on Trade in Value Added (database)*, https://doi.org/10.1787/data-00648-en (accessed on 17 May 2022).

Taken together, the German economy appears to be deepening its global integration, with the importance of foreign inputs for domestic production (e.g., FVA) and foreign demand both continuing to grow. Equally important to general GVC dynamics is how and where the German economy is integrated globally. The biggest change in the origin of value added embodied in German exports – e.g., where Germany has sourced inputs that it has then used in exported goods – has come from China. In 2000, China accounted for USD 7.8 billion of value added that was latterly embodied in German exports. By 2018, this amount had grown to USD 77.7 billion (Figure 9.3 panel A). The contribution of other countries to value added in German exports also grew over this period, but none with the magnitude of China, whose contribution to value added in German exports grew from 2.7% in 2000 to 11.1% in 2018, making China the single largest contributor (Figure 9.3 panel B).

Nevertheless, despite a downwards shift that has come at the expense of South East Asian economies and China, the OECD and EU continue to account for the majority of imports that are subsequently embodied in German exports, which in part reflects the geographical concentration of value chains for key industries in Europe, such as vehicle production. Moreover, as shown in Figure 9.4, Germany has maintained its position as one of the most central global hubs in the value chains of two of its key industries, *transport equipment* (e.g. vehicle manufacture) and *machinery and equipment* (Figure 9.4 panel B). In the service sector, the 2016 centrality metrics confirm the central position of high-income economies, including Germany, as key hubs for business services, including financial, insurance, and legal services (Figure 9.4 panel B) (Criscuolo and Timmis, 2018[10]). The other dominant hub locations across manufacturing and services are respectively China and the United States.

Figure 9.3. Origin of value added embodied in imports (2000 and 2018)



Source: OECD (2021[11]), *OECD SME and Entrepreneurship Outlook 2021*, OECD Publishing, Paris, https://doi.org/10.1787/97a5bbfe-en, based on OECD (2021), "Global value chains: Efficiency and risks in the context of COVID-19", OECD Policy Responses to Coronavirus (COVID-19) Paper. OECD calculations based on OECD (2018) Inter-Country Input-Output (ICIO) database http://www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

Figure 9.4. Top ten most central hubs in global value chains

Germany is one of the most important hubs for GVCs in the world for both manufacturing and services

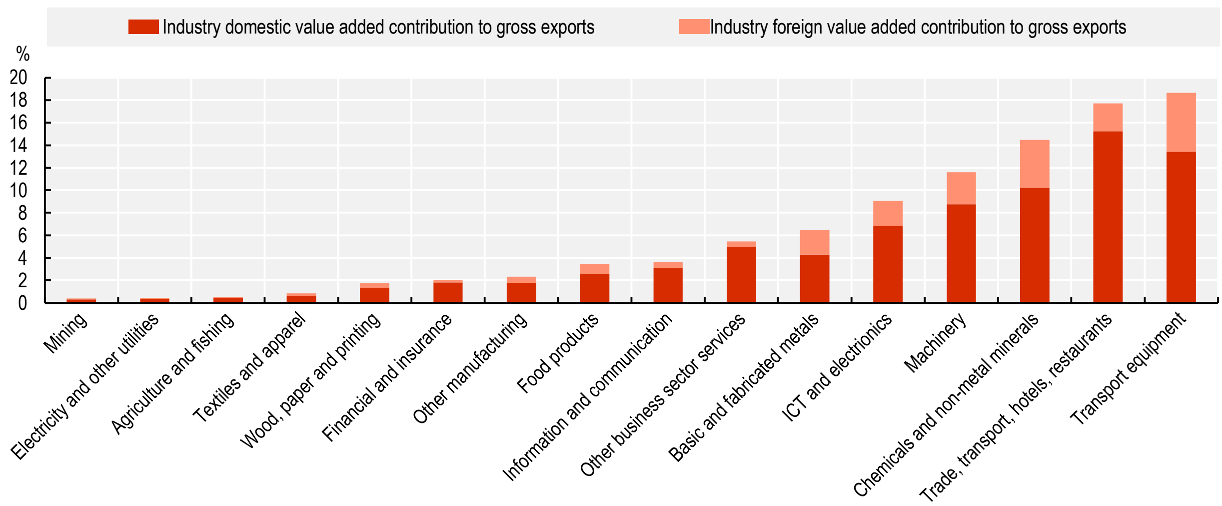
Note: Total centrality is computed as average of forward and backward centrality. Forward centrality captures the importance of a country -or a sector- as a seller of value added in intermediates for the production of exports of a specific partner. Backward centrality measures the importance of a country – or a sector- as a buyer of value added in intermediates for the production of its own exports. The manufacturing sector excludes construction while the service sector excludes electricity, gas, and water supply services. (OECD calculations based on OECD (2018) Inter-Country Input-Output (ICIO) database).

Source: OECD (2021[11]), OECD SME and Entrepreneurship Outlook 2021, OECD Publishing, Paris, https://doi.org/10.1787/97a5bbfe-en based on OECD (2021[12]), "Global value chains: Efficiency and risks in the context of COVID-19", OECD Policy Responses to Coronavirus (COVID-19) Paper. OECD calculations based on OECD Inter-Country Input-Output (ICIO) database, http://oe.cd/icio.

Reflecting the centrality of certain German industries in GVCs, the international component of the German economy has more importance in certain sectors than in others. For example, the FVA contribution to gross exports of key manufacturing industries such as transport equipment (including vehicles and vehicle components) (5.2%), chemicals (4.3%) and machinery (2.9%) is much higher than other industries where Germany has a less central role in the GVC (Figure 9.5). The prominence of the transport equipment is all the more important in a context where a general reallocation of value added has taken place within the EU automotive value chain from countries such as France, Italy and Belgium towards CEE countries such as Poland, Czech Republic, Romania, Slovakia and Hungary. Germany, however, has been resilient to this trend, maintaining its position as the main supply hub in the EU automotive value chain (Fana and Villani, 2021[13]; Balcet and Ietto-Gillies, 2019[14]; Chiappini, 2012[15]).

Figure 9.5. Sectoral contributions to domestic and foreign value added

Contribution to gross export, 2018



Source: OECD (2022[2]), "Trade in value added", OECD Statistics on Trade in Value Added (database), https://doi.org/10.1787/data-00648-en (accessed on 16 May 2022).

9.2.2. The impact of Russia's war in Ukraine on German value chains

Russia's war in Ukraine has impacted Germany's value chains in three significant ways, primarily through the impact of trade sanctions on German imports of Russian primary and intermediary goods. The first is the impact of trade sanctions on Russian oil and gas, as discussed in section 3.2. The second way is the impact of trade sanctions on the share of Russian value added embodied in German output, which is of around 1.25% and also to a large proportion linked to oil and gas imports from Russia (OECD, 2022[16]). The third and related impact is on German multinationals present in Russia.

Another important way in which Russia's war in Ukraine affects German value chains is the impact of trade and economic sanctions on German multinational firms that are active in Russia. For example, foreign affiliates in Russia accounted for 4.8% of gross output (data is from 2016, the latest that is available, and comes from the OECD Activity of Multinational Enterprises database), with the OECD countries that have enacted sanctions the largest investors in the country (OECD, 2017[17]). The most exposed of these multinationals to trade sanctions are those in the motor vehicles industry, with a hypothetical cessation of foreign-owned production in that industry in Russia potentially leading to a 62% drop in the sector's value added. Of the multinational firms in Russia, the highest contributions to foreign-owned gross output are the United States (22.4%), Germany (16.9%) and France (11.4%).

9.2.3. Implications for the STI system

Germany's GVC linkages interact with the STI system in a number of important ways:

- For one, the internationalisation of the German business sector ties firms' resources available for innovation and research within that sector to the trade performance of the German economy more generally. Disruptions or depressed external demand therefore have a direct and significant impact on domestic BERD. At the same time, depressed local demand may be counterbalanced by external demand. The nature of the shock will shape the impacts.

- Secondly, the importance of foreign inputs for domestic innovative industries means that supply disruptions or shortages more generally can have significant consequences for domestic output, affecting consequently revenues. The impacts of disruptions, however, depend on the nature of the shock, on how diversified the sourcing of inputs is as well as on the extent to which production is reliant on inputs. The next section discusses this in more detail.
- Thirdly, the central role of German firms as a source of inputs for many industries at a global level means that the German economy is affected by changes within those industries at a systemic level and is also in position to affect them. All of these characteristics have policy implications for STI, since the STI system must both support current demands of export-orientated sectors as well as supporting those same industries in adapting to change and disruption, particularly in the context of the digitalisation and environmental sustainability transitions.

9.3. International linkages, resilience and the green transition

This section introduces a number of issues relating to the highly internationalised nature of the German economy and the implications for the green and digital transition of the country. The section begins with an overview of some of the challenges that emerge from the internationalisation of the German economy and the deep integration of the business sector in global value chains. The section then proceeds with two interlinking discussions. The first is a short discussion on the challenges facing Germany in terms of energy diversification and diversification of suppliers, building on the discussion of this topic in Chapter 11. The second is a discussion on the related challenge of supply chain disruptions and resilience, building on the discussion above on the importance of GVCs for German manufacturing but extending this explicitly to the topics of inputs required for the digital and green transitions.

9.3.1. Implications of reliance on foreign demand for resilience

The strong reliance on foreign demand for domestic production and investment means that exogenous forces and trends affecting markets abroad affect the domestic economy. This will be less the case where the domestic market is the principal purchaser of output. The export-market reliance can be a source of resilience, depending on the nature of the demand shock (which countries and what products are affected). During the Global Financial Crisis of 2008-09, where external demand sustained domestic German BERD despite global financing constraints. This in part was linked to growing demand from China, which helped Germany to recover from the crisis more quickly and to suffer less long-term scarring than many other OECD countries. Between 2010-2020, China accounted for 53.9% of the growth in German exports, rising from USD 69 billion in 2010 to USD 106 billion in 2020 (Observatory of Economic Complexity, 2022[18]).

However, the COVID-19 pandemic illustrated that export-orientation does not support resilience when the global economy halts investments. In the first year of the COVID-19 pandemic, demand for German capital goods plunged as investment halted temporarily (OECD, 2020[19]). This means that, ultimately, specifically smaller firms will require support where shocks affect the economy as their capacity to invest in innovation, which relies to an important extent on internal resources, will be more affected by downturns (Paunov, 2012[20]). The introduction of the R&D tax credit among other support tools for innovation activities in these smaller firms during downturns, will consequently be important.

9.3.2. Energy security, raw material reliance and renewable energy

The Russian invasion of Ukraine exposed Germany's high dependence on Russian gas, oil and coal, with around one-third of primary energy supply coming from Russia – a significant source of vulnerability for the German economy (IEA, 2020[21]). The war has spurred a drive for rapid diversification of energy suppliers in Germany, much as it has in many other EU countries. In the short-term, the impact of sanctions on Russian oil and gas has increased energy prices in Germany. The severity of the price increases in oil and gas will also depend on responses from other oil and gas producers, affecting the cost of adjustments. This has already led to a significant reduction in the share of Russian energy imports, with the Russian oil import share falling from 35% to 12% by late April 2022, while the coal import share had fallen from 50% to 8% by the same period (OECD, 2022[22]). The Russian share of Germany's gas supply fell from 55% to 35% of total gas supply by the end of April 2022.

In addition to looking for alternative sources of energy suppliers, the federal government has emphasised stronger support for the development of renewable energy domestically to increase energy security. In April, the Federal Government put forward a legislative package – including amendments to the 'Renewable Energy Sources Act' (EEG) – which are designed to hasten the development and deployment of renewable energies, linking this explicitly with the country's energy security. The new legislation will increase auctions for wind and solar power, easy regulatory barriers to setting up windmills to increase the capacity of the country's wind and solar energy capacities. The plans also include incentives to expand the use of solar panels on residential rooftops, while making it obligatory for new commercial buildings to be equipped with solar panels (Curry, Andrew, 2022[23]). Achieving these plans, as well as those aimed at expanding the use of biomass and hydrogen fuels, will take significant innovation and, importantly, time if they are to substitute for traditional energy sources. In the case of solar and wind power, many of the technologies are now widely available and competitive with hydrocarbon equivalents, due in part to the long-term subsidies given to these energies by the Federal Government. The challenge in expanding their use is primarily one of investment and supply chain issues, as discussed below. For other energy sources, many of the technologies remain at a very early stage of technological readiness, something that is discussed in greater detail in Chapter 11 of this Review. The ability of the Federal Government to meet its ambitious renewable energy targets and aims for industrial decarbonisation depend in large part on the rapid advancement in areas of technology that remain far from a commerciable state of readiness (IEA, 2019[24]; IEA, 2021[25]). In addition, the development of these technologies – particularly without adequate signals from the government or market that they are needed more quickly – takes significant time to develop, something also noted by the IEA in their assessment of technological readiness of technologies for applications such as decarbonisation of the cement industry or the development of solar photovoltaic energy (IEA, 2018[26]; IEA, 2015[27]).To this end, subsidies and demand-side signals such as those set out in the EEG are important levers for the acceleration of innovation in these areas.

Another challenge for building the resilience for the green transition is the concentrated global supply of primary inputs that are needed for renewable energy. This includes rare earth elements (REEs), which are essential to many technological solutions, for example the permanent magnets that are vital for wind turbines and EV motors, or the huge amounts of copper necessary for the renewal of electricity networks. REEs are a family of seventeen elements comprising fifteen elements in the lanthanides group, plus scandium and yttrium. Although each REE is used in different applications, there are four elements – neodymium, dysprosium, praseodymium, and terbium – that are of particular importance to the clean energy sector. Starting around the mid-1990s, China has emerged as a major – in some case sole – producer of these REEs, leading to a highly undiversified range of suppliers of these key inputs for the green transition (IEA, 2022[28]). By 2010, China's share of REE production reached 95%, but it had fallen to just over 60% by 2019 owing to growing production in the United States, Myanmar and Australia. Nevertheless, processing operations – such as separation and refining – remain concentrated in China, which continued to have over 90% of global market share in 2019. In 2021, there were only four processing plants outside of China, with these processing only light REEs, whilst the processing of heavy REEs (less common, with demand often outpacing supply, and frequently used in clean energy technologies) remains dominated by China. These dependencies can only be addressed in a limited way by innovation – by reducing the requirement of quantities of those inputs – and highlight the role to combine strategic efforts to diversify processing of resources where available for innovation to support energy security.

9.3.3. Supply chain resilience in raw materials and key enabling technologies

Aside from relying on energy, supply chain resilience is challenged by the need for primary inputs but also for a number of intermediary products. The COVID-19 pandemic led to a number of disruptions due to supply problems, with lockdowns across the world leading to temporary closures of factories and mines and therefore shortages of goods. Surveys of the German business sector have made clear that continuing supply chain fragilities is a barrier to innovation and the transformation of the German economy more generally, with the disruptions caused by the COVID-19 pandemic and the 2022 Russian invasion of Ukraine demonstrating that firms can face unforeseen barriers in both procuring key components and exporting those in which they excel. Despite a gradual reopening of the global economy, German industry and manufacturing continues to grapple with supply chain issues. In the November 2021 edition of the monthly ifo survey of 9,000 firms, some 74.4% of surveyed firms reported bottlenecks and problems procuring intermediate and raw products (ifo, 2021[29]). The number of companies reporting supply chain problems among the surveyed business population was higher than in previous surveys in almost all industries, with the exception of manufacturers of electrical equipment – though the decrease was only 5 percentages points and from an already high 90% of surveyed firms. Of manufacturers of machinery and automotive firms, the figures were 86% and 88%, respectively. An earlier ifo survey in April 2021 found that some 45% of firms were facing bottlenecks in supplies, the highest value since 1991, and significantly higher than the 7.5% reported in October 2020 (Ifo, 2021[30]).

While the role for innovation with regards to primary inputs is limited, there are strategic questions regarding capacities in key enabling technologies, such as advanced materials, micro and nano electronics such as semiconductors, and advanced digital technologies such as artificial intelligence. To illustrate the strategic issues, in the case of semiconductors, production is concentrated among a small number of companies global, yet the downstream use of these components concerns a wide array of industries, making the semiconductor industry strategic for many economies. Production of semiconductors is generally very complex with high barriers to entry, and there are no single companies that provide all the different types of semiconductors that are used downstream (those used, for example, for autonomous driving may differ to those used in consumer electronics).

The role of semiconductors is strategically important for Germany in the context of digitalisation, which will see the digital component of manufacturing output increasingly dominate value added (as discussed in Chapter 11). Without the capacities in some component fields, it may also be harder to then innovate effectively in certain sectors. This includes such products as integrated circuit boards – an electronic circuit built on a semiconductor. Over the period 2014-19, annual German imports of monolithic integrated circuit boards, commonly used in the production of electronic equipment – increased by 3000% (USD 0.5 billion to 14.5 billion), with over 50% of this increase coming from Asian markets (Observatory of Economic Complexity, 2022[18]). Similar dynamics are visible in a range of other technologies. Imports of parts used for data processing increased by 177% (USD 5 billion to 13.8 billion) over the same period, for data storage units the figure was 128% (USD 4.6 billion to 10.5 billion). These components may be key elements for their respective products as is the key issue of batteries for electric cars and consequently having capacities in their production may turn out to be critical to be a leading innovator in these markets.

The impact of disruptions to global trade and global demand caused by COVID-19 on the manufacturing of semiconductors is indicative of the broader challenges in supply chain resilience facing the German economy. The impact of growing demand for consumer electronics and latterly with the recovery of demand for cars, coupled with the impact of rising prices of inputs such as minerals and energy, have caused the price of semiconductors to rise dramatically since the beginning of the pandemic. The rise in price has affected economies differently, perhaps linked to the extent of domestic manufacturing capacities in this area. It is notable, for example, that the average price of integrated circuits for German importers rose significantly above that seen for the United States, Korea, and China (OECD, 2022[16]). Even if supply chains remain open, the pandemic demonstrated that the cost of keeping these supply chains open differs across economies.

The Federal Government of Germany is aware of the need to develop competencies in these fields, and, as discussed in Chapter 3, has set out a wide number of strategy documents to this end. For example, in addition to the *High-Tech Strategie*, the government has numerous technology specific strategy documents for areas such as artificial intelligence, batteries and microelectronics, all of which reflect the strategic importance of these key enabling technologies for the German economy. To mitigate the high costs and risks involved in establishing semiconductor research and manufacturing capacities in Europe, a number of EU countries – including Germany – are participating in an ongoing IPCEI on microelectronics (Breton, 2021[31]).

The development of competencies and production capacities in certain key enabling technologies critically requires international collaborations (Fraunhofer ISI, 2020[32]). The example of Germany's participation in Important Projects of Common European Interest (IPCEI), such as those for the development of hydrogen and battery technologies, speaks to the government's awareness of the need for a strategic approach to developing innovative competencies in the key enabling technologies of the future. One of the key advantages of the IPCEI projects is that it removes potential conflicts with EU state-aid rules, in effect clearing the way for some EUR 8 billion of national subsidies for hydrogen projects. As of late 2021, BMWK had selected 50 projects for potential financing, including projects on electrolyzers and pipelines (Franke, 2021[33]). The transport ministry has also selected a number of projects, with these concerning fuel cell systems and refuelling infrastructure. Final decisions on the financing of these projects is expected later in 2022.

9.3.4. Green transition and international linkages

The systemic role of the German economy in GVCs, as outlined in the sections above, means that the country is in a unique position to drive decarbonisation of trade at a global level. Linked with the discussion on quality infrastructure and standards, changes in how Germany innovates and conducts business can shape processes elsewhere due to the integral importance of German output in many global industries. As set out in Recommendation 10 at the beginning of this chapter, Germany therefore can act as a global leader in driving an issue of international importance and consequence. Concretely, the Federal Government, through pushing the decarbonisation of domestic industry, can link this process with internationally agreed goals on emissions reduction, as well as ensuring that the capital goods inputs used in industries of developing economies do not lock them into high polluting activities but ensure that these economies develop in a way that is economically beneficial to their countries as well as sustainable in an environmental sense.

These leadership issues, which are linked to economic wellbeing but go beyond it, extend also to issues of ethical procurement of inputs, something which is likely to increase in importance as companies seek more raw materials which, in many cases, are exported by countries with poor oversight of labour and business processes. This creates a significant problem for firms regarding due diligence and maintaining ethical standards in the procurement of a number of critical rare minerals as laid out in the OECD responsible business conduct guidelines (OECD, 2016[34]). Attention has also been increasingly paid to the importance of responsible sourcing of rare earth materials for critical technologies for German manufacturing, such as batteries, as set out in the JRC technical report on the sustainable sourcing of raw materials for this technology (Joint Research Centre et al., 2020[35]).

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Endnotes

[1] Industries refer to the International Standard Industrial Classification of All Economic Activities (ISIC) Revision 4.

[2] Complexity here refers to the 'Economic Complexity Index' (ECI) used by the Observatory of Economic Complexity, which was developed by AJG Simoes and CA Hidalgo at MIT. The ECI is a measure of an economy's capacity inferred from data connecting locations to activities that are present within them. At an intuitive level, the ECI allows insights into how 'complex' an economy is by looking at the sophistication of the products that it trades.

Part V Business as usual? Innovation and the transformation of the German private sector

10 The contribution of the *Mittelstand* to innovation for the digital transition

The *Mittelstand* is the backbone of the German economy and a key component of the science, technology and innovation system. The "hidden champions" of the Mittelstand help drive and sustain innovation, but the digital transformation changes what they can and should contribute to future innovation. This chapter assesses the innovation contribution of the Mittelstand, focusing on two factors that may constrain the private sector's contribution in the years ahead. The first concerns its shortcomings in terms of digital transformation. The second is the lack of business creation and the limited contribution to innovation of new, potentially disruptive firms in Germany. Recognising the importance of data as an intangible asset for business sector innovation, the chapter introduces a recommendation on improving business data infrastructure and access.

Introduction

The German business sector – particularly the *Mittelstand*, the term used in Germany for SMEs, which can include slightly larger firms – plays an integral role in the German and international innovation system. Given its size and internationalisation, it can act as a locus of industrial transformation both domestically and abroad, as the private sector shapes both upstream and downstream business processes in leading manufacturing industries beyond Germany's borders.

German small and medium-sized enterprises (SMEs) account for 59% of the country's total employment and 48% of value added (OECD, 2021[1]). Many of the country's most innovative firms work in the export-oriented manufacturing sectors, producing internationally competitive and often highly specialised goods (Gnath, McKeon and Petersen, 2018[2]). The ability of the German manufacturing base to sustain such high levels of internationally competitive production is a reflection of the highly innovative and specialised firms that make up its private sector. Business-sector innovation therefore both drives and sustains international economic competitiveness and domestic socio-economic well-being, notably by guaranteeing jobs.

Historical success is no guarantor of future competitiveness, and the ability of the German business sector to act as engine of change depends on the ability of all the actors in its innovation system – from the smallest start-ups to the largest corporations – to address the structural challenges posed by the sustainability and digital transformations. If, for example, a large export-oriented machinery firm wishes to embed more digital technologies in its products, then the socio-economic benefit of such a decision for the German economy depends on the ability of SMEs and service-sector firms in its value chains and industrial ecosystem to adapt and provide intermediary inputs to that effect.

This chapter focuses on several issues affecting the contribution of the German *Mittelstand* to innovation. The first section introduces a recommendation on data access and infrastructure for the German private sector, reflecting the importance of data as a key asset for business innovation and for improving the ability of business to retain its competitiveness in export-oriented sectors. Three analytical sections follow. The first reviews the contribution of the *Mittelstand* to German innovation. The second examines the importance and extent of the digital transformation in the German private sector. The third section concludes with a short discussion of business dynamics and entrepreneurship.

Recommendation 4: Improve data infrastructure and data access, especially for industry

Overview and detailed recommendations

This recommendation highlights the particular importance of data as a necessary input for all other areas of this review, from supporting greater agility in policy making and more innovative use of procurement, to processing data at the firm level to enhance research and efficiency.

Improving the coherence and interoperability of the data infrastructure for future digital innovation should be a government policy priority. Effective collaboration between research institutions and firms for purposes of innovation also depends on the presence of an accessible and well-designed data infrastructure.

From the perspective of Germany's innovation strengths and international comparative advantages, the strategic use of more industrial data for innovation should be a priority for the public and private sectors, with a focus on the innovation-intensive automotive, machinery, chemical and pharmaceutical industries. This requires top-down and framework-related approaches, complemented by policies to improve the bottom-up uptake of data-producing and data-dependent technologies at the firm level. Open innovation platforms and collaborations to exploit those data are necessary to help activate this potential.

R4.1 **The government should support a programme to improve the country's data infrastructure, and increase the public and private sectors' absorptive capacity of both infrastructure and human capital**. This programme should have a clearly defined mission, with a strong focus on the use of data produced by the business sector and during research to support STI. The programme would be responsible for rationalising and eliminating the soft and hard infrastructure issues constraining the development of better data infrastructure and data access.

R4.2 **The government should consider the data generated by the business sector as a strategic dividend that can strengthen German innovation and competitiveness**. Having recognised the centrality of data for innovation in the Data Strategy of the Federal German Government (BKAmt, 2021[3]), Germany could exploit its position as Europe's largest economy to ensure that high-quality, interoperable and accessible industrial data become an additional strength of its innovation system and economy. From an infrastructure perspective, the GAIA-X and Important Projects of Common European Interest (IPCEI)-CIS programmes – both of which aim to support European-based cloud infrastructure services – are first steps in this direction. The same is true, to a greater extent, for the ongoing efforts to digitalise the automotive sector's value chain through initiatives such as the CATENA-X platform. While these initiatives are important, they must be scaled, the scope broadened, and the speed with which they are rolled out increased. A whole-of-industry strategy will require a coherent and systemic approach to leverage industrial data effectively for innovation, and should be pursued with the relevant actors at both the national and transnational levels.

R4.3 **To promote data-driven innovation, the German Federal Government should address barriers to SMEs' use of the data they produce and enhance SMEs' access to data produced across the economy**. Specifically, the Federal Government should support rationalising regulatory differences across the *Länder* and provide support for implementing the General Data Protection Regulation. It should increase legal certainty and, where appropriate, promote flexibility in using data for innovative processes, encouraging businesses to make the necessary intangible investments to produce, store and process data for innovative purposes. At the same time, the government should recognise the urgency of ensuring that firms are equipped with the necessary connectivity infrastructure to support data-driven innovation and production in the context of the digital transformation, including fibre-optic broadband and the 5G connections required to convey the massive volumes of data inherent to Industry 4.0 processes.

R4.4 **Promote open innovation platforms and approaches. Producing data is a necessary but insufficient condition for innovation.** To succeed in the digital era, firms must have access to data they do not produce, and be equipped with the skills and technological competencies to process and use them. In addition, while some firms may not have the internal capacity to derive value or insights from the data they do (or could) produce, other firms may be able to unlock such insights. This highlights the importance of supporting an open innovation approach – which the Federal Government has begun pursuing through its 2021 Data Strategy – and creating platforms that involve other innovation actors in producing innovations based on private-sector and industrial data. An important benefit of such open innovation platforms is that they allow more collaboration between firms as well as with PROs and universities.

Additional recommendations related to the Mittelstand

Several recommendations in this review relate to the ability of the business sector to innovate for the digital and green transitions. The following is a short overview of selected recommendations that are particularly relevant to the business sector, along with details of where these can be found in the review.

- Recommendation 1 (Chapter 14): ***Develop a shared vision for Germany 2030 and 2050.*** This recommendation provides guidance on how the Federal Government can provide greater directionality to the science, technology and innovation (STI) system. This is relevant to the business sector because firms – particularly smaller ones – may not automatically direct innovation efforts towards activities that are relevant to future competitiveness and sustainability. A longer-term vision of the STI system, and how it interacts with the private sector, could help ensure a transition that is both sustainable and inclusive.
- Recommendation 2 (Chapter 15): ***Create a public-private laboratory for innovation policy.*** Ensuring the private sector's success in the transitional context may require greater experimentation from policy makers. The policy laboratory would be a platform for testing and scaling new approaches for supporting the innovation activities of SMEs in the transitional context, as well as bringing new SMEs to the STI system.
- Recommendation 3 (Chapter 6): ***Broaden and mainstream the use of agile policy tools to support innovation efforts by SMEs and achieve the transitions.*** Business-sector innovation for the sustainability transition requires firms to move beyond the technology frontier, experimenting with unproven and entirely novel solutions. This means that policy may need to be more agile, ensuring that firms have the regulatory and policy flexibility that gives them confidence to move into new areas.
- Recommendation 6 (Chapter 7): ***Promote financial markets that are conducive to scaling up breakthrough innovations*****.** Traditional sources of private-sector finance have limited effectiveness in scaling some of the highest-potential and more breakthrough innovations. These innovations often present higher risk, with start-ups turning to sources such as venture capital to get their ideas off the ground. This recommendation looks at how later-stage venture capital and institutional investors could play a bigger role in helping to scale the most promising German start-ups and innovative firms.
- Recommendation 7 (Chapter 11): ***Strengthen the use of public procurement as a driver of innovation***. A more innovative use of public procurement could help create a demand-side signal to firms that markets are emerging for new technologies that may not yet be commercially viable on paper.

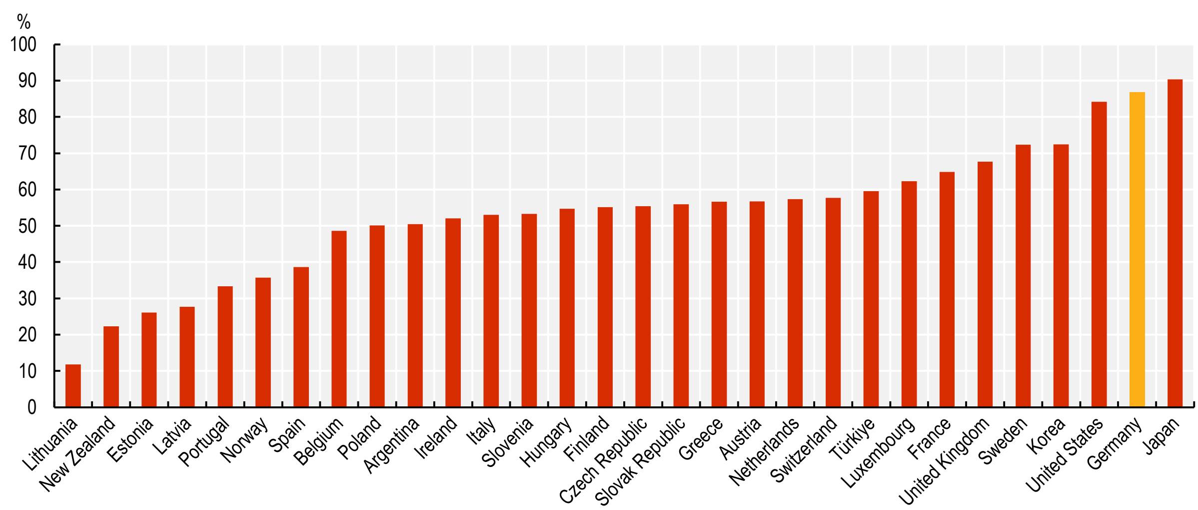
10.1. The role of the *Mittelstand* in business-sector innovation

Germany's SMEs are the backbone of its economy. In Germany, 99% of firms have fewer than 500 employees, a threshold under which German policy makers consider them SMEs – or part of the Mittelstand. Following OECD firm-size classifications, 65% of German firms have fewer than 9 employees, accounting for only 4.5% of total employment in the business sector in 2019; firms with 10-19 emplyes accounted for 16% of the business population and 5.7% employment; firms with 20-49 employees accounted for 9% of the business population and 7.8% employment, firms with 50-259 employees accounted for 7.1% of the business population and 19.5% employment; firms with over 250 employees accounted for only 2.1% of the firm population but 62.4% of employment (OECD, 2021[5]). SMEs in Germany are on average around twice as large as those in most European countries, although they are similar in size to other large industrialised economies, such as Japan and the United States (OECD, 2021[6]). Cross-country differences in value added by firm size are also significant, reflecting the concentration of some of the most productive economic activity in Germany's larger firms. For example, while micro SMEs (under ten employees) accounted for 27% of value added in the business sector across the OECD region in 2018, the figure was only 15% for Germany.

Despite their large number, German SMEs accounted for only 8% (EUR 7 billion [euros]) of business expenditure on research and development (BERD) in 2018, the last year for which disaggregated data are available. This was the second-lowest relative contribution in the OECD, behind only Japan (5%). At the same time, the SME share of BERD in Germany has been decreasing since 2009, in line with a similar trend in other major industrialised economies, such as the United States. The decreasing SME contribution to BERD is not ubiquitous across the OECD, however. In France, the second-most industrialised economy in the European Union, the SME share of BERD has actually been growing since 2002, from 14% to 27% (EUR 11 billion) in 2018. Since the global financial crisis of 2008-09, the divergence in research and development (R&D) expenditure between firm sizes has grown, perhaps owing to the asymmetrical long-term impact of supply-side crises on research activities (Figure 10.1). This does not necessarily indicate that the BERD of SMEs has not increased – indeed, it grew by 43% between 2005 and 2018 – but that the 53% increase (over the same period) of large-firm BERD has widened the absolute investment gap between the firm sizes. Other evidence also points to a downward trend in total innovation investment (i.e. BERD and other forms of innovation investment), including in intangibles, as discussed in Chapter 3.

Figure 10.1. Share of BERD performed by large firms (more than 500 employees)

% of total BERD (2019 or latest available data)



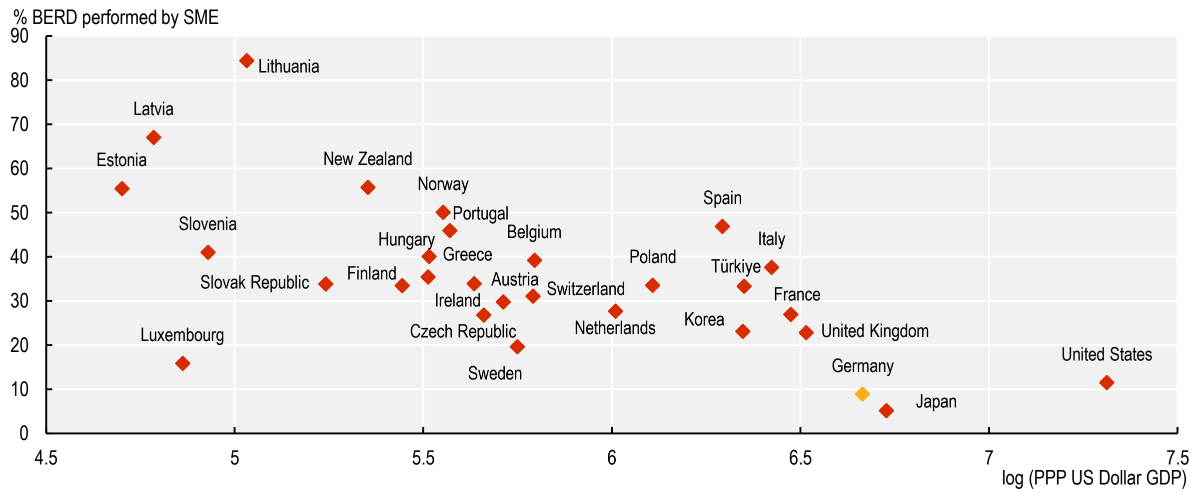
Source: OECD (2022[6]), "Research and Development Statistics: Business enterprise R-D expenditure by size class and by source of funds - ISIC Rev 4", *OECD Science, Technology and R&D Statistics* (database), https://doi.org/10.1787/7ce7448d-en (accessed on 21 May 2022).

SME-level innovation in Germany differs from other countries in the particular role played by "hidden champions", firms that are often world leaders in the manufacturing of highly specialised products. Germany has a disproportionately high number of such firms: around 1 300 are estimated to be active, mainly located in just the two states of Bavaria and Baden-Württemberg (BMWK, 2020[7]). The challenge in assessing the performance of these firms relative to other SMEs is a lack of data. Neither the German statistical agency nor private-sector organisations have a publicly available register of these firms, impeding the ability of policy makers and researchers to study their economic (including investment) activities in relation to other firms. A detailed firm survey on these hidden champions may help German policy makers exploit these domestic successes for the benefit of the broader private sector.

While in Germany BERD is highly concentrated in larger firms, this is a common feature of countries of larger size. Figure 10.2 shows a correlation between the country size, expressed by GDP, and the relative contribution of SMEs to total business R&D, the larger the GDP of an economy, the lower the relative contribution of its SMEs to R&D expenditure.

Figure 10.2. SME share in BERD relative to GDP

2019 or latest data available



Note: Data for the United States from 2018, for France for 2017; correlation coefficient is -0.63.
Source: OECD (2022[8]), "Main Science and Technology Indicators", OECD Science, Technology and R&D Statistics (database), https://doi.org/10.1787/data-00182-en (accessed on 25 May 2022) and OECD (2022[9]), "Research and Development Statistics: Business enterprise R-D expenditure by size class and by source of funds - ISIC Rev 3", *OECD Science, Technology and R&D Statistics* (database), https://doi.org/10.1787/data-00182-en (accessed on 25 May 2022)

The concentration in business R&D also depends on industry structure. For example, economies with a larger share of manufacturing generally have larger firms than those with a higher share of services in their sectoral breakdown. This is partly why Germany, Japan and the United States have such a marked concentration of larger firms.

10.2. Digitalisation in the business sector: Equipping the *Mittelstand*

The ability of the private sector – particularly the *Mittelstand* – to contribute innovation for both sustainability and competitiveness will depend on firms' competencies in a range of technology domains, as well as their abilities to use data and digital technologies. For example, the ability of manufacturing firms to innovate in their production processes largely depends on their ability to derive knowledge from the data produced by industrial robots involved in those processes. Similarly, using industry data to produce new breakthroughs means that firms must have the available skills – either internally or through new forms of knowledge transfer – to derive new knowledge and insights from such data, as well as the internal human capacities to recognise the value in doing so. This subsection focuses on the digital capabilities of the *Mittelstand*. Chapter 6 discusses many of the issues relating to the digital framework conditions.

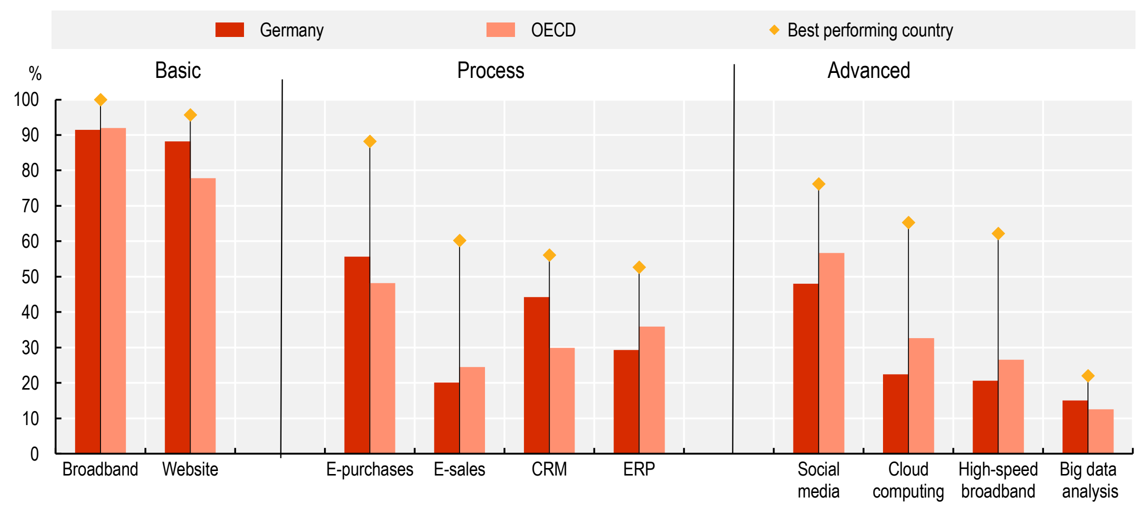
The Federal Government recognises the importance of the digital transformation for innovation in Germany, and has developed several policy programmes to support the digitalisation of SMEs in particular. Policy support has taken a number of forms, from direct finance to networking bodies. Recent examples of such initiatives include the Federal Ministry for Economic Affairs and Climate Action (BMWK)'s "Go-Digital" programme, which ran from 2017 to 2021 and provided eligible SMEs with grant financing for skill development to support digitalising business processes, developing digital markets and IT security; and the SME Digital Competence Centres, which support the adoption by SMEs of information and communication technology (ICT) and Industry 4.0 applications.

Historically, digitalisation was not a necessary condition for innovation success in Germany, but this is gradually changing in an economic context where value added and innovation are increasingly data-driven in both the traditional manufacturing sectors of Germany's economy and the less strong service areas. Similarly, ICT tools are increasingly embedded in innovations to support climate management and sustainable energy, illustrating the links between the twin digital and green transitions.

For a more comprehensive digital transformation of the German economy, firms will need to adopt newer and more advanced ICT tools and activities – particularly those that will enable them to collect, store, exchange and process large amounts of data. There is also an important disparity in ICT adoption depending on firm size. With cloud computing, for example, medium-sized firms significantly lag the OECD average in the corresponding size band (-14 percentage points) (Figure 10.3), which is surprising, given that smaller and younger firms are often the key beneficiaries of these services, which offer the cost efficiency and flexibility of scaling up or down digital operations (OECD, 2022[9]).

Figure 10.3. German firms lag in the adoption of advanced ICT tools and activities

% of all firms (2019 or latest available year)



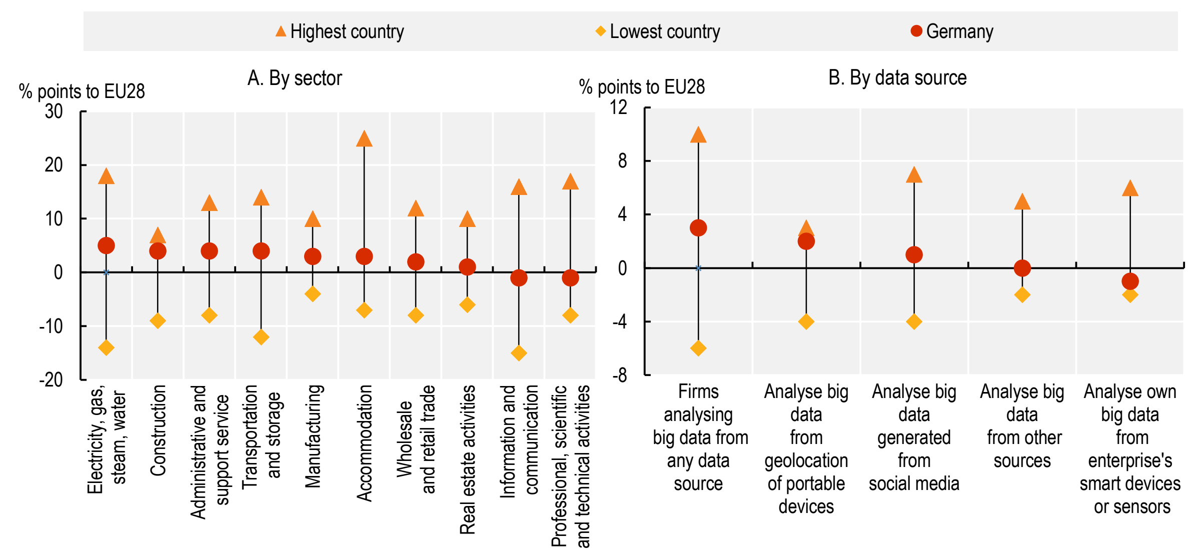
Note: Firms with 10 or more employees, excluding financial sector. ERP stands for enterprise resource planning, CRM for customer relationship management; high-speed broadband are subscriptions with 100+ Mbps.
Source: OECD (2020[11]), OECD Economic Surveys: Germany 2020, OECD Publishing, Paris, https://doi.org/10.1787/91973c69-en based on OECD ICT Access and Usage by Businesses database.

Creating value added from data, and using data for innovation, will likely be key to the German economy in the coming years. Doing so requires collecting and processing vast quantities of data, often from the services and manufacturing sectors, in the context of Industry 4.0. Notably, only 3% of German firms use data from their own sensors or devices to perform big-data analysis (Figure 10.4). This is below the EU average (4%) and significantly below the levels in leading countries such as the Netherlands (10%), Finland (8%) and Belgium (7%) (OECD, 2020[10]). The most recent evidence suggests that data from the geolocation of portable devices and social media – as opposed, for example, to data from production-line robots – are the most likely sources for firms' big-data analysis in Germany, suggesting a significant missed opportunity to create additional value from in-house data (Nolan, 2021[11]). In many ways, the limited data use – whether owing to skill shortages or technical capacities – illustrates the importance of a dynamic technology start-up ecosystem, as smaller firms are often better able to derive new insights and value from larger firms' data than their own workers (Nolan, 2021[11]).

The COVID-19 pandemic has accelerated the digital transformation of firms in Germany, as in other developed economies. According to a recent survey study of 1 000 German firms, three-quarters of large companies have increased their commitment to investing in digital technologies because of the pandemic (Bitkom, 2021[12]). The pandemic is also promoting a surge in ICT adoption – particularly in e-commerce and cloud services – among small firms. According to the German Federal Statistical Office, around one in three German companies with at least ten employees used fee-based information technology services on cloud computing platforms in 2021, an increase of 11 percentage points over 2018 levels of 22%.

Figure 10.4. Data from firms' sensors and devices remains underused for big data analysis

% firms performing big data analysis, differences in percentage points to EU28 average (2018 or 2016)



Note: EU28: European Union (before 2020 withdrawal of the United Kingdom). Firms with ten or more employees, excluding financial sector.
Source: OECD (2020[11]). *OECD Economic Surveys: Germany 2020*, https://doi.org/10.1787/91973c69-en based on Eurostat, ITC usage in enterprises dataset.

The more data firms collect, the more important artificial intelligence (AI) and machine learning will become as tools for creating value from the data collected. The diffusion and adoption of these technologies in Germany remains relatively low, and while the role of German start-ups and firms in AI markets is growing, they nevertheless lag the United States and China, the two most dominant players. In 2020, AI start-ups in the United States and China absorbed more than 80% of venture capital (VC) investments. The share of the EU was just 4%, followed by the UK and Israel with 3% (OECD, 2021[13]). Between 2012 and 2020, Germany and France accounted for over two-thirds of VC investments in the EU. Nevertheless, Germany has set out an ambitious AI strategy. The challenge in the near future will be to ensure that technology diffusion and adoption by firms is more comprehensive and commensurate with policy ambitions. Chapter 3 provides further details on the German Federal Government's AI strategy.

In contrast to the relatively slow diffusion of ICT and data use, Germany is at the forefront of global automation efforts. With 371 robots for every 10 000 workers in the industrial and manufacturing sectors, Germany has the highest level of robot density (the number of industrial robots per 10 000 workers) in Europe and the fourth-highest level globally, behind only Korea (932), Singapore (605) and Japan (390) (International Federation of Robotics, 2021[14]). In 2020, Germany accounted for 33% of total European robot sales and 38% of Europe's operational robot stock, with 221 500 owned robot units compared to 74 400 in Italy, 42 000 in France and 21 700 in the United Kingdom (International Federation of Robotics, 2021[14]). The International Federation of Robotics expects demand for robots in Germany to grow owing to demand for low-cost robots outside the manufacturing industries.

While digitalisation offers great opportunities for SMEs to raise productivity, it also risks widening the gaps between enterprises due to difficulties in financing digital investments and intangibles more broadly. The Federal Government has taken policy action in recent years to address this gap, such as providing support for technology transfer through a national network of support centres and specialists (i.e. "Mittelstand-Digital"). Within this strategy, "Mittelstand 4.0 Centres of Excellence" is a major policy instrument addressing the technology-adoption needs of SMEs. This newly created technology transfer network provides a broad range of support services nationwide, including coaching and assistance by 1 000 digitalisation experts.

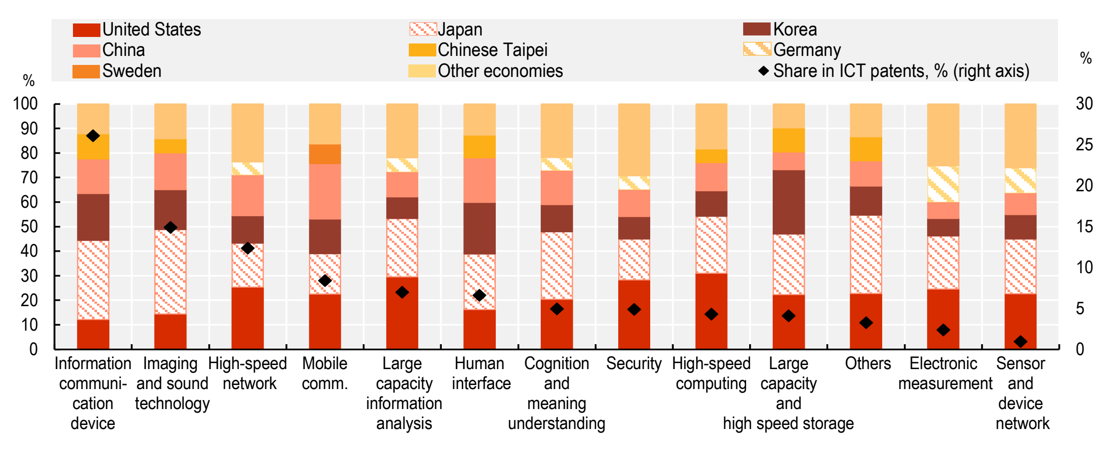
10.2.1. Business-sector performance and innovation for digital transformation

Despite the importance of digital and communications technologies throughout the German economy, few German firms feature among the leading producers of ICT-related trademarks and patents. In the 2021 European Innovation Scoreboard, only 11 German companies in digital sectors (*software and computer services, technology hardware and equipment, mobile* telecommunications) featured in the world's 2500 most innovative firms (European Commission, 2021[17]). Of these, only one – SAP – featured in the top 100. By contrast, of the 2500 top global innovative firms, 126 were Chinese companies in the same categories and 267 were from the United States.

The relative lack of German firms among the top global ICT innovators is substantiated by a more detailed breakdown of Germany's contribution to ICT-related patenting compared to the four other top economies in these fields (Figure 10.5). Information technologies and digitalisation are highly heterogeneous categories, ranging from communications and connectivity technology to machine learning and AI. Globally, Germany features among the top five countries in fewer than half of the ICT-related patent categories shown in Figure 10.5. As discussed in Chapter 3, Germany's relative under-performance in ICT innovation may partly reflect the limited diffusion of ICT in German firms and the research focus of existing industries.

Figure 10.5. Germany lags behind top economies in ICT-related patenting

Share of the top five economies' shares of patents in ICT-related technologies (2014-17)



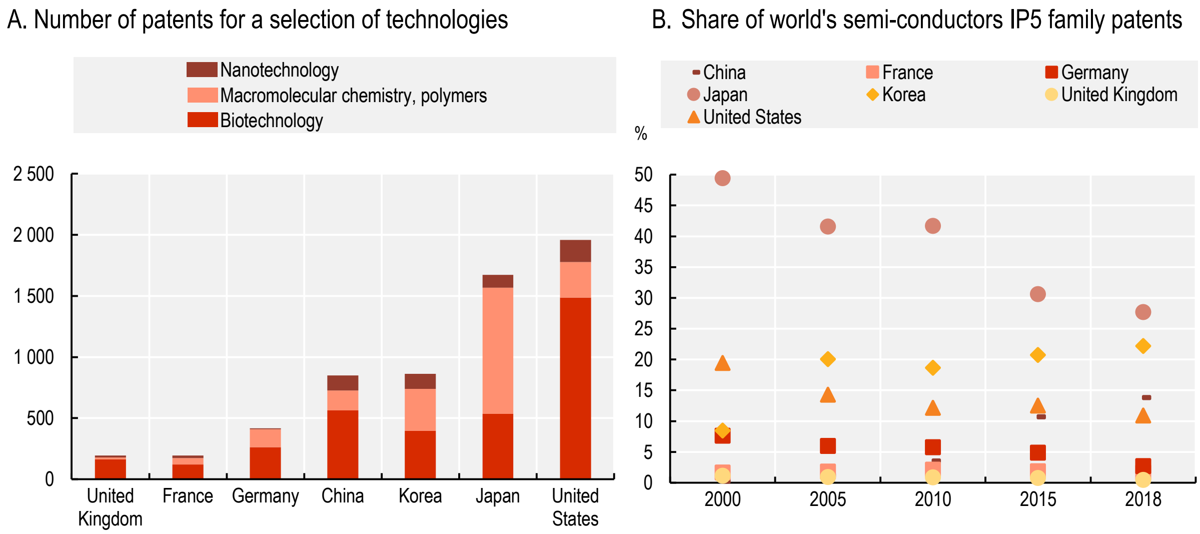
Note: Data refer to five IP offices (IP5 families), by filing date, according to the applicants' residence using fractional counts. Patents in ICT are identified using the list of International Patent Classification codes in Inaba and Squicciarini (2017[18]).
Source: As quoted in OECD (2020[12]), *OECD Economic Surveys: Germany 2020*, https://doi.org/10.1787/91973c69-en, based on STI Micro-data Lab and Intellectual Property Database (September 2020), http://oe.cd/ipstats.

Germany's limited contribution to global ICT innovation is true of both general ICT and more advanced technologies, including important general-purpose technologies such as AI. In 2017, Germany accounted for 146 AI-related IP5 patent applications, compared to 1 065 from the United States and 1 115 from Japan. Measured by publication output (which is often a more suitable metric for software and ICT innovation), only 2 of the top 50 corporations performing R&D in AI were German in 2014-16 (OECD, 2019[17]). While patenting has limitations in assessing AI innovation, the difference is nevertheless stark.

Germany also faces challenges in increasing innovative output in key enabling technologies, such as semiconductors and nanotechnologies. As the digital component of products becomes increasingly advanced, the hardware necessary to power applications concomitantly increases, and the ability to design and create these technologies will become an increasingly important component of value added. At the same time, a lack of domestic innovative and productive capacities in these technologies renders German industry vulnerable to supply-chain shocks, as demonstrated during the COVID-19 pandemic. The examples of semiconductors and nanotechnology are illustrative: nanotechnologies are a key input for the development of semiconductors, and strengths in the former are likely to underpin strengths in the latter. In 2017, however, Germany accounted for just 17 IP5 patent applications in nanotechnology, far behind the United States (140) and Japan (112), with a similarly low contribution to semiconductor patenting. Over 2000-18, only China managed to significantly increase its global share in these technology fields (Figure 10.6).

Figure 10.6. Research and patenting in selected advanced technologies

IP5 Patent families, Inventor(s)'s country(ies) of residence, priority date



Source: OECD (2022[20]), "Patents by main technology and by International Patent Classification (IPC)", OECD Patent Statistics (database), https://doi.org/10.1787/data-00508-en (accessed on 25 May 2022).

In practical terms, this means that contrary to the past, when German inventions wielded significant influence over manufacturing and industrial processes around the world, German firms will increasingly rely upon innovations – and the standards determining their use – that originated beyond its borders.

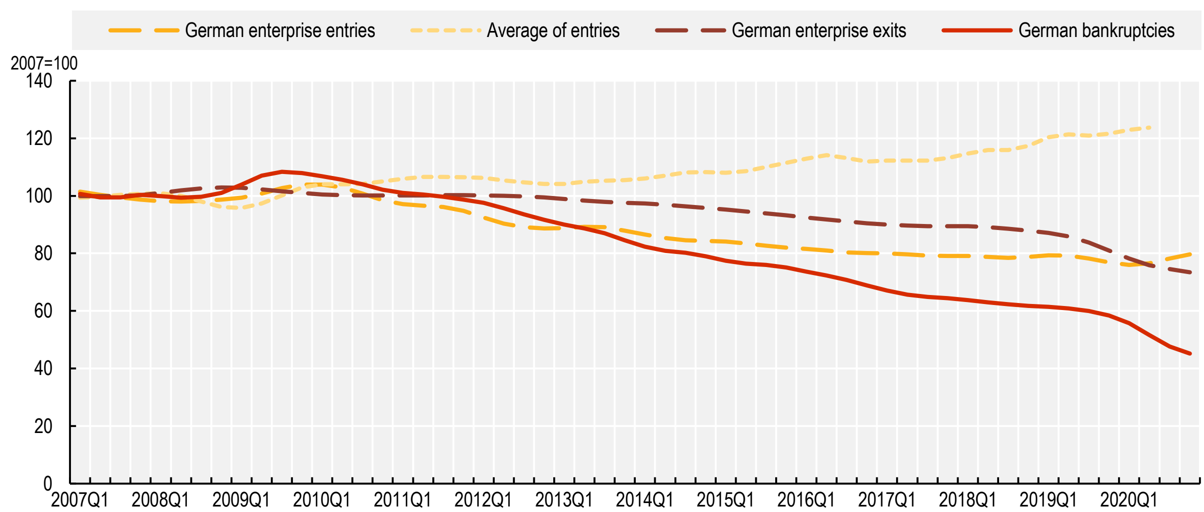
10.3. Business dynamics, entrepreneurship and implications for innovation

In Germany, innovation – particularly incremental innovation – has generally been internalised within established firms, with a relatively minimal role (and establishment) of start-ups. This reflects in part the sectoral composition and strong focus of the German economy on manufacturing and industry. The challenge for Germany's traditionally innovative sectors is that Germany's traditionally innovative firms will likely be less capable of internalising the development of many key technological inputs for future innovation and competitiveness. In the context of the sustainable and digital transitions, young firms – whether the academic spin-off of an early-stage technology or a disruptive service-based firm that challenges market assumptions – can act as agents of change and make important contributions to competitiveness and sustainability goals. This section considers business dynamism in Germany, linking to some of the issues discussed in Chapter 6 on framework conditions for innovation in Germany.

Germany exhibits a very low rate of firm exit and entry relative to other countries (OECD, 2020[10]). For example, its share of start-ups in the business sector (taken here as firms that have been active for two years or less) is the fourth-lowest in the OECD. The lower share of younger firms in the business population has several implications for both innovation and the commercialisation of innovation. One of the most striking consequences lies in the missed opportunities for scaling high-potential ideas: an OECD report found that young firms (under six years old) are two to three times more likely to scale up than an older firm of a comparable size (OECD, 2021[6]). This has clear implications for the German private sector's likely success in the digital and sustainability transitions, where there is renewed urgency for new ideas and technologies to reach the market.

As in a number of OECD countries, firm-entry rates in Germany have been declining for several years (Figure 10.7). There is growing concern that the “secular decline” in business dynamism – the entry and exit of firms, associated with job destruction and reallocation – is not specific to Germany alone and is affecting other advanced economies. In an OECD paper on business dynamism, the authors found that dynamism was declining (to varying degrees of severity) in each of the 18 countries analysed. They noted that this decline was occurring at a disaggregated sectoral level, rather than through a changing composition of economies (e.g. from manufacturing to services) or the “servitisation” of manufacturing (Calvino, Criscuolo and Verlhac, 2020[19]).[1] They also found that these declines are separate from business cycles, especially in terms of firm entry (3% average decline over 2000-15) and job reallocation rates (5% decline).

Figure 10.7. Business dynamism was slowing before the crisis



Note: Index constructed with business demography data (see http://www.oecd.org/sdd/46413155.pdf for more information on the methodology). "Average entries" includes data for Belgium, Denmark, Finland, France, Germany, Iceland, Italy, Japan, the Netherlands, Norway, Sweden and the United States.
Source: OECD (2020[11]) OECD Economic Surveys: Germany 2020, OECD Publishing, Paris, https://doi.org/10.1787/91973c69-en based on OECD (2020[22]), *Timely indicators of entrepreneurship (ISIC 4)*, https://doi.org/10.1787/888934201211.

It bears noting that high-growth firms (particularly start-ups) tend to be overwhelmingly concentrated in the service sectors, an area that has not traditionally been the focus of German STI policy makers. Trends in business dynamism result from a wide variety of factors, including key sectors’ market structure; integration in global value chains; demographics, with a shrinking share of the age group (30-50 years) most likely to start a business; relatively high wages; and a tight labour market (OECD, 2020[10]). Business framework conditions, such as regulatory burdens, bureaucracy, bankruptcy efficiency, access to finance, the strength of the innovation system and skills, also affect business dynamism.

Behind these macro-level firm-entry data are important nuances. For example, not all start-ups are necessarily innovative, and some are significantly more innovative than others. For example, these data do not show the share of academic start-ups and the ways in which they have (or have not) been affected by long-term trends or recent crises. Such data are generally lacking. An OECD analysis of high-growth start-ups using Crunchbase data found that the share of German start-up founders who launched their company within 4 years of completing an undergraduate degree was around the average of the 13 countries analysed (Breschi, Lassébie and Menon, 2018[21]). The picture is somewhat different for founders with a PhD, with Germany ranking third among the countries analysed. While interesting, these figures say little about the overall trends and drivers of academic or highly innovative start-ups in Germany, nor do they indicate how the structural transformation of the German economy will affect these trends.

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Endnote

[1] The study looked at 18 countries: Austria, Belgium, Brazil, Canada, Costa Rica, Denmark, Finland, France, Hungary, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden and Turkey.

11 German business sector innovation for the green transition: Performance, challenges and opportunities

The twin transitions – green and digital – have created new challenges and opportunities for Germany's highly innovative business sector. Germany has a range of innovative competencies in many technology areas necessary for success in the transitional context, but future global leadership requires sustained investments. This section begins by benchmarking the capacities and performance of the German business sector for innovation in the context of the sustainability transition. It examines the automotive sector as an example of the challenges and opportunities involved in industrial innovation and transformation to this aim. It then introduces some key policy programmes that support innovative capacities in key enabling technologies. It concludes with a brief discussion on the role of public procurement as a demand-side instrument to spur innovation in key technologies and their diffusion to achieve the twin transitions.

Introduction

The twin digital and green transitions pose significant challenges to Germany's historically innovative business sector. In line with the Paris Agreement on climate, which commits governments to limiting global warming to 1.5 degrees Celsius above pre-industrial levels, the Federal Government of Germany has essentially committed to reaching carbon neutrality ("net zero") – i.e. balancing emissions of carbon dioxide (CO_2) with its removal, often through carbon offsetting or eliminating emissions from society – by 2045 (BReg, 2021[22]). Following the 2021 elections, the new government reaffirmed Germany's commitment to the Paris Agreement (SPD, Bündnis 90/Die Grünen und FDP, 2021[2]). This objective will require a substantial transformation of industry and transport, two of Germany's biggest sectoral contributors to climate change. As noted by the International Energy Agency (IEA) in its 2020 Energy Policy Review of Germany, achieving the Federal Government's decarbonisation goal of reaching carbon neutrality by 2050 exceeds the capacities of mature technologies, necessitating accelerated technology development and innovation (IEA, 2020[24]). Achieving the necessary reductions requires all firms, including the small and medium-sized enterprises (SMEs) that comprise 99% of the private sector, to transform their business processes.

Substantive change will also have come to industries and markets, and consumer preferences, by 2045. If in the past, the value of a German-produced car lay in the high-quality engineering of its engine, this may no longer be the case in the future, when the strength of electric cars' battery, the autonomous driving offer, or the onboard services provided to passengers become essential. For many of Germany's most innovative industries and firms, the green transition is a paradigm shift. The challenge for policy makers and the private sector is to ensure that the undeniable strengths of the German business sector, and the science, technology and innovation (STI) system more broadly, harness the opportunities inherent to this shift, rather than face the obsolescence of their accumulated knowledge and competencies.

Ensuring that the business sector – particularly the *Mittelstand*, given its importance to the German economy – can make a success out of the sustainability transformation is paramount. The challenge for the German business sector is twofold. First, can it innovate and adapt to new consumer and regulatory demands, drastically reducing emissions and contributing to a more resilient and sustainable economy? Second, can it do more than adapt, perhaps even lead in the technologies that will underpin the greener and more sustainable economies of the future and contribute to key objectives, including attaining energy security and resilience to crises?

This chapter begins with a recommendation on the use of public procurement as a demand-side tool to support the diffusion and commercialisation of the technologies necessary to success in the context of the sustainable and digital transitions. Section 1 proceeds with a benchmarking of Germany's success in a range of technology areas for the green transition. Section 2 looks at the industrial transformation of the German automotive sector. Section 3 discusses the technological readiness of key technologies to achieve carbon neutrality. Section 4 introduces policy programmes and the corresponding technology areas necessary to the sustainable transition. By way of conclusion, Section 5 reviews current efforts in Germany to use public procurement as a tool to support the diffusion of technologies for the sustainable transition.

Recommendation 7: Strengthen the use of public procurement as a driver of innovation

Overview and detailed recommendations

use to better support the climate and digital transitions. The market-creating aspect of public procurement can also accelerate the transition of an idea to market by shortening the time required for commercialisation. Start-ups and *Mittelstand* firms in particular will be more inclined to engage in innovation efforts, as the government represents a reliable and high-profile client. A number of barriers, ranging from the low attractiveness of careers in public procurement to its fragmented and un-coordinated approach, currently prevent Germany from fulfilling the potential of public procurement as an instrument of innovative change. As discussed at Recommendation 10, using public procurement as a driver of innovation may require engagement with EU state-aid rules.

R7.1 **Commit to innovation procurement by taking legislative action and creating co-ordinated innovation procurement programmes within public agencies at the federal, state, community and city levels.** One line of action would be to require public agencies to allocate a dedicated amount or percentage to procurement of pre-competitive innovative research. Co-ordinating the different levels of public procurement (federal, state and municipal) will mitigate any potential fragmentation arising from this targeting. These efforts can support the overall "Germany 2030 and 2050" vision if it is linked to strategic projects emphasising innovation procurement, such as in sustainability, health and digitalisation.

R7.2. **Invest in building capacity and incentives for implementing innovative public procurement.** Acting on this commitment would entail a programme focusing on (i) the formulation of innovation agendas (roadmaps/challenges), as well as preparatory tasks for the definition and launch of innovation procurement programmes; (ii) capacity-building and training of staff in charge of public procurement; and (iii) offering incentives for public agencies in charge of procurement to reward innovative procurement (including through prizes). This would benefit from the support of the proposed laboratory on experimentation (see R2 in Chapter 15).

R7.3 **Direct some of the public seed funds for technology commercialisation programmes to pre-commercial procurement programmes**. This can take the form of staged-funding programmes, in the spirit of pre-commercial procurement programmes. The purpose of this approach is to add conditionality or challenges to publicly backed seed funds.

R7.4 **Create incentives for SMEs and start-ups to engage in innovative procurement.** This involves raising awareness of procurement opportunities and rationalising administrative barriers to the participation of SMEs and start-ups, such as clauses requiring past financial statements which start-ups cannot provide. Smaller and younger firms may currently be excluded from procurement tenders, limiting the ability of high-potential firms to scale and commercialise innovative solutions. The government could also create a platform that allows public authorities to issue challenge-oriented procurement tenders, which would draw smaller, high-potential firms. Such a platform would promote stronger innovative business creation through public procurement.

Relevant global experience

As in many areas examined in this review, the policies that can advance German innovation are themselves experimental and at the frontier of knowledge. This is also true of the use of public procurement as a demand-side instrument to induce innovation; this policy area continues to draw attention due to its theoretically powerful role. Public procurement represents a large share of final demand in many OECD countries, and many countries have committed to using it as a powerful, demand-side driver of innovation (OECD, 2017[25]). Yet despite widespread commitments to using public procurement to drive innovation, assessments of its effectiveness are more limited, which the European Commission duly noted in a recent report (European Commission, 2021[26]). Other research from the United States has suggested that firms actively invest in research in order to increase their chances of securing government procurement contracts, highlighting another channel through which governments can encourage research within the private sector (Belenzon and Cioaca, 2021[27]).

Public procurement can provide targeted support for pre-commercial procurement. In pre-commercial procurement, public procurers buy research and development (R&D) services from competing suppliers to devise alternative approaches to challenges, adding directionality to the research undertaken in the private (or public) sector. This echoes the approach of the Defense Advanced Research Projects Agency (DARPA) in the United States, which solicits research proposals for specific technical challenges in areas ranging from material sciences to semiconductors. In this manner, the public sector can share the benefits and risks related to the intellectual property rights resulting from the R&D.[1] This encourages the creation of new jobs and firm growth while inducing innovation in support of transitional goals which may not have otherwise occurred. The European Commission has increased the support available for pre-commercial public procurement through the Horizon Europe programme (European Commission, 2022[7]). In 2022, the European Commission is running several open pre-commercial procurement tenders, such as for profiling tumours at the molecular level and creating platforms for distance (tele-)rehabilitation services for patients in remote areas.[2]

11.1. Benchmarking Germany's innovation performance in the transitional context

11.1.1. Technology specialisation in Germany

Based on the available patent and trademark data (Figure 11.1), Germany has consolidated technological competencies in several important domains for the sustainable and digital transitions. The German specialisation in environment-related technologies is approximately the EU average. However, with the exception of wind-related technology, the patent share related to this group of technologies has been falling, despite increased public support. Furthermore, a gap prevails between energy-related innovation on the one hand, and other environmental technologies on the other.

Box 11.1. Measuring sustainability innovation: Climate-change mitigation and adaptation technologies

Advantages and shortcomings to using patent and trademark data

As discussed in the benchmarking section in Chapter 3, using patents as an indicator of innovative output is an imperfect approach. Not all innovations in this area will be patented, and consequently captured. Conversely, not all patented inventions will comprise effective and sustainable innovation for the future. Moreover, moving towards more sustainable development largely depends on businesses' adoption of those technologies. Such measures do not capture diffusion levels or the business-service innovation that will lead to the use of technologies.

Trademark data may capture some of the non-technological innovations that are also essential in this domain, since they reflect the commercialisation of research (Millot, 2009[8]). They are also rich in text and easily processed. Like patents, their metadata can provide additional insights into issues such as regional and socio-economic inclusion in innovation, collaboration and internationalisation of research, as well as tracking the commercialisation of emerging technologies. Importantly, trademarks are particularly important in the service sectors, where innovations are often non-technological.

In attempting to identify the direction of R&D and the intention of innovative output, the technological metadata in patents can give an indication of the potential contribution of innovation to sustainability goals, if not its viability. Patent data also allow international comparison of the sources of such innovation, providing insight into which sectors and industries are devoting R&D to technologies that can support the sustainability transition.

Climate change mitigation and adaptation technology patents and trademarks

The European Patent Office (EPO) has a dedicated classification scheme for climate change mitigation and adaptation technologies, the "Y02 tagging scheme" of the Cooperative Patent Classification, to identify relevant inventions in global patent databases such as the EPO PATSTAT global database (Angelucci, Hurtado-Albir and Volpe, 2018[9]). This classification system was developed by patent examiners at the EPO specialised in each technology, with the help of external experts. It classifies millions of patent documents across a wide variety of climate-change mitigation or adaptation technologies, including electric cars, renewable energy technologies, efficient combustion technologies (e.g. combined heat and power generation), carbon capture and storage, efficient electricity distribution (e.g. smart grids), hydrogen, energy-efficient lighting and energy storage (e.g. batteries and fuel cells). It has become a widely used international standard for monitoring progress in climate-related technologies across the world.

The Y02 tagging system for "Technologies or applications for mitigation or adaptation against climate change" comprises the following categories:

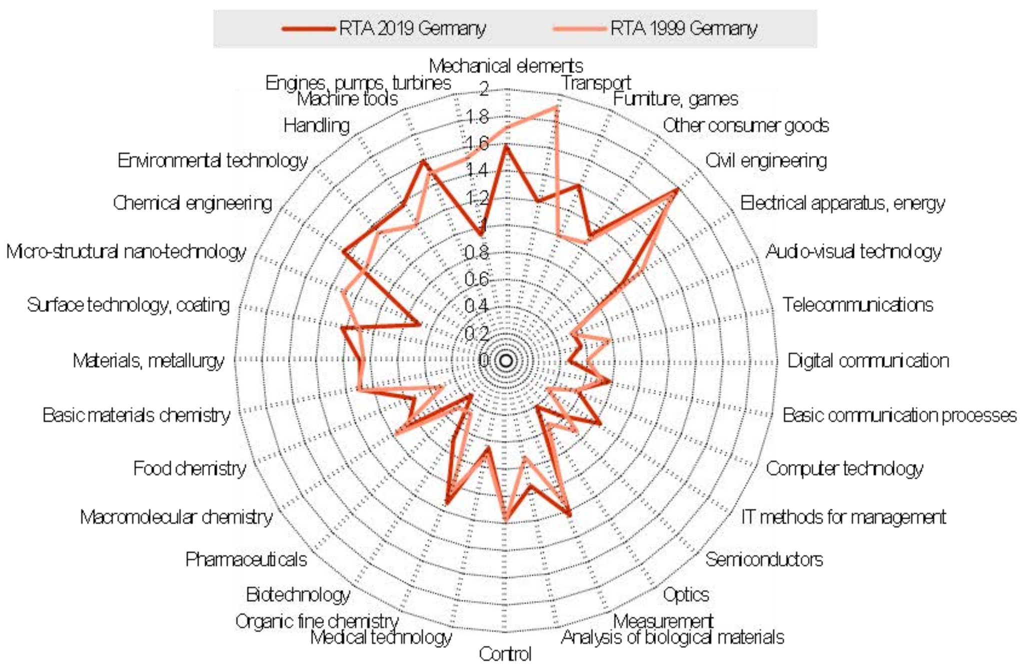
- Y02A – technologies for adaptation to climate change
- Y02B – climate change mitigation technologies related to buildings, e.g. housing, house appliances or related end-user applications
- Y02C – capture, storage, sequestration or disposal of greenhouse gases (GHG)
- Y02D – climate change mitigation technologies in information and communication technologies (ICT), i.e. ICT aiming at the reduction of their own energy use
- Y02E – reduction of GHG emissions related to energy generation, transmission or distribution

- Y02P – climate change mitigation technologies in the production or processing of goods
- Y02T – climate change mitigation technologies related to transportation

Y02W – climate change mitigation technologies related to wastewater treatment or waste management.

Figure 11.1 displays Germany's level of revealed technological advantage (RTA) – an index of the relative specialisation of a given country across the World Intellectual Property Organization (WIPO) 35 technology domains. These include several that are relevant to the sustainability transition, such as transport, engines and machinery, owing to these industries' contribution to emissions within and beyond Germany.[3] Over the last decade, Germany's technology profile has barely changed, although existing areas with relatively high levels of specialisation (i.e. transport, mechanical engineering, thermal processes and engines, pumps and turbines) have expanded.

Figure 11.1. Technology specialisation, EPO patent applications (2019)



Source: OECD Patent Data Indicators. The RTA index is computed according to the number of EPO patent applications, based on filing year and country of invention (fractional counting); it is obtained by dividing each economy's share of patents in a technology with the global share of patents in the same technology.

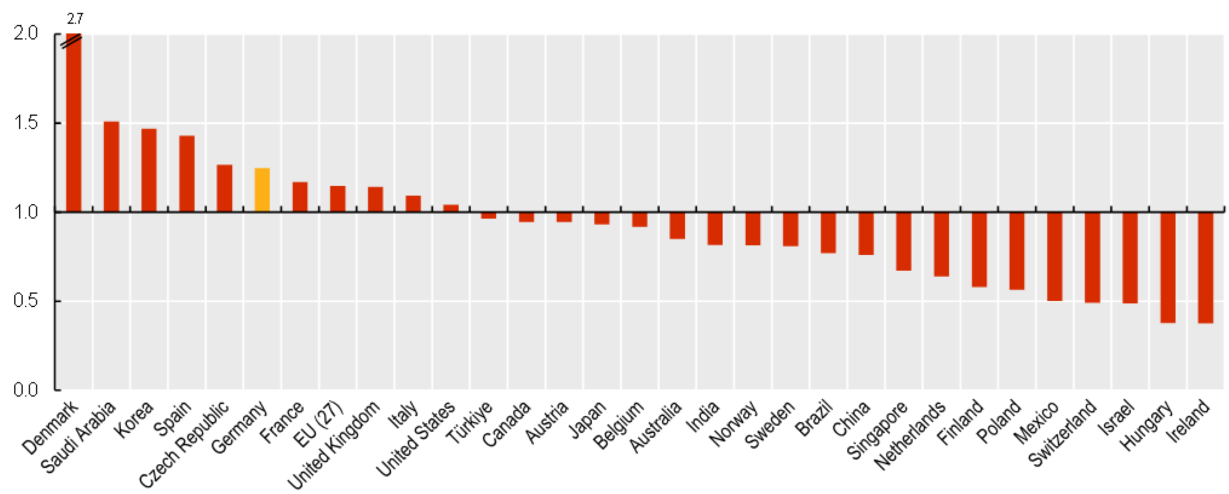
The areas where Germany displays weak specialisation have not changed. These include telecommunications and digital communication technologies, computer technologies, IT methods for management and semiconductors. The relatively low levels of German technological specialisation in digital and related technologies (represented in Figure 11.1 by telecommunications, computer technologies, IT methods and semiconductors) are in line with the overall European region. By contrast, the RTA of Korea and Japan is much more concentrated in digital and related technologies; this is also the case in the People's Republic of China (hereafter China), with an RTA of 2.9 in digital communication.

11.1.2. Technological specialisation in areas relating to sustainability

Germany has raised its level of specialisation in environmental technologies (from 1.23 to 1.44) over the past ten years, providing important opportunities for innovation and technological change in many economic sectors and fields. The German business sector also has a significant RTA in technologies related to climate-change mitigation and adaptation (see Box 11.1). As shown in Figure 11.2, Germany has the sixth-highest RTA globally (1.2) in these technology fields. As discussed in the following subsection, Germany also has a relatively successful commercialisation rate, as evidenced by the number of large patenting and trademarking firms in these fields.

Figure 11.2. RTA in climate-change mitigation or adaptation (2016-18)

Index based on inventor's location of patents

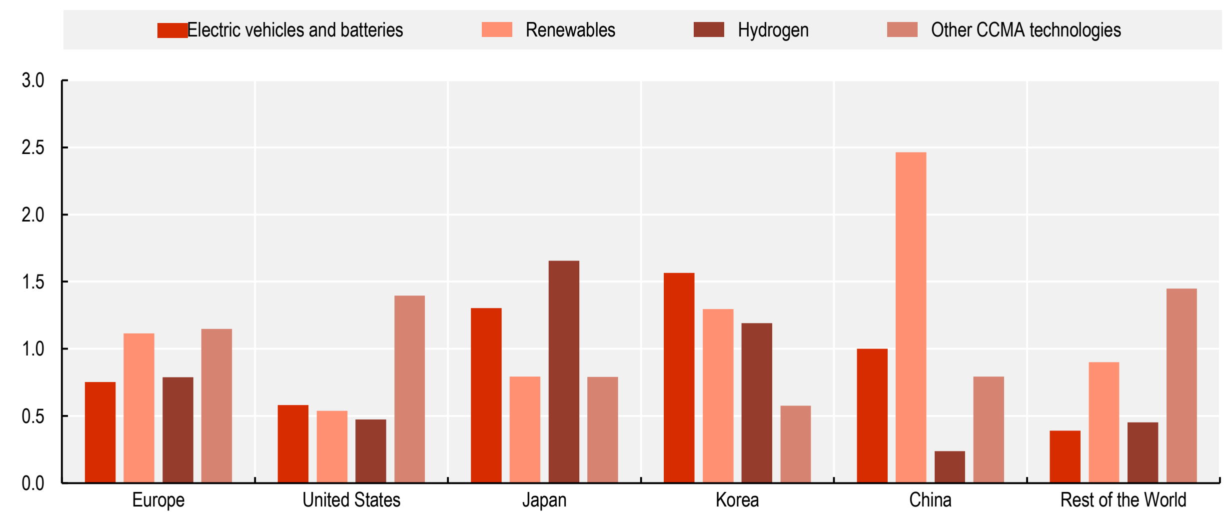


Note: Data relate to economies in which at least 250 patents owned by the world's top R&D investors were invented in 2016-18. The revealed technology advantage is defined in *World Corporate Top R&D Investors: Paving the way for climate neutrality* (Amoroso et al., 2021[10]). Patents selected are defined as outlined in Box 11.1.
Source: European Commission, Joint Research Centre and OECD (2021[10]).

Germany also has a relatively high RTA in several technologies that are essential to the future competitiveness of leading industries, such as renewable energy, and the digital and sustainable transformation of the automotive sector (Figure 11.3). Yet while Germany has a higher RTA than the United States in a number of fields, the same is not true in comparison to Japan and Korea, two key hubs in the global automotive sector. Korea has a significantly higher RTA than Germany in electric vehicles, renewables and hydrogen, as does Japan for electric vehicles and hydrogen.

Figure 11.3. Revealed technological advantage of regions, by specific technology areas (2016-18)

"Index based on IP5 patent families in climate change mitigation or adaptation (CCMA), by location of inventors"



Note: IP5: five IP offices, the name of a forum of the world's five largest intellectual property offices; data refer to fractional counts of IP5 patent families in climate change mitigation or adaptation owned by the top R&D investors in 2016-18, according to the location of inventors. RTA is obtained by dividing each economy's share of patents in a technology with the global share of patents in the same technology
Source: European Commission, Joint Research Centre and OECD (2021[10])

In terms of science-based enabling technologies (such as biotech and nanotechnologies), Germany displays competencies in micro-structural and nanotechnologies, where its specialisation index has risen over time (from 1.09 to 1.23); biotechnology remains at the same specialisation level, just above the average (1.03 in 2019) (Figure 11.1).

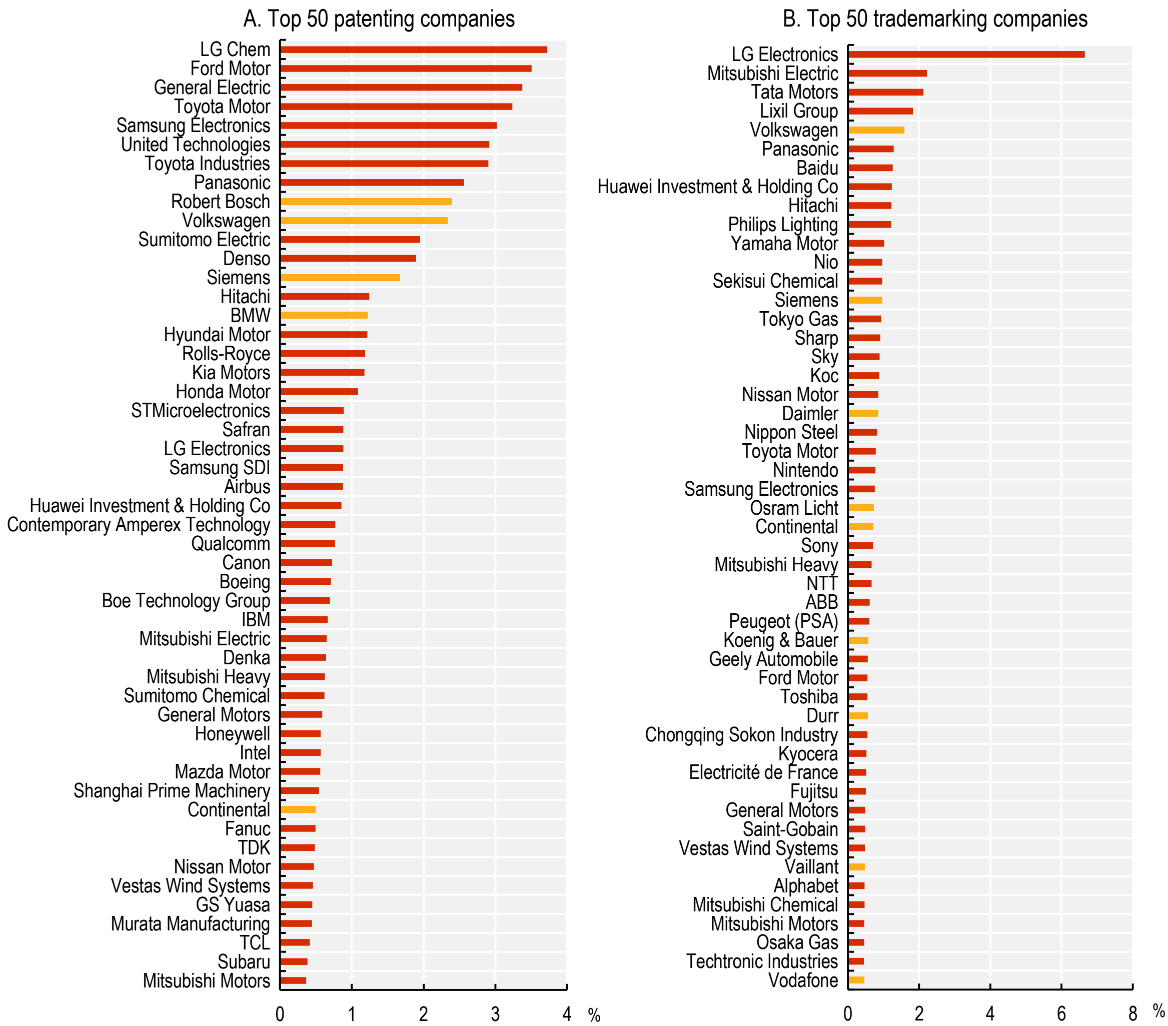
11.1.3. Benchmarking innovation capacities and performance for sustainability

This subsection examines German innovation capacities and performance for environmental sustainability in two areas. The first is the presence of German firms among the top patenting and trademarking companies globally in fields related to climate-change mitigation and adaptation. Compared to other OECD countries, the trademarks and patents created by German firms are relatively more concentrated in fields related to climate-change mitigation and adaptation. The second is the intermediary output of German firms in these technology fields. A subsequent subsection discusses environmental sustainability-related innovation in the automotive sector.

As noted in the fourth edition of the OECD and Joint Research Council of the European Commission report on the top R&D corporations in the world, large and innovative firms play a significant role in achieving environmental sustainability goals. For example, the 2 000 surveyed firms, which account for 87% of global business expenditure on R&D, hold 70% of all patents in technologies related to climate-change management or mitigation and 10% of trademarks in the same fields (compared to 63% of all patents and 6% of all trademarks) (European Commission, Joint Research Centre and OECD, 2021[31]).

The German business sector plays an important international role in this regard, with several German companies figuring among the top patent and trademark holders in climate-change mitigation and adaptation. These include firms in the transport equipment and machinery sectors, which generally spend the most on R&D and are also global leaders in trademark and patent creation related to sustainability (Figure 11.4).

Figure 11.4. Top 50 patenting or trademarking companies in climate change mitigation and adaptation (2016-18)

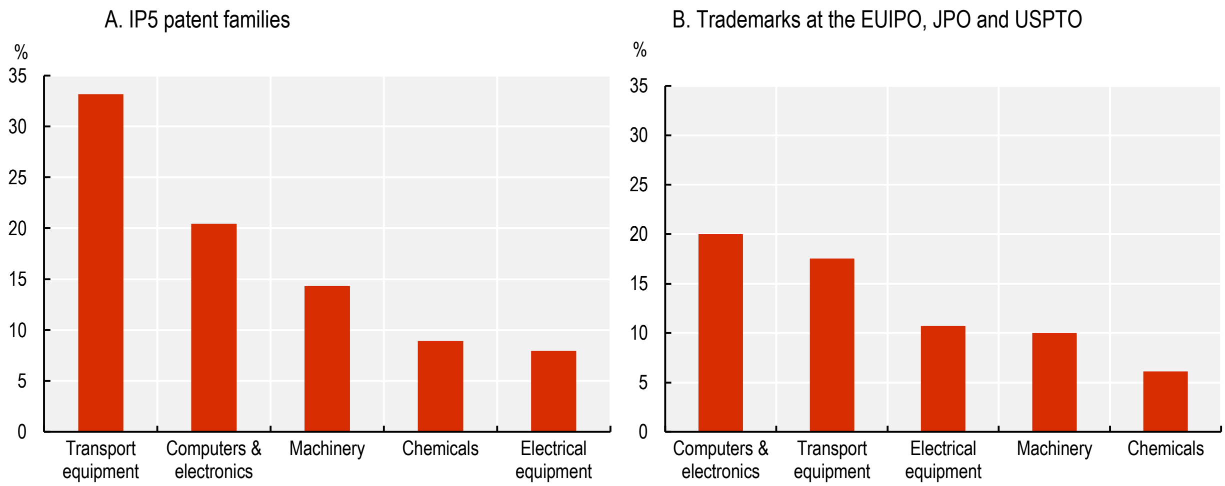


Note: Data relate to the share of the patents (respectively trademarks) related to climate change mitigation and adaptation owned by companies in total patents (respectively trademarks) in that domain owned by the top 2 000 corporate R&D sample in 2016-18. Yellow bars indicate German companies.
Source: Amoroso et al. (2021[10])

The German economy is also among those with the strongest overall specialisation in trademarks and patents in the sustainability field. Compared to other OECD countries, the trademarks and patents created by German firms are relatively more concentrated in fields related to climate-change mitigation and adaptation. Among countries with the highest R&D output, only China and Korea show a higher trademark specialisation in sustainability, and only Korean innovators produce relatively higher numbers of patents in this field (Figure 11.6). Many of the industries in which Germany is the most competitive are also responsible for the highest level of climate-related patenting activity. For example, the top five sectoral contributors to IP5 patenting in climate-related technologies are transport equipment, computers and electronics, machinery, chemicals and electrical equipment, all of which are important sources of German innovation and competitiveness (Figure 11.5). This indicates that key innovative sectors – and contributors to GHG emissions – are increasingly directing R&D towards technologies that will maintain competitiveness in the sustainability context. This, in turn, could accelerate the development of innovations that will support the transition towards greater socio-economic and environmental sustainability.

Figure 11.5. Top five sectors with patents or trademarks for climate change mitigation or adaptation technologies (2016-18)

Share of sectors in patents or trademarks in the field, ISIC Rev. 4

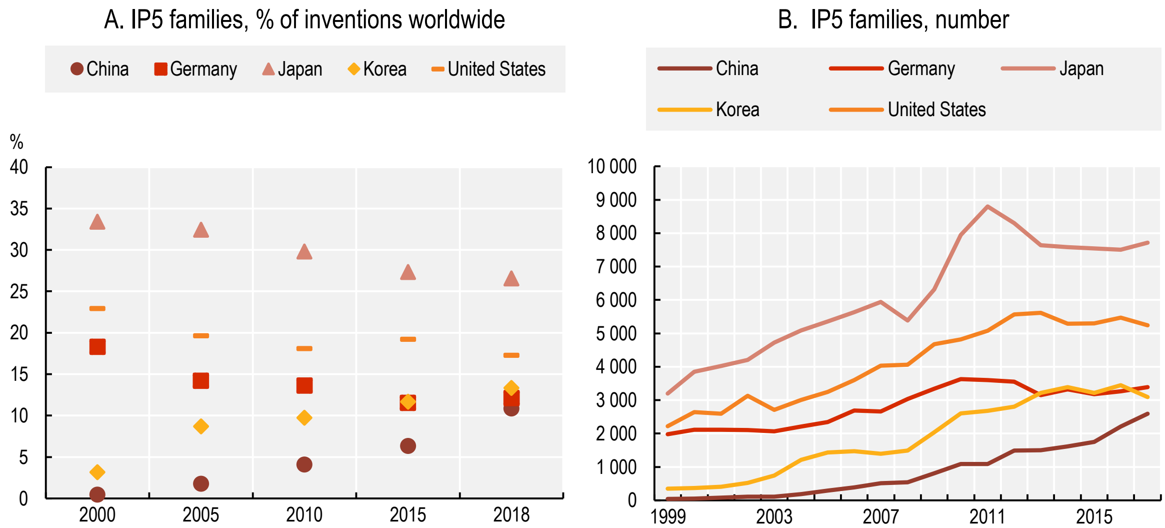


Note: EUIPO: European Union Intellectual Property Office; JPO: Japan Patent Office; USPTO: United States Patent and Trademark Office.
Source: Amoroso et al. (2021[10])

While Germany's relative contribution to the total number of annual patenting in environmental technologies has fallen since 2000, it nevertheless remains the largest single contributor in this area, accounting for 23.4% of all environmental technology patents in 2018 (Figure 11.6). As in the other top patenting countries, output has been falling precipitously since 2016. In each of these countries, this decline in output has been accompanied by a similar decline in scientific publication output in related technology areas such as energy, environmental sciences, material sciences and chemistry (OECD, 2022[32]). Germany is therefore well placed to build competitive advantages in many of the technologies that will support decarbonisation and the broader push towards more sustainable economic models.

Figure 11.6. Environment-related technology patenting (2000-18)

IP5 Patent families, priority date based on inventor's country of residence

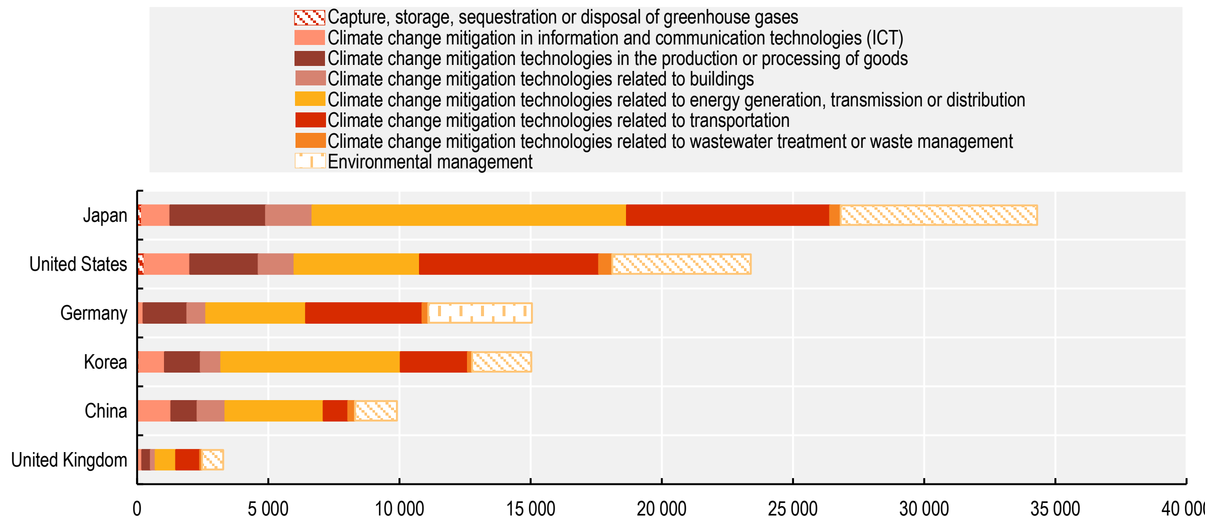


Note: IPC: International Patent Classification (WIPO). Environmental technology relates to the relevant WIPO technology classification.
Source: OECD (2022[13]) "Patents by main technology and by International Patent Classification (IPC)", OECD Patent Statistics (database), https://doi.org/10.1787/data-00508-en (accessed on 21 May 2022).

Germany is also a leading global innovator in many of the advanced technology fields that will be necessary to succeed in decarbonising industry and transitioning towards a more sustainable socio-economic model. The country is the third-largest contributor to global patenting in several of these technological fields, with particular strengths in energy transmission, generation and distribution; transportation-related environmental technologies; and environmental management technologies (Figure 11.7). These innovative capabilities augur well for the future competitiveness of the German economy, although this will largely depend on developing strengths in the key enabling technologies necessary for scaling and implementation.

Figure 11.7. Patenting relating to climate mitigation and environmental management (2015-2018)

IP5 Patent families, priority date, inventor(s)'s country(ies) of residence



Source: OECD (2022[13]), "Patents by main technology and by International Patent Classification (IPC)", OECD Patent Statistics (database), https://doi.org/10.1787/data-00508-en (accessed on 21 May 2022).

11.2. Industrial transformation for the sustainability transition: The German automotive sector

The automotive industry – Germany's largest – provides a clear indication of the structural challenges and opportunities for the business sector in the context of the sustainability transitions. Challenges ranging from the decarbonisation of energy to the implications of decarbonising private-vehicle usage itself, or the labour-force implications of electric vehicle production and the complications of sustainably procuring enabling technologies, also illustrate the "systemic" nature of the challenges and opportunities implicit in the sustainability transition.

Three interrelated issues are at play:

- First, and as in other areas of manufacturing, the core value in many cars will likely be digital or derived from new technologies (such as batteries and fuel cell design), where Germany's economy does not enjoy the same competitive advantage as it does in more traditional areas of manufacturing. Similarly, Germany lags behind many other competitor economies in terms of competencies in the design and production of enabling technologies, such as semiconductors required for autonomous driving and the rollout of the 5G networks necessary for their safe functioning.
- Second, the issue is not simply one of competitiveness. The decarbonisation of the automotive industry is also linked to social well-being. The industrial and transport sectors remain two of Germany's largest sources of carbon emissions; the state of Baden-Württemberg, a major location for the country's automotive industry, accounts for 0.3% global carbon emissions alone. The example of the Netherlands, while ambitious and in many respects successful, demonstrates the difficulty of reaching carbon neutrality while maintaining competitiveness, often in energy-intensive industries (i.e. mitigating demand-side policy instruments, such as carbon taxes, to encourage industrial decarbonisation with overlapping subsidies to industry) (OECD, 2021[14]). Product

innovation will need to be accompanied by a broader structural reorganisation of industrial and economic processes.

- Third, changes in mobility patterns are likely to affect the role and use of – and demand for – private cars, particularly in cities. Recent work by the International Transport Forum (ITF) outlines a number of trends that are likely to shape urban mobility, including shared mobility services and autonomous driving, both powered by digital technologies. Despite continuous growing demand for private cars globally, the ITF estimates that between 2015 and 2030, shared mobility will contribute the strongest growth (15%) in urban transport demand (passenger-kilometres) in the OECD region. The speed and extent of these transformations remains unclear, particularly because it will likely be a highly heterogeneous process at the global level. The trend is nevertheless clear, and the future of Germany's automotive sector and competitiveness of its exports will be highly influenced by digitalisation and decarbonisation in the decades to come, necessitating radical innovation and change throughout the industry.

The automotive industry is therefore facing one of the most drastic transformations in the German economy – not only in terms of the product themselves, but also in terms of the production process and new consumer patterns, such as the shift to mobility services or increased regulation of carbon emissions (Paunov and Planes-Satorra, 2019[34]). Electromobility, autonomous driving, mobility services and the integration of new technologies (i.e. internet of things) represent major innovation challenges for both automobile manufacturers and their supply chain. Shifts in global markets add to the changes affecting the industry.

The shift to electrical vehicles is a major component of this transformation, driven by new and stricter European regulations on CO_2 emissions. Increasing global competition from both global manufacturers and new competitors, such as Tesla and global tech companies, are further pressuring German firms to change. The market penetration of electric vehicles remains dependent on infrastructure, consumer incentives, emission regulations and carbon prices. As these factors develop, the share of electric vehicles will likely rise significantly and could represent the majority of new vehicles sales by 2035 (PwC, 2021[35]).

Although the industry took some time to commit to such a change, the pace of the transition to electrical vehicles has accelerated sharply in recent years. In principle, according to trends in R&D and patenting, German automobile industries seem well positioned to compete under this innovation paradigm. Both R&D and patenting have grown significantly, especially since 2015. Most of the large automobile manufacturers have started producing electrical versions of their mainstream models, with the commitment to convert their entire production to electric vehicles in the coming years.

The sector must overcome other important challenges, which will determine its success in transforming itself. One is the innovation in the supply chain, a critical component of the transition. Suppliers may struggle to adapt to new industry trends after producing equipment for traditional internal combustion engines for decades. They must move from a concept of product innovation towards a hybrid model linking product innovation with service innovation, and provide integrative smart services with transport mobility. Additionally, service provision based on software solutions, AI and interconnectivity will make a real difference in future value generation, which will entail adopting new organisational and business models integrating digital solutions.

In addressing the shift to electrical vehicles, a major weakness of large manufacturers in Germany (and Europe) is lagging capacity in battery innovation, where American and Asian manufacturers already have an advantage. According to a study by the IEA on international patenting, Japan leads the battery tech race with one- third of patent filings, followed by Korea (IEA, 2020[17]).[4] Over 2000-18, Japanese companies made up 7 of the top 10 applicants, but Korea's Samsung Electronics was the most prolific individual filer, with 4 787 inventions. Tesla supplier Panasonic came in second (4 046 inventions), followed by LG Electronics (2 999) (IEA, 2020[36]). This results in Germany's and Europe's dependence on Asian manufacturers and fewer opportunities for a reduction in the CO_2 impact of production using green electricity from Europe. The considerable share of batteries in the production value chain of electrical vehicles is a major incentive to invest more in this sector. Faced with the challenge of ensuring a reliable battery supply, leading firms such as Volkswagen have recently announced a commitment to battery production for electric vehicles and to establishing several “gigafactories” in Europe by the end of the decade.

As demonstrated by (Dechezleprêtre, A. et al., Forthcoming[37]), the share of patents linked to technologies for the green and digital transformations in automotive innovation attests to their growing importance for the sector. Though plateauing since 2010, the number of annual patent applications for electric vehicle-related technologies has been greater than patent applications for combustion engine-related technologies since 2007. The number of patent applications for autonomous vehicle-related technologies has also increased dramatically in the last decade, surpassing both the number of patent applications for combustion engines and electric vehicles. Patents related to automotive technologies have increased steadily over the last two decades (Ibid).

In 2016-19, Germany has the third-highest combined number of automotive patents, behind only Japan (first) and the United States (second), and ahead of Korea (fourth) and China (fifth) (Dechezleprêtre, A. et al., Forthcoming[37]). Germany also has the third-highest global share of patents relating to autonomous driving, but is significantly behind the United States (first) and Japan (second) in this regard, evidencing these two countries’ significant relative advantage in digital technologies. Germany, Austria, France and Japan have a strong RTA in a range of automotive technologies. China, Korea, the United States, the Netherlands and Switzerland, on the other hand, tend to be under-specialised in these technologies. However, these countries have significantly reduced the gap with leading economies over the last 20 years (Ibid).

RTAs vary significantly by technology (Dechezleprêtre, A. et al., Forthcoming[37]). Germany has the highest (1.7) RTA in automotive technologies globally, although it has dropped somewhat from the 2000-03 levels. By contrast, several economies, such as Korea, the United States and China, have improved their RTA in automotive technologies, although they nevertheless remain below 1. For several European economies (particularly France, Sweden and Italy), the RTA is above 1, mainly for combustion engines. In Germany and Austria, the RTA is also driven by hydrogen and electric engines. In Germany’s case, this is an indication of its increasing strengths outside of innovation in internal combustion engines. Germany does have a relatively strong RTA in battery technology (1), but it remains significantly behind Korea (2.2) and Japan (1.7). Germany does, however, account for over half of European patenting in electricity storage technologies (IEA, 2020[36]).

11.3. Technological readiness of solutions for industrial sustainability

The decarbonisation of industry is a major component of Germany’s push towards carbon neutrality. As noted in the 2020 Energy Policy Review of Germany, the industrial sector was the largest energy consumer in the country in 2017, accounting for 80 million tonnes of oil equivalent (Mtoe – a unit of energy equivalent to the amount of energy released by burning one tonne of crude oil) in 2017 (IEA, 2020[24]). Hydrocarbons dominate the energy mix in industry, accounting for 29% (natural gas) and 28% (oil). The chemical and petrochemical industry accounts for the largest share of industrial energy consumption; steel and mineral industries are other major consumers.

Decarbonising Germany’s industries – and society more broadly – will require accelerating the development and diffusion of new technologies. Many of these technologies already exist, but are at an early stage of technological readiness. As noted by the IEA, integrating these technologies into industry will be key for the country to reach its sustainability goals (IEA, 2020[24]). The issue facing German industry is therefore less what technology can do, but how quickly it can do it. Demand-side instruments (such as carbon taxes, as well as regulation and standard-setting) are an integral part of accelerating the commercial attractiveness of technologies that remain underdeveloped or prohibitively expensive. The application of carbon capture technologies to an industrial plant, for example, requires a bespoke retrofitting that can may not be economically viable if the cost of continued pollution is not priced into the firm's calculations.

In November 2021, the IEA launched its "Energy Technology Perspectives (ETP) Clean Energy Technology Guide", an interactive portal presenting information on over 400 individual technology designs and components across the whole energy system, all of which play a role in achieving net-zero emissions. The ETP platform provides a range of information for each technology, including the level of technological readiness – ranging from 1 (initial idea) to 11 (mature); the technology's importance (moderate, high or very high) in achieving net zero; and background on leading players in the given field.

The various technologies are assigned to five areas – buildings, energy transformation, transport, CO_2 infrastructure and industry. Notably, Germany is a "key" country in only three technologies – a battery technology, a direct air-capture technology that removes CO_2 from the atmosphere and an electrolyser technology necessary for industrial hydrogen (IEA, 2021[38]). None of these technologies are beyond the pre-commercial demonstration level of technological readiness. By contrast, the United States is key in 121 technologies, the United Kingdom in 38 technologies, and Sweden in 29.

The findings from the ETP platform illustrate several challenges affecting German industry and the ability of the Federal Government to reach its sustainability objectives. First, many of the technologies necessary for decarbonising remain at a low level of technological readiness, impeding the ability of industry (and the housing, transport and energy sectors) to decarbonise. Second, many of the technologies that may eventually be crucial for this process are not proprietary to German firms. By contrast with the deep integration of German industries (such as machinery and electrical components), Germany's historically central position in global industrial value chains does not seem as secure.

11.4. National strategies and policy support for the sustainable transition

The government aims to support the development of innovative and productive competencies in a range of key emerging technologies that are of central importance not only to the future competitiveness of extant industries, but also to the ability of new industries and firms (including in services) to emerge and remain in Germany. As failure to remain at the forefront of these technologies may have serious implications for German competitiveness and socio-economic well-being, German policy makers may be required to take a more systemic – and at times directional – approach to STI policy.

The government has created a number of strategic documents to support promote key enabling technologies. These strategies outline approaches to support innovation in a range of technological areas (such as hydrogen and quantum computing), as well higher-level guidelines for directing these technologies towards achieving transitional goals, such as industrial decarbonisation and the greening of the German economy. These technological capacities are also relevant to resilience and global value chains, as discussed in Chapter 15.

This section introduces three areas where innovation will be key to success in the environmental sustainability transition: energy, hydrogen technologies and battery technologies. This is not an exhaustive survey of key enabling technologies for the sustainability transition, but rather an overview of a selected group that are vital to the country's industrial transformation. Further technology-specific policy programmes that do not directly relate to the sustainability transition are also discussed in Chapter 5.

11.4.1. Energy sector

The Federal Government has an overarching approach to the transformation of the energy sector in Germany called the *Energiewende*. Led by the Federal Ministry for Economic Affairs and Climate Action

(BMWK) together with the *Länder*, this large, multidisciplinary strategy emphasises the role of innovation in achieving the transformation of the energy sector and the overall economy. The *Energiewende* therefore has significant overlaps with STI policy, given the importance of developing and commercialising technologies that can support both the decarbonisation of the German economy and the future competitiveness of the German private sector in this decarbonised context (EC, 2018[39]). The Federal Ministry of Education and Research (BMBF) also funds a large Energy Research Programme (currently the seventh edition in a long series). However, BMWK relies on a wider range of policy instruments beyond those traditionally available to STI policy makers, such as procurement, investment support, infrastructure policies, energy-market policy and a range of other "downstream" instruments, which by their nature are not available to a research ministry.

The *Energiewende* is a national effort to decarbonise energy supply and use in Germany, in line with Germany's obligations under the Paris Agreement on climate and periodic developments within the Conference of the Parties, and to shut down nuclear electricity production. The strategy's legal basis was set in 2000 through the Renewable Energy Act and firmed up in the Energy Concept of 2010, which states that with the *Energiewende,* "Germany is to become one of the most energy-efficient and greenest economies in the world while enjoying competitive energy prices and a high level of prosperity. At the same time, a high standard of supply security, effective environmental and climate protection and economically viable energy provision are necessary for Germany to remain a competitive industrial base in the long term."

A succession of BMWK-funded national energy programmes feed into the *Energiewende*. Governments periodically modify targets without necessarily resorting to legislation, a process that depends upon agreement among the governing political parties. A dedicated "think tank", Agora Energiewende, was established in 2012. It is an independent, non-profit organisation funded by a mix of public and private sources, advising – but still under the control of – the government. The *Energiewende* governance was centralised under BMWK (then the Federal Ministry for Economic Affairs and Energy [BMWi]) in 2014. The budget derives from various federal ministries and the *Länder*, and is sufficiently opaque that it appears difficult to arrive at a reliable total figure (Kuittinen and Velte, 2018[40]). The Federal Government publishes a progress report every three years. Progress in reaching energy targets is monitored by the lead ministry – BMWK – together with an expert commission of four professors in energy technology and policy, and is reported to the parliament and the government.

The co-ordination structure of the *Energiewende*' has changed and become more formalised since BMWK took over in 2014. Nonetheless, the multilevel governance may reduce the coherence of the effort. For example, *Länder* decisions can conflict with the overall design of the initiative. As discussed in Chapter 9, Russia's war in Ukraine has given a renewed impetus to Germany's energy diversification programme, and by extension, importance of STI contributions to the expansion of renewable energy in total energy supply.

11.4.2. Hydrogen technologies

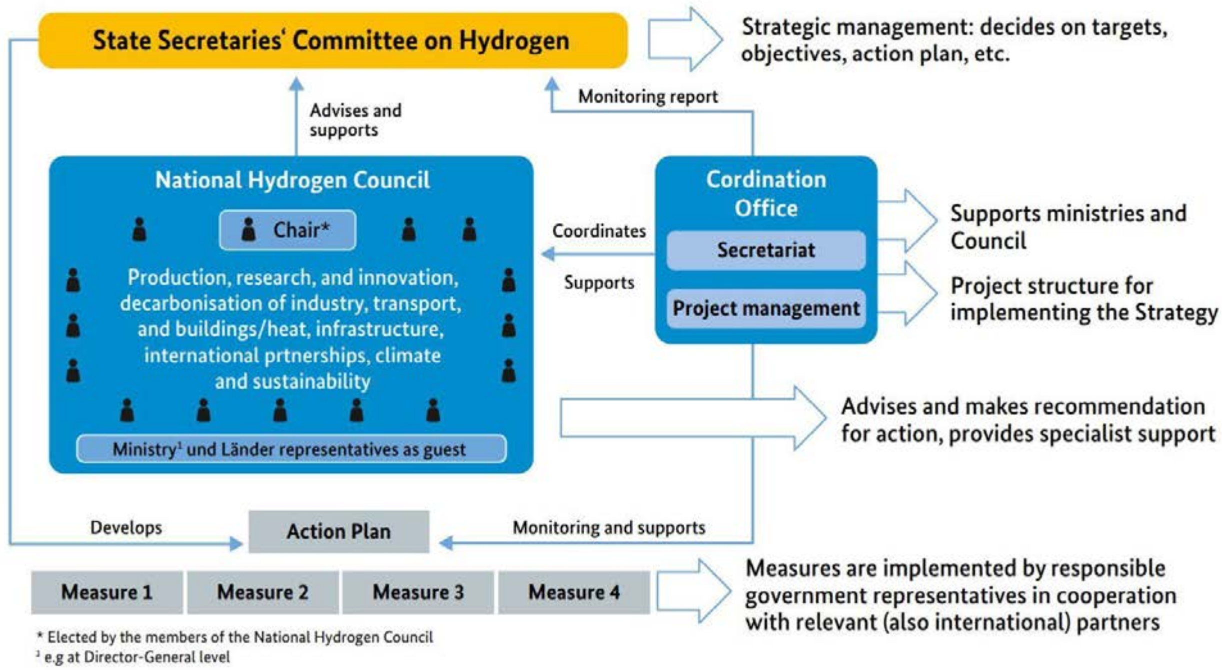
BMWK published the National Hydrogen Strategy in 2020 (BMWi, 2020[42]). This cross-ministry strategy is managed by a committee of state secretaries. The strategy has not been costed, but operates within an envelope of EUR 7 billion for hydrogen rollout and a further EUR 2 billion for international hydrogen co-operation. It builds on significant investments in hydrogen R&D, including EUR 700 million (euros) for the National Programme on Hydrogen and Fuel Cell Technology from 2006 to 2016, and a commitment to spend a further EUR 1.4 billion over 2016-26. In parallel, substantial investment of EUR 510 million is planned through the Energy Research Programme, as well as a EUR 600 million investment planned in regulatory sandboxes, and several programmes funding the development of hydrogen applications across a range of industries.

The strategy notes that many technological aspects of the hydrogen transition are maturing, and that it is therefore appropriate to move towards implementation. This involves 38 national measures, such as developing a national roadmap; market formation and regulation; new business models for electrolysis operators; funding for electrolyser development; co-operation on foreign offshore wind farms and markets to access enough electricity; regulation; national and international standard harmonisation; subsidies for investments by users to stimulate demand; cross-ministerial and international R&D initiatives; developing a hydrogen refuelling infrastructure; developing fuel cell industries; supporting the development of industrial applications; ensuring links to the development of infrastructure for natural gas distribution; and education and vocational skills. International measures include co-operation in developing an EU hydrogen roadmap; R&D collaboration; standard development; and developing international hydrogen markets. The National Hydrogen Strategy contains most of the elements discussed in the literature as being necessary to develop a new technological innovation system (Bergek, Hekkert and Jacobsson, 2007[43]) (Hekkert et al., 2007[44]).

Figure 11.8 shows the strategy's governance, headed by the State Secretaries' Committee on Hydrogen (one of several committees convened for a range of cross-ministerial policy purposes), which sets overall targets and (in principle) links the strategy to the individual ministries' activities. The committee also appoints a National Hydrogen Council, which meets every six months to review the strategy and its progress. Two *Länder* representatives attend as guests, to ensure a link with the various regional hydrogen activities occurring in parallel. A co-ordination office provides project management and monitoring of the strategy's implementation.

The strategy is thus implemented using an intra-governmental platform connecting it to broader government policy. While BMWK has the lead in practice, there is no overall "referee" or "owner" in government, and the actual pace of implementation depends on decentralised decisions by individual spending ministries. There are no specific, measurable goals, nor is there a timetable – the roadmap from 2019 contains some broad goals tied to an approximate timeline, but these do not appear binding. The strategy does not discuss strategy-wide evaluation. This is an area of weakness in German governance, where individual programmes are conscientiously evaluated, but there is no practice of conducting a portfolio-wide evaluation and reflection to support systemic development and change. The government could consider an evaluation model that provides independent, systemic feedback that is not tied to the responsible ministries.

Figure 11.8. Governance of the National Hydrogen Strategy



Source: Taken from BMWi (2020[22])

11.4.3. Battery technologies

As discussed in Section 2 of this chapter, battery technologies are essential to the future of the automotive industry. They are central to the sectors' ability to decarbonise and meet consumer's rising demand for more powerful batteries in their electric vehicles.

BMBF funds several programmes supporting the development of battery technologies, focusing on both advancing the latest battery systems (e.g. lithium-ion batteries) and those at an earlier stage of technological readiness. As early as 2014, BMBF initiated a call for research into battery technologies through the "Battery materials for future mobile and stationary applications – Battery 2020" programme. The second call came in February 2016, followed by the third in October 2017. The programme has funded 44 research projects (BMBF, 2020[45]).

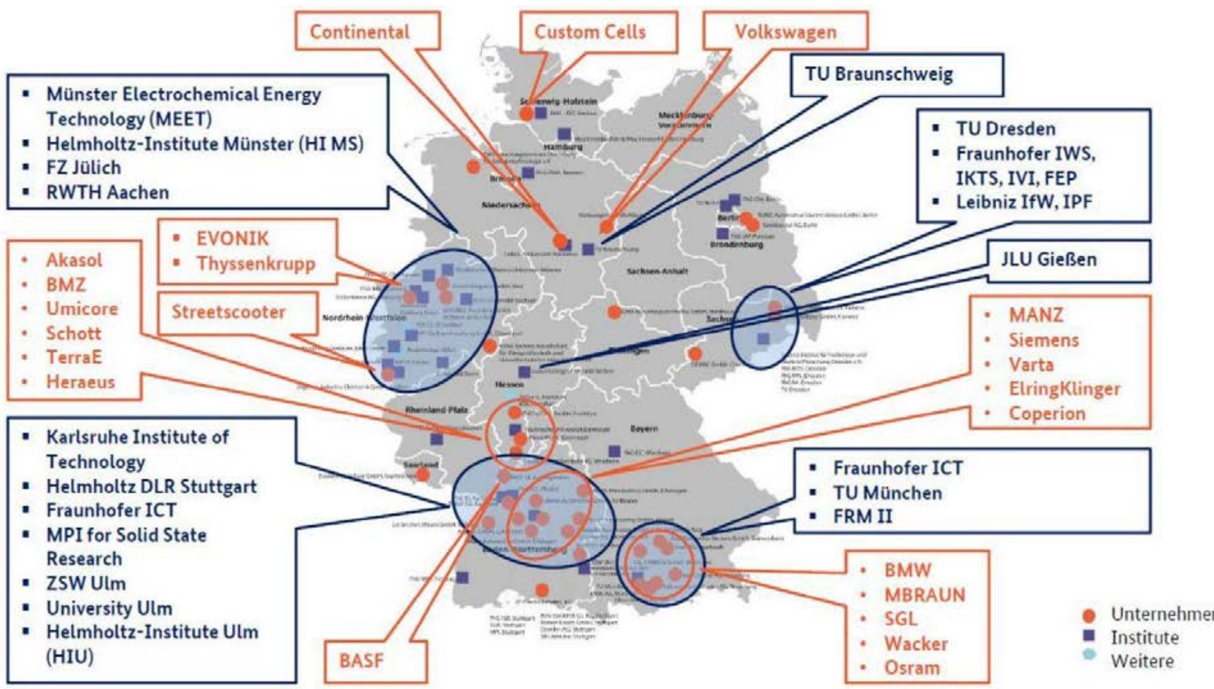
BMBF initiated the "Lithium-ion batteries (LIB 2015)" funding programme in 2007 with the aim of developing one of the most important key technologies contributing to low or zero CO_2 emissions. Since then, BMBF has provided about EUR 600 million (around EUR 60 million per year) to battery R&D, to build a broader battery community and gain knowledge along the battery value chain, from materials research to battery applications.

To transfer excellent research to an industrial scale, BMBF decided in 2018 to newly align its battery funding by combining past and ongoing funding activities and programmes under the umbrella of the "*Dachkonzept*" ("umbrella concept") (BMBF, 2019[46]). The goals of the "*Dachkonzept Forschungsfabrik Batterien*" ("Umbrella Concept Research Factory Batteries") are to support battery research, building battery cell production capacity in Germany and a more efficient transfer from research results into applications. The program will be developed further and financial support enhanced by BMBF. One component of the *Dachkonzept* is the Fraunhofer Research Institution for Battery Cell Production FFB, which is being built in Münster and funded with EUR 500 million.

The *Dachkonzept* combines the following measures with mission-oriented and thematic aspects (BMBF, 2020[47]):

- factory modules: material development and characterisation: technology development and digitisation of cells and processes; battery cell production and automation
- cross-cutting activities: analytics and quality control; battery lifecycle
- accompanying measures with regard to research and networks: international activities, young researcher programme, “Battery 2020” research programme, industry initiatives.

Figure 11.9. Important actors within the German *Dachkonzept Forschungsfabrik Batterie*



Source: BMBF (2019[26]), Batterieforschung und Transfer stärken – Innovationen beschleunigen: Dachkonzept „Forschungsfabrik Batterie“, https://www.bmbf.de/bmbf/shareddocs/downloads/files/bmbf_dachkonzept_forschungsfabrik_batterie_handout_jan2019.pdf?__blob=publicationFile&v=1 (accessed on 12 May 2022).

All parts of the *Dachkonzept* (Figure 11.9) work together to bring research results to the next level along the value chain. The concept is intended to create synergies with the European Green Deal and the Important Projects of Common European Interest (IPCEI) on batteries, which are co-funded by BMWK.

Unlike BMBF, BMWK focuses its funding and support on building competitive large-scale battery cell manufacturing, with the aim of establishing a competitive, innovative and sustainable battery value chain in Germany and Europe. BMWK is providing around EUR 3 billion in funding to two IPCEI projects (BMBF, 2020[47]).

Besides BMBF and BMWK, other ministries and agencies in Germany (e.g. the Federal Ministry for Digital and Transport (MMVD), the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) and its German Environment Agency (UBA)), as well as regional funding agencies (e.g. emobilBW), actively support research and innovation along the battery value chain.

At the European level, activities are bundled under the umbrella of the European Battery Alliance and co-ordinated by Batteries Europe under the aegis of the European Technology and Innovation Platform. Batteries Europe released the “Batteries Europe Strategic Research Agenda” in late 2020 (Batteries

Europe, 2020[48]). All 27 EU Member States are participating and represented in these networks to support the goals formulated by the national government and ministries.

The funding measures and support initiated over the past decade have helped build a German research community and industrial network. With respect to research activities, the share of German publications on batteries has developed from under 5% to well over 5% (Fraunhofer ISI, 2018[49]).The share of German patent applications has remained stable at over 10%, although this highly competitive field is dynamically expanding with both established and new market players (ibid.).

Battery production is the missing link and an identified gap in Germany and Europe. By 2020, Germany still did not have a significant share of battery cell production capacities compared to the global installations amounting to over 400 gigawatt hours (GWh). During the next decade (i.e. until 2030+), battery cell production capacities of 400-800 GWh have been announced in Germany and 800-1 800 GWh in Europe. Compared to the announced production increases from 4 terawatt hours (TWh) to almost 8 TWh globally, this would mean that 10% of global battery cell production capacities would be located in- Germany and 20% or more in Europe (VDMA, 2018[50]).

The demand for battery cells from German original equipment manufacturers (OEM) has increased from 0% to over 5% percent in the past decade and is expected to reach 10% by 2030 (Fraunhofer ISI, 2018[49]). If the announced production capacities are realised in this time frame, a European battery value chain would be created in the coming decade. This value chain will consist of not only European but also Asian and other global market players, since at least half of European battery cell production capacities will be built by Chinese, Korean and Japanese companies.

11.4.4. Other areas of critical policy support

The green transition relies on several innovation policy actions:

- Succeeding in the sustainability and digital transitions will require progress in radical and breakthrough technologies, rather than only incremental improvements to existing technologies. Promoting innovation entails a different approach that allows and supports more cross-disciplinarity, greater use of data, and more experimentation in policy and regulation. As discussed in Chapter 15 on policy agility, the Federal Government can do much more in this regard. The establishment of the Federal Agency for Disruptive Innovation (*Agentur für Sprunginnovationen*), or "SPRIND", is an important step towards expanding the policy and institutional support for breakthrough innovation. As discussed in Recommendation 3, however, these efforts can be significantly expanded (see Chapter 15).
- Uneven capacities across different actors in the economy may limit the diffusion of technologies. Addressing co-ordination failures – between the public and the private sectors, but also within those sectors – is another major challenge for policy makers. The co-ordination challenges involved in transforming the automotive sector are a salient example (see Section 2 of this chapter). As discussed in Chapter 13 on knowledge transfer and its Recommendation 5 on improving multidisciplinary transfer and co-operation, overcoming these challenges requires more effective diffusion of new technologies and knowledge, particularly when they are interdisciplinary.
- Insufficient infrastructure development is another area where policy support is critical. Achieving the green transition means developing a supportive infrastructure allowing industry and consumers to push in the same direction. The automotive sector is again telling in this regard, with a growing share of electric vehicle sales largely dependent on key infrastructure, such as charging stations. The public sector therefore has an important role to play, as it can invest – or support private investment – in areas of infrastructure that will increase the attractiveness and viability of greener approaches.

- Policies that create demand-side incentives for “green” over “brown” products and approaches are also important. Demand-side policy interventions can be enacted through taxation (such a carbon taxes), as well as regulatory interventions that mandate, for example, the use of certain low-carbon heating technologies in construction; a similar logic can be extended to the infrastructure necessary for electric vehicles, such as requiring new developments to have charging sockets. For example, the introduction of carbon taxes and gradual increase of carbon prices will make energy from renewable sources more appealing than hydrocarbon fuels, increasing end-user demand for such solutions. Similarly, tax rebates applied to the purchase of an electric vehicle rather than a car with an internal combustion engine may encourage more people to switch to electric mobility, increasing demand and therefore investment in the technologies necessary to further lower the cost of such technologies. An important instrument in this regard is public procurement.

11.5. Public procurement to support innovation

Public procurement can be a powerful tool to induce innovation supporting transitional goals, such as economic sustainability and digitalisation. This is particularly true of pre-commercial procurement, where public procurers purchase research on specific challenges rather than specific technological solutions, adding a level of directionality to public- or private-sector research. One example of this approach may be a German procurement agency soliciting a tender for the best solutions to decarbonise railway infrastructure, rather than procuring a specific technical solution (such as carbon capture). In this way, public procurement can act as a powerful demand-side driver for innovative solutions, lowering the risks inherent to investment in novel areas of research and eventually creating new markets for products or services that can support overarching policy objectives. Expanding the use of public procurement can be done by introducing mandatory public procurement criteria or targets in national sectoral legislation (though from a coordination perspective this encounters challenges linked to fragmentation over different administrative levels); creating an observatory or library of different products and services with a ”sustainability” focus; imposing mandatory annual reporting on the environmental aspects of public procurement, which would also improve transparency and data collection; providing training on public procurement for sustainability to contracting authorities and the private sector; and engaging environmental protection agencies in the implementation of public procurement (European Commission, 2021[26]).

Germany is one of the first European countries to revisit its public procurement framework to improve the contracting of innovation and R&D services. New rules were adopted with the Procurement Law Amendment Act in 2009. In 2011, innovation procurement programmes were launched at the federal and regional levels by ZENIT, a public private partnership and the agency for innovation and European affairs of North Rhine-Westphalia. In 2013, BMWK (then BMWi) launched the Competence Centre for Innovation Procurement (KOINNO) to support capacity-building, information and guidance, and best practices.

However, public procurement of innovation remains underutilised in Germany. Germany invests in innovation procurement with the same intensity (10%) as the EU average (9.37%) (European Commission, 2021[51]). In general terms, it features in the group of moderate achievers in innovation procurement, both in terms of policy frameworks and investments. Its numbers are even smaller for R&D procurement (0.68%) and far from the EU target (3%). Public procurement of innovation still faces important barriers to uptake in Germany. These include strong risk aversion (i.e. especially when solutions need to be developed and co-financed) and resistance to change at public agencies; difficulties in engaging with external actors (i.e. for market consultation and competitive dialogue); budgetary restrictions; and difficulties in implementing and managing pre-commercial procurement (e.g. launching a competition) (OECD, 2017[52]). A major challenge is building the skills of a large procurement staff to enable procuring agencies to apply increasingly complex criteria, as is the case with strategic procurement (e.g. green procurement and innovation procurement).

Yet the potential to expand use of public markets for innovation is large, as evidenced by the effectiveness of innovation procurement in driving firm innovation and performance, as well as private investment. A 2016 study estimated that innovation procurement could apply to approximately 12-15% of Germany's public procurement, representing approximately EUR 40-50 billion (Eßig and Schaupp, 2016[53]).

Germany has no targets related to the allocation of innovation procurement or R&D-related procurement. Other EU Member States have taken action in this area, setting quantitative targets. These include Finland (5% target for innovative public procurement), France (2% of procurement for innovative SMEs), the Netherlands (2.5% of procurement for innovation) and Spain (3% new investment for innovation procurement) (OECD, 2017[32]). In 2021, the Lithuanian government also increase its target for the share of innovation in total public procurement as part of the National Progress Plan for 2021-30 (OECD, 2021[34]). Encouraging contracting authorities to adopt a strategic perspective to innovation procurement is also fundamental, as is collaboration with different actors around public needs.

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Endnotes

[1] A list of open tenders solicited by DARPA can be found at the following link: https://www.darpa.mil/work-with-us/opportunities

[2] Tenders for pre-commercial procurement can be found at the following address: https://digital-strategy.ec.europa.eu/en/related-content?topic=61

[3] The RTA is defined as a country's share of patents in a particular technology field, divided by the country's share in all patent fields. The index is equal to zero when the country holds no patent in a given sector; it is equal to 1 when the country's share in the sector equals its share in all fields (no specialisation); and it is above 1 when a positive specialisation is observed. Data are drawn from the OECD Patent Database.

[4] In 2018, Japan published 2339 international patent applications for 2339 inventions related to batteries, almost twice as many as the second-ranked South Korea (1230). China ranked fourth in patent filings, followed by the US in fifth.

12 From incrementalism to breakthrough: New challenges and approaches to innovation

This chapter considers the potential role of breakthrough innovation in the German economy. It discusses the essential factors that will support its propensity for engaging – and succeeding – in breakthrough innovation in the context of the green and digital transitions.

Introduction

In 2019, the Federal Government of Germany created the Federal Agency for Disruptive Innovation (Agentur für Sprunginnovationen [SPRIND]) to better support breakthrough innovation. SPRIND adopts a different approach to policy support for such innovations – one that is more conducive to risk-taking, and acknowledges that their success and significance exceeds the traditional competitiveness rationale for science, technology and innovation (STI) policy interventions. Breakthrough innovation involves the creation of new markets, as well as market disruption and displacement, with profound societal implications. Such innovation has always happened, as illustrated by electricity or (more recently) the internet. However, it has often emerged organically (even randomly), rather than being deliberately cultivated.

The digital and green transitions have heightened the need for more of these innovations. For the world to meet the net-zero ambitions set in the Paris Agreement, technological solutions will need to be developed rapidly to drastically decarbonise the global economy. Many of these solutions will require innovative breakthroughs (i.e. entirely new technologies, the application of existing technologies to new areas, and the systematised use of certain technologies and processes in businesses' and citizens' lives and work) in the short- and medium-term future. Not achieving these breakthroughs could mean irreversible damage wrought by climate change, with profound implications for socio-economic well-being and stability.

The rise of the digital economy, and the ever-increasing use of data as an input in research and innovation, have created new opportunities for breakthrough innovation. Indeed, many breakthroughs stem from combinations of knowledge and data that are only possible thanks to advances in digital technologies and information and communication technology (ICT). The importance of breakthrough innovation has grown owing to the sustainability transition, along with the capacity of the STI system to act.

Policy intervention to support breakthrough innovation largely involves correcting market failures that may stop breakthroughs from occurring more frequently. For example, opportunities for investment may be lower because breakthrough innovation involves a higher degree of risk. If the cost of inaction is not factored into market and business operations, then technologically viable solutions for decarbonisation may not be generalised enough to be effective. If breakthroughs require new combinations of knowledge and experience, then the existing innovation orientation of the research base and private sector may not make these new connections, or make them quickly enough.

This chapter introduces some of the ways in which policy support for breakthrough innovation differs from traditional STI policy. It considers how policy interventions can overcome some challenges to accelerate the development and diffusion of new breakthroughs, drawing on a policy paper prepared for this review (Paunov, Einhoff and Mackle, Forthcoming[1]). The chapter discusses the justification for a policy focus on breakthrough innovation and provides some related evidence. It continues with a more detailed look at how support for breakthrough innovation differs from traditional STI support, and concludes with a series of open questions for policy makers in Germany.

12.1. Business as usual? The case for a new approach to innovation

Addressing some of the complex socio-economic and environmental challenges facing Germany requires combining previously disparate areas of science and industry – for example, data and energy technologies, or artificial intelligence and pharmaceutical research. This type of innovation is often referred to as "breakthrough" or "radical". In many cases, such innovation is considered "disruptive", insofar as it challenges the status quo of established sectors, from retail to network sectors (such as communications). A key departure from traditional modes of innovation (particularly in the manufacturing sector) is the growing importance of data, which have become a key input for innovation in general, and radical and breakthrough innovation in particular. Recommendation 4 (Chapter 10) on access to data and data infrastructure is partly a response to this new reality.

12.1.1. The significance of breakthrough innovation in Germany's transitional context

The complexities facing large and industrialised economies, such as Germany's, in the context of the twin transitions of digitalisation and environmental sustainability are unprecedented. No major industrialised economy has ever had the very basis of its competitiveness and resilience so systematically challenged by changing social, environmental and regulatory pressures. Moreover, these pressures are profoundly complicated by the deep interconnections between the German economy and international markets.

If the German economy has historically been very innovative, then it might follow that it will continue to be so, regardless of what *type* of innovation is necessary for success. The reasons for which this may not be so straightforward, and historical success does not always guarantee future success, can be found at the firm level. Kodak, a global leader in photography whose entire business model was rendered obsolete by the technological leap to digital cameras, may be the most famous example. Other examples include Nokia, a world leader in mobile phones displaced by new entrants as smartphones took hold, and Blockbuster, the globally famous video rental service whose model was disrupted by the rise of online streaming.

These stories share a number of commonalities that are relevant to STI policy in Germany, even if it is necessary to take a theoretical leap to appreciate them. First, these firms were innovative leaders and at the cutting edge of their industries. In the case of Kodak, the firm was so innovative that it actually invented the world's first digital camera in 1975, but did not have the foresight to see how this could upend its business model. The second commonality is the importance of breakthrough innovation, and how easy it can be for large, innovative firms to slip into obsolescence when certain breakthroughs are made and begin to disseminate through an economy.

What does this mean for Germany? Many German firms are highly innovative, world leaders in R&D, and act as large employers. And yet, they have business models which could be fundamentally challenged by the digital and green transitions. The digital transition may engender a growing preference for connected and shared mobility, or for vehicles and machinery with embedded digital services. The sustainability transition will likely lead to a preference for electric vehicles, while decarbonisation may hamper the competitiveness of German industrial firms to the benefit of firms those located in countries with lower wage pressures.

The German economic model – and the innovative firms that power it – will likely not face obsolescence, but policy makers should nevertheless consider whether the current direction of STI policy will lead to the private sector's deep well of knowledge and innovative competencies being utilised in a way that secures the economy's future resilience, sustainability and competitiveness. For example, that the American car manufacturer Tesla, which focusses on electric vehicles and has particular competencies in battery technologies, had a market capitalisation of USD 1,074 billion in April 2022, a valuation USD 200 billion greater than the ten next firms *combined*. Yet, this valuation is in spite of the fact that Tesla was not even in the top ten automotive firms by annual earnings in 2021, and had a price-to-earnings ratio in April 2022 of 343, compared, for example, to Volkswagen, which had 2021 revenues of USD 241 billion and a price-to-earnings ratio of 4.49.

The gulf between the present valuation of Tesla compared to other automotive firms stems from the perceived likelihood that the American firm will deliver some of the breakthrough innovations that will underpin the automotive industry's future competitiveness in a net-zero future. The high valuation also shows that investors are looking forward to the creation of new markets, even if that involves some speculation. German automakers may well master the technologies needed to become global leaders in electric vehicle manufacturing, but Tesla's competencies in fields such as battery technology likely factor into investor sentiment.

12.1.2. Supporting breakthrough innovation in Germany: SPRIND

Created by the German government in 2019, SPRIND aims to identify and develop research ideas with the potential to produce radical or breakthrough innovation, as well as accelerate the commercialisation and diffusion of highly innovative ideas. The agency falls under the aegis of both the Ministry of Education and Research (BMBF) and the Ministry for Economic Affairs and Climate Action (BMWK). Its governing board comprises ten members from industry, academia and politics, as well as one representative each from the Ministry of Finance, BMBF and BMWK. Like the Defense Advanced Research Projects Agency in the United States (DARPA), SPRIND plans innovation challenges or competitions around specific themes. Such innovation incentives and initiatives became popular during the COVID-19 pandemic, but are already well-established in information technology sectors (such as coding).

The projects supported by SPRIND reflect the institution's technologically open nature, touching on areas ranging from a potential cure for Alzheimer's disease to water purification. As of June 2022, SPRIND had led three projects to completion and was supporting eight ongoing projects. The first three projects had a strong ICT focus, while the ongoing projects were more varied. The agency also runs two innovation challenges, focusing on decarbonisation and approaches to combatting viral infections. SPRIND selects a relatively small number of projects from a large pool of applicants: in 2021, the agency only selected 4 projects from among 440 proposals, with an initial funding of EUR 2-4 million (euros).

While they are not exact analogues, both SPRIND and DARPA have a similar purpose and model – lean, risk-tolerant institutions that aim to accelerate the development of breakthrough innovations. SPRIND remains at an early stage of development and has been allocated a EUR 1 billion budget for the initial ten-year period. The scale of the funding influences the number of projects the agency can support, both in terms of direct financing and institutional capacity. DARPA, which has operated for over 50 years, has a 2023 budget of EUR 3.9 billion (DARPA, 2022[2]). It numbers more than 200 government employees, including 100 project managers allocated across 6 technical programme offices (Congressional Research Service, 2021[3]).

The ability of SPRIND to support breakthroughs may be constrained by national and EU-level regulation, a point argued by the president of the National Academy of Sciences of Germany, Gerald Haug (Handelsblatt, 2021[4]). The director of SPRIND, Rafael Laguna, also voiced his concerns over regulatory constraints on the institution's ability to support breakthrough and disruptive innovation in a 2021 interview (Handelsblatt, 2021[5]). These constraints – particularly those relating to state aid and public procurement – have led to calls from within the institution for a "SPRIND law" that would lighten the regulatory burden on the agency and allow it to be more agile – and impactful – in its project selection and support. From a governance perspective, ministerial presence on SPRIND's supervisory board may also limit the agency's ability to act autonomously.

While it is too early to judge its successes, the establishment of SPRIND illustrates the kind of institutional development that will likely support the innovation activities sought by political and industrial leaders. However, the agency's current size and budget may not be large enough to support breakthrough and disruptive innovation at a systemic level. Complementary measures are also necessary, such as targeting rules and evaluation criteria for existing innovation programmes to support disruptive solutions and risk (including in public procurement); setting anticipatory regulation featuring the right standards and mechanisms; and promoting serious opportunities for scaling successful solutions.

12.2. Breakthrough innovation and its policy implications for Germany

The introduction to this chapter asked whether the German business sector can adapt and thrive in the context of the sustainability and digital transitions, or whether (at least in some of its largest and most innovative industries) there exists a risk of obsolescence in certain technological and innovative capacities.

Germany's strong STI system, which features diverse competencies and innovative know-how across a range of sectors and firm sizes – including the *Mittelstand* – should augur well for the sustainability transformation.

Compared to incremental innovation, breakthrough innovation is associated with the launch of new markets and the novel application of or new technologies (Ahuja, Yang and Shankar, 2009[6]).[1] Radical inventions combine previously unconnected knowledge domains, an uncertain and risky process (Castaldi, Frenken and Los, 2014[7]; Fleming, 2001[8]).

From a policy perspective, what can the government do to support breakthrough innovation, and how does such support differ from the already well-established policy programmes for STI that have consistently and effectively supported the private sector? While overlaps exist – firms and entrepreneurs still require investment, access to finance, support for R&D, access to skilled staff, etc. – the policy implications for breakthrough innovation as opposed to "incremental" innovation differ in important ways. These different needs reflect the logical conclusion of a breakthrough innovation – new markets and products, and disruption and displacement, often with socially important implications.

As discussed above, the establishment of SPRIND is a reflection of the need for a new approach to STI policy making that explicitly supports breakthroughs, with a number of policy implications (Table 12.1). For example, SPRIND can provide finance to riskier innovation endeavours. It can provide the research and physical infrastructure necessary to innovate. It can mitigate regulatory, legal and co-ordination challenges, in theory linking with other government policy areas (such as public procurement) to support publicly driven market creation. In fact, linking innovation support to pre-commercial procurement for specific challenges (such as energy) is a clear demonstration of how institutions such as SPRIND can help implement a more directional and explicit approach to STI policy and support for breakthrough innovation.

Table 12.1 Breakthrough innovation and policy implications

Type of challenge	Policy implications
Cost	1. Provide funding to produce and scale (increase the number of new business ideas), with less private funding potentially available for incremental innovations
Combination	2. Support collaborative projects across industries and policies to support industry-science-civil society collaborations even more than for incremental innovations 3. Support cross-disciplinary and cross-sectoral collaborations and innovation platforms
Market creation	4. Use public procurement to incentivise products with the potential to create new markets and be a frontrunner, which is not needed for established products 5. Expand civil society engagement in policy design and innovation processes, which is an advantage but not as essential for incremental innovations 6. Promote industry-government collaboration in shaping demand for more environmentally friendly products/transitions (e.g. mobility in cities)
Risks	7. Expand venture capital-type funding and support for riskier projects 8. Support firms with expertise in dealing with risks 9. Invest in research relevant to questions around key enabling technologies 10. Anticipate future tech forums, etc. 11. Provide incentives for public officials, firms (including start-ups and small and medium-sized enterprises [SMEs]) and science to take on riskier important research (including through prizes)
Infrastructure	12. Improve digital and other infrastructures necessary for disruptive innovation, especially where this may diverge from traditional innovation needs 13. Support dialogue between various areas of government and industrial and other stakeholders on infrastructure use
Regulatory and legal constraints	14. Expand regulatory sandboxes 15. Support regulatory and policy agility
Co-ordination failure	16. Devise strategies/visions for countries, industries and regions 17. Support cross-governmental collaboration around key challenges 18. Support ecosystem thinking involving adjustments across the entire value chain
Inclusivity	19. Design STI, education and social policies (including migration approaches) to respond explicitly to existing

		challenges
Skills and capabilities	20.	Provide on-the-job training and skill training
	21.	Provide knowledge services and support for collaborations
	22.	Expand skilled migration policies

Source: Paunov, Einhoff and Mackle (Forthcoming[1])

The remainder of this section expands on some of these policy challenges and how they relate to Germany.

12.2.1. Co-ordination challenges in transition contexts

Whenever a country's industrial focus shifts, a number of complex co-ordination challenges arise. In the context of the sustainability transition, these challenges manifest themselves in an array of social and economic areas. While there may be benefits for all stakeholders to shift to an entirely new product/process or market, no stakeholder can do so alone, as this would be too expensive and inputs from all other stakeholders are required. For example, the shift from combustion engines to electric vehicles requires not only an adjustment of the entire supply chain to produce inputs for the new products, but also deep infrastructure changes. Electric vehicles can only be a viable alternative for German automotive manufacturers if the supportive infrastructure – i.e. charging stations and the necessary battery technology – is in place. These challenges require heightened co-ordination and joint action, as proposed in Recommendation 1 on the establishment of the forum.

12.2.2. Financing challenges

As discussed in Chapter 7, SMEs in Germany traditionally have good access to finance, which is a key strength of the STI system. Nevertheless, SMEs face difficulties in accessing finance when the investment is intended for intangible capital. Physical capital has sustained industrial investment and innovation for decades, but in a context where more widespread and quicker diffusion of digital technologies; greater use of data; and increased cross-disciplinarity, reskilling and upskilling, and experimentation are required for success, investment in intangible capital will become even more important. As long as SMEs struggle to access finance for these intangible investments (often owing to the impossibility of collateralising the asset), they may adapt more slowly to the sustainable transition and be less engaged in such innovations than their peers in other economies, compounding the issue of financing for innovation (see Recommendation 6).

Beyond investment in intangible capital, financing breakthrough innovation invariably involves higher risk – at least early on, even though the payoffs may be greater in the end. Furthermore, innovators may be start-ups or individuals with few assets they can collateralise or an underdeveloped business plan. In these important respects, financing for breakthrough innovation can differ significantly from financing "incremental" innovation, or innovation by established STI actors. Financing institutions may be ill-equipped to deal with the additional risk. They may not appreciate the implications of the innovation activity, or have misaligned incentives (expecting a return on investment that does not reflect the innovation's socially impactful nature). Public institutions that finance STI programmes may face similar problems. This implies a different approach to innovation financing if policy makers wish to see more breakthroughs (and greater systemic uptake thereof).

12.2.3. Management, skills and capabilities

One of the issues discussed in this section (and in the review more broadly) is the slow diffusion of ICT in the private sector and the impact on innovation – particularly the digital and data-driven innovation necessary for technological breakthroughs. One factor not mentioned so far is the issue of management, skills and capabilities. Recent studies have shown that one reason for the slow diffusion of technology in

German SMEs lies in their relatively weak management practices. Similarly, actors in the STI system (whether factory workers, procurement officers or academic researchers) must possess the technological and human-resource capabilities to innovate, recognise opportunities for innovation (e.g. in public procurement) and be empowered to make these decisions.

Given their critical role in boosting corporate productivity and the effective use of new technologies, upgrading management methods must be central to business-innovation strategies. Adopting advanced management practices, such as target setting, performance monitoring and providing incentives, is a key factor explaining differences in firm productivity both within firms and across countries (Bloom and Van Reenen, 2007[9]). These two interlinking questions – managing people within the STI system and the capabilities of actors within that system – apply equally to the public and private sectors.

In addition, identifying opportunities for breakthrough innovation, or seeing the potential impact of such breakthroughs, may require different management skills. A manager who appreciates the market implications of incremental improvements to a product may not appreciate the implications of a breakthrough, because it deviates from a previously planned course of action. Broadly speaking, the management capabilities for innovation in general may be misaligned with the requirements of more breakthrough innovations. In such cases, the ability to see across technological disciplines, factoring in the broader social implications of innovation activities – and feeling motivated by them – may be more important.

12.2.4. Service-sector contributions

The German economy's innovative strengths lie in the manufacturing sector. However, the digital transformation continues to generate significant opportunities for service innovations, because it is now much easier to interact with customers and assess their specific needs (e.g. for on-demand transportation services). Another consequence of the digital transformation is the servitisation of manufacturing (Guellec and Paunov, 2018[10]). Success in the sustainability transition may therefore entail increased attention to service-sector innovation and potential linkages across sectors to drive future transitions.

12.2.5. Increasing participation in policy programmes that help breakthrough innovation

A key challenge for STI policy makers is to increase the participation of SMEs in the programmes they design, and to garner policy support for breakthrough and radical innovation. The policy avenues for incremental innovation are relatively clear for many firms, particularly when they are already engaged in innovation activities. This is not necessarily true for firms engaged in breakthrough and radical innovation, which implies a departure from normal activities and the risk of taking a new direction. Support programmes for breakthrough and radical innovation face the same participation challenges as traditional policy support mechanisms, compounded by many firms' unfamiliarity with the concept, and the need to bring a greater diversity of firms and actors – often from outside the formal STI system – into the fold.

A related question is societal engagement in innovation activities with possible social implications. Transitions entail fundamental changes to markets, and consequently involve not only producers, but also customers and society at large. Engaging those stakeholders will therefore be critical in order to make the right choices and take joint actions (see Chapter 16).

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Endnote

[1] A close definition of radical innovation is disruptive innovation. In business theory, a disruptive innovation is an innovation that creates a new market and value network, eventually displacing established market-leading firms, products and alliances (Bower and Christensen, 1995[11]).

13 Technology and knowledge transfer for industry innovation and transformation

Germany has a well-established network of knowledge transfer and co-creation between science and industry, which has helped ensure that German firms are at the cutting edge of technology. Yet the digital and sustainable transitions require more cross-disciplinary and cross-sectoral efforts in the transitional context. This chapter begins with a recommendation on improving cross-disciplinary and cross-sectoral knowledge transfer. It introduces the key actors and institutions involved in knowledge and technology transfer in the German innovation system. It proceeds with an analysis of how knowledge transfer between science and industry can support breakthrough innovation. Finally, it discusses constraints to and public policies supporting knowledge transfer in the German science, technology and innovation system.

Introduction

Knowledge transfer and co-creation between research, industry and other stakeholders are important drivers of innovation. Increasing their effectiveness and frequency of use is therefore a key component of German science, technology and innovation (STI) policy. Knowledge transfer promotes industrial competitiveness and addresses societal challenges by transforming scientific knowledge into new products and services, whereas co-creation is the joint production of innovation between stakeholders (Kreiling and Paunov, 2021[1]).

Knowledge transfer is particularly important to the innovative capacities of the small and medium-sized enterprises (SMEs) that comprise the German *Mittelstand*. While large corporations may be able to dedicate significant investment to research and development (R&D), the same is not always true of smaller firms. Hence, the ability to engage jointly in – and learn from – high-quality research conducted in the broader STI system can markedly improve the innovation capacity of SMEs. Collaborative innovation is even more important in the transitional context, where new knowledge and technology that are often not widely diffused in the business community may be required to innovate successfully. A major challenge for policy makers is to accelerate the transformation of ideas from science into successful innovations, which requires exploiting existing and newly developing competencies in the broader STI system. Germany's strong research capacity and scientific leadership in numerous disciplines are a source of strength and resilience as firms innovate in the sustainable and digital transitions.

Supporting knowledge and technology transfer from research and scientific institutions to the private sector remains a key policy priority for the Federal Government. The Federal Ministry for Economic Affairs and Climate Action (BMWK)'s flagship innovation policy, "From the Idea to Market Success", explicitly seeks to accelerate the transfer of ideas, research and technology into marketable solutions, ensuring that German firms are equipped to commercialise and apply the most promising research. However, most programmes are shaped by – and oriented towards – the country's large manufacturing sector. While the transfer of knowledge and technology between research and historically strong innovative industries must remain high on the innovation policy agenda, policy makers must also keep in mind that new forms of transfer may be necessary in the context of the sustainability and digital transitions.

The challenge for German policy makers is to strike a healthy balance between supporting formal and informal channels of exchange between industry and research to maintain current industrial competencies, while allowing the emergence of new firms and ideas. Ensuring that *Mittelstand* contribute to this end remains essential.

This chapter of the Innovation Policy Review begins with a recommendation on improving cross-disciplinary and cross-sectoral knowledge transfer. It then assesses key aspects of the country's knowledge and technology transfer ecosystem, and reviews in detail the policy options available to improve it.

Recommendation 5: Improve cross-disciplinary and cross-sectoral knowledge transfer and collaboration

Overview and detailed recommendation

Extensive and inclusive knowledge exchange and collaboration across institutions, disciplines and sectors, as well as multidisciplinary open innovation approaches, should become cornerstones of German STI policy. Success in this area would have other positive spillover effects on inclusivity in STI, such as engaging in innovation activities a wider share of the population with skills beyond STEM. Germany's traditional innovative strengths have generally been intra-sectoral, so that knowledge is created, and technology transferred and applied, within a particular cluster and industry. In a digital world, however, knowledge and technology transfer increasingly occurs at the intersection of digital technologies and "analogue" sectors. In addition, the type of innovation necessary to succeed in the sustainable development challenge is – and will continue to be – disruptive. This requires significant breakthroughs, which are achieved through effective knowledge transfer and industry-science collaborations, and based on open innovation approaches and industry-science collaborations across all sectors of the economy. The support for knowledge transfer and collaboration should transcend traditional innovative sectors. The success of the government's recent pilot phase of the Innovation Program for Business Models and Pioneering Solutions (IGP) programme (see Section 2 of this chapter) also demonstrated the potential of government-supported programmes to promote non-technical and multidisciplinary innovation in areas ranging from digital platform design to social impact.

R5.1 **Improve universities' engagement with industry and support research institutions in playing a leading role in the transitions required to achieve the** "Germany 2030 and 2050" vision**.** Part of the vision should consist in reframing the relationship between research institutions and industry, so that it supports knowledge transfer and innovation collaboration in areas of future importance, as well as an "ecosystem" approach to innovation. In this light, ensuring that innovation actors contribute to knowledge transfer and collaboration could become a formal pillar of German research organisations' responsibilities, with a training and information campaign accompanying this change. This strategy would benefit from incorporating these objectives into performance-based funding and developing a set of metrics, including qualitative measures, to improve the visibility of related programmes. The "Germany 2030 and 2050" vision could also establish a formal mechanism, encompassing the forum proposed in R1, the policy laboratory and the higher education system, to engage research institutions in Germany's transformational processes, including by contributing to environmental development objectives.

R5.2 **Encourage and facilitate the development of university proof-of-concept funds to support academic spin-offs and start-ups.** Through its direct funding of higher education R&D, the government should encourage the establishment of proof-of-concept funds within universities, which could be complemented by industrial contributions. These funds would help accelerate technology transfer commercialisation. The government should explore regulatory channels that would allow (and make it simpler for) universities to engage directly with external finance actors, such as VC firms and the banking system more broadly, as happens in Belgium, Denmark and the United Kingdom. Moreover, the government should take a long-term approach to monitoring and assessing the development of proof-of-concept programmes within higher education – a luxury that the private sector (particularly SMEs) cannot afford.

R5.3 **Reinforce incentives for academics to engage in innovation.** Policy makers and universities need to improve incentives for academics to pursue innovation activities, and address relevant barriers. Establishing clear performance evaluations that take into account knowledge transfer and collaboration at the institutional and researcher levels will be important in this regard. This entails raising entrepreneurial awareness and knowledge among students and faculty, encouraging academic staff to support students who approach them with ideas, or indeed to develop and pursue their own ideas. Academics should be encouraged to avail themselves of industry secondments. At the same time, the government and the higher education system should address financial incentives (such as equity participation and licensing revenues) or barriers to university-based start-ups.

R5.4 **Support multidisciplinary and entrepreneurship training across the entire education system to promote entrepreneurialism, as well as spin-offs and spin-ons.** Training efforts should also be inclusive and involve groups throughout society. The government should encourage under-represented groups, such as women and migrants, to engage in innovation activities, from participating in academic spin-offs to contributing to knowledge transfer and collaboration. Academic "spin-ons", which connect researchers with entrepreneurs, can be an effective way to exploit complementary skills to drive innovation, rather than attempting to transform all researchers into savvy entrepreneurs.

R5.5 **Enhance accountability and develop a framework for performance metrics.** The government should promote the creation of a core set of knowledge-transfer metrics and consistent reporting mechanisms, conducted on an annual basis. This requires strengthening measurement at the institutional level, by establishing reporting cultures and related processes, as well as collecting more holistic metrics, including qualitative measures (e.g. pathways and examples) and new approaches to evaluate the impact of knowledge transfer.

R5.6 **Increase opportunities for open innovation and co-creation.** German SMEs could benefit from further open innovation and co-creation initiatives. These include joint innovation labs (and joint/shared infrastructure and equipment); digital innovation hubs; open innovation platforms; open fab-labs; and testing/demonstration platforms, living labs and hackathons. Co-creation and innovation labs can take the form of digital platforms and virtual laboratories allowing research and data sharing, as well as the co-design and co-creation of solutions, and their piloting and testing. This pooling of diverse competencies would significantly reduce infrastructure and research costs, and accelerate development.

Relevant global experience

International experience has shown there exist multiple ways to facilitate knowledge transfer between science and research on the one hand, and industry and entrepreneurs on the other. While these approaches are varied, they feature a number of recurrent themes, which are outlined below.

Improving networks and mobility between STI actors is important to promote effective collaboration. This can be done by better balancing demand-oriented research with curiosity- (or supply-) driven research at public research institutions (PRI). Formal consultation mechanisms between universities and industry/SME stakeholders and universities' involvement in regional/national innovation/competitiveness agendas can help define research priorities and agendas. So can facilitating researcher mobility across sectors (i.e. academia, industry and government) and towards SMEs through collaborative projects, industry secondments and sabbaticals, and recognising researchers' efforts in career and research evaluations. Moving back and forth between industry and academia through industry secondments, joint R&D projects and sabbaticals must become easier and more attractive for researchers.

A practical example is the "Knowledge Transfer Partnership Programme" from the United Kingdom. Knowledge transfer partnerships enable businesses to tap into academic expertise by bringing them together with a suitable partner university. In this manner, the business can access knowledge, technology or skills within the university to resolve a strategically important business or technical issue, while academics can test apply and translate their research into industry. Typically, a suitably qualified graduate or postgraduate student is employed to conduct the strategic project under the guidance of funded by the government; businesses make a financial contribution that is matched by an Innovate UK grant. The company receives a full-time staff member of staff (a knowledge transfer partnership associate) and the ongoing support of two academics with relevant expertise to guide progress. The knowledge transfer partnership associate remains employed by the university, but is wholly or partly based at the firm (working under its terms and conditions) to ensure that new knowledge and innovation are embedded in the company.

Easing the interfaces between business and research actors can facilitate transfer and collaboration. It is important to develop user-friendly interfaces, improve the research community's communication with SMEs, and enhance the visibility of research competence and outputs (e.g. through digital platforms). Likewise, helping intermediation structures (i.e. universities) adapt to a broader innovation engagement, and matching suitable partners, should further exploit knowledge transfer opportunities (e.g. clusters/regional platforms, regional innovation and cities/government). Examples include Interface, the knowledge connection hub from the University of Edinburgh, and the strategic network of the University of Barcelona, where strategic network units (i.e. cluster-focused knowledge transfer units) drive connectivity through mobility linkages, matching partners, and linking with innovation networks or clusters, and government (i.e. regional governments, cities, living labs, open innovation platforms and hackathons).

In the context of transitional challenges, it is particularly important to promote multidisciplinary and cross-sectoral collaboration. In Germany, as in other OECD countries, there exists a need to facilitate more interdisciplinary and multidisciplinary collaboration in knowledge transfer and, more broadly, research. If current operating models for knowledge and technology transfer do not facilitate multidisciplinary collaboration, then barriers must be addressed, encouraging increased participation by actors from new sectors and regions. Practical examples from industry show that inter-sectoral linkages provide complementarity gains – especially when addressing complex challenges – enhance the cross-fertilisation of ideas (e.g. Montresor and Quatraro (2017[2])).

The number of cross-sectoral innovation platforms and programmes has been increasing in OECD countries. In the United Kingdom, the Cross-Sector Battery Systems Innovation Network is a collaborative community of technology developers and end-users from multiple sectors. The Cross-Sector Innovation Programme in Defence, for its part, supports the alignment and exploitation of knowledge between the defence and other sectors to expand the UK defence supply chain by generating "exploitation pathways". Using an open innovation platform, the programme aim to create opportunities for the co-development and co-application of new technologies to address future export performance in the sector. At the European level, the GreenOffshoreTech (Horizon 2020) programme aims to support innovation in SMEs and the development of "blue economy" industries by promoting cross-sectoral and cross-border value chains addressing common challenges through new technologies. Cross-border collaboration between clusters, firms and cities are also flourishing, to address common innovation issues.

Policy makers must improve incentives for academic spin-offs. In addition to raising awareness of entrepreneurial opportunities among academic staff, higher education institutions (HEIs) and public research institutions should promote more flexible career paths for their researchers and academics. Academics often require greater incentives to become involved in knowledge transfer, particularly where it is not their institution's mission or mandate. Clearly defining and highlighting knowledge transfer activities in the evaluation framework for scientists, researchers, teachers and their institutions may create more incentives to participate in such activities.

A strong network of intermediation infrastructures underpins knowledge transfer. Firms and research-performing organisations often rely upon intermediaries, in the form of knowledge transfer offices, to facilitate funding and information for knowledge transfer activities. These knowledge transfer offices and other intermediaries often face a range of challenges in attracting, retaining and training knowledge transfer professionals. Improving the attractiveness of such institutions for professionals, including through better training and accreditation programmes, could underpin more effective co-ordination between different actors in the knowledge transfer system.

As discussed in Chapter 7, it is necessary to improve pre-seed and intermediate stage funding to support technology transfer. Many of the projects involved in knowledge transfer are often pre-commercial. Therefore, better alignment between private and public funding and the goals of knowledge transfer programmes could accelerate and increase the commercialisation of high-potential research into products.

Encouraging open innovation and co-creation is particularly important for innovation in the context of the sustainability and digital transitions. Several programmes in OECD countries have increasingly focused on an open and co-creative approach to knowledge creation. These include the Catapult Centres in the United Kingdom (e.g. the "digital and high value manufacturing" and "advanced assembly" Catapult Centres, which focus strongly on technology transfer by SMEs) and the Italian (Emilia-Romagna region) Open platform for advanced technological services in the machine-tool manufacturing sector.

13.1. An introduction to knowledge transfer in Germany

13.1.1. Overview

While knowledge transfer is a broad concept, the goal is generally singular: ensure that the STI system facilitates the transformation of promising research into meaningful socio-economic innovations. In achieving this, German policy programmes and interventions must address a number of interrelated questions, such as: how can more firms be encouraged or enabled to participate in knowledge transfer? How can policy makers best support the commercialisation of public research, increase the contribution of HEIs to knowledge transfer and measure the influence of knowledge transfer on innovation (Box 13.1)?

Box 13.1 Measuring knowledge transfer

Measuring the effectiveness and performance of knowledge transfer, like other areas of the STI system, is complicated. While this section of the review primarily maps the current channels of knowledge transfer in Germany, some indicators of its performance – for example, in collaborative research output – can be found in Chapter 4.

When measuring the impact of knowledge transfer, researchers tend to use a combination of the following metrics:

- survey data and case studies
- patent data
- publications data
- labour force and university graduate survey data.

Each of these approaches has advantages and disadvantages. A full discussion of these strengths and weaknesses can be found in earlier OECD work, such as the 2019 OECD STI report on knowledge transfer from universities to industry, *University-Industry Collaboration: New Evidence and Policy Options* (OECD, 2019[3]).

Source: OECD (2019[4]), *University-Industry Collaboration: New Evidence and Policy Options*, https://doi.org/10.1787/e9c1e648-en.

German policy makers have created policy programmes and initiatives to facilitate knowledge transfer. As of 2022, Germany had 60 ongoing publicly funded policy initiatives, equivalent to 26% of all German STI policy initiatives listed in the EU-OECD STIP Compass database (OECD, 2022[5]). As in other areas of the STI policy mix, Germany's knowledge transfer policy programmes are well-resourced. Of the 60 initiatives mentioned above, 7 have a budget of EUR 50-100 million (euros), 4 have a budget of EUR 20-50 million, and nearly half of the programmes (28) have budgets of EUR 1-20 million (OECD, 2022[5]). By way of international comparison, France, the second most industrialised country in the European Union, has 27 initiatives, of which 1 has a budget of EUR 100-500 million (the 2005 French cluster initiative), 6 have budgets of EUR 50-100 million, 2 of EUR 20-50 million, and 4 of EUR 1-20 million.

The most recurrent instruments in the German policy mix for knowledge transfer are project grants for public research and grants to the private sector for business R&D; networking and collaborative platforms for knowledge transfer are the third most frequently used instrument. Many of the instruments outlined above are administered through Germany’s mature and well-developed institutional framework for knowledge transfer, whose main contours are outlined below.

13.1.2. The institutional framework for knowledge transfer in Germany

Germany has a well-developed and large network of research organisations, which often work in collaboration with industry associations to support research and knowledge transfer to industry through several channels (Box 13.2). Five main groups of actors and institutions are involved in knowledge transfer, whose key characteristics are given below.

Universities of technology (TUs)

Germany numbers around 20 technical universities (*Technische Universitäten*). These institutions differ from general universities primarily through their role in knowledge transfer. They operate large engineering faculties, which generally focus on applied research. By training engineers who generally move into industry after graduation, these institutions typically have close links with the private sector. In addition, a professorship in a TU generally requires industrial experience, which implies experience in private-sector R&D. These faculties are often financed by industry R&D contracts, including joint supervision of academic theses by industry and faculty. Lastly, TU professors are often involved in a particular type of academic entrepreneurship called ”An-Institute”, which perform R&D contracts independently from the faculty.

Universities of applied sciences

Universities of applied sciences (*Fachhochschulen*) have been a feature of the German knowledge transfer system since the 1960s, when they were created through the upgrading of existing secondary schools focusing on engineering or industrial domains (*Ingenieurschulen, Fachschulen*). After reunification, a large number of universities of applied sciences were established in the former East Germany. Their main mission is to equip the business sector and other public or private instructions with sector-specific skills. The majority focus on engineering, information technology and management skills, with their graduates subsequently employed in a range of firm departments, including R&D. The federal funding arrangement for universities of applied sciences is designed to develop applied science, knowledge and technology transfer, and promote student education.

In line with the Framework Act for Higher Education, which defined “knowledge and technology transfer” as a third task for HEIs in 1998, both TUs and universities of applied sciences have an explicit commitment to this mission. In fact, most universities of applied sciences operate separate institutes or companies (e.g. institutes for applied research) dedicated to knowledge transfer activities.

Fraunhofer-Gesellschaft

The Fraunhofer Society is explicitly dedicated to technology transfer and is the most important public research institutions (PRI) in the German knowledge transfer system. It is also Europe's largest and most successful organisation for applied research and technology transfer. Like the Max-Planck-Gesellschaft and Helmholtz-Gemeinschaft, Fraunhofer enable companies to outsource expensive fundamental research, reducing the financial risk associated with the development of new products and decreasing R&D costs. Chapter 4 discusses these institutions’ governance and funding.

Fraunhofer-Gesellschaft comprises more than 80 research units (institutes), each specialising in a specific technology field. It has grown significantly over time, with around 19 200 people in full-time employment in 2019, compared to 7 300 in 2000. Around one-third of its annual budget of EUR 2.8 billion comes from institutional funding (90% from the Federal Government and 10% from the *Länder*), one-third from contracted research for industry, and the remaining from other funding programmes such as *Zentralen Innovationsprogramms Mittelstand* (ZIM) or EU-level initiatives.

Like the Leibniz-Gemeinschaft discussed in Chapter 4, Fraunhofer primarily serves SMEs (65% of its private-sector clients), giving these firms access to top-quality research (Fraunhofer-Gesellschaft, 2021[6]). Over 2015-18, 77% of Fraunhofer's industry partners in publicly funded projects were SMEs, another 11% were medium-sized businesses with 500-5 000 employees, and only 3% were large firms with over 5 000 employees (Frietsch et al., 2022[7]). Collaboration between Fraunhofer institutes and industry – and SMEs in particular – is supported by public R&D programmes. In most federal technology programmes that finance co-operative R&D projects (V*erbundforschung*), Fraunhofer institutes (together with TUs) are the most frequent scientific partners.

Industrial co-operative research institutes

Although co-operative research institutes are not formally part of the science system, they play an important role in the knowledge transfer system. These institutions conduct science-based applied research (similarly to PROs) and are represented by two umbrella organisations.

The first is the German Federation of Industrial Research Associations (AiF), which was founded in 1954 as an industry initiative to promote branch-specific R&D supporting innovation activities by SMEs. Today, the AiF numbers 100 member organisations, each focusing on a branch or area of application (often outside the high-tech industries, e.g. on certain materials). Some have their own research institutes, while others act as umbrellas to co-ordinate R&D projects within their area of expertise. The R&D activities of AiF member organisations are mainly financed through the Industrial Collective Research (IGF) federal programme. In 2020, IGF provided EUR 201 million to R&D projects (AiF, 2021[8]).

The second umbrella organisation is the Deutsche Industrieforschungsgemeinschaft Konrad Zuse (Zuse Association [ZA]). A relatively recent addition to the knowledge transfer system in Germany, ZA was founded in 2015 by private-sector, non-profit research institutes specialised in sector-specific industrial R&D. ZA focuses on contract R&D for SMEs and pursues a nationwide approach, although many of its founding members are regionally concentrated in eastern Germany, like most institutes emerging from the R&D units of publicly owned enterprises and branch research organisations of the former German Democratic Republic. While the AiF focuses on managing (through the IGF programme) its member organisations' R&D projects, ZA is more policy-oriented, promoting its members' common interests in policy circles. The founding institutes of ZA have been supported by special R&D programmes of the Federal Government since 1990, to maintain a knowledge infrastructure in eastern Germany supporting innovation in SMEs. The "INNO-KOM" funding programme (see Chapter 5 for further details) is still running and was extended beyond east Germany in 2017 to support non-profit industrial R&D institutes in western German regions with structural problems (as defined by the *Gemeinschaftsaufgabe Verbesserung der regionalen Wirtschaftsstruktur* [Joint Task Improvement of the Regional Economic Structure]). The programme provides about EUR 75 million per year for R&D projects and R&D-related investments. Knowledge transfer takes place through contract R&D for SMEs and other firms, based on the knowledge and technologies obtained through the publicly funded projects.

Intermediary organisations.

The above organisations and institutions are complemented by private independent service providers (e.g. Ascenion GmbH, Atrineo AG PROvendis GmbH and TransMit) and industry associations). These organisations assist SMEs and industries in linking with research partners, as well as with other needs related to technology transfer. A large network of technology transfer offices located within universities assist researchers with the process of patenting, contracting and commercialising technology. Knowledge transfer offices were created at German universities during the 1980s and 1990s when the discussions on knowledge transfer intensified. Since the reform of patent-based technology transfer at HEIs in the early 2000s (abolishing the so-called "professors' privilege"), an increasing number of organisations and infrastructures has evolved to facilitate the transfer of technology and research findings between public research and firms. However, substantial challenges across the broader university system remain (i.e. providing incentives for researchers and management of technology transfer offices, and sustainability), and most transfer activities still originate from individual chairs and institutes rather than faculties or chancelleries. In addition to dedicated knowledge transfer service providers, two important knowledge transfer associations exist in Germany: Transfer Allianz and Forschungs- und Transfermanagement e.V. (FORTRAMA).

13.1.3. Knowledge transfer channels used by German firms

Universities and PROs play a key role in national innovation ecosystems as sources of scientific knowledge and new breakthrough technologies that can be transferred to industry to support innovation. Knowledge and technology transfer can take many forms; among the most frequent approaches are researcher mobility and training, collaborative R&D, contract R&D and patent licensing. Knowledge transfer can also take informal forms, such as accessing scientific and technical publications or industry meetings and exhibitions (Box 13.2).

Germany also has a strong presence of researchers (PhDs) employed in the business sector. According to data from OECD STI Scoreboard 2021, about 62% of total researchers were employed in private companies in 2019, compared to the OECD average of 50% (OECD, 2022[9]) This intensity is similar to that reported by France, Austria and Denmark, while countries such as Sweden, Japan and Korea display rates superior to 70%.

Box 13.2. Channels of knowledge transfer

Channels for science-industry knowledge transfer can be both formal and informal. Formal channels include the following:

1. **Collaborative research** refers to research projects carried out jointly by public researchers and private firms, which can be fully or partly funded by industry, and can range from small-scale projects to strategic partnerships with multiple stakeholders (i.e. public-private partnerships).
2. **Contract research** is research that a private firm commissions universities or public research institutions to perform, generally involving the creation of new knowledge in line with the specifications or goals of the client, and frequently more applied than collaborative research.
3. **Academic consultancy** denotes research and advisory services provided by public researchers to industry clients.
4. **Intellectual property transactions** cover the licensing and selling of intellectual property generated by universities and public research institutions to industry.
5. **Research mobility** refers to both university researchers working in industry and the converse, including temporary assignments.
6. **Academic spin-offs** denotes the entrepreneurial route to commercialising knowledge developed by public research.
7. **Labour mobility** refers to university graduates that join industry.

Informal channels of science-industry knowledge transfer include the following:

1. Public research is published in scientific journals and other specialised media.
2. Public researchers and industry actors interact and network at formal conferences or dissemination events, but also in more informal settings (e.g. at meetings of former classmates employed in public research and industry sectors).
3. Networking facilitated by geographic proximity denotes informal interactions between public research staff and industry researchers, which might be facilitated by locating science parks near university campuses or firms' laboratories within university campuses.
4. Industry and public research share facilities (e.g. laboratories and equipment).
5. Universities provide courses and continuing education to enterprises, and industry employees give lectures at universities.

The advantages of assessing channels 1-8 is that they are traceable, as these interactions produce outputs (e.g. contract agreements, patents, human resources) that demonstrate the presence and extent of collaboration. By contrast, informal linkages are much more difficult to measure, although their importance is significant.

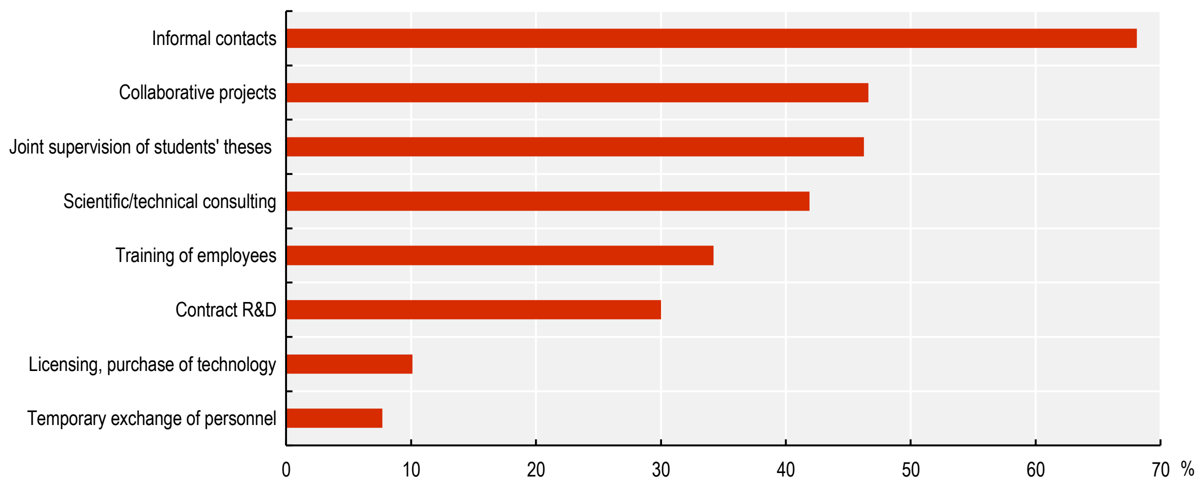
Source: OECD (2019[4]), *University-Industry Collaboration: New Evidence and Policy Options*, https://doi.org/10.1787/e9c1e648-en.

The Mannheim Innovation Survey, which interviews a representative sample of firms, indicates that 68% of all collaborating firms globally rely on informal exchanges for knowledge. A substantial share (47%) also engage in collaborative projects; the most frequent forms of collaboration with research institutions are joint supervision of students' MA and PhD theses (46%), followed by scientific and technical consulting (42%) (Figure 13.1, Figure 13.2). As in other countries, the most widespread form of collaboration with public research institutions are informal contacts; licensing or purchasing of technology derived from science (10%) and temporary exchange of personnel (8%) are infrequent.

In terms of their effectiveness in providing access to science organisations' knowledge, collaborating firms consider rate contract R&D as highly effective, followed by collaborative projects, scientific and technical consulting, and employee training (Figure 13.1 and Figure 13.2). The few firms that use licensing or purchasing of technology from science and temporary exchange of personnel do not consider these types of collaboration very effective in this regard.

Figure 13.1. Types of collaboration with science (2015-17)

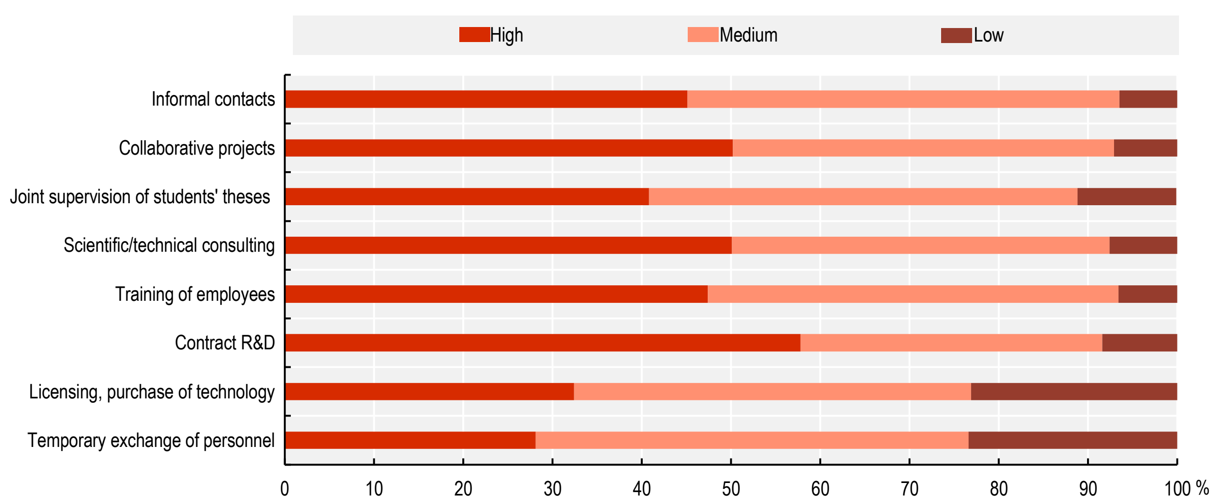
Share in all firms collaborating with HEIs/PROs (%)



Source: OECD calculations based on ZEW (2021[10]); Mannheim Innovation Panel

Figure 13.2. Importance of different types of science collaboration for accessing the knowledge of science organisations (2015-2017)

Share in all firms using the type of collaboration (%)

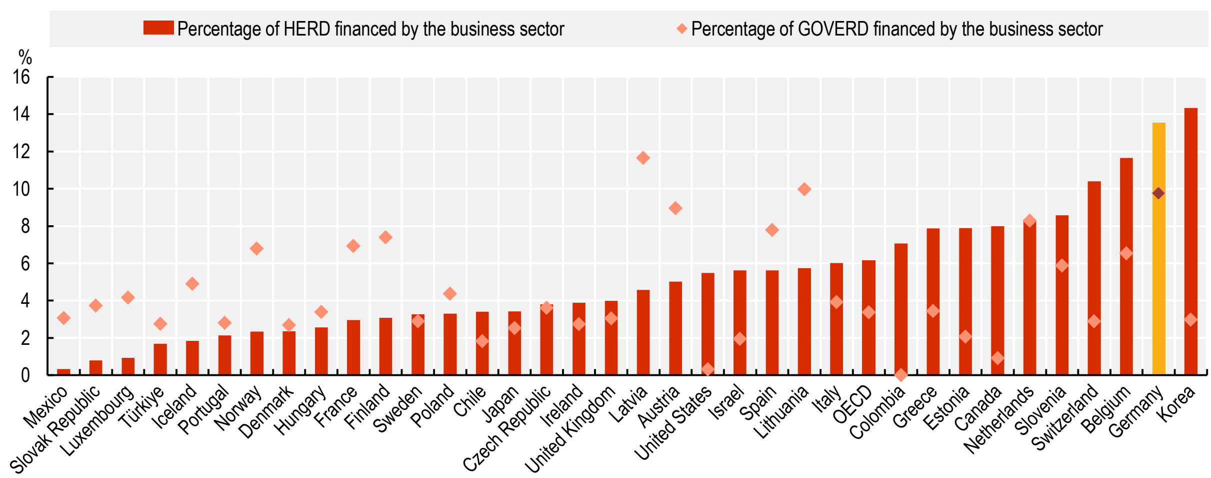


Source: OECD calculations based on ZEW (2021[10]); Mannheim Innovation Panel

13.1.4. Research contracting and collaboration

Germany ranks high in terms of private-sector funding of R&D performed at HEIs and PROs. At HEIs, 13.5% of R&D is funded by the private sector (one of the highest figures registered in the OECD region), and in government research institutions 10% of R&D is financed by the private sector (Figure 13.3). In addition to HEIs, many PROs, such as the Steinbeis Centres and the An-Institutes, have strong financial links with industry through contracted and collaborative R&D. At TUs, faculty positions are traditionally financed in large part by industry R&D contracts, including joint supervision of theses by faculty and enterprises.

Figure 13.3. Industry funding of R&D in HEIs and government institutions (2019)



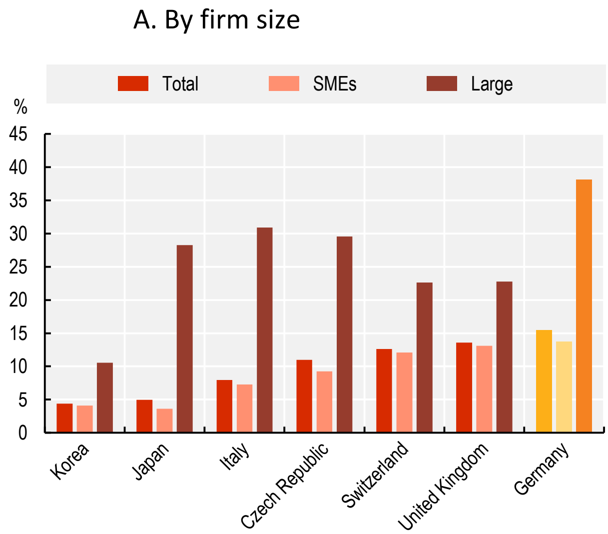
Source: OECD (2022[11]), "Main Science and Technology Indicators", OECD Science, Technology and R&D Statistics (database), https://doi.org/10.1787/data-00182-en (accessed on 22 May 2022).

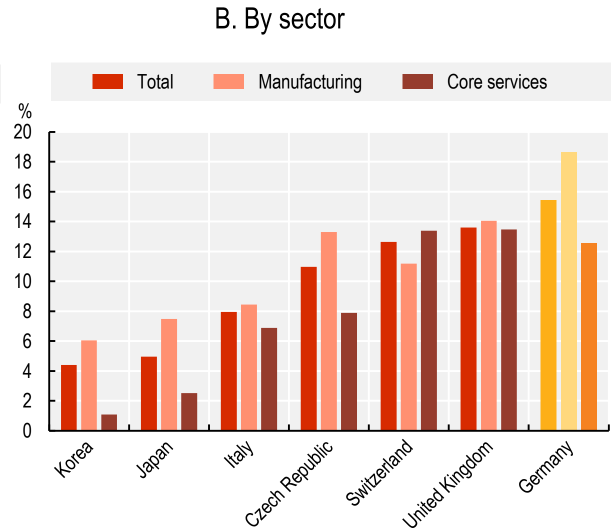
The high levels of co-operation do not, however, mean that all firms – particularly smaller ones–engage in knowledge transfer activities. According to the 2021 Mannheim Innovation Survey, the propensity of German firms to collaborate with research institutions stands at about the OECD average: 7.2% of all surveyed firms reported undertaking some type of collaborative R&D or other innovative activities with either HEIs or PROs between 2016 and 2018 (ZEW, 2021[10]). About 38% of innovating large firms conduct collaborative research with HEIs or PROs, compared to only 17.5% of innovating SMEs (Figure 13.4).

Moreover, manufacturing firms in Germany engage more frequently in collaborative R&D with HEIs and PROs compared to service firms; there is less of a sectoral bias for firms in the United States and France. In contrast, start-ups appear to have closer linkages with PROs than other firms. According to one survey (PWC/Bundesverband Deutsche Startups/net Start, 2021[12]), nearly 80% of all start-ups report good or very good access to universities, and 55.4% co-operate actively with universities or PROs.

Figure 13.4. Firms co-operating on innovation activities with universities or other higher education institutions

As a percentage of innovation-active firms within each group

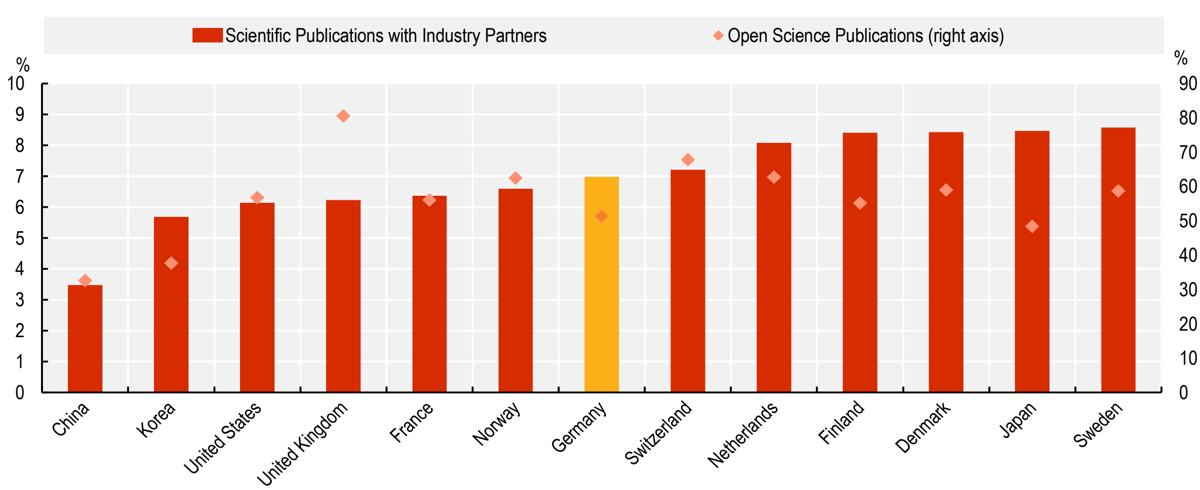




Source: OECD, based on the Business Innovation Statistics and the Eurostat's Community Innovation Survey (CIS-2018), https://www.oecd.org/sti/inno-stats.htm, April 2022

Regarding research collaborations as indicated by co-publication activity with private-sector partners, Germany's three-year average percentage of co-publications increased from 6.6% in 2006-09 to 6.97% during 2015-18. Countries such as Denmark, Finland, Japan and Sweden reported slightly higher shares of publications co-authored by universities and industry partners (Figure 13.5). The low numbers indicate the generally low propensity of universities to engage in joint research with the private sector, which is a global phenomenon.

Figure 13.5. Co-publication with private-sector entities by HEIs and open-science publications



Note: The ranking includes 1176 universities worldwide. These universities have been selected based on their number of Web of Science indexed

Source: CWTS Leiden Ranking (2020[13])

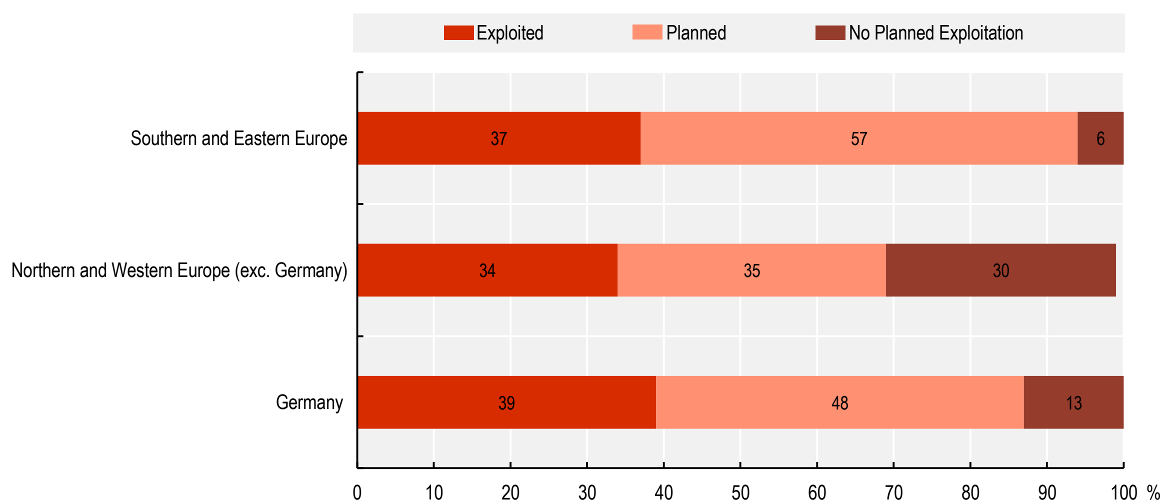
13.1.5. Licensing and patenting: Opportunities for partnerships

According to a recent survey by the European Patent Office (EPO) of a sample of patents from PROs, German public institutions exploit about 39% of their inventions within two years of registering a patent with the EPO, a figure slightly higher than the average reported by other western European countries (Figure 13.6) (European Patent Office, 2020[14]). As in other countries, licensing is by far the most preferred commercialisation channel in Germany (84% of interviewees), followed by patent sales (26%); only 7% of German interviewees planned exploiting patents to engage in R&D co-operation, compared to 23% in other western EU countries.

However, the rate of unexploited patents remains substantial. For about half (48%) of the total inventions considered for patent protection in the surveyed period, commercialisation is planned but not yet achieved; 13% have no exploitation plan at all. The need to increase the commercialisation of research, such as through patent licensing, is one focus of the "idea to market" approach of the Federal Ministry for Economic Affairs and Climate Action (BMWK) (see Chapter 5 for a comprehensive review).

Figure 13.6. Stage of Exploitation of Patented Inventions by Geographical Region

% of patents per status according to interviews with PROs and universities in 2019



Note: Number of interviews (unweighted) N=633; of which 1% do not know or gave no statement.
Source: European Patent Office (2020[14]), Valorisation of scientific results Patent commercialisation scoreboard: European universities and public research organisations, https://documents.epo.org/projects/babylon/eponet.nsf/0/f90b78b96b1043b5c1258626006cce35/$FILE/Valorisation_of_scientific_results_en.pdf.

Patenting activity at PROs has slowed in recent years, which carries a risk that technology transfer through patent licensing will concomitantly decrease in the short and medium term. Data for the four largest PROs and HEIs showed a clear shift from patenting towards more publications between 2005 and 2018. This trend stems from the expansion of R&D resources in the public science sector in Germany since 2006, which occurred in the context of strengthening research excellence and therefore strongly focused on increasing research quality and output, rather than increasing knowledge transfer and application-oriented development of new technology.

13.1.6. Academic spin-offs and science-based start-ups

Despite an increased emphasis on academic entrepreneurship, the number of academic spin-offs (Box 13.3) remains relatively low. A 2021 study found that intellectual property-based spin-offs from German PROs grew by 7.3% annually between 2011-19, with Fraunhofer showing a higher rate (12.7%) (Fraunhofer/ZEW, 2021[15]). As with other areas of the German STI system, academic entrepreneurship is highly concentrated in few cities and regions, with Berlin, Karlsruhe and Munich making the biggest contributions (Fraunhofer/ZEW, 2021[15]).

The growth in German academic spin-offs is broadly similar to growth at elite universities and PROs in other EU countries and the United States. German PROs produced 58 spin-offs in 2019, compared to 102 for the University of California and 95 for the French National Centre for Scientific Research (CNRS) (Fraunhofer/ZEW, 2021[15]). At the institutional level, most German PRO spin-offs originate from Fraunhofer and Helmholtz; in 2017-19, researchers from these two institutions formed 81 (Fraunhofer) and 61 (Helmholtz) intellectual property (IP)-based spin-offs, compared to 287 from the University of California, 273 from the CNRS, 117 from the University of Texas and 86 from MIT (Fraunhofer/ZEW, 2021[15]). The expansion of academic spin-offs in Germany is supported by a range of policy programmes, the largest of which is *Existenzgründungen aus der Wissenschaft* (EXIST). Chapter 5 provides more details on these programmes.

Box 13.3. Overview of academic spin-offs

Academic spin-offs can take a number of forms. The following is an overview of the most common forms of spin-offs and the avenues for their creation, based on a 2021 report by ZEW and Fraunhofer (Fraunhofer/ZEW, 2021[15]).

Forms of academic spin-offs

1. **Spin-offs based on IP.** The main purpose of these spin-is to commercialise IP generated at the PRI, based on an IP contract between the PRO and the spin-off. PROs may take a share in the company, or sell (or license) the IP to the company. These spin-offs can be entirely owned by the PRO or joint ventures.
2. **Spin-offs based on research.** These are start-ups by researchers from PROs aiming to commercialise R&D. This type of spin-off does not involve an IP contract between the spin-off and the institution.
3. **Spin-offs based on expertise.** These are spin-offs where researchers commercialise their capabilities and competencies. They do not necessarily follow from a particular project or piece of research, but rather stem from the cumulative experience of their founders.
4. **Student or graduate start-ups**. These are start-ups founded by students or graduates not employed at their university. They can occur in any sector, but are more common in services. Such start-ups rarely emerge directly from research activities, but nevertheless utilise the knowledge and skills obtained from experience within research or academic institutions.
5. **Funded start-up projects.** Researchers or graduates fundraise for these start-ups from PRIs or government programmes, often complemented by their own private contributions. EXIST (see Chapter 5) is an example of a programme that facilitates this type of spin-off.
6. **Alternative forms.** Spin-offs may take many other forms. For example, researchers may launch a start-up that is not explicitly linked to a particular piece of research, but

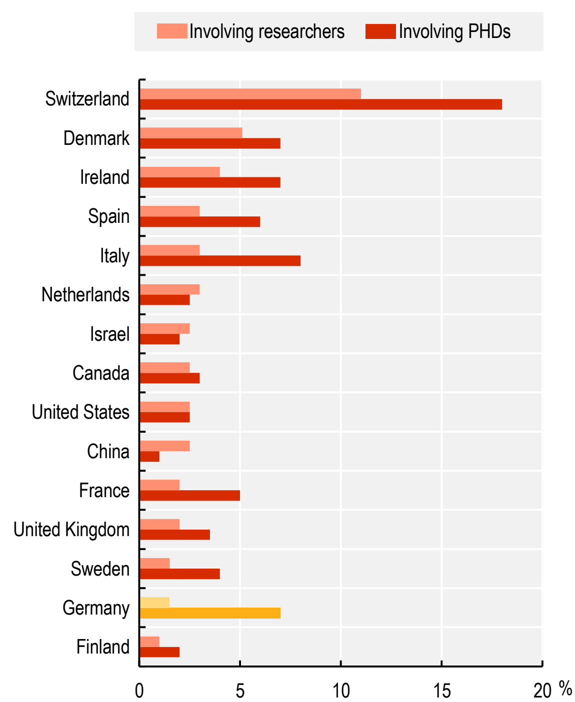
nevertheless indirectly facilitates the transfer of knowledge through their experience and competencies.

Source: Fraunhofer/ZEW (2021[15]), *Spin-Offs from Public Research Organisations in Germany: A Comprehensive Analysis based on Bibliometric, Patent, Website and Company Register Data*, https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cci/2021/Report_Allianz-Studie_final.pdf.

According to an OECD study based on Crunchbase data, German start-ups featured on Crunchbase involving researchers comprised 1.5% of all start-ups that received VC investment (Figure 13.7) whereas the share of VC firms involving PhDs is 7% (Breschi, Lassébie and Menon, 2018[16]). Evidence also shows that the rate of new firm creation in R&D intensive sectors in Germany is lower than in other European countries, including for knowledge-intensive services (KIS) – a measure that can be used as a proxy for academic business creation (Figure 13.8). Ongoing work by the OECD has shown that government VC funds are significantly more likely to target new technology-based firms that have close ties to academic research, and that such academic-linked firms are more likely to produce radical innovations.

Figure 13.7. Share of academic start-ups in Crunchbase, by country and type (2018)

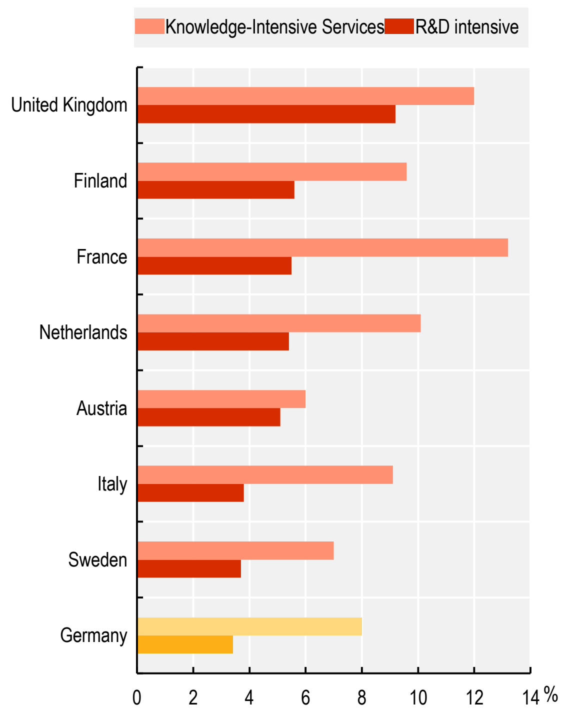
% in VC-backed companies



Note: The sample is limited to companies created after 2001 and having received at least one VC investment.
Source: Breschi, Lassébie and Menon (2018[16]), "A portrait of innovative start-ups across countries", https://doi.org/10.1787/f9ff02f4-en, for OECD, based on Crunchbase.

Figure 13.8. Rate of new firm creation in R&D intensive sectors (2017)

% in all companies



Source: From Kulicke (2021[17]) based on Business Demography Statistics (Eurostat) and Mannheimer Unternehmenspanel. ZEW calculations in Bersch and Gottschalk (2019[18]) and EFI (2020[19]).

Moreover, a low rate of spin-off creation is also reported in PRIs, although important efforts have been deployed to enhance spin-off creation and support innovative start-ups through accelerator programmes (Lambertus, Schmalenberg and Mathias, 2019[20]). Fraunhofer and Helmholtz Centres have established spin-offs support programmes (e.g. Fraunhofer Venture) which have proved very effective in enhancing the technology transfer rate, and improving firm survival and funding. Such programmes are similar to the Start-up Unit of the French Alternative Energies and Atomic Energy Commission; Eurecat's Valorisation Area (Spain); Tecnalia Ventures (Spain); the Technology Transfer team at the TNO (Netherlands); and VVT Ventures (Finland). FDays® have become the flagship programme of Fraunhofer Venture and one of the most prominent high-tech accelerators in Germany (Box 13.4). A total of 55 such new companies were created at the 4 largest PRIs in 2016, followed by 51 in 2017, 64 in 2018, 58 in 2019 and 56 in 2020, with most emerging from the Fraunhofer Society, Max Planck and the Helmholtz Centres (GWK, 2021[21]). Since 2013, Leibniz, Helmholtz, Fraunhofer and Max Planck have teamed up every year to offer Start-Up Days, two-day workshops facilitating networking between budding entrepreneurs and industry professionals. To date, Fraunhofer has spawned more than 350 companies involving more than 150 shareholdings, while Max Planck Innovation has supported 160 spin-offs.

Box 13.4. Innovative start-up support at PRIs: Fraunhofer Venture

Fraunhofer Venture was created as a dedicated department in 2001 with the purpose of providing comprehensive support for Fraunhofer spin-off projects. Today, the aim of Fraunhofer Venture is to activate and maximise the transfer potential of the Fraunhofer-Gesellschaft by actively connecting IP and technologies, entrepreneurs, investors and industry partners. The Fraunhofer spin-off support system has been helping de-risk spin-off projects internally before spinning them off. It does so with a team of 25 people comprising venture managers, lawyers and company-building experts. The spin-off support system consists of four phases (Business Ideation, FDays®, FFE and FFM) and three key components: programmes, coaching and funding. The deliberate interplay of these three components paves the way for technology transfer via spin-offs on a larger scale.

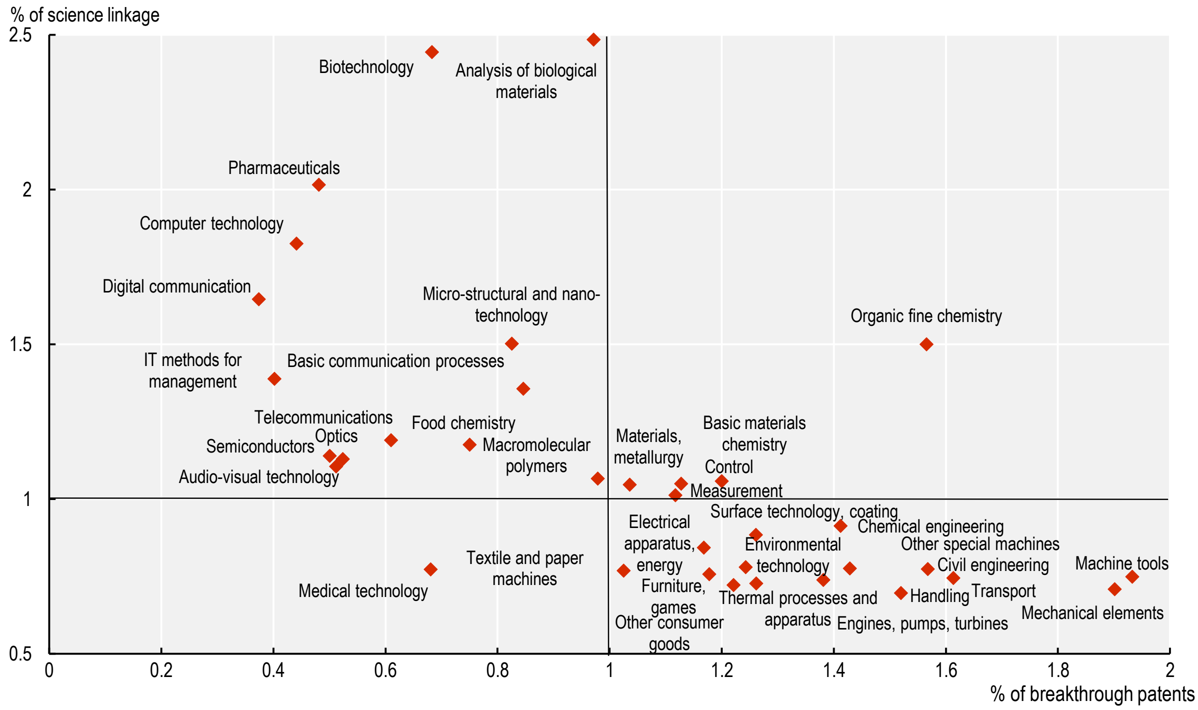
FDays® have become the flagship programme of Fraunhofer Venture and one of the most prominent high-tech accelerators in Germany. Two factors probably lead to these results: first, Fraunhofer Venture serves as the central hub of spin-off expertise and can support projects going through the funnel. Second, the strong ties between Fraunhofer institutes and industry lead to the generation of high-quality business ideas, since technology development projects are often rooted in real market insights. To date, Fraunhofer has spawned more than 350 companies, involving more than 150 shareholdings.

Source: Lambertus, Schmalenberg and Mathias (2019[15]), Case study on programmes to promote spinoffs at Fraunhofer-Gesellschaft, Germany. Contribution to the OECD TIP Knowledge Transfer and Policies Project, https://stip.oecd.org/assets/TKKT/CaseStudies/16.pdf

13.2. The use of science in fostering breakthrough inventions

Science has been at the origin of many technological breakthroughs in history. The use of scientific knowledge for innovation has increased over time due to growing complexity in technological innovation, although its importance differs across economic sectors and technology areas (Narin, Hamilton and Olivastro, 1997[22]). However, an analysis of patent indicators suggests that breakthrough developments by German inventors are only weakly related to science, as measured by their references to research papers. Science linkage refers to the number of references patents makes to non-patent literature such as peer-reviewed scientific papers, conference proceedings or databases relative to the maximum number of references to non-patent literature by other patents in a given field and year. For example, patents that are normalised relative to the average display a lower-than-average science linkage (Figure 13.9). In other words, fields with more intense breakthrough invention display lower-than-average science content (bottom-right square), whereas fields known for science intensity, where the science linkage is higher (top-left square), show a lower-than-average propensity to generate breakthrough inventions compared to the average propensity across fields. Chapter 11 discusses breakthrough innovation in more detail.

Figure 13.9. Breakthrough patenting by Technology Field (WIPO 35 classes) (2012-15)



Note: Breakthrough inventions refer to the top 1% of the most cited patents (field-year distribution) within the first five years after publication (Squicciarini, Dernis and Criscuolo, 2013[23]); the indicator on the y-axis refers to the average intensity of citations to non patent literature (scientific publications) relative to the average in the same field-year of filing; the indicator on the horizontal axis displays the relative specialization (Revealed Technological Advantage) in breakthrough patenting (i.e., the share of breakthrough patents in country total relative to the average share in the world).
Source: Own calculations based on patent data from the OECD Patent Quality Indicators Database based on Squicciarni, Dernis and Criscuolo (2013[23]); "Measuring Patent Quality: Indicators of Technological and Economic Value", OECD Publishing, Paris, https://doi.org/10.1787/5k4522wkw1r8-en

13.3. Constraining factors for knowledge and technology transfer

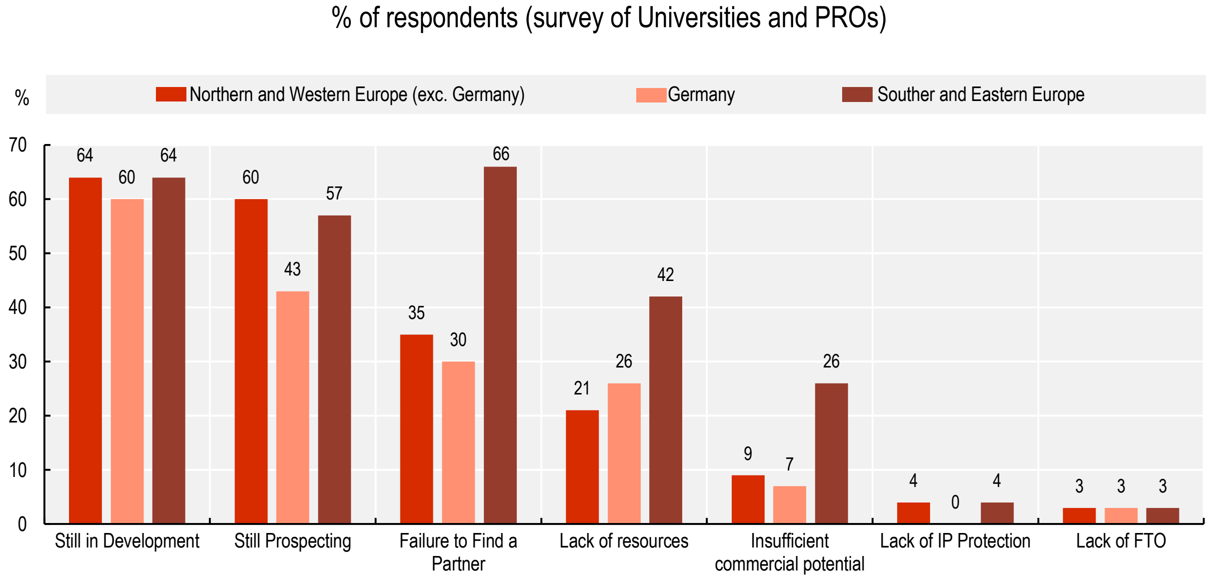
Several barriers hinder knowledge and technology transfer through patenting, licensing, academic spin-offs or informal channels. These exist both on the side of firms, and researchers and their institutions.

13.3.1. Constraints faced by firms

Technology readiness and development funds

A major handicap to improving technology transfer through research commercialisation at HEIs and PRIs is the lack of technology readiness of research discoveries and clear market applications (see earlier findings from the 2021 EPO survey (European Patent Office, 2021[24]). The most important reason given by respondents to the EPO survey was the innovation’s lack of technological maturity (60% of German interviewees, compared to 64% on average for respondents in Northern and Western Europe), followed by lack of prospecting (43% vs. 60%); about one-third of respondents in Western Europe highlighted difficulties in finding a partner as a major reason for the lack of commercialisation of patents (Figure 13.10). This is also the case because most public funding at HEIs targets basic research and first stages, whereas funding for development and product applications, as well as long-term support for knowledge transfer offices, are missing.

Figure 13.10. Reasons for no-exploitation by region (planned exploitation and no-exploitation)



Note: Number of interviews unweighted N=400, of which <1% do not know and <1% no statement.
Source: European Patent Office (2020[14]), Valorisation of scientific results Patent commercialisation scoreboard: European universities and public research organisations, https://documents.epo.org/projects/babylon/eponet.nsf/0/f90b78b96b1043b5c1258626006cce35/$FILE/Valorisation_of_scientific_results_en.pdf.

Absorptive capacities: Human capital and skills for knowledge transfer

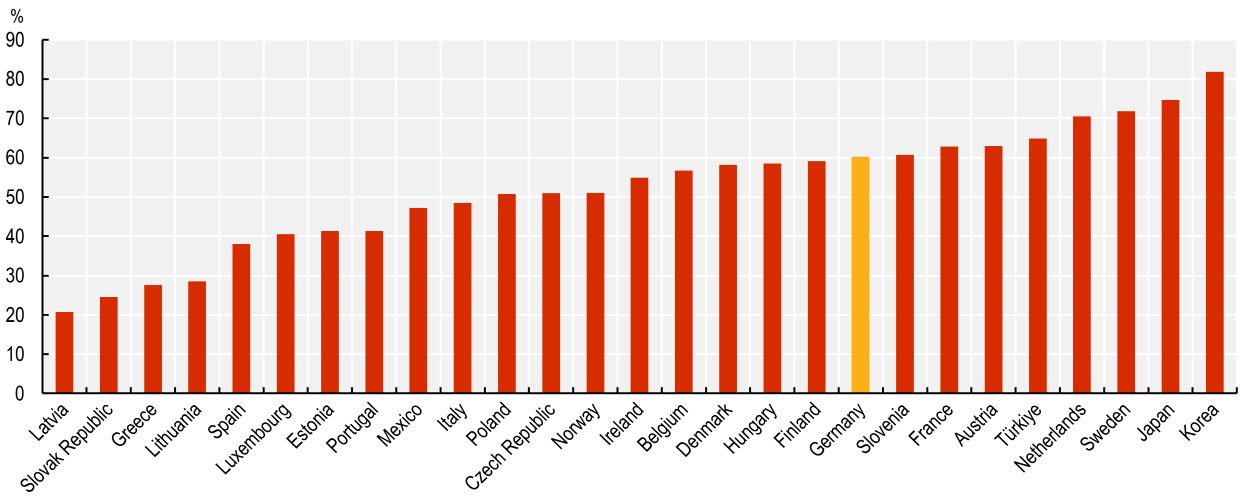
Successful knowledge transfer depends on the provision of human capital from the higher education system (HEIs) to the economic system, and the formation of new skills within the labour force. In Germany important policy efforts over the last two decades have aimed to maintain the supply of highly qualified labour to industry. Concomitant to changes in labour markets and the emergence of new industries, the HEI system experienced an important expansion in both resources and outputs.

The number of first-time university graduates in the population has increased steadily since 2002, especially after the shift from a diploma-based to a BA/MA system (2009), and peaked in 2015. The share of higher education graduates in the total population of the same age expanded from about 17% in the early 2000s to 32% in 2019, and has continued at this rate ever since (OECD, 2019[4]). However, this expansion has been accompanied by a steady decline in the number of graduates in vocational training and education (VET), an issue which has led to calls for greater policy attention for achieving a sustainable balance in the skill mix (OECD, 2021[25]).

STEM graduates are particularly key to addressing new technological and societal challenges, and industry transformation. The share of STEM university graduates in Germany is higher than in almost all other comparator countries except Japan (OECD, 2022[26]). Moreover, the number of MA and PhD graduates in STEM fields has been increasing faster than the total number of graduates.[1] In terms of doctorates and the placement of researchers in the business sector, Germany also stands high in international comparisons. Roughly 29 000 graduate students complete a doctorate in Germany every year, far more than in any other EU Member State (OECD, 2022[26]). In total, Germany's share of population with a doctoral degree (1.6% in 2020) is above the OECD average (1.3%); it is similar to that of Australia, Norway and the United Kingdom, but lower than the United States (2.0%) and leading countries like Switzerland (3.0%) or Slovenia (5.2%) (OECD, 2021[27]).

Germany also displays a strong presence of researchers employed in the business sector. In 2019, about 62% of total researchers were employed in private companies, compared to the OECD average of 50% (Figure 13.11). It is similar to the intensity reported by France, Austria and Denmark, but lower than in Sweden, Japan and Korea (over 70%).

Figure 13.11. Percentage of researchers in the business sector as percent of total national



Note: Provisional data for the following countries: Austria, Belgium, Czech Republic, Denmark, France, Germany, Greece, Ireland, Italy, Lithuania, Luxembourg, Netherlands, Poland, Slovenia, Spain

Source: OECD (2022[11]), "Main Science and Technology Indicators", OECD Science, Technology and R&D Statistics (database), https://doi.org/10.1787/data-00182-en (accessed on 22 May 2022).

Yet the emergence of new technological paradigms and skill needs poses a critical challenge for knowledge transfer from German HEIs and PRIs to the private sector. To some extent, the HEI system remains strongly anchored in traditional industry's structure and needs. Although curricula have evolved, changes may not been sufficiently rapid to address pressing innovation needs in the private sector, especially regarding the development of new industries and skills (e.g. digital skills).

There exist indications of growing labour shortages in key areas for future German competitiveness, such as information and communication technology (ICT), digital skills and new technology fields (e.g. artificial intelligence). It is estimated that by 2023, German firms will need around 700 000 more people with technological skills (e.g. related to complex data analysis and user-centric design) than were available in 2019 (Kirchherr et al., 2020[28]). The same survey study also predicts a shortage of 2.4 million workers with cross-disciplinary skills, who will have to be retrained in key skills such as agile working, digital learning and collaborative methods (Kirchherr et al., 2020[28]). These skill and labour-market pressures will have an impact on the effectiveness and strength of the country's knowledge and technology transfer institutions.

Moreover, as evidenced in several surveys, both academics and HEI institutions consider the weak innovation (and absorption) capacity in SMEs as a major barrier to eliciting partnerships with research institutions (Davey et al., 2018[29]).

Use of intellectual property

SMEs require help with and knowledge about protecting and exploiting their own IP, as well as licensing IP from academia. Sectoral differences prevail regarding expertise and professionalism in handling IP issues. For example, engineering companies are less likely to engage in knowledge transfer involving IP than pharmaceutical firms.

13.3.2. Constraints facing research institutions

Intermediation support capabilities in HEIs

While the technology transfer departments in PRIs (especially Fraunhofer institutions) have well-established operating models, university knowledge transfer offices face operational difficulties. Although most of the larger TUs have effective knowledge transfer offices that are increasingly staffed with experts in diverse fields, challenges across the broader university system remain substantial, both in terms of operations and governance. In addition, most knowledge transfer activities still originate from individual chairs and institutes, rather than from faculties and chancelleries.

According to a 2020 study of 39 German HEIs, 89% included knowledge transfer within their mission, and their knowledge transfer offices had 10.6 full-time employees on average (Roessler, 2020[30]). However, knowledge transfer support units in many German universities suffer from several limitations related to financing, infrastructure and incentives. In terms of funding, there currently exists no top-down directive requiring HEIs to dedicate a specific share of their budget to knowledge transfer activities. It is common for only 50% of the staff in German knowledge transfer institutions to be base-financed. The other half depends on project and other time-bound funding, so that transfer structures and their knowledge assets and social capital (networks, contacts, etc.) are highly volatile and prone to high staff turnover. Moreover, the implementation of the third mission is not considered a criterion for success in the German academic system and therefore does not influence careers or result in additional career opportunities for shaping the future at the management level. There exist some exceptions, like Fraunhofer-Gesellschaft, where knowledge transfer and the third mission are a more integral part of performance appraisal and career paths.

HEIs are increasingly concerned with finding ways to improve their impact on society through social innovation that produces sustainable solutions. This calls for multidisciplinary collaboration and resource mobilisation, such as through open-access policies (e.g. free licensing and open-source software) and open innovation approaches. It should be noted that knowledge transfer offices focus mostly on hard technologies (i.e. high-technology projects) at the expense of other academic fields with social impact and more multidisciplinary projects tackling broad innovation challenges (e.g. involving social sciences in environmental innovation projects). In the same vein, there is scope for knowledge transfer processes to become more open and involve other societal actors (co-creation partnerships).

Another challenge for knowledge transfer offices is attracting and retaining talent, including through accreditation and continuous training to improve professionals' awareness of new trends. Learning from peers is another form of education, hampered by the lack of established international knowledge transfer mentoring structures in Europe.

Other constraints for HEIs and PRIs

PRIs have raised a number of issues related to formal and informal knowledge transfer:

1. Researchers do not always have insufficient incentives to engage and support knowledge transfer activities due to research evaluations that focus on publications. This affects research commercialisation as they remain dependent on the interests of the research groups. The extent to which incentives are weak varies, however, strongly across Germany's research-performing institutions. Among the PRIs in particular several have set up very effective schemes.
2. Interviews conducted by the OECD pointed to the lack of IP culture in academia as major issue hampering patent exploitation.
3. Certainty among researchers about the legal status of IP is necessary to embed long-term investments and knowledge transfer needs more systematically within the missions of HEIs and PRIs.

4. The tripartite division of royalties from licensing (one-third to universities, one-third to inventors and one-third to agencies) is not sufficiently attractive for some universities.

The following barriers have been identified with regard to academic spin-offs:

1. The lack of spin-offs and science-based start-ups is strongly rooted in the limited incentives (both at the individual and institutional level) and funding for intermediate stages (i.e. validation and readiness).
2. Regulatory and bureaucratic issues hinder business creation at universities. This is also due to unfavourable structures in the science and funding system for academic entrepreneurship.
3. The lack of an entrepreneurial mind-set prevents researchers (and graduates) with the potential for technology and expertise transfer to engage in spin-offs.
4. The lack of alternative entrepreneurship strategies, such as bringing in external entrepreneurs to act as firm founders, also hinders academic spin-offs.

13.3.3. Common challenges for knowledge transfer

Lack of metrics and indicators on the state of knowledge transfer practices

There exists no comprehensive and consistent national metric about knowledge transfer activities at HEIs and PRIs in Germany, although most PRIs do report knowledge transfer activities and commercialisation indicators in their annual reports. The resulting lack of visibility on the national (and regional) level complicates steering and capacity-building. Examples of established national knowledge transfer surveys and metrics used in other countries include Réseau Curie (France), RedOTRI (Spain), Research England (United Kingdom), Netval (Italy) and AUTM (United States). It must be said, however, that the complex reality of knowledge transfer and commercialisation processes is not easily expressed in metrics, and that the types of engagement (i.e. the knowledge transfer strategy) can differ across universities and regions according to their specialisation, strengths and innovation demands. While PRIs report their knowledge transfer and innovation activities more consistently, information from HEIs is sparse and seldom published. New knowledge transfer indicators are also required to track broader types of engagement and new forms of interaction (e.g. open data, open innovation labs, co-creation).

Bureaucracy and regulatory hurdles

A 2016 survey of 992 German HEIs identified several barriers to university-business collaborations (Davey et al., 2018[29]). Respondents indicated that industry-science linkages are obstructed by bureaucracy related to collaboration with industry and by universities granting insufficient work time to academics for university-business collaboration. Additionally, academics perceive that university-business collaboration conflicts with their teaching and research responsibilities. From the industry side, the key deterrents to firms collaborating with academia remain differing time horizons and motivations to conduct research, followed by bureaucratic barriers.

13.4. Policies in support of knowledge transfer

The Federal Government supports the transfer of knowledge and technology between research institutions and SMEs through a variety of programmes and initiatives, including start-up funding for developmental stages, R&D funding and collaboration support. The largest and most prominent are the IGF) and the “Central Innovation Programme for SMEs” (ZIM), both of which are discussed in Chapter 5. The following provides a brief overview.

13.4.1. Policies and projects under ZIM

ZIM aims to help SMEs gain access to state-of-the-art knowledge and new technology development. The ZIM module for co-operation is its largest and most popular module, promoting R&D co-operation projects between SMEs, and between SMEs and RTOs. ZIM is open to all technologies and sectors. It has been administered by the Federal Ministry for Economic Affairs and Energy (now Federal Ministry for Economic Affairs and Climate Action [BMWK]) since 2008, when it was launched as a merger of a few different predecessor programmes. ZIM includes funding opportunities for (1) R&D projects in individual enterprises, (2) collaborative R&D projects (between SME or between SMEs and research organisations), and (3) co-operation networks between six or more enterprises in projects that are market-oriented, innovative and risky. By 31 December 2021, about 37 400 R&D co-operation projects with a funding volume of approximately EUR 5.5 billion had been initiated (AiF, 2022[31]).

According to a recent evaluation (Kaufmann et al., 2019[32]), SMEs consider the ZIM programme a valuable instrument thanks to its extensive experience, funding support and network advantages. Yet the evidence indicates room for improvement. Although ZIM is in principle inclined to incentivise R&D projects in less R&D-experienced firms, the eligibility criteria, the projects' innovation threshold and the amount of investment required have in practice made it more applicable to existing SMEs with experience in R&D (Kaufmann et al., 2019[32]). A reform of the ZIM funding guidelines in 2020 addressed these findings by (among other improvements) easing access for first-time-innovators and strengthening the incentives for innovators from economically underdeveloped regions. Continued efforts to promote inclusivity and interdisciplinary or cross-sectoral activities will help promote innovation and technology diffusion.

13.4.2. Other policies and projects for knowledge transfer

Under IGF, industry associations organise pre-competitive collective research projects and provide comprehensive service support on R&D matters, helping SMEs to address shared innovation and technological challenges. In 2020, AiF reported that almost 25 000 SMEs were involved in the 1 876 projects funded by IGF in 2020 (amounting to about 13 SMEs per project).[2] The "Research Campus" programme (*Forschungscampus*) and the "Leading-edge Clusters" programme have also been major strategies addressing the need for more strategic and longer-term approach to research partnerships. Research Campus was unique in its ambitions of having companies and universities pursue a joint research agenda "under one roof", which resulted in new forms of knowledge exchange between university and industry researchers.[3]

New support measures for non-R&D innovation and innovation management in SMEs have recently been introduced, including the "Innovation programme for business models and pioneering solutions", and innovation assistance programmes for the recruitment of young academics. Among other issues of concern, the rules and eligibility criteria of funding programmes have sometimes challenged inter-disciplinarity and cross-sectoral collaboration. In addition, the KMU-NEtC programmes of the Federal Ministry of Education and Research (BMBF) promote ambitious R&D and innovation collaborations through networks and clusters, with significant participation of SMEs.

Other examples of federal programmes include WIPANO (supporting the identification, legal protection and exploitation of IPR by universities and non-university research institutions); VIP+ (to test and demonstrate the innovative potential of research results, and explore application areas); GoBio (supports researchers in life sciences with innovative ideas to connect with business); EXIST (promotes university spin-offs); Digital Hubs (helps build digital ecosystems with SMEs, start-ups, corporations and research institutions); and specific funding for sub-areas of (among others) knowledge transfer and infrastructure development.

Since the later 1990s, entrepreneurship and spin-off activities at higher education and non-university research organisations are supported by the programme "EXIST - University-based Business Start-Ups", under the auspices of BMWK. The programme supports up to 240 projects each year through monthly stipends, mentoring, and covering personnel and material expenses up to EUR 250 000 in the early funding phases. A second instrument focuses specifically on promising pre-seed, pre-market projects that often lack the necessary infrastructure and funding for implementation. Following the example of the Defense Advanced Research Projects Agency in the United States, the German Federal Government established the Federal Agency for Disruptive Innovation (*Agentur für Sprunginnovationen* [SPRIND]) in 2019, funded with EUR 1 billion. Based in Leipzig, SPRIND funds pre-market phase projects selected through regular innovation challenges and does innovation scouting. Given the prevailing constraints related to government administration and procurement regulations currently inhibiting its operability, it remains to be seen whether the agency's funding and setup are sufficient, and the supported projects result in market-ready products.

The Federal Government established the *Hightech-Gründerfonds* ("High-tech start-up fund") as a powerful, platform-based structure for start-up support. As a platform with its own investment managers, it combines funding from different public and private sources. While not primarily science-oriented, the fund can also support the best and most relevant ideas from science. The "High-Tech Strategy 2025" further promotes innovation partnerships with the concept of innovation clusters and networks. Its central goals are to boost the number of new, more open forms of co-operation between companies, civil-society stakeholders and scientific institutions.

Launched in 2019, the "Transfer Initiative" of BMWK supports companies' innovative and collaborative activities. The initiative's central aim is to identify barriers to science-industry collaboration among businesses that have not previously participated in scientific collaboration and to increase their innovation activities. It consists of a series of public events on innovation-related issues, including discussions with representatives from business, science, associations, project management and government, and nationwide roadshows with local chambers of commerce and industry.

In the context of SMEs, practice shows that successful knowledge transfer requires professionalised support for both the definition and implementation of technology and knowledge transfer projects. Recently launched policy actions to improve SMEs' innovation capacity, technology adoption and participation in innovation partnerships are moving in this direction, but the programmes' funding and scale should be strengthened. Improving knowledge transfer opportunities for SMEs goes hand in hand with improving SMEs' entry into R&D, and enabling them to access and retain advanced human capital and new skills. This objective can be supported by enhancing funding for R&D projects (with project preparation assistance), placing advanced human capital (i.e. through a two year co-financing of salaries), or linking SMEs with supportive researchers and technologists at public institutions.

Overall, the government's commitment to improving the translation of scientific research into new products and innovative solutions in markets is reflected in the different policy strategies and funding programmes for start-ups, industry-science collaboration and technology commercialisation. Yet the relationship between science and innovation policies has suffered somewhat from ineffective co-ordination and divergent goals. The lack of a meaningful change in the intensity of knowledge transfer in a context of improved framework conditions for research and science suggests that past research policies, despite achieving meaningful results in terms of research quality did not translate into innovations.

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Endnotes

[1] The share of MA graduates in STEM fields rose from 30% in 2005 to 36% in 2019. For PhD graduates in these fields, the increase was even more marked, from 36% in 2005 to 46% in 2019.

[2] R&D projects are performed by the member organisation's research institutes (in 2020: 30%), by HEIs (55%) and by PRIs (15%), usually in the form of co-operative projects. SMEs do not receive funding directly but are involved in the definition of R&D projects and can use their results.

[3] The *Forschungscampus* approach took up the new standard of introducing a 5+5 year support perspective for key projects that was less common 10-15 years ago, but is now relatively prevalent.

Part VI Steering the ship: governance and policy for the German innovation system in transition

14 National STI governance, EU leadership and international commitments

This chapter discusses the governance of Germany's science, technology and innovation (STI) system, including national agenda-setting, inter-ministerial collaboration, federalism and its implications, and Germany's EU and international leadership role in this policy field. The chapter focuses on German STI governance challenges in the context of the twin transitions of sustainability and digitalisation. Critical to guiding Germany's future with those transitions, the section discusses the recommendation on developing a shared vision for Germany for 2030 and 2050.

Introduction

Germany's science, technology and innovation (STI) system is governed by a diverse and well-resourced set of institutions at both the federal and regional levels. These institutions – ministries, research institutions and agencies, higher education institutes, as well as private-sector organisations – have enabled the German innovation system to continuously play an important role in the competitiveness of the economy and by extension socio-economic well-being.

Given its maturity and historical success, it could be argued that ensuring the German innovation system's future success requires only minor improvements and adjustments to its governance. The extent to which this is true, however, depends on the goals policy makers have set for the innovation system. The nature and pace of technological change, combined with time-sensitive contextual and transitional challenges (such as digitalisation of industry and emissions reduction), mean that Germany's structures and processes for STI governance may need to adapt in order to maintain the country's position of strength. In this context, policy makers must respond to specific challenges in STI governance:

- Political and social expectations for the STI system have changed, and competitiveness is no longer the principal rationale for policy intervention. Orienting the STI system towards additional socio-economic "goals" is a more complex objective for governance.
- The political economy of the environmentally sustainable transition is challenging, as the STI governance system is now confronted with policy ambitions that go beyond – and sometimes even run counter to (at least in the short term)– the notion of competitiveness. The STI system must therefore be equipped to navigate emerging tensions and facilitate transitions, e.g. by striking a balance between non-directional and technology-neutral approaches to governance, and those with greater direction.
- A great number of actors are involved in innovation for transition and the STI system must facilitate more multidisciplinary approaches to bring to bear diverse expertise. Governance institutions – whether within federal ministries or research institutions – must also improve co-ordination and collaborative innovation, as cross-ministry collaborations (e.g. between energy, environment, economy and research with regard to sustainable energy) are more important in the new context. The social implications of the digital and sustainability transitions, which may have asymmetrical impacts on employment across sectors and raise the need for certain skills at the expense of others, also requires civil society as well as institutions in charge of social affairs to be more involved.

This section assesses the governance of the German STI system in the context of the challenges outlined above. The section begins with two recommendations. The first concerns the establishment of a whole-of-system "forum" to steer and manage the complexities of STI policy in the context of transitional challenges. It is recommended that the forum undertakes a foresight exercise for the whole of the German STI system, which we refer to as the "Germany in 2030 and 2050" initiative. The second concerns Germany's role as an international leader in STI governance, and looks at how Germany can leverage its international position to support innovation at both the domestic and European levels. The section then proceeds with an assessment of current aspects of the governance system crucial to meeting the challenges discussed throughout this review.

Recommendation 1: Develop a shared vision “Germany 2030 and 2050”

Overview and detailed recommendations:

Most transformational challenges posed by the transition to sustainability and digitalisation challenge Germany’s existing innovation governance system. This has resulted in important experiments, notably within the strategy for research and innovation (R&I) (see Chapter 5), to devise new governance arrangements for STI. This recommendation foresees the establishment of a whole-of-system “forum” to steer Germany’ STI system towards specific goals and ambitions described in a strategic vision. The proposal offers a time-bound and collaboratively developed vision for Germany. For its implementation, this recommendation complements Recommendation 2 on the creation of a public-private laboratory for innovation policy experimentation.

R1.1 **The government should create a cross-ministerial, federal-state, cross-institutional and cross-sectoral forum to steer the process of developing a shared vision founded on identified key priority areas for action**. The purpose of this forum would be to ensure broad engagement in policy making and identification of priorities, both to promote the type of horizontality and multidisciplinary approaches implicit in the challenges posed by transitions, and to secure the social and political legitimacy of the proposed actions. The forum would also provide an environment where all areas of policy (such as digital policy, social policy, education, environmental and health policies) can be discussed as they interact with STI. Although these issues fall outside traditional STI policy portfolios, they invariably affect the effectiveness of policy interventions.

R1.2 **The forum should develop pathways for innovation to realise the desired vision for Germany in 2030 and 2050 , as well as define approaches to deal with future risks and inclusivity issues in orienting innovation policies.** All countries will face important socio-economic transitions resulting from the digital transformation and the ambition to develop environmentally sustainable development pathways, as well as the increased risks – including health threats (such as the COVID-19 pandemic), geopolitical conflicts and climate change – arising from the interconnectedness of the global economy. Defining a shared vision can underpin steadier and more and strategic action, rather than addressing challenges in an ad hoc and reactive manner. The debate on inclusivity should also address the question of potential trade-offs of innovation excellence and inclusivity, and how to best approach these challenges.

R1.3 **The vision and its forum must be recognised as central at the highest level of government, as well as by key industry stakeholders and society, to effectively promote an agenda of change in the STI system**. The forum should receive high-level political support to allow it to engage government ministries and institutions at both the federal and state levels, as well as STI stakeholders more broadly.

R1.4 **Effective implementation requires establishing a public-private budgeted strategic plan for the realisation of the “Germany 2030 and 2050” vision. The plan should focus on key thematic areas for action and the monitoring of progress made at different stages. Core themes will be achieving the digital and environmental sustainability transitions, and the role of innovation and STI more generally in that regard.** Other related topics include preparedness for future disruptions (e.g. supply-chain preparedness), key enabling technologies, the industrial transformation and diversity in the innovation system (gender, age, ethnicity and socio-economic background). More granular topics could be developed, depending on which key priorities are identified for the “Germany 2030 and 2050” vision.

R1.5 **Importantly, implementation defined along key missions should not be top-down, but rather bottom-up and market-driven.** Bottom-up approaches can help accelerate implementing pathways for realising the “Germany 2030 and 2050” vision. Adopting actor-driven approaches, in particular, can hasten transition efforts that “reward” lead actors in specific states, regions, sectors, cities and policy fields that undertake innovative actions for change. Market-driven dynamics are also a key aspect of the vision’s implementation plan, which should identify and agree on transition pathways and partnerships with industry partners. In this manner, both government and industry commit to investments and other contributions or initiatives (such as “fossil-fuel free Sweden’”, with its industry roadmaps negotiated between industry and government) that will drive transitions. The “transformation dialogue for the automotive industry” (*Transformationsdialog Automobilindustrie*”) is a first attempt in this direction.

R1.6 **Important goals of the forum, and the “Germany 2030 and 2050” vision, would be to draw upon systemic capacities for STI and better co-ordination in mission-oriented approaches.** Germany has developed a number of mission-oriented approaches for STI, but they are not always sufficiently “transformative” and suffer from a lack of coherence and co-ordination among missions.

Relevant global experience

Given that some of the key STI governance challenges stem from the complexities of managing the contributions and expectations of different disciplines and constituencies, German policy makers may benefit from a high-level advisory and governing body such as in in Finland. The principle of a high-level arena, building on system-wide strategic intelligence and advice, and connected to the centre of government, could usefully be transferred to the German context. While the council’s scope would need to be wider than in Finland, such a body could generate greater systemic coherence in STI policy interventions, particularly where success in STI is linked to different policy domains.

Finland has historically had a governance model for STI that combines a high-level advisory body with the decision-making power of government. This governance model has been successful in setting STI policy priorities based on a systemic view of the national innovation system (OECD, 2009[1]) (Schwaag-Serger, Wise and Arnold, 2015[2]). Finland’s Research and Innovation Council has had various names and compositions. It has, however, consistently been chaired by the prime minister and has included a handful of ministers key to R&I policy, as well as a small set of R&I stakeholders. The council has functioned as a policy “arena” which has access to the strategic intelligence and systemic perspective needed to propose intelligent policies, and has the political legitimacy and power to decide on priorities. In previous iterations, the prime minister made a key contribution the council by raising the level of discussion and decision-making from the ministry level to the whole-of-government level. Another factor of success was that council decisions were limited to high-level, directional questions, leaving the existing R&I structures to handle design and implementation. A third success factor was the broad political agreement about the importance of investing in STI and higher education for economic growth and development. As long as this was agreed, political cycles had little effect on STI policy, because there were no major disagreements between successive governments in this domain.

This construction is not infallible, however, as it depends on the prime minister’s interest and willingness to take the leading role. That interest – and the political consensus about using R&I policy to drive economic development and growth, even during periods of recession – was lost over the last decade. As a result, Finnish R&I policy became fragmented and failed to maintain the national effort in research and development (R&D) for key technologies, so that the country lagged behind other countries in devising policies to tackle societal challenges (OECD, 2017[3]). In December 2021, Finland reinstated the target of boosting R&D spending to 4% of gross domestic product (GDP) by 2030 and reached a political agreement to increase public R&D spending to 1.33% of GDP to achieve this target (Finnish Government, 2021[4]).

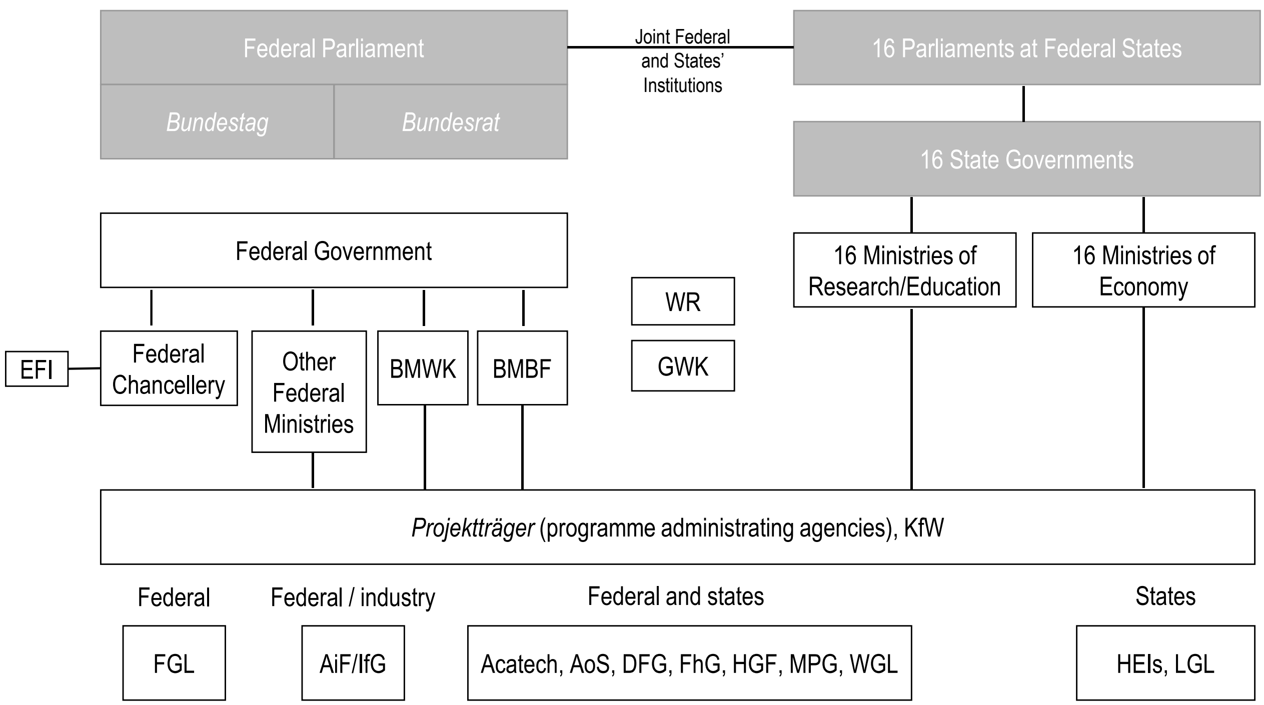
14.1. Overview of STI governance

The following section assesses STI governance in Germany, including its ability to manage the added pressures placed upon the STI system by the transitional challenges of climate change and digitalisation.

14.1.1. R&I governance structures in Germany

In general, the organisational structure for R&I governance in Germany follows a fairly standard division of labour. R&I policy is overseen by several line ministries, with input from external expert bodies, such as the Commission of Experts for Research and Innovation (EFI). Germany differs from other countries in the strong role of regional STI governance, with parallel institutions in the regions endowed with a high degree of policy and strategic autonomy (Figure 14.1).

Figure 14.1. German research, development and innovation (RDI) governance structure



Acatech: German Academy of Science and Engineering
AiF: Association of Industrial Research Institutes
AoS: German National Academy of Sciences Leopoldina
BMBF: Federal Ministry of Education and Research
BMWK: Federal Ministry for Economic Affairs and Climate Action
DFG: German Research Foundation
EFI: Commission of Experts for Research and Innovation
FhG: Fraunhofer Society
FGL: Federal Government Research Organisations
GWK: Joint Science Conference of the Federal Government and the Federal States
HEIs: Higher Education Institutions
IfG: Institutes of Cooperative Industrial Research
KfW: KfW Banking Group (state-owned investment and development bank)
LGL: State Government Research Organisations (State Agencies and other research organisations funded by State governments)
MPG: Max Planck Society
WGL: Leibniz Association
WR: German Science and Humanities Council

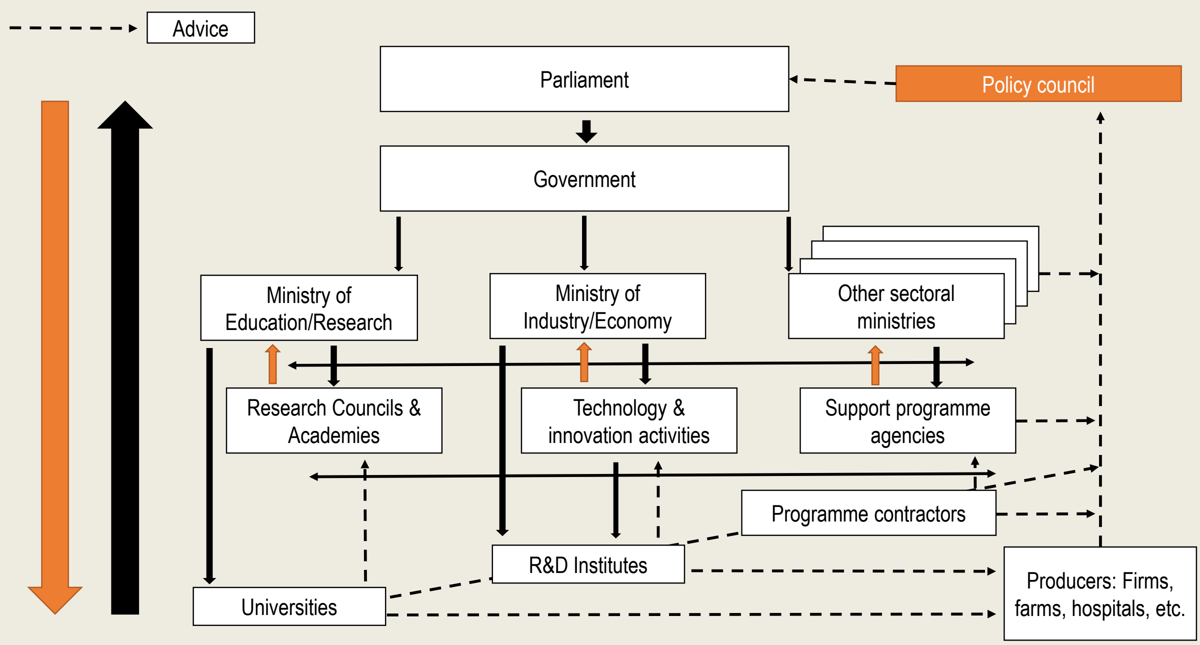
Source: OECD elaboration

One strength of the German R&I governance system is that temporal inconsistency – i.e. the misalignment between short political cycles and longer time frames for R&D – does not appear to present a major problem, as it might in other economies (Box 14.1). R&I policy evolves incrementally, rather than being subject to major discontinuities. There are several high-level organisations that provide advice to government, but none of them serves as a "highest instance" or involves members of the government. Importantly, there is no single ministry in charge of overall R&I.

Box 14.1. Standard governance structures for STI

Figure 14.2 shows a generic structure for STI governance in developed economies. Black downward arrows indicate delegation of tasks and authority; red upward arrows indicate flows of information and accountability. It is immediately obvious that this form of organisation creates ministry-based "silos".

Figure 14.2. Schematic of a generic STI governance structure



Source: OECD elaboration

This generic structure has implications for STI. An overview of key pillars of the generic governance structure is as follows:

- Governance structures can suffer from temporal inconsistencies between the shorter political cycles that affect the parliament and government, and the much longer natural R&I cycles. This creates a need for some consensus and consistency about R&I policy across political parties to avoid policy changes so radical that each government can undo the achievements of past governments during a single government period. Countries with successful policies tend to experience little political controversy about R&I; successive governments tend to make incremental adjustments to policy, rather than radical changes in approach.
- Most R&I systems are "two-pillar" systems, where two categories of ministries dominate government R&I expenditure: the education and research ministries generally focus on academic (often misleadingly referred to as "basic") research, while the industry ministry has a strong interest in applied R&I. To the extent that these ministries respectively act as proxies for

the academic community and industry (which have different value systems), they are engaged in a constant tussle for attention and resources.

- Traditionally, governments rely on a high-level policy council for advice. Such a solution provides a foundation for decision-making and co-ordination, and an arena in which policy alternatives can be debated within government and with key non-governmental stakeholders (OECD, 2009[1]) (Schwaag-Serger, Wise and Arnold, 2015[2]). Until about 2010, the Finnish Science and Technology Policy Council (now restructured and renamed "Research and Innovation Council") was widely regarded as the international best practice (see above).
- The widespread use of agencies to implement policy can create "principal-agent" problems, where agencies do not act in the best interests of their principals. On the other hand, agencies can forge stakeholder relationships and strategic intelligence closer to the area of policy implementation that ministries cannot themselves assemble, and may therefore generate ideas for programme design and implementation.
- The most effective level of co-ordination is the government, provided the prime minister is willing to act as the ultimate referee in the system. Inter-ministerial co-ordination is the next most effective: ministers have power, but also compete with each other for "turf" and budgets. Agencies are less effective co-ordinators, insofar as their decision-making authority is limited: inter-agency dialogue is constrained by the need for individual agencies to remain within their ministry's area of responsibility and their inability to make decisions that implicitly overrule ministry-level decisions.

14.1.2. Ministerial responsibilities in STI governance

Germany has 15 federal ministries (plus the Federal Chancellery). In practice, these cover the same set of responsibilities as in most other countries, though with a mixture of steering and co-ordinating roles at the *Länder* level. Ministry responsibilities shift over time, apparently more in response to politically driven rearrangements than to changes in wider strategy (Edler and Kuhlmann, 2008[5]). Every ministry is responsible for the research it needs to fulfil its responsibilities (*Ressortforschung*), which is carried out by a mix of government labs, public research institutes (PRIs) and other external research contractors.

Most German STI governance at the ministerial level is split between two ministries, the Federal Ministry for Education and Research[1] (BMBF) and the Federal Ministry for Economic Affairs and Climate Action (BMWK).[2] High-level governance therefore follows the two-pillar approach common across many STI governance systems. In practice, however, both ministries address overlapping constituencies: BMBF has responsibilities that affect innovation, and BMWK connects many of its innovation actions with research. This fuzzy overlap promotes co-operation and increases the ministries' joint ability to tackle R&I policy in a more integrated manner than in many other countries.

The main responsibility for education, including the universities, lies at the *Länder* level. The federal and *Länder* levels are jointly responsible for research, although the federal government provides most of the money. Table 14.1 outlines the main responsibilities of the two federal ministries.

BMBF (together with the Länder) essentially governs education and research policies that are implemented through the higher education and other state research-performing institutions, as well as businesses. It runs the Excellence Initiative, focused on the universities. It leads the strategy for R&I (previous editions of the HTS, the current HTS 2025 and the upcoming Future Strategy for R&I), which attempts to pulls together R&I efforts from across all the ministries. And it links the research and higher education sector in Germany to the European Union and international levels. BMBF also leads the Bioeconomy Strategy.

BMWK tackles the use and implementation of research results in business, as well as change more broadly. It sometimes requires the participation of research performers in its innovation programmes and needs to co-operate with other ministries to link its innovation and industry policies to other sectors of society, such as health, transport or the environment. BMBF and BMWK have overlapping responsibilities for vocational education and training (see Table 14.1).

Table 14.1. STI responsibilities of BMBF and BMWK

Federal Ministry for Education and Research (BMBF)	Federal Ministry for Economic Affairs and Climate Action (BMWK)
• European and international co-operation in education and research • General and vocational training • Lifelong learning • Higher education • Research (across universities and the PRIs) • Research for technological sovereignty and innovation • Basic research	• Economic policy • Energy policy • Industrial policy • Innovation policy • Small and medium-sized enterprise policies • Domestic policies for climate protection • European economic policy

Source: Extrapolation from BMBF and BMWK websites.

14.1.3. Advisory bodies

As shown below, several independent bodies advise the Federal Government. A key challenge is streamlining the advisory channels for STI that can inform public policy and result in concrete policy action; the forum outlined in Recommendation 1 (jointly with Recommendation 2) could help achieve this.

- Established in 2002, the **National Academy of Science and Engineering** (Acatech) is funded by the Federal Government and the *Länder* to provide strategic policy advice on engineering and technology policies. It comprises a mix of scientific and industrial experts, and sets its own agenda. One of its most conspicuous contributions has been the generation and elaboration of the "Industry 4.0" idea. Most of its projects address policy issues relating to technology, such as the potential for creating closed-loop plastic packaging systems, carbon pricing, and resilience as an economic and innovation policy goal.
- Established in 1652 as a scholarly society, **Leopoldina** currently has about 1 600 scientific members, but no research facilities of its own. In 2008, the Joint Science Conference (Gemeinsame Wissenschaftskonferenz [GWK]) designated it as the German National Academy of Sciences. Leopoldina aims to represent German scholars in the international community, as well as provide policy makers and the public with science-based advice. It is funded by BMBF (80%) and by the *Land* of Saxony-Anhalt (20%), and produces numerous statements and publications on science and science policy.
- The ***Wissenschaftsrat*** (German Science and Humanities Council) advises both the federal and the *Länder* governments. It comprises a mix of federal and *Länder* representatives, and distinguished scientists. Its advice spans both broad matters of science policy and specific questions, often in response to issues raised by its constituents. It is frequently entrusted with high-profile evaluations at the federal level. Overall, it provides "soft co-ordination" rather than specific instructions.
- **GWK** membership comprises BMBF, the Federal Ministry of Finance (BMF) and the corresponding ministries at the *Länder* level. GWK manages the joint funding of universities and PRIs, the German Research Council (DFG), Acatech, Leopoldina, the German Centre for Higher Education Research and Studies (DZHW) and the *Wissenschaftskolleg zu Berlin.*

- Established in 2009, the ***Innovationsdialog*** (Innovation Dialogue) is a regular series of high-level discussions between the Federal Government (chancellor, head of chancellery and ministers for education and research, economic affairs and finance) and representatives of science and industry. The dialogue's steering committee is chaired by the president of Acatech. The discussions cover a wide range of innovation policy issues, including innovation ecosystems, supply-chain resilience, the European Green Deal, quantum technologies, hydrogen, and the strengths and weaknesses in Germany's innovation system in international comparison. Six such dialogues took place during the 2017-21 legislative period.
- Created by BMBF in 2006, **EFI** is a group of six professors who annually produce policy advice for the government. Its members are experts in science and innovation policy, who substantially consult with the wider German science and innovation policy community when preparing their reports. EFI is the closest organ to what Figure 14.2 calls a "policy council", although its function is strictly advisory.
- **The High-Tech Forum** was established in both 2015 and 2019 to advise the government on the implementation of the HTS and its successor, HTS 2025. It additionally published discussion papers different on different aspects of R&I policy. In its latest edition, which ended with the parliamentary term in 2021, the forum comprised 21 experts from science, industry and society, and was co-chaired by the state secretary of BMBF and the president of the Fraunhofer Society. The High-Tech Forum is another organ that has similarities with the policy council mentioned in Box 14.1.
- The ***Rat für Technologische Souveränität*** (Council for Technological Sovereignty) is a group of 11 representatives from science, industry and society created in 2021 to advise BMBF on how to strengthen the technological sovereignty of Germany and the European Union in key technology fields.

14.1.4. Agencies

Like other countries, Germany maintains a research funding council or national science foundation in the form of the German Research Foundation (Deutsche Forschungsgemeinschaft [DFG]). While the DFG is functionally an agency of BMBF, legally, it is an association under private law whose beneficiaries are its members – the universities and PRIs. It is formally autonomous, although it derives its income primarily from BMBF and, to a lesser extent, from the *Länder*. Like other research councils, it is led and managed by members of the research community, and its predominant funding mode is bottom-up. The DFG has a strong international reputation and was used as a model in the establishment of the National Natural Science Foundation of China.

Most European countries tend to use government agencies to run their other R&I funding programmes. In Germany, R&I funding at the federal and *Länder* levels has long been outsourced under competitively won five-year contracts to programme management organisations (*Projektträger*), which currently number 19 (Förderberatung des Bundes, 2022[6]). In almost all cases, the *Projektträger* are departments of organisations that run technological infrastructures and provide technical or project management services. The largest of *Projektträger* include:

A. the German Aerospace Centre (DLR), which is the national space and aeronautics centre

B. Forschungszentrum Jülich, a very large (6 400 people) scientific research institute within the Helmholtz Association

C. the Karlsruhe Institute of Technology

D. the technology centre of the German Association of Engineers (VDI Technologiezentrum), an organisation which focuses on programme management and technology consulting services

E. VDI/VDE Innovation + Technology GmbH, a leading service provider for issues related to innovation and technology.

14.2. Coherence and agenda-setting for STI

If inter-ministerial and cross-sectoral co-ordination is challenging in a non-transition context, then it is even more so in the context of the added complexities of transition ambitions. As outlined above, overlaps, lack of co-ordination and alignment, and even contradictory policies (across sectors, ministries and governance levels) hamper Germany's ability to meet its transition ambitions. One example is the interface between STI policy and climate policy: Germany has both a strong R&I system and a long-standing commitment to sustainable energy (illustrated particularly in the *Energiewende*), environmental protection and biodiversity preservation (Walz et al., 2019[7]). However, the alignment between policy areas could be stronger, given their mutually reinforcing role in ensuring each other's effectiveness.[3]

The authors of an analysis of Germany's eco-innovation policies commissioned by the Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV), found the following weaknesses: too little focus on transition (except for energy), unconnected institutional and social innovation perspectives and policies, weak (or lack of) support of "green" start-ups and insufficient attention to innovation (Walz et al., 2019[7]). The report also identified considerable untapped potential for harnessing digitalisation as a driver of environmental protection and eco-innovation. It called for a stronger integration of innovation dynamics and perspectives in environmental policies, and for a "greening of the innovation system". Moreover, although Germany excels in the production of a number of green technologies, the government needs to raise the demand for green innovation and solutions, particularly with regard to waste, noise reduction and air purification. The heterogeneous applications of eco-innovation domains, such as bioeconomy, and their potential relevance to a wide range of sectors, make it difficult to design effective demand-side instruments or support market creation (Edler et al., 2021[8]).

The example of environmental sustainability and innovation illustrates the impact of long-standing co-ordination issues on increasing the contribution of STI to transition goals. There exists significant potential not only to strengthen elements of innovation policy in climate and environmental policies, but also to strengthen the environmental sustainability – and more generally, the transformative – perspectives in innovation policy. Indeed, the analysis of the interaction between innovation policy and environmental policy show a need to enhance common agenda-setting and policy coherence (Rogge and Kristin, 2016[9]) (Edler et al., 2021[8]).

Difficulties in improving the interaction between the environmental sustainability and innovation policies points to the co-ordination challenges in applying more systemic approaches to policy in general, and specifically STI policy. There is significant leeway for reinforcing innovation policy's support for the necessary transitions by enhancing the interface between innovation policy and other relevant areas, including climate, environment policies, social and health care policies. Echoing the findings of the BMUB report, in March 2020, the High-Tech Forum called for treating sustainability in all its dimensions as a key objective of R&I policy and removing obstacles to sustainable innovations (HighTech Forum, 2020[10]). A desire for greater co-ordination is therefore visible across a range of STI actors, and further government support would be welcome in this regard.

14.3. Inter-ministerial collaboration in STI governance

Strikingly, Germany has no single locus for whole-of-government co-ordination of R&I policy. Some countries may have a council, committee or "policy arena" – a platform that will involve senior politicians and stakeholders in key ministries (OECD, 2009[1]; Schwaag-Serger, Wise and Arnold, 2015[2]) – which allow policies with systemic importance to be widely debated. Other countries may have a unified system of policy monitoring and control, such as an observatory, but no singular institution driving R&I policy debates and prioritisation. German policy is made at the level of the government itself, driven in part by the shape of the current coalition and the pattern of ministries controlled by the individual political parties. Importantly, Germany uses committees of state secretaries to oversee initiatives relevant to more than one ministry, but no single institution takes responsibility for systemic co-ordination across the whole national R&I system.

In all government structures, ministries compete for budgets, policy priority and attention. Hence, policy co-ordination and co-operation at the ministry level is less effective than co-ordination at a higher, all-of-government level. In Germany's case, this universal dynamic is compounded by the weight of the *Ressortprinzip*, a departmental principle enshrined in the constitution. It is further strengthened by the tradition of coalition governments, which in practice connects different ministries to different political parties, creating incentives for a lack of co-operation among ministries.

A long-standing example of this separation, central to STI policy, is the division of labour between BMBF and BMWK, with BMBF responsible for RDI, and BMWK for innovation and implementation. And yet these ministries must co-operate closely to connect STI to societal needs, users and new markets, as evidenced by the growing number of strategies and policies on which they actually co-operate.

Individual German ministries have a track record of running strategies within their own areas of responsibility, such as the Pact for Innovation, the Excellence Initiative and the BMEL strategy (all under BMBF) discussed at Chapter 5. The *Energiewende* was reinvigorated in 2014, when the then-BMWi took over its leadership, reducing reliance on voluntary inter-ministerial co-operation. Thus, while the ministries operate well within their traditional silos, the lack of systemic perspective or system-level prioritisation reduces successive strategic choices to a series of ad hoc decisions taken in different parts of the overall governance system, rather than serving as building blocks of a holistic national STI policy.

Ministries do increasingly co-operate to a certain extent in the design and implementation of national strategies, such as the R&I strategy and the Hydrogen Strategy. This flexible and pragmatic use of the ministries' existing silos makes it possible to address new challenges through the established structures. On the negative side, however, the ministries do not co-operate in practice; instead, they establish a division of labour in which each separately uses a portion of its own budget to implement its own programmes. Joint management happens only at the top level, so there are few synergies. This separation impedes reflexivity and learning, as illustrated by current evaluation practices. Ministries evaluate their own programmes separately, in line with Germany's strong tradition in this regard, but the overall strategy undergoes little or no evaluation. For example, comprehensive evaluation of the HTS only began more than 12 years after its launch.

As a whole-of-government platform, the forum outlined in Recommendation 1 could provide a platform to expedite the resolution of co-ordination issues and support inter-ministerial collaboration.

14.4. Directionality, mission orientation and outcome-based STI governance

A growing trend at the international level is "directionality" in STI policy, with interventions tailored to societal challenges. Missions and transitions exacerbate existing co-ordination issues as the involvement of actors outside the R&I community, both in determining the challenges to be addressed and in implementing changes, becomes even more important. This is not a trivial exercise – stakeholder have diverse views reflecting their own interests and viewpoints. Integrating these perspectives fairly is even more challenging, as some stakeholders have a louder voice and more resources than others. In effect, societal challenges expand the scope of R&I policy from the two pillars to a much broader swath of society. Various governance arrangements for such policies are being experimented internationally, including putting single ministries in charge, creating cross-ministerial platforms, devising external platforms reporting to a central point in government, and establishing inter-agency platforms or programmes. However, there exists insufficient experience to define “best” (or even “good”) practice at this stage. A related issue is the need to establish a dedicated arena for each programme or mission targeting a societal challenge, allowing it to cope with greater stakeholder consultation and involvement compared with more routine R&I policy questions.

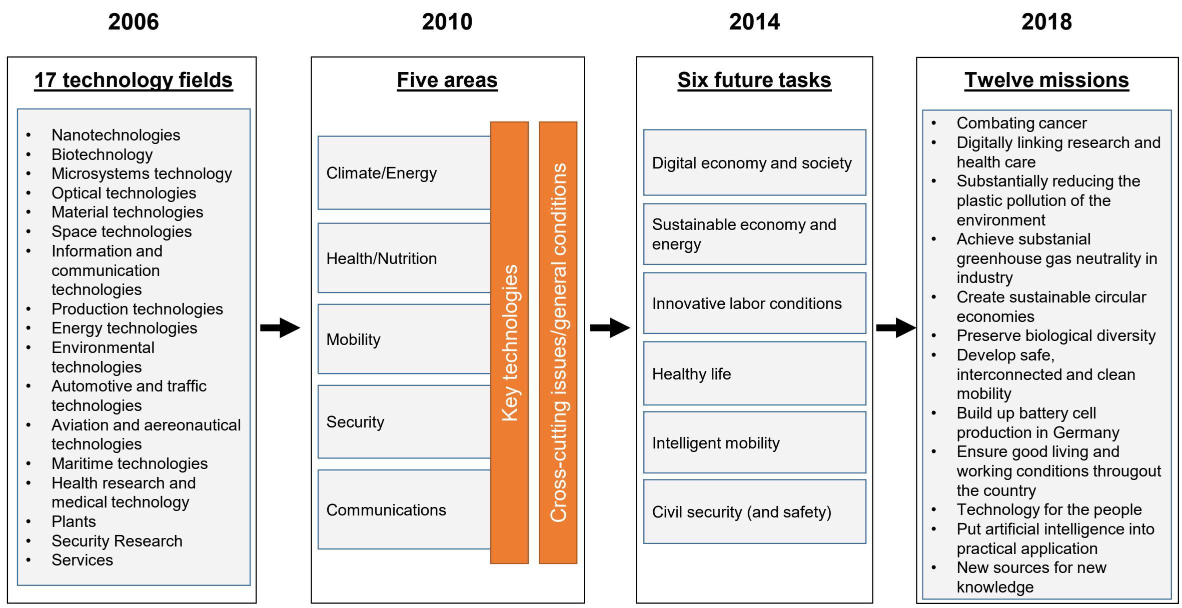
The growth in national strategies featuring an STI component points to an increased understanding across German government of the need for a more mission-oriented approach to solve societal challenges at various levels. This requires not only greater horizontal co-ordination within and among ministries and other state actors, but also a willingness within government to actively guide innovation activities in socially agreed directions the private sector would not necessarily take on its own. EFI, therefore, rightly proposes “a market-oriented version of New Mission Orientation, characterised by an openness to problem-solving and catalytic market interventions” (EFI Commission of Experts for Research and Innovation, 2021[11]). As EFI noted, the strong sector-focused approach of German STI policy could turn into a barrier to mission orientation. It may be necessary to revisit this approach to lower this barrier.

The essence of directionality cuts directly across the principle of technology neutrality implicit in *Ordnungspolitik* (governance) and which the then-BMWi emphasised in the past, even though many of its successful interventions were strongly thematic in nature. Examples include supporting dissemination and industrial capacity-building in new and key technologies, ranging from microelectronics and computer-aided design/computer-aided manufacturing in the 1980s, to digitalisation and artificial intelligence (AI) today. The *Industriestrategie* (industrial strategy) of 2019 included a list of key innovative industries to be safeguarded in order to support competitiveness, based on the principle of European technological sovereignty (BMWi, 2019[12]). Strategies for climate protection, also including guarantees for preserving the business environment (BMWi, 2020[13]), also focused on specific technologies, such as hydrogen (BMWi, 2020[14]). Key interventions by BMBF, such as in quantum technology, are similarly thematic. At the same time, the adoption of R&D tax credits in 2019 strengthened the weight of technology-neutral innovation policy tools within the envelope of innovation policies.

The high risk aversion of the government system also challenges mission orientation, which often involves experimentation, reflexivity and adjusting goals during the lifetime of an intervention. National strategies in areas like AI, hydrogen and bioeconomy tend to be supply- or technology-focused. To the extent that missions address transition needs, they should also be intimately connected to societal needs and the demand side. This introduces many more actors and stakeholders, whose actions affect the shape of needed interventions. It also entails a focus on problem-solving, not only in terms of supply-driven technological development, but also of processes for applying the results of that development to problems. Mission policies need to distinguish between “weak directionality” (such as “decarbonisation” or “hydrogen”, which in a broad sense specifies the direction of the search for solutions), and “strong directionality” (such as convergence on particular technical standards or the emergence of “dominant designs”), which creates or involves markets. Here, the missions of the HTS 2025 provide potential laboratories for testing the government’s role as mission results move towards markets, but the STI policy system as a whole will need to tackle the tension between directionality and technology neutral approach of policymaking (EFI Commission of Experts for Research and Innovation, 2021[11]).

The most well-known example of mission-oriented STI policy in Germany is the strategy for R&I. The strategy has evolved considerably since its launch in 2006, transitioning from technology-focused innovation goals to orienting technologies towards measurable socio-economic outcomes (Figure 14.3), and is now one of the clearest expressions of “mission-oriented” policy in German STI (in Chapter 5).

Figure 14.3. Evolution of the German strategy for R&I: From technology to mission orientation



Source: Based on information provided by BMBF on the respective strategies (BMBF, 2014[15]; BMBF, 2018[16])

The 2014 revision of the HTS set missions, this time identifying the following “priority challenges”: “digital economy and society”, “sustainable economy and energy”, “innovative world of work”, “healthy living”, “intelligent mobility” and “civil security” (BMBF, 2014[15]). Within each priority challenge, the HTS listed areas of action or emphasis. A new feature of this version of the HTS was the addition of “transparency and participation” as one of five core elements of innovation policy, besides “priority challenges with regard to value creation and the value of life”, “networking and transfer”, “the pace of innovation in industry” and “an innovation-friendly framework” (BMBF, 2014[15]). Ensuring transparency and participation involves including stakeholders, particularly citizens, in innovation processes and policy design. Interestingly, key enabling technologies play a much less prominent role than in previous HTS versions, as they are only mentioned in a sub-section entitled “Using the potential of key technologies for the benefit of industry”. During the implementation period of this version of the R&I strategy, policy platforms on industry (e.g. Industry 4.0), but also on bioeconomy, future mobility and city of the future gained visibility and momentum.

The latest iteration of the R&I strategy, adopted in 2018 as HTS 2025, takes the mission orientation one step further by identifying 12 missions in 3 action fields (see Figure 14.3). At the same time, key enabling technologies feature again more prominently and concretely under the heading “Developing Germany’s future competencies” (BMBF, 2018[16]). Finally, HTS 2025 includes a new emphasis on an “open innovation and venture culture” and entrepreneurship.

Yet Germany continues to develop mission-oriented policies, a conclusive assessment of their effectiveness remains difficult for a number of reasons:

- First, the missions are defined at different levels of granularity, and hence do not fulfil all the criteria set for mission-oriented policies (Mazzucato, 2018[17]). For example, only some of the missions (e.g. the mission on circular economy) define targeted, measurable and time-bound objectives.
- Second, not all the missions are transformative; some aim to accelerate knowledge generation or market uptake and are thus the continuation of classical mission-oriented approaches. Although this is an appropriate approach to some of the identified challenges, some missions have the

potential to further develop their transformative character (for example, the cancer mission could be extended to include healthier lifestyles).

- Third, the mission approach of the HTS 2025 puts STI at the centre of activities. Some of these STI-driven missions acknowledge that broader societal developments (such as behavioural changes) are necessary to yield transformative impact, or that STI policy should be linked to other policy domains. While these links are planned, not all of them have been realised. The existing linkages to environmental, energy and climate policies were established earlier in the context of the energy transition and sustainability policies, but the missions of HTS 2025 do not normally operate through cross-ministerial co-ordination at the cabinet level and can therefore not be regarded as whole-of-government missions.
- Fourth, another dimension to be considered, especially in light of their high institutional autonomy, is how to make better use of the universities and institutes in missions. This could involve utilising those parts of the research institute system that works with higher technology-readiness levels, accelerating the transfer of promising research to the market.

14.5. Federalism and its implications for STI governance

Germany's federal structure makes governance more complex than in many other countries, which is a particular issue for R&I. The post-war constitution was designed to impede the centralisation of power at the national level. Rather than treating the *Länder* as regions or provinces of the nation-state, the constitution makes them responsible for government but delegates certain functions to the federal level, including defence, foreign policy, citizenship, health care and fiscal policy (including the task of raising federal taxes – a large proportion of which are remitted to the *Länder*).

Flowing from the logic of pre-eminence of the *Länder*, the "upper" or "revising" house in the parliament, the *Bundesrat*, comprises *Länder* government delegations whose size reflect their respective populations. Members of the "lower" house (*Bundestag*) are chosen in national elections using mixed-member proportional representation, normally resulting in coalition governments. The *Bundeskanzler*, whose role corresponds roughly to prime minister in other systems, is elected by the *Bundestag* upon the proposal of the president and subsequently appointed by the president.

Managing STI policy at both the federal and *Länder* levels entails co-ordination costs. However, there exists a clear and systematic division of funding responsibilities between the two levels, and policies are actively co-ordinated through the GWK. Strong regional autonomy promotes the development of diverse policies and approaches, providing opportunities for experimentation. Variations among *Länder* policy approaches can, for example, orient research organisations' thematic specialisations towards regional needs. Still, some national and European programmes do somewhat mitigate wealth imbalances among *Länder* in the development of regional policies, and the smart specialisation they impose on regional strategies is likely to increase their quality and specificity. Although levels of wealth, and the administrative capacity to develop and implement policy, varies among the *Länder*, the European structural funds ensure they all have regional innovation policies. At the national level, programmes like "Innovation and Structural Change" promote the development of regional innovation ecosystems (see Chapter 16 for a discussion on territorial inclusivity).

The disadvantages of the federal system that affect STI policy also tend to affect other domains, suggesting there is scope for reconsidering aspects of the division of labour. For example, maintaining data protection agencies at both the regional and national levels gives ample opportunity to interpret the 353 pages of the General Data Protection Regulation in 17 different ways, impeding innovation and undermining the domestic single market. It also leads to the fragmentation of procurement in areas of government for which the *Länder* have responsibility, such as procuring medical equipment. This is a long-standing barrier to innovation, which will become even more significant as the policy focus in STI shifts from supply to demand.

Correspondingly, harmonising standards and practices will not only produce efficiency benefits, but also benefits in promoting innovation.

The of decentralisation of German STI governance is an asset, insofar as it enables trialling or adapting various policy approaches to local circumstances. Approaches such as “smart specialisation” and lead-actor innovation can help regional authorities draw upon national strategies while adapting their interventions to local realities and needs. The autonomy of the *Länder* provides some flexibility and means that approaches such as regulatory sandboxes can be aligned at the regional level with industrial and technological needs and capacities. The challenge for governance lies in maximising the lessons from these localised approaches to achieve national objectives. The forum proposed in Recommendation 1 could enable a more holistic approach to utilising the lessons and best practices of regional-level approaches to STI, as well as support their diffusion to underpin more systemic innovation support.

14.6. EU-wide and international leadership of German STI governance

Germany’s domestic innovation system is both informed by external trends and an actor in those trends, given the size of its economy and the strength of its STI system. All national innovation systems are part of the global innovation system, and shaped by international technology and market developments. They are also connected with foreign direct investment; international technology transfer and collaboration; and trade relations, including global value chains.

Germany is the largest EU Member State, and its STI governance is set within the EU context. Germany plays a very significant role in the EU Framework Programme, as well as the European Cooperation in Science & Technology and Eurostars funding programmes. It is a key participant in the multilateral European R&D programme Eureka and in facilities-based co-operation, including the European Organization for Nuclear Research, the European Molecular Biology Laboratory and the European Spallation Source. In 2014, Germany was the first country to publish a strategy for participating in the European Research Area, including 40 nationally specific action points. It is a major player in the Europe 2020 strategy and the European Semester, which co-ordinate aspects of EU industry policy. Moreover, Germany has both the largest number of participations and receives the biggest share of the EU budget contribution in Horizon 2020. The competitive nature of the framework programme means that the strongest R&D performers at the national level also tend to win the biggest share of framework funding, so Germany’s large share suggests a strong convergence between R&D focal points at the German and EU levels. The German Space Centre, Fraunhofer and the Max Planck Society normally feature among the biggest beneficiaries of framework funds. The Fraunhofer Society typically has the largest network of collaborators within the programme, connecting German research with more EU R&D performers than any other body.

While Germany has the opportunity to play an influential role in future transitions at the EU level, the European Union will be critical to the future success of Germany’s innovation system. Several of the technological competencies needed to ensure the future competitiveness of the German economy – including in areas such as the decarbonisation of industry through the development of hydrogen-based energy generation – will require investment, research capacity and commercialisation at a scale beyond what individual countries can provide. Germany can take a leading role in steering transnational initiatives that help both its own economy and other economies. Given the importance of meeting challenges such as the sustainability transition, exploiting Germany’s strong international position could help expedite the development and commercialisation of globally significant innovations.

The current German debate on “technology sovereignty” focuses on key technologies (such as semiconductors, AI, future communication technologies, cybersecurity, quantum technologies and advanced materials) which benefit from an EU-wide effort that originated in the 1985 EU Framework Programme. A key question for German policy is whether Germany should pursue development and capacity-building in such key technologies at the national or European level. Since such technologies are global in character, history suggests that working at the European level is key. However, the strong link between success at the national and European levels also means that Germany's ability to operate at the EU level depends crucially on strengths at the national level. These two levels are complements, not alternatives. There are precedents to Germany's engagement in EU-level efforts aimed at building sovereignty. The principle of subsidiarity[4] has been central in setting the agenda of the EU Framework Programme since its launch in 1985, with the framework only tacking issues of such magnitude that they are better handled at the European rather than national level. Thus, from the beginning, the European Strategic Programme on Research in Information Technology (ESPRIT) and Research and Development in Advanced Communications Technologies in Europe (RACE) programmes helped support European capacity in semiconductor and telecommunications technologies in the face of US and Japanese leadership, in order to ensure Europe's independence in procuring them (the framework programme was considerably less successful in supporting the European computer industry.)

To strengthen the European economy following the COVID-19 pandemic, the European Commission recently revived another co-operation instrument outside the framework programme, namely, Important Projects of Common European Interest (IPCEIs). These are member state-funded industrial collaborations for which public aid rules have been relaxed, allowing high subsidies for establishing manufacturing and other activities downstream of R&D. So far, projects have been established in areas including microelectronics, batteries and their supply chains, hydrogen, cloud computing and data storage, and health technologies. Germany is a prominent participant, as the current IPCEIs cover areas of great economic and technological importance to the German economy. IPCEIs are supposed to contribute to job creation, growth and European competitiveness, as well as strengthen the European Union's strategic autonomy by tackling market or systems failures, or addressing societal challenges. However, their governance has not been clearly specified at the level of the EU, and is not transparent. Liberalisation of the state aid rules for the IPCEIs also makes it possible for Member States to compete against each other, for example by providing subsidies encouraging companies to establish factories in their territories. Thus, public-private partnerships (PPPs) provide important opportunities for Germany to expand STI and industry policies at the EU level[5], benefitting from the resulting scale and collective industrial strength, but there is also scope to heighten these activities' support of societal goals, for example by contributing to more environmentally sustainable development.

Finally, several EU-wide tools can help build strengths in the German STI ecosystem. In recent years, the framework programme has grown to include PPPs. Horizon 2020 contains two PPP types: "Joint Undertakings", involving the European Commission, industry associations and companies; and "Joint Technology Initiatives", which are industry-led platforms pursuing collaborative R&D agendas.[6] Germany features prominently in both. However, devising a form of governance that ensures that such partnerships operate in both the public and the private interest has been an important issue (Luukkonen, Arnold and Martínez Riera, 2016[18]).

Besides its European leadership, Germany maintains many bilateral co-operation initiatives as part of its foreign scientific policy but has committed to promoting more multilateral formats, such as establishing a regular meeting of science and research ministers within the framework of the Group of Seven, first held in Germany in 2015. In 2013, Germany hosted the meeting of the newly created Global Research Council (BMBF, 2017[19]). Germany actively participates in international STI collaboration initiatives and international organisations. Within the OECD, it is active in the Committee for Scientific and Technological Policy, its Working Parties and the Global Science Forum. Within the United Nations Educational, Scientific and Cultural Organization (UNESCO), Germany is particularly engaged in the Global Action Programme on Education for Sustainable Development (2015-2019). It also supports vocational training through the Germany-based UNESCO-UNEVOC International Centre for Technical and Vocational Education and Training, and was an elected member of the United Nations Commission on Science and Technology for Development from 2016 to 2020.

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Endnotes

[1] Created in 1994 by merging the previous Ministry of Education and Research (BMBF), which had been responsible for basic and academic research, with the Ministry for Research and Technology (BMFT), which had focused more on applied and industrially relevant research, and had initiated the tradition of technology programmes.

[2] Called the Ministry for Economic Affairs and Technology from 2005 to 2013, then the Ministry for Economic Affairs and Energy (BMWi) until 2021.

[3] Under the new government, the responsibility for domestic climate policy has shifted since December 2021 to the BMWK, which also has partial responsibility for STI policy (next to the Federal Ministry of Education and Research).

[4] This is embedded in the so-called Riesenhuber Criteria (named for the then-German minister for science), which determined what could be included in the Framework Programme. The list of criteria was later extended, for example to include the European Research Council.

[5] The Franco-German GAIA-X initiative to establish a powerful cloud business operating within European rules is another opportunity, though ensuring governance in the public interest may be even more difficult as it falls outside the EU umbrella.

[6] An earlier form of PPP – contractual PPPs (cPPPs), of which there were ten – was phased out in 2020.

15 Agile, responsive and experimental policy for innovation

This chapter discusses the importance of policy and governance agility for STI in transition. The innovation challenges involved in the sustainable and digital transitions require new approaches from policymakers and governing institutions, with an onus on greater flexibility and experimentation. The chapter introduces role of the public sector as an agent of change, and discusses how policymakers can use policy and regulatory experimentation to spur innovation, with a particular focus on disruptive innovation. The chapter presents a recommendation on developing a public-private policy laboratory for experimentation.

Introduction

German STI policy has both supported and been shaped by the successes of its innovators. Its varied set of comprehensive and well-resourced policies (see Chapter 5 focuses specifically on including *Mittelstand* firms, as illustrated by the Federal Ministry for Economic Affairs and Climate Action's (BMWK) Central Innovation Programme for SMEs (ZIM). There are also diverse approaches to support start-ups, and efforts to support key enabling technologies for the future, such as industry 4.0, AI and hydrogen (s).

The pace of technological change, and the complexity and societal implications of transformative challenges, require more agility, flexibility and experimentation in policy making than before. Increasing the contribution of the science, technology and innovation (STI) system to achieving transitional goals is rife with issues, to which policy makers must respond.

- First, many of the solutions necessary for success, particularly in the sustainability transition, are rapidly developing at the frontier of technology. This raises questions on the ability of regulatory frameworks to both accommodate and encourage important innovations. Experimentation will be essential: the many uncertainties concerning future technological developments makes it difficult to set fixed roadmaps. Managing this experimentation and adopting the most promising approaches also introduces a range of governance challenges (see Chapter 14).
- A second, related issue is that many of these potentially important technological solutions remain at a low level of technological readiness and are therefore not yet commercially viable. In other cases, the technology might be viable, but market failures – such as the under-pricing of carbon and other environmental externalities – may lower the innovation's commercial potential. In both these cases, policy makers may have to do more to bring high-potential technologies to the market more quickly, including by supporting the development of new markets where necessary.
- Finally, the government may find it necessary to take a more directional approach to STI policy making by targeting its interventions at specific missions or goals, requiring even more agility, flexibility and experimentation to reach the intended direction. The rationale for leaving this success to the market may be weaker – particularly given the time-sensitive nature of several objectives, such as carbon-reduction commitments.

This section assesses the agility, flexibility and experimentation of Germany's STI policies. It provides a set of recommendations on next steps that can enhance the government's agility to support STI policies and future success. The recommendations and assessment presented in this section should be seen as complementary to the existing policy mix for STI. Germany remains at the cutting edge of STI policy in many respects, particularly when it comes to supporting the innovative capacities of the country's small and medium-sized enterprises (SMEs). The importance of these challenges will not diminish in the years to come; on the contrary, they will be more complex. A key question is therefore whether current STI policy making in Germany is prepared to step into a context where there exists in many areas of technology and science a need to move to more agile, responsive and experimental policy making, where new ideas and approaches are tested in practice.

The first key recommendation presented in this section is to build a policy laboratory that could function as an incubator and accelerator for the most promising STI policy interventions in the context of Germany's transition. The section then assesses agile and experimental policy for German innovation.

Recommendation 2: Create a public-private laboratory for innovation policy experimentation

Overview and detailed recommendations

The pace of technological change and the nature of the transformative challenges facing Germany's socio-economic future require more agility and experimentation in policy making. STI policy approaches require foresight strategies, co-creation of policies with civil-society actors and digital tools to inform innovation-policy approaches, such as semantic and big-data analyses to gather and interpret data relevant to the STI system. More agile STI policy could enhance the effectiveness of mission-oriented interventions, help scale the most effective policy approaches and allow recalibrating the chosen course of action more quickly. This is essential if Germany wants to take the lead in introducing new disruptive innovation sand associated business models. The proposed public-private policy laboratory would introduce policy agility in key areas linked to the proposed forum's vision of keeping up with the global pace of change needed to lead in the transitions (see R1 above).

R2.1 **The laboratory should act as the forum's institutional arm (see R1) to support policy agility, increased and accelerated responsiveness, experimentation and learning, and the major changes needed to achieve its future vision**. To this end, the laboratory would have a mandate to support champions – those who engage in experiments – and promising innovations across the STI system, including public bodies undertaking regulatory experimentation (R3) and innovative public procurement (R7), as well as city initiatives and other bottom-up efforts supporting transitions. This would include promoting lead-actor mechanisms across Germany's *Länder* to experiment with core missions – such as the digitalisation of the public sector – and new approaches to innovative procurement across all levels (including municipalities). The laboratory would also have a mandate to mitigate co-ordination failures across line ministries and public institutions, industry and civil society. It would exploit regional competencies and priorities to hasten the development and scaling of the most promising regulatory and policy approaches to innovation challenges. Importantly, the laboratory would look for ways to promote responsiveness and learning from policy experiments, as well as (where needed) facilitate fundamental policy changes.

R2.2 **The laboratory would promote implementation and monitoring, and the vision for Germany in 2030 and 2050 (see R1).** Concretely, it could implement a strategic foresight exercise that will produce the "Germany 2030" vision, as well as monitor developments and co-ordination challenges that may impede the transitions. This means considering the full innovation chain, from idea generation to market introduction, driving transfers across different actors. The laboratory would also support agents of change – notably through prizes, competitions, etc. – that help markets and different actors of the STI system to achieve the vision. For example, it would support the development and implementation of regulatory sandboxes and other forms of regulatory simplification (as detailed under R3), and could similarly support innovative public procurement (R6). It would also promote demand-side mechanisms for stimulating innovation, such as innovative procurement, and promote framework conditions conducive to innovation. Finally and importantly, the laboratory would support breakthrough innovation by promoting the activities of SPRIND and, more broadly, risk-taking entrepreneurship.

R2.3 **The laboratory would have the autonomy and means to recruit staff with different profiles through more flexible employment options, as well as to engage flexibly with innovation actors.** This would promote a greater level of industrial engagement through secondments or temporary positions, ensuring that policy making in frontier and complex areas of science and technology is underpinned by technical and entrepreneurial experience, and practical knowledge. To avoid adding further complexity to an already extensive set of STI policy actors, the laboratory would fulfil a temporary role, designed to set in motion a new agenda of change for future transitions.

Relevant global experience

In recent years, as policy making has become more complicated (partly because of wider scope and objectives) and urgent (owing to the speed of technological progress and climate change), policy laboratories have gained increasing attention as a way of testing new regulations or policy interventions. Policy laboratories allow policy makers to design initiatives in close interaction with users and stakeholders, as well as to implement policies in a real – but contained – thematic or geographic setting. By enabling policy makers to co-design, test and fine-tune approaches over time, policy labs can enhance and accelerate learning and reflexivity, thereby improving the quality and effectiveness of policies. Overall, they can strengthen and accelerate change and innovation in the public sector, improving not only the services it provides, but also its ability to support innovation in general.

Policy labs and related experimental platforms target certain policy areas – such as taxation, financial services, health care and mobility solutions (Austria), organised crime (Sweden), immigration (Finland) and employment systems (Denmark) – or promote innovative, experimental and inclusive policy making in the public sector (EUPAN, 2018[1]). They can be used not only for policy design, but also for purposes of implementation and evaluation – which involves testing the effects or consequences of new regulations or policy approaches on people, organisations and systems. According to the UK Government, policy labs bring people-centred design thinking to policy making: “Policy Lab is bringing new policy techniques to the departments across the civil service, helping design services around people’s experience, using data analytics and new digital tools” (GOV.UK, 2022[2]). Other examples of policy laboratories can be found in Denmark, Austria, Finland and Sweden (The GovLab, 2016[3]; Social Innovation Community, 2018[4]; Arge ITA-AIT Parlament, 2021[5]; Verket för innovationssystem, 2017[6]).

15.1. The public sector as an agent of change

Germany has long striven to improve its public administration. Co-creation programmes ("Work4Germany" and "Tech4Germany") introducing bringing innovative ways of working into the public sector by temporarily employing private-sector professionals have been launched, and new strategies for implementing (*Umsetzungsstrategie “Digitalisierung gestalten”*) and data-sharing (*Datenstrategie*) have been designed and implemented (Federal Government, 2018[7]). Germany has also implemented the “Federal Cloud” for intra-governmental online services. A new law on the harmonisation of registers in Germany (*Registermodernisierungsgesetz*) to facilitate the structured and secure digital exchange of citizens’ data between different government departments was passed in July 2021. This law is in line with the government’s legal commitment to offer a broad range of digital public services by 2022 (*Onlinezugangsgesetz*), for which efforts have recently been accelerated. As of May 2021, 315 of the 575 public services encompassed in the law were at least partially available online (European Commission, 2021[8]).

However, a number of significant public-sector administration challenges limit policy makers’ ability to implement new approaches to STI. Central to these challenges is the question of public-sector modernisation (including its digitalisation) and the ability of the public sector not just to keep pace with the private sector, but to lead by example. If, for example, the pace of public-sector digitalisation remains slow, and data integration and interoperability remain poor, then how can the public sector and STI policy makers be expected to make the most of new and complex sources of information as evidence for public intervention?

The National Regulatory Control Council (Normenkontrollrat), created in 2006, has consistently pointed out the urgent and critical need of modernising and future-proofing the German public administration (Nationaler Normenkontrollrat, 2021[9]; Süddeutsche Zeitung, 2021[10]). Areas of particular concern include the slow pace with which Germany's public sector is responding to digitalisation (both in terms of changing its own way of working, and of hampering digitalisation in society and industry); overly lengthy legislative and regulatory processes that are out of touch with their practical contexts (Nationaler Normenkontrollrat, 2021[9]); excessive regulatory and bureaucratic burdens for citizens and businesses; and, more generally, a public sector that is not adapted to current needs and realities of society and the economy (Nationaler Normenkontrollrat, 2020[11]). Since 2011, the council has been monitoring the compliance costs accruing to the private sector, the public sector and citizens as a result of rules and regulations (*Erfüllungsaufwand*). In its 2021 annual report, the council concluded that while compliance costs have increased significantly for enterprises and the public sector, they have declined slightly for citizens (Nationaler Normenkontrollrat, 2021[9]).

In October 2021, 23 experts and stakeholders, including the head of SPRIND, published a position paper identifying a modern public administration as a critical prerequisite for Germany's future prosperity and democracy, and listing eight concrete areas where they see an urgent need for action (Zenodo, 2021[12]). They called for a fundamental change in the functioning, culture and mindset of the public administration, which they argue will be essential in ensuring Germany's ability to handle the coming decades of transformation. Their concrete recommendations include creating organisational-development competence; fundamentally reforming human-resource management in the public sector; working with foresight and participatory policy processes; designing a public administration for a digital world; strengthening horizontal and vertical policy co-ordination and governance; and increasing transparency, interaction and societal participation in public administration.

15.2. Agencies

The institutional arrangement in Germany, where the management of R&I programmes is handled by 19 programme management organisations (*Projektträger*), also shapes policies' agility, experimentation and responsiveness (Förderberatung des Bundes, 2022[13]). One advantage is that the long-standing nature of this practice has led to the creation of organisations that have acquired substantial experience, allowing them to provide feedback and use their institutional memory when implementing new projects. In addition, the competitive process for winning five-year contracts introduces a competitive element in project management costs and incentivises these organisations to seek high-quality research and programme management. *Projektträger* are usually active in different thematic fields, so that they bundle different perspectives and experiences.

However, this arrangement also presents potential downsides, particularly in terms of agility, responsiveness and experimentation. Programme management organisations' arm's-length and contractual relationship with the ministries means that policy implementation distances programmes from the policymaking process. The organisations' strict contractual relationship with the ministry, and their lack of independence, also make it more difficult for Projektträger to support riskier innovations that might underpin the most innovative projects (Edler and Fagerberg, 2017[14]). The German system contrasts with the broad and deep experience available in organisations like Vinnova in Sweden or Research Council of Norway, which as a result can play more active roles in programme design and policy development, in partnership with their ministry principals.

The arrangement may change in coming years as the coalition agreement of the government that came into office in December 2021 foresees creating an agency for transfer and innovation ("Deutsche Agentur für Transfer und Innovation" [DATI]) to support social and technological innovation at applied science institutes and universities, in co-operation with SMEs, start-ups, and social and public organisations (SPD, Bündnis 90/Die Grünen und FDP, 2021[15]).

15.3. Leveraging policy and regulatory experimentation for innovation

German innovation policy has increasingly focused on spaces and laboratories for policy experimentation (BMWi, 2021[16]). Several initiatives at the federal and state levels have sought to promote policy labs, particularly in digitalisation and energy, but also in areas such as urban development. A key feature of experimentation has been improving the agility of regulators to support potentially high-impact new technology.

As discussed in Chapter 6, anticipatory and experimental regulatory approaches, such as those used in regulatory sandboxes, are likely to be an increasingly important lever for supporting the development of the most innovative and high-potential technologies.

The BMWK defines sandboxes (*Reallabore*) as follows:

> *Regulatory sandboxes enable in a real-life environment the testing of innovative technologies, products, services or approaches, which are not fully compliant with the existing legal and regulatory framework. They are operated for a limited time and in a limited part of a sector or area. The purpose of regulatory sandboxes is to learn about the opportunities and risks that a particular innovation carries and to develop the right regulatory environment to accommodate it. Experimentation clauses are often the legal basis for regulatory sandboxes* (BMWi, 2021[16]).

One element of support for sandboxes has been an innovation prize for policy labs (BMWi, 2021[17]), in which the winners are awarded a quality seal. At the Länder level, governments have also supported policy laboratories in various ways (see, for example, (Ministerium für Wissenschaft, Forschung und Kunst Baden-Württemberg, 2020[18]).

15.4. Policy to support breakthrough and disruptive innovation

Momentum has been gathering in German policy, industry and the broader STI community for pushing the German government to strengthen the country's ability to produce disruptive, breakthrough and radical innovation. In a 2018 report, the presidents of the Max Planck Society and the Fraunhofer Institute, as well as the chair of the board of trustees of the National Academy of Science and a number of industrial leaders, called for reforming the innovation system to support more radical innovation (Harhoff, Kagermann and Stratmann, 2018[19]). The authors' (and many commentators') opinion is that tackling the transformative societal and economic challenges facing Germany and other countries requires more transformative – and at times disruptive – innovation. Given Germany's sophisticated innovation system and the globally leading strengths of many of its key industries, there is no "off-the-shelf" policy approach that is immediately available and applicable to promote this type of innovation in the German context.

To this end, following examples of institutions such as the U.S. Defense Advanced Research Projects Agency (DARPA), in 2019 the German government founded SPRIND, perhaps the most concrete manifestation of German policy makers' acknowledgement of the need to provide greater support to radical and breakthrough innovation activities. The principal tasks of SPRIND are to identify and develop research ideas that have the potential to lead to radical or breakthrough innovation, and to accelerate the commercialisation and diffusion of highly innovative ideas. In this regard, the agency is an extension of the already well-established tradition of publicly backed knowledge transfer between science and industry, but its outlook responds to the concerns voiced by STI actors.

SPRIND has a continuously growing budget, which is planned to amount to EUR 1 billion over the first ten years. Organisationally, the agency falls under the aegis of both the Ministry of Education and Research (BMBF) and BMWK. The supervisory board comprises high-ranking members from industry, academia and politics, as well as one representative each from three ministries: finance, education and research, and economic affairs and climate action. Like DARPA, SPRIND will issue innovation challenges or competitions around specific themes, continuing a form of innovation incentives and initiatives that grew in popularity during the COVID-19 pandemic but are already well-established in information technology sectors (e.g. "a quantum shift for new antiviral agents").

While it is too early to judge its successes, the establishment of SPRIND illustrates the kind of institutional development that is likely to support the types of innovation activities favoured by political and industrial leaders. However, the agency's ability to live up to its mission and mandate is currently hampered by bureaucratic, legislative and institutional factors. SPRIND faces a number of operational barriers that could mitigate its effectiveness. For example, the agency is bound by several institutional and legal constraints – such as state aid rules and rules around regulatory compliance – that may prevent it from fulfilling its intended purpose. At this time, the agency can only possess wholly owned subsidiaries, to which the agency or the ministries can then extend loans, with the obligation to sell the subsidiary after a maximum of five years. At the same time, the agency's governance, with responsibilities split between the BMBF and BMWK raises the problem of co-ordination and inter-ministerial co-operation. Securing consensus among these ministries (and the Federal Ministry of Finance) delayed the establishment of the agency, while the COVID-19 pandemic also was a preoccupation at the time, and the risk of ongoing struggles in inter-ministerial co-ordination could seriously limit its operational and strategic capacity. These factors should be identified and addressed. Furthermore, even if SPRIND is given the space and resources to function optimally, its impact is limited to the projects it funds and their potential impact. SPRIND therefore needs to be complemented with other measures, both to allow it to function effectively and achieve long-term impact, and to support breakthrough and disruptive innovation more systemically and effectively, ensuring they are not limited to certain pockets. In recognition of those constraints, SPRIND was granted more legal freedom, and further legal simplifications are in the planning stage to allow the agency to work with more agility, flexibility and independence (BMBF, 2022[20]).

First, the government should place an emphasis on initiatives and programmes that fund more high-risk and breakthrough research. These should be viewed not as a substitute, but rather as a complement to Germany's strong research system. Second, existing research funding could be complemented with initiatives that seek to link or connect existing basic research in different academic disciplines around a common societal challenge, as with the National Science Foundation's "Convergence Research" initiative in the United States (National Science Foundation, 2020[21]). Third, the government should seek to fund disruptive innovation more systematically, aside from the SPRIND. This involves changing mindsets, rules and evaluation criteria for existing innovation and other funding programmes. It might also require designing new programmes that are more specifically tailored to breakthrough innovation. Fourth, the government should explore ways promote a more systematic upscaling of successful disruptive solutions. In addition to channelling funding to this effort (e.g. through an earmarked programme), this will most likely require a stronger focus on anticipatory regulation, conducive standard-setting processes, and a mechanism for identifying and investing resources into scaling successful solutions in the public sector. Finally, the government should revisit and significantly ramp up its earlier efforts to use public procurement to promote disruptive innovation (e.g. in digitalisation, environmental technologies and sundry sustainability solutions).

Overall, it is important to recognise, communicate and anchor the belief – among policy makers, relevant stakeholders and society at large – that supporting breakthrough and disruptive innovation is necessary to break path dependencies and advance desirable transitions, and that it requires a shift in mindset, mandate and management.

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16 More seats at the table: Participation and inclusivity in German innovation

This chapter considers issues of inclusion in the science, technology and innovation (STI) system. While Germany's STI system is strong, it nevertheless faces a number of inclusion challenges, particularly along gender lines. The chapter introduces these challenges, and also discusses aspects of territorial and industrial inclusion. The potentially uneven impact of the sustainable and digital transformations makes it more important than ever to ensure a broader range of voices are heard in the policymaking and policy implementation process. To this end, the chapter presents a recommendation on more participatory policymaking for STI in transitions.

Introduction

Inclusivity is important to innovation. Who takes part in innovation has consequences for who benefits from the productivity and income gains engendered by such innovation. The reverse is also true: those marginalised from innovation activities may be negatively affected by the socio-economic changes that benefit others. Inclusivity results in STI policy that better reflects socio-economic goals. Considering a greater range of voices during decision-making – including those that do not traditionally participate in the science, technology and innovation (STI) system – can produce better-informed and more effective public interventions that enjoy a higher level of social buy-in and mitigate resistance to change.

Beyond these direct impacts, both the geographic distribution of innovation activities and their industrial composition also affect inclusion. When the geographic dispersion of innovation and innovative capacities is low, the opportunities for individuals across the geography will differ. In industry, the allocation of innovation resources and capacities between firms, and the sectors in which they operate, affect inclusivity as they determine differences in salaries and returns on capital. Both questions therefore relate to the challenge of social inclusion, since they imply an uneven distribution of the gains from innovative performance and the ability to participate in innovation.

Despite the general strengths of Germany's innovation system, several inclusivity challenges affect innovation. As discussed in Chapters 3, 10 and 11, private-sector innovation activities are overwhelmingly concentrated within large firms, with a comparatively small contribution of small and medium-sized enterprises (SMEs). While this section does not focus on these industrial issues, they are nonetheless related to the challenges discussed here. For example, the industrial concentration of innovation and innovative sectors has a territorial dimension, with a handful of regions accounting for the bulk of innovation output. As a result, as some regions have become world leaders in certain technology fields, capacities in other regions have lagged, contributing to an interregional inequality. Similar inclusivity challenges are mapped along gender lines. Again, due to the industrial focus of German innovation, the private sector has historically favoured science, technology, engineering and mathematics (STEM) skills, a domain where women continue to be under-represented. These combined inclusion challenges mean not only that the country has missed out on input from under-represented groups, but that the capabilities in the innovation system – for example, in skills outside of STEM that are more readily held by women or migrants – may be insufficient to meet the innovation needs of the sustainability and digital transitions.

While the sustainable transition aims in particular for a greener, fairer and more sustainable economy, the innovation that will achieve this can – at least in the medium term – have asymmetrical socio-economic impacts. For example, the transition to renewable energy will create new jobs, investment opportunities and wealth, but it will also involve shutting down Germany's coal mines and hence a loss of employment. Similarly, the "winner-takes-all' and disruptive dynamics that sometimes accompany digital innovation can lead to further concentration of the actors who can participate in and benefit from these innovation gains (unlike the relatively broad base of participation in industrial innovation). Managing these socio-economic impacts of innovation – particularly where they map along existing territorial, industrial, socio-demographic and gender-inclusion divides – will be key to ensure that the success of STI in supporting transitions delivers an equitable settlement for society.

Policy responses to these inclusiveness challenges vary, but their core goal is tackling the misallocation of resources in the economy caused by exclusion. In correcting that misallocation, policy makers can broaden the range of contributors to innovation, and even STI policy making, thereby supporting inclusive economic growth and job creation. Regarding participation in innovation, this means addressing capacities to innovate, from primary to tertiary education and reskilling programmes; reducing barriers to innovation facing firms and citizens; promoting more collaborative forms of innovation; and mitigating the territorially and industrially uneven allocation of capacities and opportunities. In terms of policy making, this means bringing more people to the table when setting priorities and making decisions; instituting more collaborative policy making between society and the STI system; and learning from local experience in approaches to STI.

This section focuses on territorial and social inclusiveness challenges in the German STI system. The section begins with a recommendation on improving social inclusion and the decision-making process in the STI system. It then presents an overview of inclusion challenges in the STI system. It concludes with a discussion of the opportunities offered by open science to expand contributions to the innovation system.

Recommendation 8: Increase the involvement of civil society and key stakeholders in STI policy for transitions

Overview and detailed recommendations

Many of the economic and technological challenges facing Germany have asymmetrical, often significant consequences, with societal impacts . The debates around ethics in the use of artificial intelligence (AI) tools and gene editing illustrate such impacts. STI policy making, therefore, should further include civil society in STI, ensuring that government policy and direction reflect the concerns and ideas of a broad range of actors. Broader civil-society engagement would also increase the *supply* of policy ideas and provide testbeds for experimentation, including especially at the city or municipal level. Participation of diverse social groups in innovation activities will also promote wider societal involvement, aside from helping to introduce transitions. Moreover, engaging civil society and STI stakeholders in a dialogue on the best ways to design STI policy programmes targeting or impacting them has important benefits. Such participation can improve diversity in participation and boost programme quality by incorporating the potential difficulties the intended beneficiaries may experience in engaging with those programmes.

R8.1 **Create citizen councils to debate innovation and innovation policy**. These councils could be formally linked to the forum proposed in R1, thereby providing structured input into STI policy making and direction. The citizen councils' discussions could centre on the same thematic agenda as the forum's. Testing policies and defining innovation challenges could also be elements of such exchanges.

R8.2 **Develop "city innovation laboratories"**. The government should consider developing of city laboratories where municipal authorities would have the autonomy to test new approaches to innovation policy. These approaches could take the form of public-private partnerships; partnerships with research institutions or start-ups; and procurement from innovative firms to address local issues linked to transitional challenges, such as electric mobility. City laboratories could provide real-world testbeds for bottom-up and entrepreneurial-driven innovation targeting a range of complex challenges, and serve as a springboard for scaling successful approaches at the state or national level. As an additional advantage, they would provide a more direct and responsive line of communication between STI policy makers at the national and local levels, which could significantly improve policy responsiveness and agility.

R8.3 **Create a policy programme that allows cities or municipalities to apply for special status that grants regulatory flexibility for innovative experimentation**. Allowing local authorities to apply for special status would streamline and accelerate bottom-up innovation as they could create more responsively the conditions conducive to innovation for local firms and better utilise these innovative capacities to solve place-specific challenges. Such localised approaches could encourage the emergence of regional leaders in a range of areas, including policy agility and co-ordination, public-sector digitalisation, innovative procurement, innovation for sustainability, innovation missions, citizen science and innovation, and social innovation.

R8.4 **Use co-creation programmes for innovation at the city and regional levels.** Local co-creation could be especially useful in encouraging innovative public procurement and open innovation systems, such as living labs, regulatory testbeds, and hackathons. Co-creation between the public and private sectors in particular could help de-risk innovation investment in emerging areas of technology for both parties. Sustainable mobility activities in cities are an important example of where innovation activities could benefit from local co-creation.

R8.5 **Boost diversity in the innovation system.** Engaging a more diverse set of actors will support diversity and inclusion, but it can also help improve the quality of innovation. In the context of an ageing society, attracting and involving skilled migrants, women, minorities and individuals from disadvantaged socio-economic backgrounds in innovation training and careers will be essential to ensure the innovation system has the talent it needs to succeed. Unequal representation of women, minorities and individuals from disadvantaged socio-economic backgrounds at senior levels of management could therefore be a source of weakness for the German private sector. The need for new skills – soft as well as technical –for success in the context of the sustainable and digital transitions also means that STEM skills that predominate in corporate boardrooms and leading innovation may pose a challenge for the future and also reduce inclusivity. Women tend to be more represented in these fields than STEM fields, and therefore supporting more those innovations could both bring more women into the innovation system in addition to improving Germany's innovative output in an area where it is comparably weaker. Widening the support for innovation could potentially also increase diversity beyond gender. Importantly, boosting about diversity needs to be also about diversity in the management and steering of innovation activities and not only about participation. Supporting citizen science and innovation activities are also important, as is involving civil society in knowledge co-creation activities.

Relevant global experience

Important examples of approaches to increasing the inclusion of people in STI policy making include collaborative innovation, participatory policy making and open science initiatives. When enacted successfully, each of these approaches has the dual effect of supporting *better* innovation outcomes (insofar as it promotes the type of multidisciplinary and cross-sectoral knowledge, as discussed in this report, that drives success in the transitional context), as well as social buy-in for these innovative outputs and the decision-making that led to them.

The importance of collaborative STI was clear during the COVID-19 pandemic: co-creation between innovation actors helped design solutions to diverse and challenging problems including vaccine development, ventilator manufacturing, and real-time data processing underpinning evidence-based policy interventions. In this sense, the pandemic highlighted that co-creation in STI can be a driver for innovation in both the public and private sectors. Another important dimension for co-creation that is relevant to Germany is the importance of relying on existing research institutions and promoting interactions with industry. For example, Canada's Pandemic Response Challenge relied on the National Research Council's established collaborative research and development (R&D) platform, as well as networks supported with grants and funding, to assemble collaborative teams for the COVID-19 response. Similarly, Chile's Scientific Research Fund *(Fondo de Investigación Científica*) is an existing programme led by the research development agency (ANID) and funded by the Government Ministry of Science (MINCYT) that was quickly adapted to address pandemic-imposed challenges. MINCYT offered strategic direction to the initiative, by communicating pandemic-imposed government priorities to steer the programme's focus on proposals. The initiative received 1 056 applications and granted funding to 75 projects (de Silva et al., 2022[1]).

Governments can also build inclusivity goals into STI policy interventions. For example, Ireland's Competitive Start Fund for Female Entrepreneurs provides equity investment to women entrepreneurs to support the costs (including salaries, travel expenses and consultancy fees) associated with developing the business plan and reaching key technical and commercial milestones. Successful applicants receive an equity investment of up to EUR 50 000 (euros) from Enterprise Ireland, in return for a 10% share in the firm. A similar programme exists in Sweden, where the government created a state-owned venture capital company to support firms with growth potential in the country's northern regions that experience difficulties in accessing finance. In both these cases, policy makers have embedded clear inclusivity objectives in their STI policy interventions (Paunov and Planes-Satorra, 2017[2]).

As discussed in this recommendation and in Section 2 below, one avenue to improve inclusion in STI is to ensure broader participation in the actual design of policy interventions, so that they tackle local problems. An example of the effectiveness of more participatory approaches to innovation is the BruSEeau project, which ran from 2017 to 2020 and involved a collaborative approach between different research centres, an NGO and designers, with the aim of devising a community- and user-driven innovative solution to a local problem (in this case, water management). One of the key motivations in this programme was how to elevate an issue discussed by a narrow range of experts, but endowed with broader social importance, to an issue of political significance – a question that is relevant to many of the challenges discussed in the context of the sustainability transition (Kreiling and Paunov, 2021[3]; Crespin, 2020[4]).

16.1. Overview on innovation and inclusivity linkages

Innovation and inclusive growth interlink in six important and reinforcing ways (Paunov, 2019[5]). The first is the role of innovation in "increasing the pie", i.e. its contribution to growth, as well as the trade-offs involved in this growth. The second is the role of innovation in addressing societal challenges, such as ageing or climate change. The third is increasing societal engagement in innovation and getting more actors to participate in innovative activities. The fourth is the question of innovation disparities, i.e. the territorial, industrial, social and indeed, international divergences in innovation inclusivity and benefits. The fifth is the question of digital innovation, and the ways that the particular types of innovation prevalent in the digital economy can aggravate or mitigate inclusivity challenges. Finally, there is the question of participatory innovation and participatory STI policy making, which are discussed below. Greater participation in the design and implementation of STI policy can help identify unintended negative social consequences of policy interventions, and raise social buy-in for decisions taken by national and subnational governments. Box 16.1 presents the ways in which these linkages interact with territorial, industrial and social inclusion.

An additional, related question is that of STI inclusion and the success of technology and science diffusion. The development of vaccines during the COVID-19 pandemic exemplifies the intersection of inclusivity and uptake of science and technology: despite broad success, governments struggled to implement vaccine programmes owing to low societal trust. People who lived in countries with generally high aggregate levels of social trust in science were more likely to feel confident about being vaccinated, regardless of their individual level of trust in science (Sturgis, Brunton-Smith and Jackson, 2021[6]). The experience with COVID-19 vaccinations is an important lesson for the transitional context: if policy makers want the innovations and scientific knowledge necessary to the digital and sustainability transitions to diffuse across the economy, then it is imperative that society trusts the STI community. Inclusive and participatory approaches to policy making can play an important role in this regard.

Similarly, in light of the role played by the STI system in tackling the COVID-19 pandemic, societal attitudes towards – and expectations of – the STI system are changing. This presents both an opportunity and a challenge. On the one hand, greater societal support for the STI system in tackling "non-traditional' issues such as competitiveness can drive more public support and intervention for innovation. On the other hand, higher expectations of what the STI system can deliver (and when it can do so) can lead to disappointment.

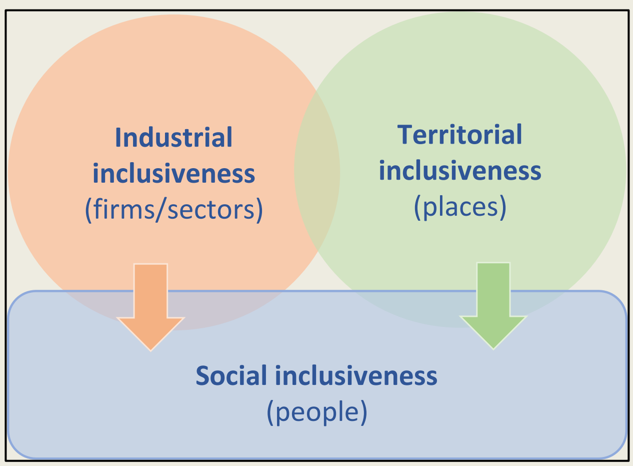
Greater participation and inclusion in the deliberation, design and implementation of STI policy is key to addressing these challenges.

Greater inclusion in innovation also has a higher instrumental value for policy makers, as it can support the *type* of innovation required for the digital and sustainability transitions. For example, given the importance of multidisciplinary approaches and facilitating new forms of knowledge transfer, the onus is on policy makers to support approaches to innovation that bring a wider range of participants to the table. As discussed in Chapter 11, innovative success in the sustainability transition is likely to require greater collaboration between disciplines, as well as new voices from outside the traditional confines of the STI system.

Box 16.1 Innovation and inclusivity

The features of a country's productive system play an important role in shaping inclusive growth. The concentration of innovation activities in certain industries and regions therefore has a complex but important relationship with inclusion and well-being. The sectoral and regional aspects of inclusion in innovation are referred to as "territorial inclusion" and "industrial inclusion"; both are closely linked to social inclusiveness.

Figure 16.1. Innovation and inclusivity



When innovation capacities are not widely distributed across sectors and regions, the well-being of individuals working in less innovative sectors or living in less innovative regions can suffer, inequalities can harden, and it may become more difficult to move into economic activities or regions with potentially higher participation in innovation.

Source: OECD (2017[7]), *Making Innovation Benefit All: Policies for Inclusive Growth*, https://www.oecd.org/innovation/inno/making-innovation-benefit-all.pdf.

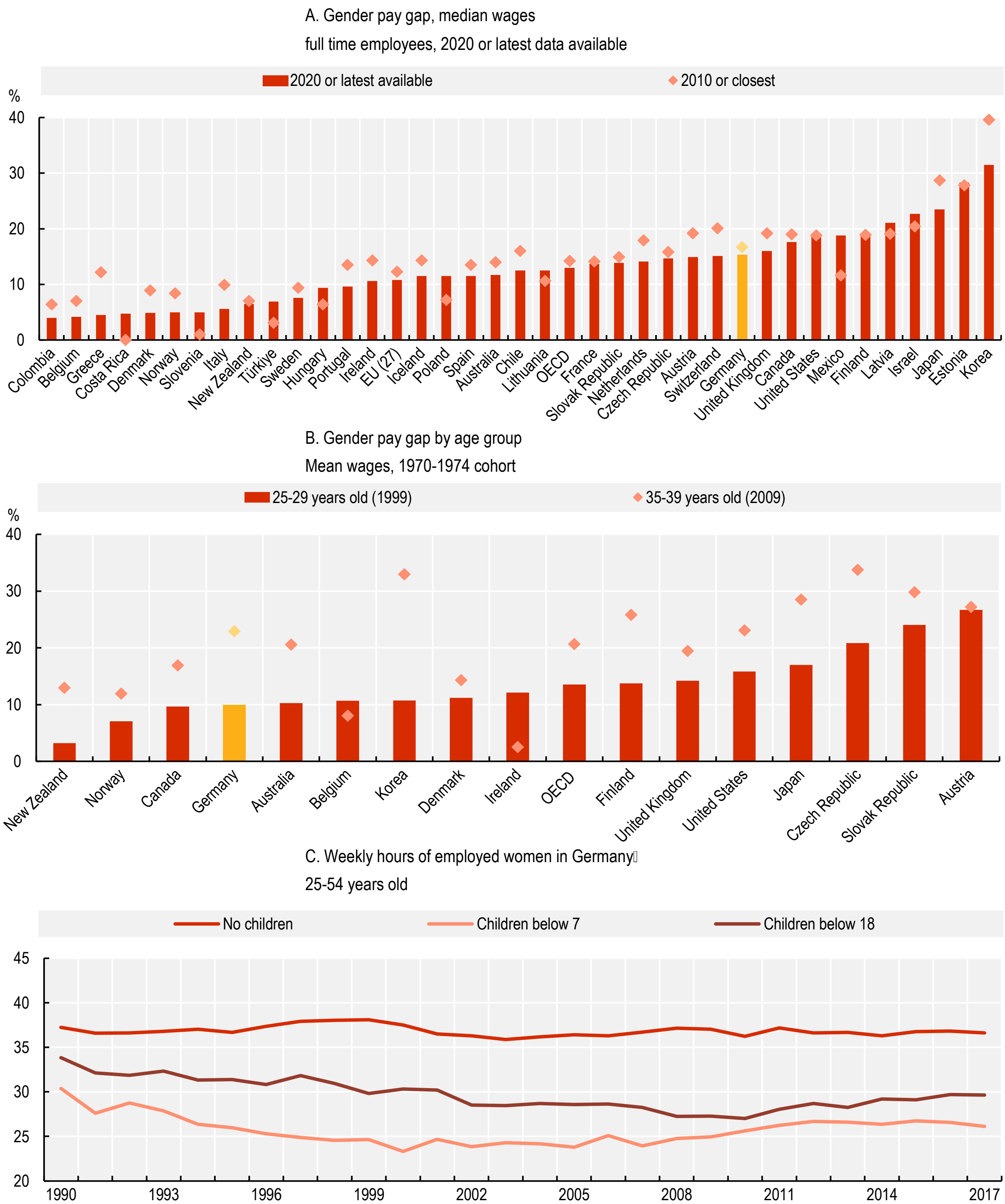
16.2. Participation in innovation

16.2.1. Gender and other inclusion challenges in the STI system

The distributional effects of the digital and sustainability transitions occur in the context of pre-existing inclusion challenges in Germany's STI system. One of the most notable examples of these challenges is that despite its strengths, participation in and gains from Germany's innovation system are unequally distributed along gender lines. As noted in the Overall Assessment and Recommendations (OAR) of this review and in the 2020 OECD Economic Survey of Germany, promoting participation in innovation and innovative entrepreneurship among women is likely held back by the same factors that discourage women's full-time employment – notably the high tax burden on second earners, and insufficient supply of full-day childcare and full-day schooling (Yashiro and Lehmann, 2018[8]).

Policy efforts to improve the inclusion of women in STI must take into account the broader socio-economic inclusion challenges for women. For example, the unadjusted gender wage gap of 20% has remained relatively unchanged for ten years (Panel A, Figure 16.2). The distribution of this gap shows age-related differences, with the gap increasing as women reach an age where they are most likely to have children (Panel B, Figure 16.2). There are a number of reasons for this persistent gap, including the high share of women engaged in part-time work and sectoral segregation (which explains about 30% of the wage gap) due to women being overrepresented in jobs with lower pay (OECD, 2020[9]). The high share of women in part-time employment is also linked to childcare, with the incidence of female part-time employment increasing significantly among women who have children under 7 years old. This likely has an impact on the careers of many women in sectors where they already face structural challenges (Panel C Figure 16.2), as detailed in the following sections.

Figure 16.2. Gender inclusion challenges in the German economy



Note: "Panel A: The gender wage gap is defined as the difference between male and female wages divided by the male wages. Full-time employees are defined as those individuals with usual weekly working hours equal to or greater than 30 hours per week. Panel B. Data for 25-29 years old refers to 1998 (instead of 1999) for Denmark, Korea, Norway and the Slovak Republic; to 1997 for Ireland. Data for 35-39 years old refers to 2008 (instead of 2009) for Australia, Austria, Denmark, Finland, Germany, Norway, Korea, and the Slovak Republic; to 2007 for Belgium, the Czech Republic and Ireland. For Austria, 25-29 refers to 20-29, 35-39 refers to 30-39.

Source: OECD (2022[10]), Gender wage gap (indicator). https://doi:org/10.1787/7cee77aa-en (Accessed on 06 April 2022) ,OECD (2012[11]), Closing the Gender Gap: Act Now, OECD Publishing, Paris, https://doi.org/10.1787/9789264179370-en, OECD (2020[12]), OECD Economic Surveys: Germany 2020, OECD Publishing, Paris, https://doi.org/10.1787/91973c69-en based on OECD calculations based on GSOEP v34.

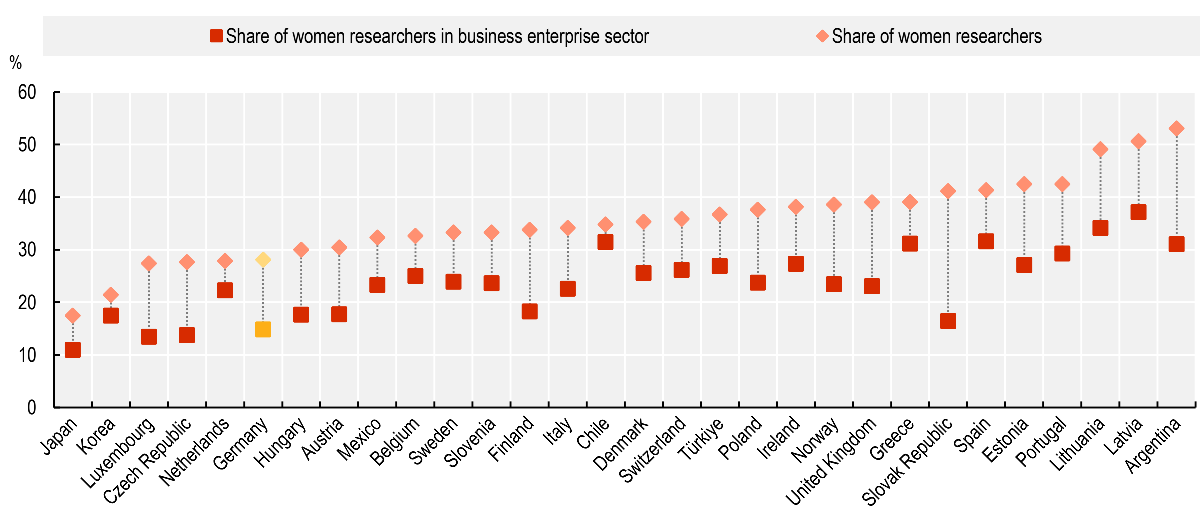
The under-representation of women in innovative activities also stems in part from the large share of business expenditure on research and development undertaken in fields of industry where the inclusion of women has historically been low, partly owing to the gender gap in STEM studies. Two out of three STEM tertiary graduates in 2018 were men, perpetuating the under-representation of women in key sectors. It is necessary to improve women's inclusion in STEM and the skills competencies of future innovators as innovation becomes increasingly digital and data-driven (OECD, 2020[9]).

Gender inclusivity gaps in the research base

The lack of female participation in the STI system starts with the orientation of the research base towards the STEM fields that support the country's leading innovative industries. The significant contribution of a handful of industries to German innovation and the traditionally male-dominated STEM domains underpinning these industries act structural barriers to women's participation and career advancement in innovation. In Germany, female STEM graduates numbered 11.8 individuals per 1 000 population in 2018, compared to 27.8 per 1 000 for male graduates (OECD, 2021[13]).

Given this under-representation of women in STEM, it is unsurprising that women are concomitantly under-represented in the leading innovative sectors. Notably, women account for 28% of total full-time employed researchers across the German research base, but only 15% in the business sector (Figure 16.3). Among the large industrial economies in the OECD, only Korea and Japan – two countries with a similar innovation focus on STEM areas – have lower levels of female representation than Germany.

Figure 16.3. Women are underrepresented in the German research community (2019 or latest year available)



Note: Headcount based, 2020 data for Japan, Korea, Mexico, Portugal, Slovak republic and Turkey
Source: OECD (2022[14]), "Main Science and Technology Indicators", OECD Science, Technology and R&D Statistics (database), https://doi.org/10.1787/data-00182-en (accessed on 06 April 2022).

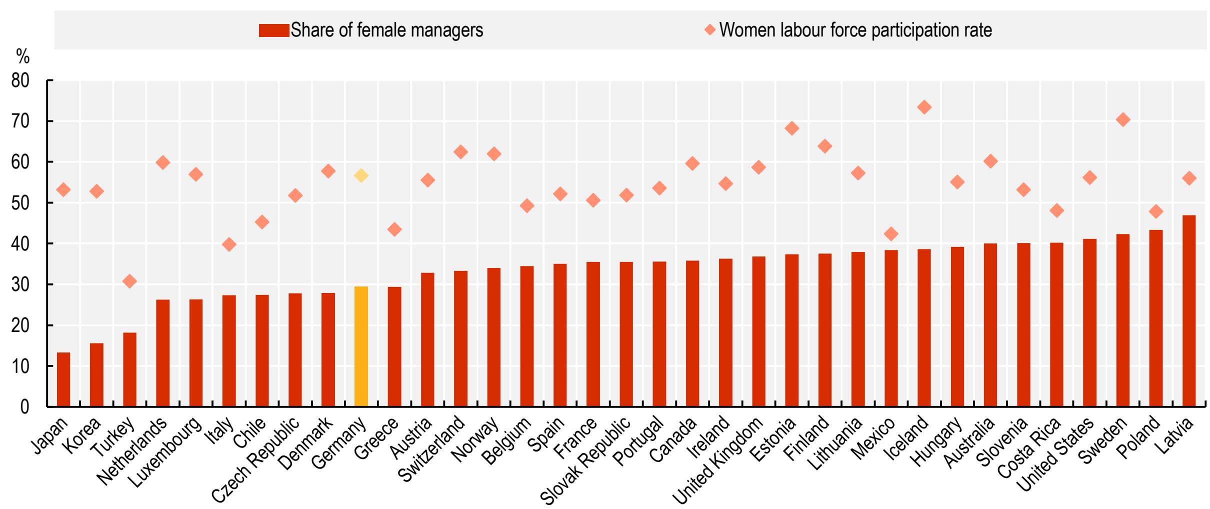
Output from the innovation system is indicative of the gender inclusivity challenge and the potential missed innovation contributions. For example, less than one in ten German Patent Cooperation Treaty (PCT) applications published in 2020 came from female inventors, likely reflecting that female inventors remain under-represented in some of Germany's key innovative sectors, such as transport (9.1% female PCT applicants globally in 2020), chemical engineering (15.1%) and electrical machinery (11.7%) (WIPO, 2021[15]).

Women in STI leadership

Women remain a minority in management positions in both established sectors and the start-up community. This could have an impact on the future competitiveness of the German economy, as well as on inclusivity. In 2018, only 29% of women worked in a managerial position, despite accounting for 46% of the labour force (Figure 16.4). The dearth of women in leadership positions is even more pronounced in start-ups: according to the latest OECD data, only 13% of technology start-ups in Germany were led by women in 2015 (OECD, 2020[9]).

Figure 16.4. Women are under-represented in managerial positions

Female share of management employment and female share of labour force, all ages, %, 2020 or latest available year

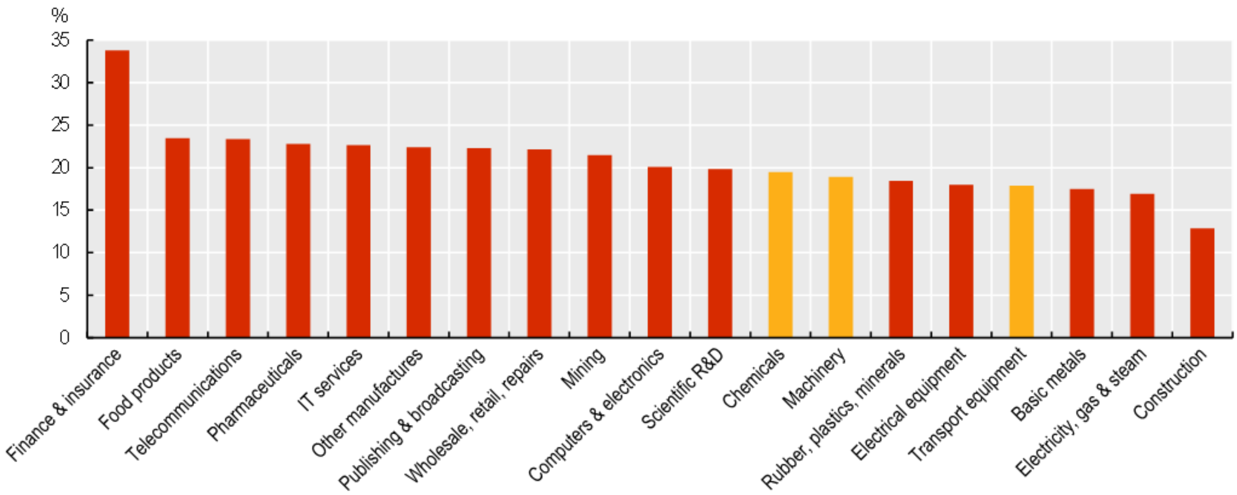


Note: Data corresponds to 2019 value for Germany and United Kingdom
Source: OECD (2022[16]) Gender employment database https://stats.oecd.org/Index.aspx?DataSetCode=GENDER_EMP based on ILO (2021), SDG indicator 5.5.2 - Female share of employment in managerial positions (%) - via https://ilostat.ilo.org/data (accessed on 1 June 2022)

The sectoral distribution of innovation activity in Germany also likely acts as a structural barrier to female leadership in the STI system. In chemicals, machinery and vehicle manufacturing– the rate of female leadership is particularly low. The average share of women on the board of directors of the world's top R&D investors in these sectors was 19.5% (chemicals), 18.9% (machinery) and 17.9% (vehicle manufacturing) (Figure 16.5). The low level of female participation at leadership levels in top R&D corporations in a range of sectors also demonstrates that the low levels in Germany are not necessarily a country-specific challenge, but rather an internationally structural challenge with domestic ramifications.

Figure 16.5 Gender leadership of the world's top R&D investors, by sector (2018)

Average share of women on the board of directors, ISIC Rev.4



Note: Data relate to sectors with at least 20 company headquarters in the top 2 000 corporate R&D sample.
Source: OECD/JRC (2021[17]), *World Corporate Top R&D Investors: Paving the way for climate neutrality*, http://dx.doi.org/10.2760/49552.

Beyond gender, barriers to participation in innovation, and their impact on social inclusion, exist along socio-economic lines. The inclusion of migrants plays an important role, not just in counteracting demographic pressures and associated labour shortages, but also in enhancing countries' innovation capacities and knowledge base. In Germany, migrants with a foreign qualification are at least three times more likely to be overqualified for their job compared to native peers, even when they have similar literacy skills – a higher gap than in other OECD countries (OECD, 2020[9])). With regard to entrepreneurial activities, individuals with a migration background make up 21.6% of all start-up founders surveyed in the recent German Start-up Monitor – about 3 percentage points less than the share of individuals with a migration background in the entire population (Kollmann et al., 2021[18])). This issue of lost innovation potential due to socio-economic inequalities, such as low social mobility (Chetty et al., 2018[19]), significantly below OECD average in Germany (OECD, 2018[20]), has been referred to as the "Lost Einsteins", namely that most successful scientists, entrepreneurs and innovators come from higher-income groups where they are more exposed to opportunities than in disadvantaged groups (Bell et al., 2018[21]).

Limited access to entrepreneurial and innovation activities is also an issue for youth. Germany features among the European countries where those aged 20-29 report the lowest levels of knowledge and skills necessary for starting a business relative to the entire adult population (OECD/European Commission, 2020[22])). Also, the share of youth who are business owners with employees (around 3%) is at the bottom end in European comparison and does not exceed the low overall level of business dynamism in Germany (OECD/European Commission, 2020[22])). Exclusion from innovation activities is often due to limited access to high-quality education (especially in important fields such as STEM), an issue that has been aggravated by the COVID-19 pandemic and the associated school closures (OECD, 2020[23]).

16.2.2. Participation in innovation: Open science and innovation in Germany

One important avenue for improving both the inclusion of society in innovation and the effectiveness of policy making in supporting innovation are open science and innovation programmes. To a certain extent, this relates to the participatory decision-making outlined in Section 2.4, although the focus here is on similar approaches applied to the innovation process itself. Examples of inclusive innovation processes involving civil society, such as BrussEAU, are provided in (Kreiling and Paunov, 2021[3]) and discussed above.

Open science can be an important means to support this collaboration, and in so doing, address some of the territorial and industrial barriers to participation in innovation hindering social inclusion. For example, open science and open innovation approaches can help SMEs participate in innovation activities with firms and research actors at the frontier, something that might not be possible through traditional knowledge and technology transfer avenues. A similar dynamic is true at the sectoral level, where sectors not traditionally involved in innovation activities can collaborate with innovative sectors, advancing the cross-sectoral diffusion of knowledge and technology.

16.3. Public attitudes towards STI

The COVID-19 pandemic led to an unprecedented level of public attention, scrutiny and hope vested in the STI system. In many ways, the global health crisis provided a glimpse of the expectations that may be placed upon STI in the years ahead, where innovation will play an ever-greater role in addressing challenges – such as demographic pressures caused by ageing societies, decarbonising industries and managing the consequences of climate change – impacting the daily lives of citizens and businesses. Ensuring that STI policy and innovation has the support of society is therefore key to the social and political sustainability of the directions that countries will take to meet these complex and transitional challenges. This is particularly true within the context of the sustainability and digital transitions, which are likely to have uneven distributional effects on society. If, for example, policy makers wish to decarbonise their economies, then bringing those who will be affected by this process to the decision-making table to discuss the consequences and opportunities will be critical to ensuring social acceptance of these decisions.

Encouragingly, Germany has a strong public majority in favour of government investment in scientific research and innovation, with some 77% of Germans answering a 2020 survey by Pew Research Center considering such investments a worthwhile use of public money (Pew Research Center, 2020[24]). Moreover, a clear majority (88%) consider it important that Germany is a world leader in scientific achievements (54% considered it very important, 34% somewhat important). These views correlate with those surveyed by the *Wissenschaft im Dialog*, the German organisation for scientific communication and social engagement, which found that 62% of respondents trust science and research, particularly by virtue of the expertise and integrity of scientists (Wissenschaft im Dialog, 2020[25]). It is notable that the figure was 52% before the COVID-19 pandemic, highlighting the potential role played by the health crisis in changing social attitudes towards the STI system. These social attitudes are important, since they legitimate – or repudiate – the approach taken by the federal and regional governments in supporting the international leadership role of the STI system.

Nevertheless, survey results indicate that attitudes towards "science" vary depending on the domain. For example, 43% of adults in Germany consider the use of robots and the development of AI to be bad for society, and 48% of adults considered the use of genetically modified foods to be unsafe (Pew Research Center, 2020[24]). It is here that the question of participatory decision-making and inclusive STI policy can help mitigate certain reservations. The point is not to say that reservations about certain innovations are without foundation, but to acknowledge that innovative progress will not always be automatically accepted by society. Bringing a greater variety of voices to the policy-making table can ensure not only that policy makers address reasonable reservations, but also take into account – and indeed learn from – social attitudes.

Social buy-in of STI will be important to the success of the sustainability transition, and policy makers must ensure that a broad swathe of society are pulling in the same direction. In the short and medium term, even if the changes that engender these costs render positive effects for well-being (e.g. lower greenhouse gas emissions and levels of particulate pollution, improved productivity through technology diffusion) at an aggregate level, some socio-economic groups will likely face costs. For example, the transition towards greener energy production will entail the closure of Germany's remaining coal mines, while continued and advanced digitalisation and automation in manufacturing may also lead to further labour displacement. Ensuring that civic society has a say in how policies are made and implemented, and are involved in discussions on the costs and benefits of such decisions, is therefore vital if policy is to be seen as legitimate and durable.

16.4. Participation in STI policy processes

Supporting greater societal inclusion and participation in STI policy making offers a number of benefits. It would improve the quality of STI policy, by integrating the experience and knowledge of those affected by these processes in policy design and implementation. This also enhances social buy-in and legitimacy, as society is presented with decisions that have that have factored in stakeholders' expectations and concerns, rather than facing a technocratic *fait accompli*.

Germany already has several participatory processes for policy making. The challenge in the years ahead will be to expand these efforts and ensure that they support society through the twin transitions, all the while improving the effectiveness of the policies enacted to achieve them. The most notable example of German experience in participatory policy making is the *Bürgerrat* (citizens' assemblies) initiative. These assemblies convene randomly selected participants to discuss a variety of different policy domains, from democracy promotion to science, in a format similar to a focus group. The aim of these assemblies is to increase the diversity of the voices heard during the policy-making process. Once it has completed its deliberation, the assembly produces non-binding recommendations, which can be linked to direct democracy through referenda.

As part of the *Bürgerrat* process, a citizens' assembly was organised on the topic of research and science. The assembly' purpose was to issue recommendations on improving – rather than increasing – society's participation in science, creating opportunities for society to influence scientific processes, and defining the measures needed to promote social participation. The assembly met seven times between November 2021 and March 2022 – a period that saw increased societal interest in science owing to the COVID-19 pandemic and the role of the STI community in managing the crisis.

Germany also has experience with bottom-up and open approaches to participatory policy making. As part of the Innovation Strategy for the City of Hamburg, the local authorities set a particular focus on inclusion and consultation in its approach to STI policy making (City of Hamburg, 2021[26]). Over 300 representatives from industry, research and higher education, cultural organisations and civil society were brought in and consulted from the beginning of the strategy development process. This allowed a wide range of stakeholders to provide input, and jointly identify priorities, objectives and initiatives.

16.5. Territorial and industrial inclusion in STI

16.5.1. Regional inclusiveness

Innovation expenditure is concentrated in Germany's southern states, where leading industries (such as the automotive and machinery industries) tend to be located (Figure 16.6). Many of these *Länder* are also the country's most populous, meaning that they offer significant opportunities for the innovative output of these industries to benefit local socio-economic well-being. The challenge is largely an intra-regional one: it is less about bringing down the country's most leading regions than about bringing up those that are lagging, so that they can make a larger contribution to inclusive growth.

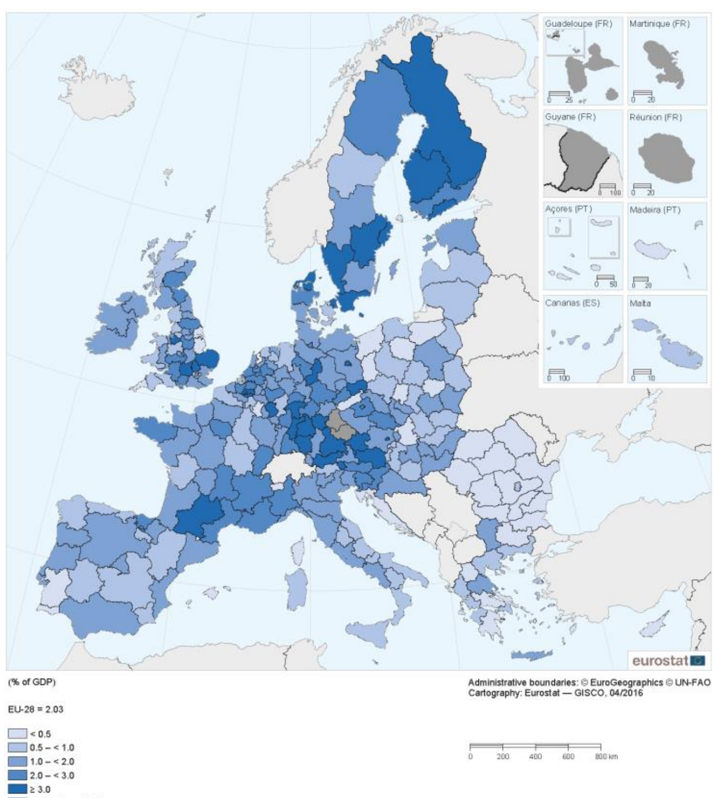
The uneven regional dispersion of R&I underscores the challenge of industrial path dependencies, their implication for the allocation of public research finance and the need to address regional divides. For example, the location of many of Germany's largest automotive manufacturers in top-performing states –

Munich (8.2% of European Patent Office patent applications), Stuttgart (8.2%), Frankfurt (4.2%), Düsseldorf (3.9%) – illustrates the extent to which the presence or absence of certain industries can determine a region's innovative success, and highlights the interconnectedness of innovation output and industrial location. In practical terms, the concentration of certain high productivity industries in a relatively small number of regions means that the gains are not evenly dispersed throughout the country.

The regional output of German innovation correlates strongly with the high geographical dispersion of the country's most innovative industries, which is nevertheless significantly lower than in other OECD countries. Germany does, however, have a lower geographical concentration in patenting among the top 10%, 5% and 1% of cities compared to key comparator economies such as Japan, the United States, the United Kingdom and France (Paunov et al., 2019[27]).

The gains and losses in the transformation of existing innovative industries, and the emergence of new ones, may correspond to existing regional inclusions divides and have implications on future territorial inclusiveness. Similarly, the issues discussed here relate to the uneven regional rollout of infrastructure investment necessary for an inclusive digital transition – which, if accelerated, could provide more opportunities for firms and entrepreneurs to become involved in innovation activities.

Figure 16.6. Gross expenditure on research and development (GERD) in Germany is concentrated in the southern states



Source: European Commission (2020[28])

The share of Germany's five most populous *Länder* (North Rhine-Westphalia, Bavaria, Baden-Wuerttemberg, Lower Saxony and Hessen) in GERD was 78% in 2017, largely linked to the location of the automotive sectors in these states and the network of SMEs that support them.

16.5.2. Industrial inclusion: The distributional effects of digitalisation and the green transition

The systemic diffusion of technologies such as AI and robotics will likely have significant consequences on labour displacement in existing industries, potentially making it harder for certain SMEs to participate in new areas unless they significantly upgrade their capacities. A 2021 study by the Federal Ministry of Labour and Social Affairs found that approximately 5.3 million jobs will disappear in the next 20 years (i.e. by 2040), while 3.6 million new jobs will be created (BMAS, 2021[29]). Although these findings integrate a range of issues other than just digitalisation, they are in line with OECD observations on the impact of technological transformations on the labour market. In addition to labour displacement through automation and digitalisation, Germany is likely to see labour-market challenges that will be compounded by the sustainability transition and an ageing population. A 2018 analysis of automation in OECD countries estimated that up to 18% of jobs in Germany are at high risk from automation, with another 36% at risk from significant disruption – one of the highest levels in the OECD (Nedelkoska and Quintini, 2018[30]).

The impact of digitalisation and the embedding of advanced technologies (such as robotics in manufacturing) will improve the efficiency of many private-sector firms but will cost jobs, although this may be offset by new jobs and higher productivity through the diffusion of these newer technologies (Aghion et al., 2020[31]). Labour markets are not perfect, however, and these labour-market imperfections may actually slow down the labour market's adjustment to automation, and weaken the diffusion of productivity gains and job creation. These challenges can be compounded by issues such as a lack of skills necessary to use these new technologies, the pace of digitalisation and automation, or (as argued by (Acemoglu and Restrepo, 2018[32])) the introduction of these technologies at the expense of other productivity-enhancing technologies (due, for example, to tax-code biases favouring investment in physical capital over human capital). The purpose here is not to argue against the diffusion of such technologies, but to note that their introduction can have socio-economic costs. STI policies should therefore be complemented by social and readjustment policies that support workers and firms during these transitions.

The "winner-takes-all" aspect of certain digital innovations can also compound social exclusion from technological progress. Furthermore, the skills necessary to succeed in the digital economy may disproportionately lock out certain groups and limit opportunities for firms of different sizes. Digital innovation in particular has several attributes that increase both inclusion opportunities and challenges. First, digital innovation is characterised by the "digital non-rivalry" rule governing one of its most important inputs – data. This means that data can be used by multiple users at any given time and can circulate at a very low marginal cost. In principle, therefore, location should no longer matter for innovation, as any person in any location should be able to participate (Guellec and Paunov, 2018[33]). The reality, however, is more complicated. The skills (e.g. coding) required to participate in digital innovation differ from those emphasised by the German education system. This means that the pool of people who are able to participate in digital innovation is smaller than it might be for other forms of industrial innovation. This dynamic is further complicated by the "winner-takes-all" aspect of digital innovation (due in part to the lower cost economies of scale and the resulting rentier economic models digital innovation can produce). The advantages derived from pooling data may reward large players, leaving little for smaller-sized firms. At the same time, the reduced scale of digital innovation activities may offer more opportunities. These combined factors therefore have significant consequences for social inclusion in digital innovation. As the transformation progresses, these effects should be assessed, and adjustments made to address critical inclusivity challenges. It also means that policy efforts aimed at building opportunities for *Mittelstand* firms and start-ups to participate in innovation processes create returns for social inclusiveness.

The sustainability transition will also have a profound impact on the current industrial composition of Germany's private sector, with related consequences for job creation and displacement. As noted in the 2020 OECD Economic Survey of Germany, although electric vehicles are simpler to manufacture than internal combustion engines (ICE) equivalents, many of the most valuable components (such as batteries and the semiconductors necessary for autonomous driving functions) are not yet manufactured in Germany. Achieving success in the sustainable transition – which would imply a larger uptake in electric vehicles – may therefore lead to a situation where fewer jobs are available in one of the country's most innovative industries (OECD, 2020[9]). A 2018 study by the Institute for Employment Research found that if 23% of new cars were electric by 2035 – the year the European Union will ban the sale of new petrol and diesel cars – then up to 114 000 jobs would be at risk and gross domestic product could decline by 0.6% (Mönnig et al., 2018[34]).

Owing to the geographically concentrated nature of mining regions, the push for industrial decarbonisation – and the related question of greening Germany's energy mix – will affect territorial inclusion. Just as the most innovative sectors in the German economy will be transformed by the sustainability transition, so too will the important network sectors – such as energy and transport – that support them. The sustainability transition will have a profound impact on these sectors, sometimes with asymmetrical socio-economic consequences. A notable example is the phasing out of coal in the German industrial mix. Germany's continued high levels of coal use for electricity production – the main reason the country has a higher per capita emissions output than other European OECD countries – is a major barrier to achieving the government's sustainability targets. Yet the mining of the lignite (brown coal) used in German coal-fired power generation is concentrated in some of the country's poorest regions, and the phasing out of coal production could harden existing territorial inclusion divides unless supported by social and labour-market policy interventions. A successful transition from the use of hydrocarbon energy sources to renewables, something which is a key policy goal of the government and a process in which the STI community must play an important role, will nevertheless involve a short-term social cost. Without appropriate social and economic policy interventions, this transition could engender long-term consequences for inclusion and wellbeing.

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GERMANY

BUILDING AGILITY FOR SUCCESSFUL TRANSITIONS

The COVID-19 pandemic and the Ukraine war have revealed vulnerabilities in Germany's economic model: undiversified energy supply, an over-reliance on fossil fuels, delayed digitalisation and disruptable supply chains. Digital technologies may significantly disrupt manufacturing industries Germany has dominated for decades, threatening future competitiveness. The green transition also requires significant industrial transformations. Germany can call upon one of the world's most advanced innovation systems in dealing with these challenges, but a new more agile and experimental approach to STI policy is needed. This Review outlines how to develop such an approach and what STI policies need to focus on: create markets for future innovations, more significant and more risk-tolerant finance for innovation, inter-disciplinary knowledge exchange, improved data infrastructure and capabilities. Given the internationally shared challenges of dealing with transitions, the insights presented in the review will be of interest to policymakers, stakeholders and analysts from Germany and across the OECD.

PRINT ISBN 978-92-64-31566-2
PDF ISBN 978-92-64-95887-6

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2022