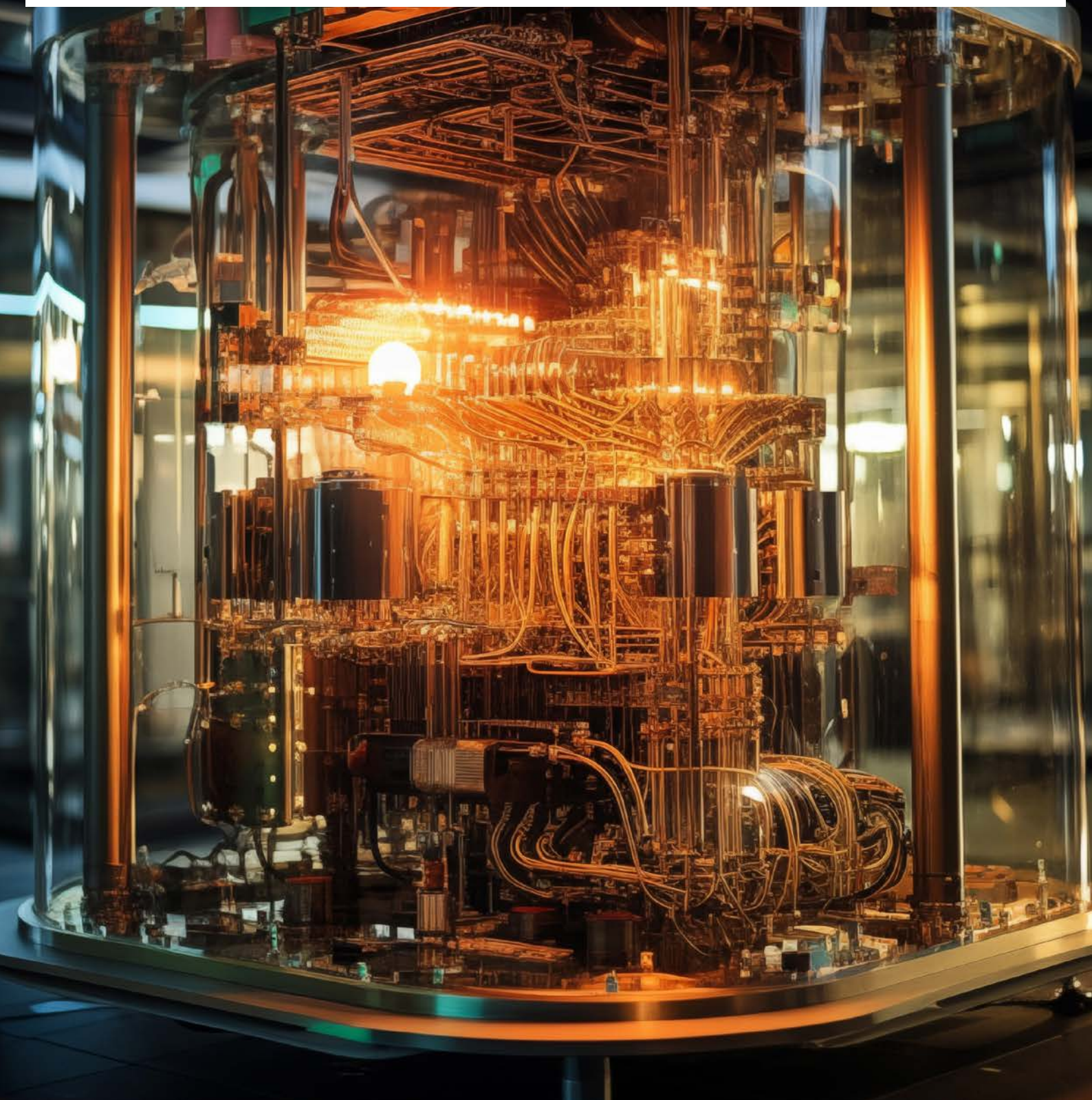
Federal Ministry
of Education
and Research

fits 2030
Forschung und Innovation für
Technologische Souveränität

Technological sovereignty for Germany and Europe

Framework programme: “Research and Innovation for Technological Sovereignty 2030 (FITS2030)”



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1. Abstract

With the present framework programme "Research and Innovation for Technological Sovereignty" (FITS2030), the Federal Ministry for Education and Research (BMBF) is placing existing funding approaches on a new footing. The framework programme is a central pillar of the Federal Government's Future Research and Innovation Strategy. It consistently implements its mission of "securing Germany's and Europe's digital and technological sovereignty and harnessing the potential of digitalisation" (Mission 4), pursuing goals regarding digital and technological sovereignty in the BMBF's area of responsibility. The BMBF wants to promote and create deep-tech innovation ecosystems in key technologies that take a comprehensive view of the entire spectrum of the science and innovation system, from basic research to the transfer of innovations. While Germany is already well positioned in basic research, the BMBF is using this approach to strengthen other components of healthy, innovative ecosystems, including the recruitment, training and mobilisation of skilled workers and the transfer of research results into application-oriented development, patents, marketable innovations and start-ups "Made in Germany". New centres and systems such as research factories, transfer bridges, the German Agency for Transfer and Innovation (DATI) and the new freedoms of the Federal Agency for Disruptive Innovation (SPRIND) are in place to take the application of research results in Germany to a new level.

FITS2030 is the BMBF's response to **a large wave of technological breakthroughs** that have already been achieved and are expected in key technologies such as artificial intelligence, quantum technologies, innovative materials and more.[1]

The economic potential of **artificial intelligence** (AI) is huge and wide-reaching. Repetitive tasks can be automated, and decision-making and business processes can be improved. Innovations are not only capable of transforming existing industries, but also creating completely new ones. At the same time, AI is revolutionising research itself.

Quantum technologies likewise offer impressive market potential.[2] This is based primarily on the expected exponential increase in computing power compared to conventional computers. The technology can solve complex problems in areas such as financial modelling, climate research and drug development that would not be possible with conventional computers.

Innovative materials create the basis for a resource-efficient circular economy and are essential for a technologically sovereign, resource-efficient economy. Those who invest in research and development in this area can achieve huge competitive advantages and revenues while reducing dependencies. Battery technologies for a sustainably electrified energy and mobility system demonstrate the leverage that can be gained through material innovations.

By **international standards**, Germany and the European Union (EU) are still in a good position. At the European, national and regional level, research on key technologies is already being funded in a variety of ways. However, other economic powers are investing significantly more and are pursuing a targeted strategy of strengthening their technological leadership in their strategic funding and location policies. Examples of this are ambitious plans such as "Made in China 2025", the US "Chips and Science Act" with a budget of USD 250 billion for technological research and development, or the US "Inflation Reduction Act" with around USD 370 billion.

1 The current list of key technologies funded by the BMBF can be found in **Chapter 2** "Introduction".

2 **mckinsey.com/de/news/presse/quantum-technology-monitor-2024**

For selected technology areas, the consequences are already being felt: In central technology fields such as quantum technologies and AI, the number of publications and patents in Germany is increasing in absolute terms. However, due to more dynamic landscape in countries such as China and the USA, the relative share of German publications and patents has decreased dramatically in the last ten years. For example, in the field of AI the share of the top 20 % of the most-cited publications in Germany fell from 6 % to 3 %, while the share of Chinese publications rose from 9 % to 25 % over the same period.

This trend poses a significant risk to the technological sovereignty of Germany and the EU.

Germany cannot and must not rest on its current positive ratings and rankings. The prevailing aspiration must remain to continue being a world market leader in innovative products such as computer programs, machine tools and electric mobility.

Since unilateral dependencies are problematic, especially in the case of key digital technologies, the BMBF is paying particular attention to this. Having said that, the key industrial technologies in which Germany has traditionally been strong must also be transferred into the future. The aim must be to be among the world market leaders in digital and industrial technologies such as machine tools and electric mobility.

One particular aspect of the added value of FITS2030 is the development of cross-technology solutions for tackling selected cross-cutting issues. Germany will only be able to hold its own in international competition in the long term if it produces sufficient numbers of **young scientists, skilled workers and new founders** who can help shape the technological transformation of the 21st century.

Standardisation during the development phase is an effective tool for scaling up and commercialising innovations more quickly and for implementing important technology policy requirements such as the safeguarding of civil liberties as well as the protection of consumers, data and the environment in technological development paths. BMBF funding is intended to improve the development of expertise and the participation of researchers in standardisation bodies.

An important pillar is the synergetic integration of the different funding approaches in Germany. This includes **basic institutional research**, technological project funding and the SPRIND and DATI transfer initiatives.

Strengthening **European and international cooperation** in the research and development of key technologies is also a central element of this framework programme. The EU's goal of asserting itself as an independent global player in selected technology areas "Made in Europe" requires joint European strategic action. The EU Chips Act, AI Act and other central areas in the context of European research funding are milestones of this policy. The European Commission and the EU member states must continue along this path. The aim is to work together with the best research partners worldwide while keeping an eye on our own sovereignty interests. The next important milestone will be the EU's Multiannual Financial Framework for 2028–2034 and, with it, crucial funding programmes such as the 10th EU Framework Programme for Research and Innovation. As a leading European nation in the field of technology, Germany must boldly lead the way with its own programme of technological sovereignty.

2. Introduction

New, powerful key technologies will permeate all areas of our lives in the coming years. They will entail enormous opportunities for progress in the fields of health, energy, food and sustainable development. This technological development, to some extent exponential in nature, is paving the way for fundamentally new forms of work and value creation.

The future prosperity of Germany and the European Union (EU) will largely be based on participation in these global developments, which are taking place in the fields of artificial intelligence (AI), data engineering, microelectronics, new materials, communication and quantum technologies, as well as new production technologies/Industry 4.0. A broad base of expertise in these fields of technology is a prerequisite for innovation and thus for a strong economy and high-quality jobs. It creates the conditions for overcoming societal challenges such as comprehensive decarbonisation, digitalisation and demographic change. The use of key technologies to serve and benefit people is a central aspect of policy design.

Box 1: What are key technologies?

There is no standardised definition for key technologies. They are sometimes also referred to as general purpose technologies or critical technologies. According to the definition of the Commission of Experts for Research and Innovation[3], key technologies are characterised by three features:

1. High potential for performance increases in a key technology itself and in its areas of application:
   Example: AI systems are currently doubling their performance every three months on average. The computing power of microchips has doubled every two years so far (Moore's Law). Meanwhile, a quantum computer is expected to be up to 100 million times faster than a conventional computer in selected fields of application in just a few years.

2. Wide applicability in a variety of technology areas or industries
   Example: The transformation of the automotive industry towards software-defined vehicles and electric mobility is an example of the broad penetration of German industry by key digital and industrial technologies. Their integration will be crucial for the future viability of German industry.

3. Strong, irreplaceable complementarity to a multitude of other technologies
   Example: Innovative materials characterise the functionality of almost all objects in our environment, from battery-powered lawn mowers to all types of digital tools.

This also creates great potential at the interfaces of key technologies; they multiply in their results. Artificial intelligence, for example, is a tool that can be used to dramatically increase the effectiveness and efficiency of a wide range of scientific disciplines. In turn, progress in AI would be inconceivable without the development of the computing power of the latest supercomputers, which are based on highly integrated microelectronics. Key technologies are research-intensive and characterised by a high demand for capital in their development and application.

A research and innovation policy that is open to technology and that explores different paths of technological change in science and industry without prejudice requires a broad base of expertise in all key technologies.

2.1 Strengthening technological sovereignty, avoiding unilateral dependencies

Germany is integrated into complex international science, technology and value networks. As a high-tech trading nation, it is particularly dependent on stable supply chains and secure foreign trade conditions. The Covid-19 pandemic made it clear, if we needed any further proof, just how fragile international relations can be. Germany has also been strongly reminded of the consequences of unilateral dependencies on other states or market-dominating companies abroad by Russia's war of aggression against Ukraine. In terms of research and innovation policy, it is therefore clear that Germany and Europe must continue to be able to shape the development and application of technologies internationally on an equal footing and in line with our liberal-democratic values. In order to avoid being controlled by others, for instance in security-critical technologies, Germany and the EU must remain a central global player in the design of key technologies in this decade with technology-oriented research and innovation. We need to maintain and expand our technological sovereignty. This will not only strengthen our competitiveness and social resilience, but also the defence capabilities of Germany and the EU.

3 Commission of Experts for Research and Innovation (Expertenkommission Forschung und Innovation - EFI) (2022): Report on Research, Innovation and Technological Performance in Germany 2022

Box 2: What is technological sovereignty?

"Technological sovereignty is the ability to guarantee access to those key technologies that are necessary to implement societal priorities and needs at all times. This includes the use and further development of technologies and products, taking into account available resources and necessary services, making gaps visible and closing them where possible, and helping to set standards in global markets.

Technological sovereignty may also require the independent development of key technologies and technology-based innovations in Europe and the establishment of own production capacities within the value networks, if this is necessary to maintain the state's ability to act or to avoid unilateral dependencies, taking into account changing geopolitical boundary conditions. This requires the ability to understand and evaluate all relevant technological development and manufacturing processes, and the ambition to work on an equal footing with strategic partners."

Definition of the Council for Technological Sovereignty (2023)

In line with the definition of the Council for Technological Sovereignty, the BMBF conceives digital and technological sovereignty as the ability to understand and master key technologies, to transfer them into applications and innovations and also to build up a critical level of independent production capacities and the necessary base of skilled workers if this is necessary to maintain the ability to act or to avoid unilateral dependencies. Technological sovereignty also includes the ability to formulate requirements for technologies, products and services in accordance with liberal-democratic values, as well as to have a say in setting standards on the global markets. This also includes promoting the development and advancement of digital skills as well as an open and trusting data culture overall. Furthermore, greater attention must be paid to research security requirements in international R&D collaborations.

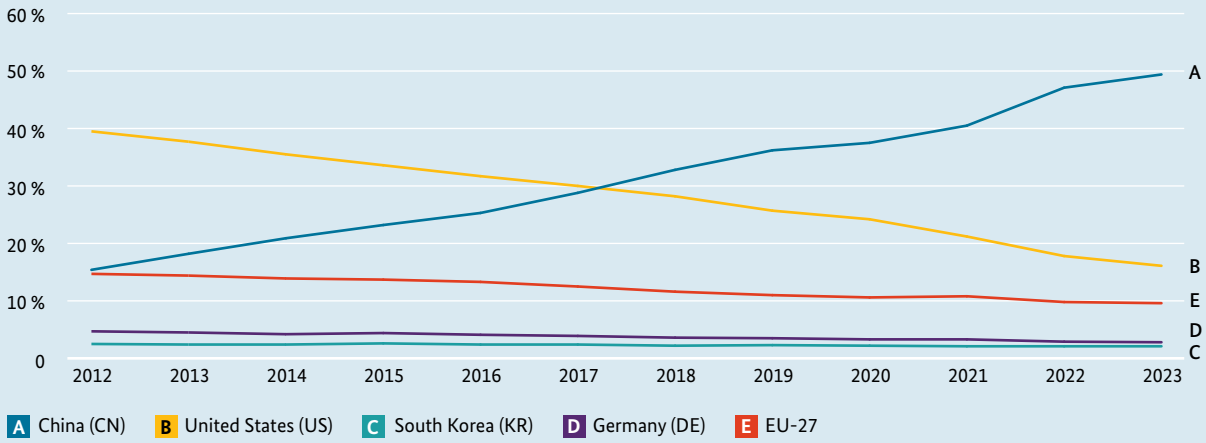
Since Germany or the EU cannot achieve digital and technological sovereignty equally in all areas of technology, it is also a matter of developing a strategy to maintain a balance of mutual dependencies. The aim is to optimise basic skills and focused technological specialisations. Technological sovereignty does not mean isolation or autarky, but rather competent and informed cooperation on an equal footing that ensures access to key technologies at all times and is aware of, and reduces, the risks of unwanted expertise leakage. The concept of Germany's technological sovereignty is to be seen as a contribution to a closely interwoven, prosperous European innovation and economic area based on the division of labour. It does not question Germany's open global economic and scientific relations. Division of labour, networking and multilateral cooperation are central building blocks for Germany's, and Europe's, ability to shape global developments according to their own ideas and interests, while upholding liberal-democratic values.

2.2 Strengthening Germany's global technological position

Germany and Europe must achieve technological sovereignty in an increasingly fierce competition for knowledge and skills and the dominant business models based thereon. The EU's Science, Research and Innovation Performance Report (SRIP) 2022[4] states that the EU is still a "R&D powerhouse" in a global comparison across all fields of science and technology: Although the EU produces around 10 percent of the world's scientific and technological output with only 7 percent of the world's population, the position of the EU and the US in the global technology race has shifted sharply in favour of China in recent years. China is now the world leader in terms of the volume of high-quality scientific publications (see **Figure 1**). Both the US and China are expanding their national R&D investments at a rapid pace. Germany and Europe, on the other hand, are falling behind.

4 research-and-innovation.ec.europa.eu/strategy/support-policy-making/support-national-research-and-innovation-policy-making/srip-report_en

Figure 1: Shares of the top 20% of the most-cited publications of relevant research institutions relating to key technologies



Source: Prognos (2024): Own calculation based on OpenAlex, as of June 2024

Within Europe, Germany is generally well positioned. In 2022, Germany came first in the EU's Sovereignty Index[5] of Member States, but fell back to 11th place in the ranking of technologies, just above the EU average. As the largest and most powerful economy in the EU, Germany only ranked fifth in terms of its contribution to Europe's economic sovereignty. This is due in particular to Germany's dependencies on Russia and China.

In the Global Innovation Index (GII) 2024[6] of the World Intellectual Property Organization (WIPO), Germany remains in the top 10 of the 133 economies considered in 2024. Germany continued to perform well in the areas of human capital and research as well as creative outputs (5th place in both). It lagged behind in the areas of "business sophistication" and institutions (19th place in both) and, in particular, in infrastructure, where Germany only came in 27th place.

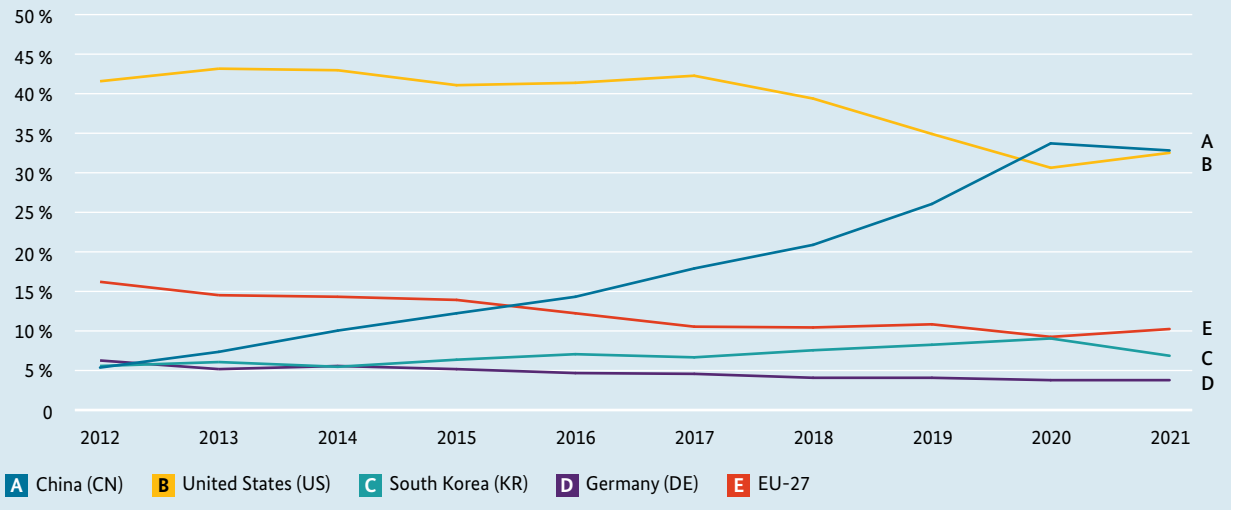
In the Innovation Indicator, leading German economic research institutes rank Germany's technological performance in the field of key technologies in 7th place among a group of 35 leading economic nations. To do this, they analyse a broad set of science and technology indicators. Here, too, Germany has lost ground in recent years; the investment dynamic in key technologies is higher in other parts of the world.

Calculations commissioned by the BMBF show a negative trend for Germany and the EU in global science and innovation competition for key innovation indicators in the area of key technologies[7] over the last ten years. Specifically, Germany's share of the most important global publications on key technologies fell from 4.7 percent in 2012 to 2.8 percent in 2023 (EU-27: from 14.7 to 9.6 percent; see **Figure 1**) and in the most important patents from 6.3 percent in 2012 to 3.8 percent in 2021 (EU-27: from 16.3 to 10.3 percent; see **Figure 2**). These relative losses (up to 40 percent) also affect other scientific nations, such as the USA, and are mainly due to the concurrent increase in the importance of the achievements of the Chinese innovation system. A glance at foreign trade in physical goods reveals a smaller decline in Germany's share of global exports of key technologies from 5.7 percent (2012) to 4.7 percent (2022) (see **Figure 3**).

5 ecfr.eu/special/sovereignty-index
6 Global Innovation Index 2024 (wipo.int)

7 These calculations were based on publications, patents and trade goods for the following fields of technology: advanced manufacturing, cyber security technologies, data technologies, energy storage, communication technologies, artificial intelligence, microelectronics, nanotechnology, new materials, photonics, quantum technologies, robotics.

Figure 2: Shares of the top 20% of the most-cited PCT patents relating to key technologies of selected countries from 2012 to 2021



Source: Prognos (2024): Own calculation based on Patstat, as of June 2024

All this shows the need to strengthen key technologies and the innovations that build on them. Germany continues to be internationally competitive, especially together with its EU partners. However, this position must be secured and built on in order to keep pace with rapidly growing nations and future-relevant fields of technology.

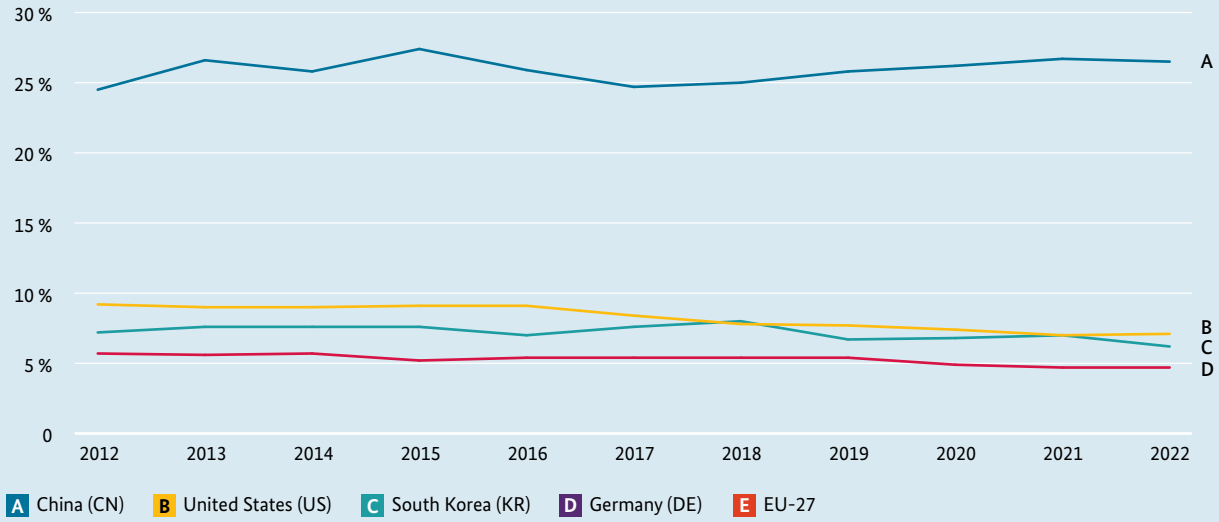
The danger is there, because according to analyses by the Council for Technological Sovereignty[8], nation states around the world have never before invested so much in the promotion of key technologies. The intersection of the technology fields considered to be key technologies is very large. Numerous countries have launched major programmes to promote these technologies in the last two years. In all these initiatives, a wide range of interventions in research and development funding, industrial policy, subsidisation of company relocations and the design of framework conditions overlap and are difficult to separate.

In particular, Chinese research and innovation policy aims to achieve global dominance in key technologies in the coming decades. The Chinese investment programme "Made in China 2025", for example, aims to significantly strengthen the innovative capacity and industrial production capacities of ten domestic core industries in the country, including information technology and energy supply, by 2049. Strong growth in publications, patents and the share of world trade in key technologies underlines the success of this strategy.

Semiconductors have become a symbol of the global struggle for technological dominance. The US has committed to investing USD 280 billion in chip manufacturing and research over the next ten years, while China is providing USD 145 billion in subsidies and the EU has passed its own law to promote chip production in Europe to the tune of EUR 43 billion.

8 Council for Technological Sovereignty (2024): Focus on Critical Technologies – The Race for Leadership in Industry and Technology Policy: "Technological sovereignty" in an international comparison

Figure 3: Shares of global exports of physical goods relating to key technologies of selected countries from 2012 to 2023



Source: Prognos (2024): Own calculation based on Comtrade, as of June 2024

2.3 Setting the course and prioritising

Securing technological sovereignty is an overarching goal of the entire Federal Government. It encompasses various areas, from education and research policy, the provision of the necessary infrastructure and services of general interest, health, climate and environmental policy, to financial and industrial policy measures. The BMBF is primarily responsible for contributing to solutions in the fields of education and research policy.

Box 3: Council for Technological Sovereignty

At the end of 2021, the BMBF appointed the Council for Technological Sovereignty to support its research and innovation policy work. It is composed of experts from science and industry whose expertise covers the spectrum of key technologies.

The Council for Technological Sovereignty advises the BMBF on cross-technology foresight and on identifying technology fields of long-term strategic importance. To this end, it analyses the potential of science and industry in various fields of technology, as well as the interactions between the technologies. On this basis, the Council members develop recommendations for the BMBF that aim to sustainably strengthen the most relevant technologies and cross-cutting topics and secure the technological sovereignty of Germany and Europe. The Council for Technological Sovereignty was involved in the development of the present framework programme on several occasions and provided the BMBF with valuable input.

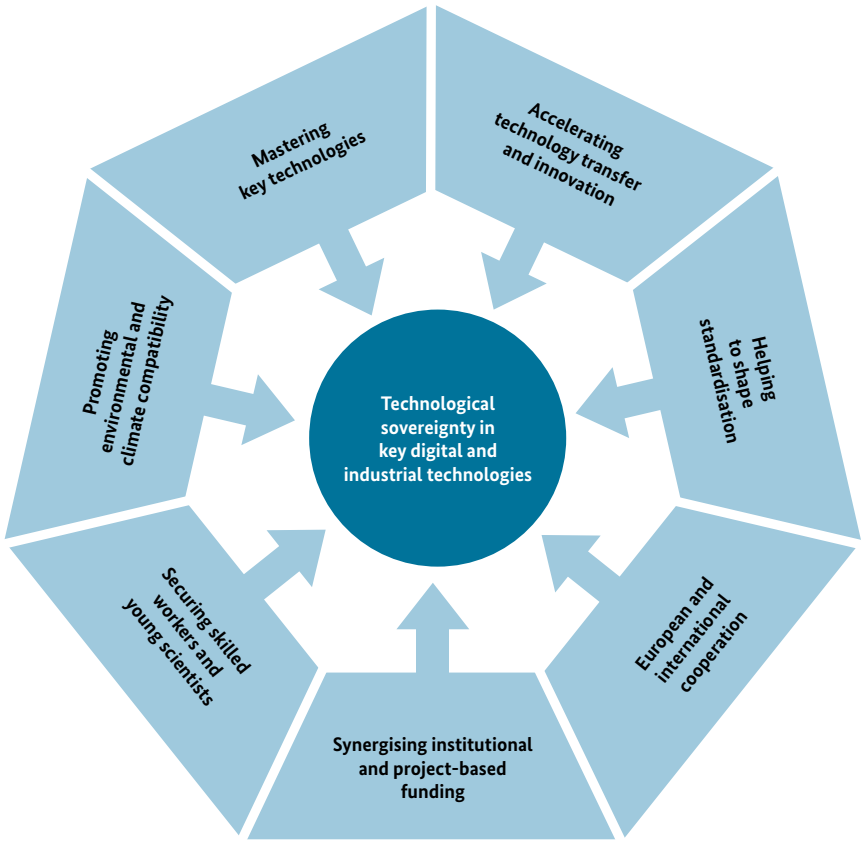
Further information and publications of the Council are available at **bmbf.de/rat4ts**.

Box 4: The Federal Government's Future Research and Innovation Strategy ("Zukunftsstrategie")

The Future Research and Innovation Strategy is the Federal Government's overarching, cross-departmental strategy for research and innovation. The implementation of the six missions of the Future Research and Innovation Strategy is coordinated by cross-departmental mission teams. Each mission team of the Future Research and Innovation Strategy is supported by three mission patrons from the Forum #Zukunftsstrategie. Representatives of the Council for Technological Sovereignty are involved. The Forum #Zukunftsstrategie is the central independent advisory body of the Future Research and Innovation Strategy. It comprises over twenty individuals from business, science and civil society. This framework programme primarily implements the goals of Mission 4, "securing Germany's and Europe's digital and technological sovereignty and harnessing the potential of digitalisation".

Because technological sovereignty is so relevant to Germany's future prosperity and security and to overcoming global challenges, the Federal Government, under the leadership of the BMBF, has made it a prominent part of its Future Research and Innovation Strategy under Mission 4, "securing Germany's and Europe's digital and technological sovereignty and harnessing the potential of digitalisation". This goes hand in hand with the clear claim and goal that Germany and the EU should be able to act with political and technological sovereignty in selected fields of technology.

Figure 4: Target areas of the BMBF framework programme Research and Innovation for Technological Sovereignty (FITS2030)

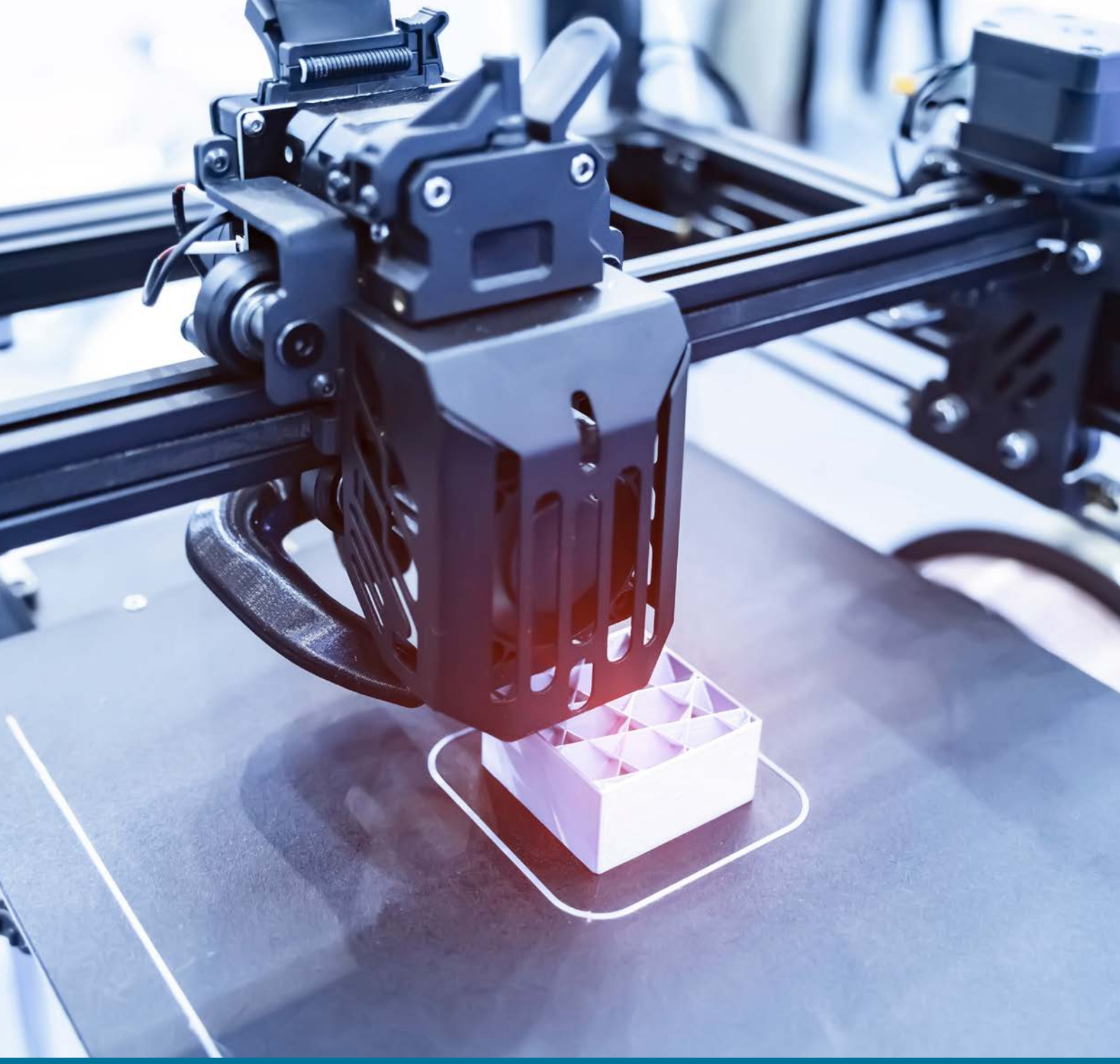


With this framework programme "Research and Innovation for Technological Sovereignty", which formulates a mandate for action initially until 2030, the BMBF is fleshing out Mission 4 of the Future Strategy in its area of responsibility. Beyond FITS2030, other missions of the Future Research and Innovation Strategy – implemented in corresponding framework and research programmes – also contribute to strengthening technological sovereignty (see **Box 5** for an example). At the heart of the BMBF's activities to strengthen the digital and technological sovereignty of Germany and the EU is the funding of innovative and excellently networked deep-tech innovation ecosystems. FITS2030 combines research funding measures, the funding of ecosystem infrastructures, support for innovation capacity and the strengthening of young talent in key digital and industrial technologies – including artificial intelligence and software engineering, microelectronics and high-performance computing, communication systems and cyber security, quantum technologies and photonics, materials and battery technologies, and robotics and Industry 4.0. This selection of key technologies is in line with Mission 4 of the Future Strategy. Individual funding programmes have been presented for all topics. Measures for open-topic innovation funding – such as validation funding, the Federal Agency for Disruptive Innovation or transfer bridges – and highly interdisciplinary applications of key digital and industrial technologies – such as in civil security research – go beyond the key technologies mentioned (see **Chapter 3.3**). And last but not least, the work on cross-cutting topics (see **Chapter 3.4**) is intended to develop solutions that can also be useful for other technology areas. **Figure 4** visually illustrates the different target areas of FITS2030.

Box 5: The BMBF funding biotechnologies

Biotechnology is a key technology as defined in **Box 1**. It is anchored in Missions 1 and 3 of the Future Research and Innovation Strategy and promises significant contributions to solving problems facing society as a whole, such as climate change, food security and health, and is a central building block for the transition from a fossil-fuel-based economy to a resource-efficient, climate-friendly circular economy. Biotechnological applications are strongly research-driven and require continuous investment in the research and development of innovative and future-oriented solutions. The technology field benefits from ongoing digitalisation, the use of big data and the use of AI methods. The BMBF funds biotechnologies across the board and in their entirety, whether "white", "red" or "green". This ranges from research into active ingredients and the production of biogenic fuels to new genomic processes and breeding techniques for the plants of the future. The Federal Government's Future Research and Innovation Strategy and the National Bioeconomy Strategy provide the framework for this.

Further information:
go-bio.de/gobio/en/home/home_node.html, biooekonomie.de



3. Our vision: securing the technological basis for tomorrow

Technological development at the highest international level is like a marathon. The BMBF's activities are summarised in technology-specific research funding programmes. In the context of funding for key technologies, ground-breaking innovations have already been developed in recent years that have successfully found their way into the market and into socially important applications (**Box 6**). The goal of the BMBF's research and innovation policy is the long-term development and expansion of cutting-edge research and expertise in key technologies at a world-leading level, as well as the transfer of inventions into applications.

Box 6: Ten funding successes of the BMBF relating to key digital and industrial technologies

Software for industry: ARAMiS, a BMBF-funded consortium of renowned research institutions, leading industrial companies, and software and tool manufacturers, developed a planning and control system for applications in the automotive and aviation industries as well as for Industry 4.0. The software can be found in numerous products worldwide.
aramis2.org

EUV lithography: Many years of BMBF funding enabled the breakthrough of so-called extreme ultraviolet lithography, the decisive technology for the production of the most modern chips for computers and mobile phones.
Team 1 – 2020 | German Future Prize (Deutscher Zukunftspreis, deutscher-zukunftspreis.de/en)

Quantum computer at the high-performance computing centre: In June 2024, a quantum processor was connected to a high-performance computer for the first time at the Leibniz Supercomputing Centre LRZ in Garching – a milestone for quantum computing in Europe. The processor was developed by the BMBF-funded Finnish–German start-up IQM Quantum Computers.
quantentechnologien.de/forschung/foerderung/quantencomputer-demonstrationsaufbauten/q-exa.html

Glass components from a 3D printer: A group of young researchers developed the material "Glassomer", which can be used to produce delicate and transparent glass components for the first time using an injection moulding process and 3D printing that is suitable for mass production. The process is successfully used for camera lenses, spectacle lenses, in chip manufacturing and medical technology.
glassomer.com

Lower-emission concrete production: As part of the "KMU-innovativ" (innovative SME) funding programme, the UltraBePro project was the first in the construction industry to scale up the physical activation of the cement hardening reaction using ultrasound to an industrial production level. A 30 % reduction in CO_2 was confirmed during the construction of the maintenance plant for ICE4 trains in Cottbus.
sonocrete.com

Body scanner for security checks: Researchers, with the help of security staff, developed a contactless full-body scanner that uses harmless millimetre-wave technology to make security checks in security gates faster, more effective and more comfortable. It is used at airports in Germany, Europe and worldwide.
sifo.de/qpass

Autonomous driving: UnicarAgil, a BMBF-funded consortium of German cutting-edge research institutions and companies, developed completely new vehicle structures, innovative sensor technology and software. This created a basis for the development of driverless vehicles in the German automotive industry.
www.unicaragil.de/en

An app that saves lives: The KATRETTER app allows emergency services to actively request assistance from voluntary first-aiders in the event of an emergency (e. g. cardiac arrest) if they are in the immediate vicinity of the scene. In the first two years since the app was launched, almost 2,000 patients in Berlin alone were resuscitated by first-aiders activated via KATRETTER before the ambulance service arrived.
sifo.de/ensure

Innovative light sheet microscope: From the BMBF-funded projects "3D Super Resolution" and "nanoSPIM: Gentle high-resolution fluorescence microscopy of living cells with freely adjustable light sheet", Carl Zeiss Microscopy GmbH from Jena developed a microscope that for the first time allows live and 3D observation of living cells over a period of days without damaging them.
deutscher-zukunftspreis.de/en/federal-president-awards-deutscher-zukunftspreis-2022

mRNA technology: In the "Cluster for Individualised ImmuneIntervention (Ci3) e. V." (2012–2017), the Mainz-based company BioNTech benefited from its targeted integration into BMBF funding at an early stage. Today, BioNTech is one of the world's leading companies in cancer immunotherapy and vaccine development, and is a partner in the next generation of regional innovation networks.
Cluster for Individualized Immune Intervention (Ci3) e. V.

The thematic programmes for research and innovation funding are guided by the idea of innovative ecosystems. Deep-tech innovation ecosystems cover the entire innovation chain from basic research to application in research factories and experimental spaces. Their task is to look at research and innovation fields as a whole and to launch initiatives that leverage potential, limit deficits, overcome institutional or regulatory rigidities and reduce barriers. The most important instrument here is pre-competitive project funding in transdisciplinary consortia to network researchers with users. But support is also provided for infrastructure development, start-up incubator programmes, the co-design of technology regulation, student exchange programmes and other tools. The measures build on the strong basic and application-oriented research conducted by universities and non-university research institutions (MPG, HGF, WGL, FhG) in Germany. The approaches of the thematic programmes are changing: in an early, very basic phase of a technology, the primary focus may be on scientific excellence; in a later phase, it may be on the rapid diffusion of knowledge into industry and society.

Since technological sovereignty can only be achieved with more researchers at the top and more users at the bottom, the recruitment and training of skilled workers and the promotion of young scientists are an integral part of the funding.

Box 7: Technology foresight and technological convergence

In order to expand its orientation knowledge, the BMBF has reorganised its overarching foresight process and is now focusing on key technologies. The process includes both continuous technology monitoring and the use of data-based analyses for the early identification of trends or convergence developments in the field of key technologies. The aim is to provide evidence-based information for setting new priorities. The BMBF-wide and cross-technology foresight process is complemented by technology-specific foresight activities within the thematic research programmes. Opportunities and risks for Germany and Europe are to be identified in dialogue with the Council for Technological Sovereignty and in consideration of international reference recommendations such as the Organisation for Economic Co-operation and Development's (OECD) Framework for Anticipatory Governance of Emerging Technologies.

One such trend is the biologisation of technology. This emerging future trend at the interface between biology, materials science as well as production and information technologies involves the transfer of biological knowledge and principles to technical systems. The technology describes how the potential of natural processes and nature itself can be used for resources, procedures, processes or principles in industrial applications.[9] More efficient material synthesis and self-repairing or self-adapting materials are just a few of the future applications. The biologisation of technology is paving the way for bio-intelligent value creation, a fascinating symbiosis of biological and technical systems with information systems – which ultimately aims to achieve the convergence of bio-, hard- and software.

9 Acatech (2019): Materials Research: Inspired by Nature. Innovation Potential of Biologically Inspired Materials

Box 8: The German National Research Data Infrastructure (NFDI)

To improve the accessibility and quality of research data in Germany, the BMBF and the federal states are funding the development and operation of the NFDI, initially until 2028. In the NFDI, valuable data from science and research is systematically indexed, linked and made available for long-term and high-quality use by the entire German research system. The FAIR data principles are also applied here, according to which data should be made available in a findable, accessible, interoperable and reusable manner. More than 400 universities, research institutions, data centres and research museums are working on the development of the NFDI in 26 specialist consortia and a consortium network that is to develop basic services for all consortia. The activities are coordinated by the office of the non-profit organisation National Research Data Infrastructure (NFDI) e. V., based in Karlsruhe. The NFDI is also involved in setting up the European Open Science Cloud, the Europe-wide network of infrastructure services that provide access to research data and services.

3.1 Key digital technologies

Key digital technologies are the tools for tomorrow's world. They are the basis for numerous applications and products that are changing and facilitating people's lives worldwide at an ever-faster pace. In a modern society, digitally and technologically sovereign, self-determined action as a whole can only succeed if skills are developed and the basis for this is laid in the individual fields of technology. A large proportion of current key technologies are digital. Hardware and software, as well as digital infrastructure such as mainframe computers and data economics, must be addressed as a whole. The boundaries between individual digital technology fields are fluid, and this is also increasingly the case between industrial and other key technologies. The main focus is on the deep-tech aspects of digitalisation, such as in the field of quantum technologies, microchips and AI algorithms. Individual processes and fields of knowledge in which Germany is a leader will be specifically integrated into the funding.

3.1.1 Artificial intelligence

Artificial intelligence (AI) is a key technology that is changing economies and societies worldwide. The BMBF has been a driver of AI development in Germany and Europe for many years. Research funding in the field of AI goes back more than 50 years; the German Research Center for Artificial Intelligence (DFKI) was founded as early as 1988. The Federal Government's AI strategy and its updates are driving important initiatives in the areas of research, "minds" and skills, infrastructure and transfer. This will create an excellent basis for AI research and the training of AI specialists in Germany for years to come. Since Germany lacks

strong AI companies, an AI ecosystem is particularly important to avoid being left behind.[10] Beacons of this ecosystem include, in particular, the AI competence centres, the AI service centres, 150 newly created and filled AI professorships, over 40 AI junior research groups, and application hubs in the areas of production, health and the circular economy.

With its AI action plan, the BMBF is offering new ideas and inspiration in the coming years against the background of highly dynamic technological development and new challenges, such as those arising from the AI Act. The focus is on three areas: Firstly, the central elements required for AI development and use will be further strengthened in a targeted manner. This includes the expansion and accessibility of data and computer infrastructure, the development of expertise and the training of AI specialists, and an excellent research base at the cutting edge of technology. Secondly, the European AI Alliance is to be sought in an even more targeted manner, and to this end, coordination within the European Research Area is to be stepped up. Thirdly, attention is being paid to accelerating the implementation of AI in regards to specific economic and social benefits: this includes both the transfer to fields of application such as robotics, climate research, health, and vocational and academic education, as well as the targeted funding of AI start-ups and the use of AI in SMEs.

Further information:
softwaresysteme.dlr-pt.de/de/kuenstliche-intelligenz.php

3.1.2 Software engineering

Software determines the range of functions and thus the performance of today's technology products and accounts for the largest share of value creation in many industries. Safety-critical systems and infrastructure in particular require reliable software. For technological sovereignty, the skills and expertise required for producing and evaluating high-performance software systems are indispensable. However, there are only a few software companies in Germany; often, developments are driven by the user industry itself. Overall, non-European actors dominate the field: in 2022, US companies accounted for around three quarters of all global R&D spending in the software sector.[11] In this competitive environment, the BMBF has, through its research funding, laid the foundations for developing software in Germany using modern methods and efficient and reliable software development tools. The V-Modell XT – the basic software development methodology and process model for IT development projects in the Federal Republic of Germany – is based on research funded by the BMBF. The fields of application range from embedded systems for Industry 4.0 and the Internet of Things to high-performance computing. In addition, funding is provided to the open-source community (through Software Sprint) and competence development (through Software Campus).

The development of expertise in software engineering, support for open-source approaches and the further development of methods and tools are also the central pillars of research funding until 2030. One focus here is on new challenges arising from the growing complexity of systems, for example due to the advance of networking (so-called "systems of systems") or their adaptivity, for example through AI. To this end, the BMBF will continue and expand established formats such as Software Campus and Software Sprint, further advance the transfer of methods, tools and expertise to important fields of application and to SMEs, and accelerate its strategy process with a view to new challenges and solutions.

Further information:
softwaresysteme.dlr-pt.de

10 **ifo Schnelldienst 04/2024: Innovations in Germany and the EU – The way of strength?**, p. 21

11 **ifo Schnelldienst 04/2024: Innovations in Germany and the EU – The way of strength?**, p. 9

3.1.3 Microelectronics

Microelectronics is a driver of digitalisation and necessary for a wide range of applications, from autonomous vehicles, intelligent production and medical technology to telecommunications and energy technology. In an international comparison, Germany is only in a leading position in some sub-areas, such as electronics for industry and in the automotive area.[12] With a share of around 3 percent of global chip production, Germany is so far only a minor player. However, the establishment of new chip factories in Germany and Europe offers new opportunities for a substantial gain in technological sovereignty by 2030.

By 2030, the BMBF will have taken advantage of the opportunities provided by the EU Chips Act to significantly expand expertise in chip design in Germany and to strengthen the base of skilled workers in microelectronics in a targeted manner.

The BMBF will significantly expand the transfer "from lab to fab" through European projects and pilot lines under the EU Chips Act. With its design initiative, the BMBF is prioritising a vibrant open-source ecosystem for chip design. The initiative will also introduce universities and students to the topic. As part of a major skilled labour project, the BMBF is creating new content and formats for training and continuing education, which will also benefit from access to the infrastructure of the microelectronics research factory.

Further information:
elektronikforschung.de

3.1.4 High-performance computing

High-performance computing is an integral part of numerous research fields: for example, in energy research, materials and life sciences, climate research and even AI research. High-performance computing (HPC) is a critical factor for the success of Germany as a centre of science and research. In international comparison, Germany has good access to high-performance computing resources, but the field is developing very dynamically.[13]

In its "High-Performance and Supercomputing for the Digital Age" programme, the BMBF is therefore funding the long-term expansion, operation and networking of high-performance computing, particularly in the Gauss Centre for Supercomputing (GCS) and in National High-Performance Computing Network (NHR). This will create the conditions for sustainable and powerful data technologies, applications and scientific innovations. With its funding of NHR, the BMBF – together with the federal states – is providing computing capacities for scientific research at universities that cover the entire country and meet demand.

In 2030, Germany should still be the leading location in Europe for high-performance computing, both in terms of computing capacity and expertise in the use of supercomputers. The BMBF will expand the computing capacity of the GCS into the exascale range, also in conjunction with the European initiative EuroHPC. One focus will be on computers that are also suitable for computationally intensive AI applications such as training large language models. The BMBF will also create further opportunities for users to acquire the skills to use supercomputers effectively and efficiently.

Further information:
gauss-centre.eu, nhr-verein.de/en

3.1.5 Communication systems

Communication systems are the nervous system of a hyper-connected society. They permeate all areas of life and all fields of technology and are a key driver of innovation and an essential prerequisite for successful digitisation. Germany and Europe are well positioned in the field of mobile and fibre-optic technologies.[14]

12 Microelectronics – Analysing the trends up to 2025, ZVEI, 2021

13 TOP500 List – June 2024 | TOP500

14 bmbf.de/SharedDocs/Publikationen/de/bmbf/5/31677_Souveraen_Digital_Vernetzt.pdf

However, the enforcement of essential societal priorities – such as sovereignty, sustainability and trustworthiness – requires an ever deeper understanding of communication technologies.

The aim of the BMBF funding is to establish a strong German and European innovation ecosystem for future communication technologies by 2030. The aim is to reduce existing dependencies in the supply chains for electronic components and devices, for example in the area of critical infrastructure. In addition, a joint design of relevant technology standards is to be achieved in cooperation with international partners.

The BMBF's current funding priority is research, development and preparation for the upcoming 6th generation of mobile communications (6G). It is foreseeable that 6G mobile communications will change the way we handle data – for example, in the trusted exchange of data, distributed data processing in AI systems and the secure connection and control of intelligent robotic systems. From 2025, the BMBF will focus on the transfer of research results into socially relevant applications and economic benefit, as well as the value-oriented co-design of a global 6G standard with the help of a 6G roadmap.

Further information:
forschung-it-sicherheit-kommunikationssysteme.de/forschung/kommunikationssysteme

3.1.6 Cyber security

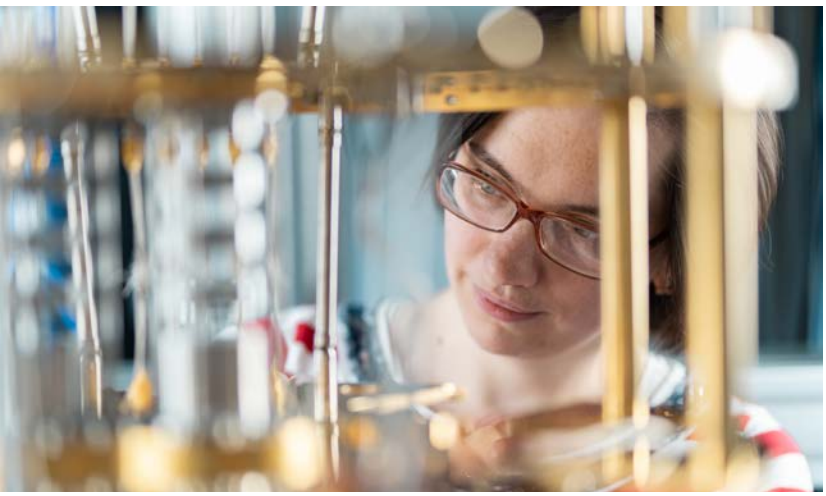
According to Bitkom, cyberattacks cost the German economy over EUR 200 billion in damages every year.[15] Developments in technology areas such as artificial intelligence and quantum computing bring with them not only great opportunities but also further potential threats from cyberattacks. Research into cyber security is essential to shaping a free and self-determined digital future in Germany, maintaining democratic structures and strengthening European values.

The BMBF's goal by the end of the decade is for Germany to play a leading role in shaping a secure digital world based on liberal and democratic values, and to achieve a higher level of immunity and resilience against cyber threats through fundamental and disruptive innovations.

BMBF funding will help to secure critical infrastructure, make AI systems secure and comprehensible, enable confidential communication in the quantum age, guarantee privacy and data protection, and effectively and efficiently ward off cyberattacks, digital manipulation and disinformation. This is supported by start-up incubators and start-up funding, which should help to bring research results to market faster.

Further information:
forschung-it-sicherheit-kommunikationssysteme.de/forschung/it-sicherheit

15 bitkom.org/Presse/Presseinformation/Organisierte-Kriminalitaet-greift-verstaerkt-deutsche-Wirtschaft-an



3.1.7 Quantum technologies

Quantum technologies are a future-oriented field with disruptive potential and high global momentum. Quantum computing, quantum communication and quantum sensors open up numerous new opportunities for the economy and society. Germany is well positioned in this field in an international comparison[16] – with world-renowned, cutting-edge research and an innovative landscape of companies and institutions that has developed in recent years on the basis of strong funding from the Federal Government.

By 2030, the BMBF will have helped to make Germany and Europe global leaders in innovation in quantum technologies. The goals are to achieve a leading international position in the development and use of quantum computers and quantum sensors, and to establish high-performance infrastructure for secure communication.

With its funding initiatives, the BMBF is promoting the development of quantum computers and their use by the end of the decade. Measures address the technological foundations as well as infrastructures for pilot production and applications of quantum computers in the fields of simulation, optimisation or machine learning. In quantum sensor technology, the BMBF is funding flagship applications in medical technology, production and logistics to pave the way for broad industrial use. In quantum communication, the BMBF's measures are aimed at technologies and overall network architectures for secure communication systems. Dedicated measures for start-ups, for promoting talent and for international cooperation with value partners support the development and expansion of strong innovation ecosystems with research and industry.

Further information:
quantentechnologien.de

3.1.8 Photonics

Germany is one of the world's leaders in photonics. In 2022, around a thousand German photonics companies with more than 190,000 employees generated a turnover of over EUR 50 billion, with an export rate of 73 percent.[17] This success is the result of close cooperation between science, research-based companies and users.

The aim of BMBF funding until 2030 is to further strengthen this cooperation and to maintain and expand Germany's leading position in photonics. The aim is to successfully shape the transformation to integrated and digital photonics, to open up new research-intensive lead markets and to ensure access to material platforms and manufacturing capacities.

Funding measures up to 2030 will focus on the high-level integration of photonic systems and applications in automated production, medical technology, environmental sensor technology and autonomous systems. Research and development in the field of high-power lasers aims to generate high-energy radiation for use in analytics and, in the future, as a beam source for fusion research. In addition, the BMBF is funding photonics as an important basic technology for quantum technologies. At the same time, the BMBF is strengthening research infrastructure and is establishing the Leibniz Centre for Photonics in Infection Research (LPI) in Jena, the "Optical Valley".

Further information:
photonikforschung.de

16 **Steady progress in approaching quantum advantage | McKinsey**

17 SPECTARIS: "2023/2024 Trend Report Photonics"

3.2 Key industrial technologies

Industry and society are facing a double transformation towards a well-connected, highly digitised and, at the same time, climate-neutral economy and way of life. In industry, material-based technologies and the resulting applications are playing a key role, either complementing each other or creating strong synergies. Advanced materials promise great potential for substituting critical raw materials and reducing the demand for primary raw materials in the future, and lead to higher-performing products, for example in battery production. Material and process innovations benefit equally from key digital technologies. Machine-readable data that describes the entire life cycle of products and systems and is represented in the form of a digital twin is the basis for recyclable value creation and the starting point for digital product passports.

Data is becoming a strategic resource for redesigning products, processes, business models and value creation systems. Networked data spaces are creating a new quality of value creation and revolutionising established industrial structures. The prerequisites for successful implementation are data protection and quality, security and ethical aspects, as well as ensuring data sovereignty when exchanging data. These challenges are met by ensuring conformity with the requirements of the European Gaia-X data infrastructure.

The BMBF is testing and developing data trust models for secure and trusted data exchange in research and industry in order to leverage the social innovation potential of data and develop new forms of data sharing, thus paving the way for a new data culture. In this way, the BMBF is making a significant contribution to strengthening digital and technological sovereignty.

3.2.1 Materials research

New materials are the backbone of the competitiveness of German research and industry, laying the foundation for technological leadership in key future fields and ensuring social prosperity. However, recent studies show that Germany has some catching up to do in the research of new materials compared to competitors from Southeast Asia (China, Japan, Korea) and the United States[18, 19]. The BMBF is working to counteract this trend, for example with the new BMBF materials research programme starting in 2025. A central focus of this programme is to accelerate research and development of advanced materials through digitalised materials research. A link to the “Industry 4.0” concept should enable digital representations of materials and chemicals throughout their entire life cycle, thus laying the foundation for the development of a sustainable circular economy. In addition, the topic of resource sovereignty is being given more weight in the development of material innovations.

18 APRA Study FhG-ISI, Commission of Experts for Research and Innovation (Expertenkommission Forschung und Innovation - EFI) report, Bertelsmann Foundation (**bertelsmann-stiftung.de/de/publikationen/publikation/did/weltklassepatente-in-zukunftstechnologien**)

19 **Industrial R&D&I investments and market analysis in advanced materials – Publications Office of the EU (europa.eu)**

The BMBF programme supports the EU initiative "Advanced Materials for Industrial Leadership"[20] launched by the European Commission at the beginning of 2024, which aims to establish a dynamic, secure and comprehensive innovation ecosystem for advanced materials in Europe.

Further information:
werkstofftechnologien.de/en

3.2.2 Robotics

Robotics is the key technology for cross-industry automation and for overcoming societal challenges such as demographic change. Germany is one of the countries with the highest robot densities in the world and one of the largest markets for robotics solutions.[21]

The basis for Germany's excellent position is a strong ecosystem of innovative providers of robotics solutions and an excellent research landscape.

The BMBF will use the traditional strengths of the German economy in mechanical engineering and mechatronics to advance AI-based robotics with the Robotics Research Action Plan by 2030, so that Germany remains a leading industrial hub.

To this end, the BMBF is funding, among other things, comprehensive research into basic technologies such as electronics, sensor technology, communication technologies like 5G/6G and artificial intelligence, which is helping to boost the performance of robotics. This is opening up disruptive new applications such as learning robots that can provide support in skilled trades. The Robotics Institute Germany will network cutting-edge German research in robotics and develop it into a talent pool. This will give it international visibility and strategic clout.

Further information:
www.bmbf.de/EN/Research/EmergingTechnologies/Robotics/robotics_node.html

3.2.3 Battery technologies

Batteries are the heart of sustainable electric mobility and central to the efficient use of electricity from renewable, volatile sources. Over the past 15 years, a globally competitive innovation ecosystem has grown with BMBF project funding of over one billion euros. With the help of efficient funding, this ecosystem should remain strong, especially in view of the intensifying international competition surrounding this key technology. The BMBF's funding concept is designed to enable the mass production of competitive, resource- and energy-efficient battery cells in Germany along the entire battery value chain (material production, mechanical and plant engineering, cell production, second life and recycling). Key pillars of this strategy include the battery competence clusters, in which important research infrastructure is also embedded, including in the field of scaling research – with the Research Institution for Battery Cell Production (FFB) in Münster at the head. The competence clusters are flanked by collaborative research measures, which are used in particular to optimise and accelerate the transfer of innovative ideas and concepts into industrial applications. The transfer of new and disruptive approaches into industrial use is currently a focus of the BMBF's research funding in the field of battery technologies.

20 COM communication of 27 February 2024 "Advanced Materials for Industrial Leadership"; COM (2024) 98 final
21 World Robotics 2023 – Industrial Robots, International Federation of Robotics, 2023

By networking academic research with industrial development in a synergised manner, the BMBF also aims to ensure that German mechanical and plant engineering is once again involved in the construction of battery giga-factories by 2030. The aim is for batteries from Europe not only to be competitive by 2030, but also to set the international standard. Furthermore, the series production capability of at least one rechargeable battery technology, other than the current lithium-ion technology, is to be successfully demonstrated – in addition to sodium-ion technology, the BMBF is particularly promoting the further development of solid-state batteries.

Further information:
werkstofftechnologien.de/programm/batterieforschung

3.2.4 Industry 4.0

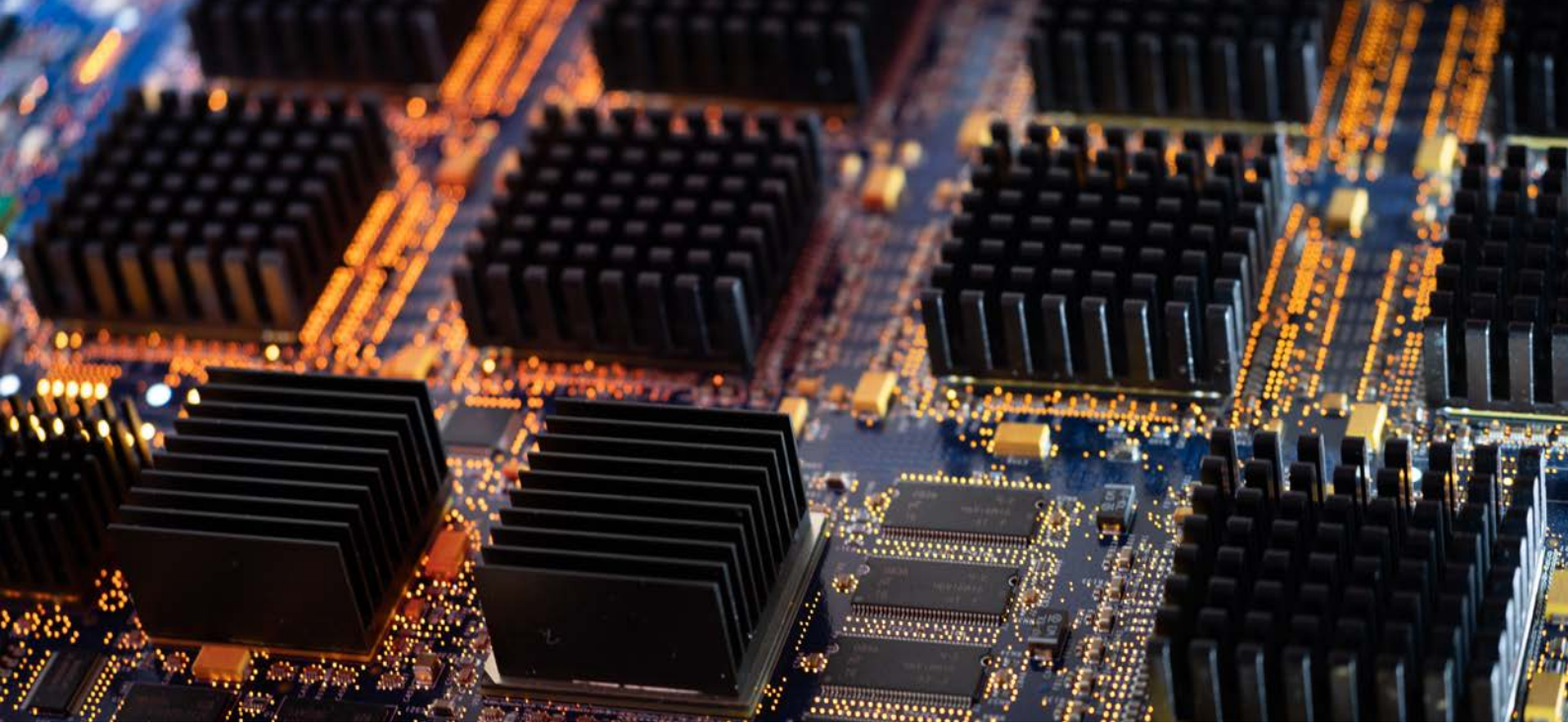
Industry 4.0 stands for the profound change in industrial value creation through the digital networking of value creation processes across company boundaries and process steps. Research on Industry 4.0 contributes to the further development and networking of people, technologies and organisations: Competences are emerging that directly contribute to technological sovereignty in the field of digitalisation and to the innovative strength of companies.

In the coming years, the BMBF will focus on supporting small and medium-sized enterprises in developing research-based innovations for Industry 4.0, thus also enabling the application of innovative technologies. For example, possibilities are to be created for making production processes for small batch sizes or recyclable value creation more flexible and for reacting to disruptions in real time by continuously analysing process and product data. Industry 4.0 technologies – such as smartglasses or the digital twin – are changing the organisation of work in production. Last but not least, established business models are being questioned and innovatively developed on the basis of new technological possibilities. With data room models and industrial AI, value creation can be digitally organised in a completely new way.

By 2030, new research questions about the control and interaction of data rooms will come to the fore. Digital twins and systems engineering will continue to develop, as will trustworthy data room structures and their frameworks. Questions about the future of industrial work, new business models and the role of people will arise again and again.

The future issues of Industry 4.0 will be continuously developed: with scientific expertise, innovative ideas and the networking of people and technologies. For research and development up to 2030, it remains important to develop ideas for Industry 4.0 and to implement them in the sense of sovereign value creation. This requires an integrated view of people, technology and organisation.

Further information:
zukunft-der-wertschoepfung.de



3.3 Accelerating technology transfer and innovation processes

The thematic priorities in the previous chapter serve to systematically present the central objectives and measures for strategically relevant key technologies up to 2030. The aim is to transfer these key technologies into applications and innovations that contribute to the realisation of societal priorities. To this end, the BMBF is funding application-oriented, technology-neutral programmes. Other funding approaches target talent, networks and ideas beyond thematic restrictions. This is because transfer and innovation do not automatically follow from excellent research results. That is why the BMBF is strengthening continuous cooperation between researchers and users in industry and society. The funding of key technologies in deep-tech innovation ecosystems includes the funding of all essential steps from research to innovation – often in project networks of research institutions and companies. The close networking of science, industry and society in the early stages of technological development is one of the great strengths of the German innovation system. The BMBF's collaborative research acts as a catalyst for this cooperation.

A balanced and innovation-friendly regulatory framework is important to create incentives for private investment in research and innovation as well as planning security for innovative companies. Taking regulatory requirements into account at an early stage in research and development partnerships helps to ensure that products are designed to be safe, sustainable and/or recyclable as early as the design and development phase. Equally important for the pace of innovation are regulatory freedoms that create new scope for researchers and innovators. The BMBF will therefore make greater use of regulatory sandboxes and similar regulatory approaches in its funding.

In implementing Mission 4 of the Federal Government's Future Research and Innovation Strategy, these measures should also help to ensure that a modern legal framework for regulatory sandboxes is in place by 2030, enabling the testing of innovations under real-life conditions to make a better contribution to digital and sustainable change.

3.3.1 Strengthening technology-neutral transfer funding and innovation networks

The technology- and topic-neutral funding of research and development projects on key technologies opens up spaces for (completely) new, disruptive and seminal ideas, even beyond thematically focused funding. It opens up possibilities for interdisciplinary and cross-industry exchange that does not stop at the boundaries of the thematic funding programmes.

Such networking-oriented approaches are particularly suitable for identifying ground-breaking developments at the interface between two or more scientific disciplines at an early stage. The BMBF therefore provides long-term funding for selected future clusters and research campus models, thus supporting the innovation ecosystems, value chains and jobs of tomorrow and beyond. These networks also create valuable stimuli, particularly in newly emerging fields of innovation that are of particular importance for future technological sovereignty.

Current projects are, for example, researching the development of novel approaches at the interface

between quantum technology and microelectronics or new medical diagnostic and treatment methods using a combination of molecular biological and optical methods.

In the long term, the BMBF's network-oriented funding aims to develop and expand the potential of selected regions in a targeted manner in order to establish internationally visible beacons in relevant key technologies and thus strengthen Germany's overall innovative strength. To this end, the BMBF will continue to develop its funding approaches and combine needs-based financial support with approaches to overcome barriers to innovation and create innovation-friendly conditions.

The BMBF is also exploring further avenues for the topic- and technology-neutral funding of key technologies:

- The gap between the initial results of basic research and a possible application in universities and non-university research institutions is closed by BMBF-funded, technology- and topic-neutral validation research. The VIP+ funding programme acts as a technological hothouse and helps to identify trends and new topics.

- The strength of the German innovation system is based in particular on the diversity of small and medium-sized companies in all parts of the country. The BMBF is strengthening the R&D activities of small and medium-sized companies in numerous sectors and areas through the "KMU-innovativ" (innovative SME) programme.

With a new initiative, the BMBF is throwing new ideas and stimuli into the mix to strengthen transfer and innovation in Germany:

- The "transfer bridges" instrument aims to tap the transfer potential at German universities and non-university research institutions and to use it for economic development and social transformation. The transfer bridges focus on talent and aim to identify potential start-up founders at an early stage and support them from the outset. The aim is to raise the awareness of and activate students, doctoral candidates and researchers at scientific institutions regarding the possibilities of founding start-ups and technology transfer. Another important starting point is the qualification and professionalisation of personnel in transfer centres, start-up institutions and the administration of scientific institutions. In addition, the focus is on improving the institutional framework conditions necessary for start-ups and transfer, as well as on strengthening the importance of transfer and start-ups as relevant scientific performance dimensions. The aim is to generate a broad foundation of start-up-relevant ideas and people, of which, due to selection processes, not all would be expected to be transferred into concrete start-ups. With their focus on the pre-seed phase, the transfer bridges supplement existing support services and funding programmes of the Federal Ministry for Economic Affairs and Climate Action (BMWK) (e.g. EXIST) and come into play even before the first private investment or financing by private venture capital or SME funding.

In implementing Mission 4 of the Federal Government's Future Research and Innovation Strategy, these measures should also indirectly contribute to the following goals by 2030:

- An increase in the start-up rate (new start-ups in relation to the number of companies) in the high-tech sector.

- An increase in the number of academic spin-offs and start-ups.

- An increase in the innovator rate of SMEs.

- Strengthening of the cooperation between companies, especially SMEs, civil society actors and research institutions in order to research and find solutions to practical issues.

Further information:
clusters4future.de,
forschungscampus.bmbf.de/homepage,
validierungsfoerderung.de,
www.bmbf.de/EN/Research/Society/FutureOfWork/futureofwork_node.html

Box 9: The German Agency for Transfer and Innovation (Deutsche Agentur für Transfer und Innovation, DATI)

DATI seeks to broaden and accelerate the transfer movement in Germany. Its aim is to put research results into economic and social practice through an effective transfer of ideas, knowledge and technology, and to leverage new innovation potential. The idea is for it to adopt a topic- and stakeholder-neutral approach, offer "transfer from a single source" and explicitly include social innovations in its underlying understanding of transfer and innovation.

The BMBF has initiated the accompanying pilot measure "DATIpilot – Fördern & Lernen für Innovation und Transfer" (Funding and Learning for Innovation and Transfer) with two objectives: Firstly, the measure is intended to identify research-based innovation ideas for transfer projects in the various regions of Germany and to tap into transfer potential. Secondly, it is intended to test new approaches for simplified and more flexible funding of transfer across regions. By founding DATI, the BMBF is creating an experimental space for agile transfer and innovation policy, as well as a store of experience and ideas for the design of the agency and the further development of innovation funding as a whole.

Further information:
bmbf.de/dati

3.3.2 Targeted funding for disruptive innovations

The targeted, early and high-risk funding of disruptive innovations is a major new focus of the Federal Government. Disruptive innovations are innovations that open up new markets or radically change existing ones, or that solve a significant technological, social or ecological problem. With the Federal Agency for Breakthrough Innovation (Bundesagentur für Sprunginnovationen, SPRIND), founded in 2019, the BMBF is funding ideas with the potential for such disruptive innovations in an open manner that is not restricted to any specific topics. SPRIND stands for new ways of funding and networking in the German and European research funding system and is thus a key to increasing our technological sovereignty.

The SPRIND Freedom Act, which came into force in 2023, made SPRIND more independent and agile: As a result, SPRIND should be able to offer innovators autonomous, customised support for the implementation of their disruptive ideas, from basic research to implementation in markets, in order to be internationally competitive. The use of private-law funding and financing instruments, which is now possible, should in particular facilitate co-financing with private investors in the future.

In order to further develop SPRIND, the Federal Government will identify further potential for improvement on the basis of an evaluation. In implementing Mission 4 of the Federal Government's Future Research and Innovation Strategy, these measures should also help to ensure that, by 2030, disruptive innovations that have been identified are also brought to market by the Federal Agency for Breakthrough Innovations (SPRIND).

Further information:
sprind.org/en

3.3.3 The future of value creation

The research funding programme on the future of value creation uses six perspectives that are combined into thematic fields of action:

(I) people and
(II) resources in value creation,
(III) socio-technical methods and innovations and
(IV) value propositions as well as
(V) networking and
(VI) dynamics in value creation systems.

In this way, the programme also bridges the gap between key technologies and transfer, because value creation is always based on technological possibilities, combines these with people and contributes to the goods, services and business models for use in economic processes.

In the field of "Circular Value Creation", digital twins are to be further developed in the coming years so that they have interfaces to the value creation system and can map information about the materials they contain. Process control is to be further developed on the basis of Industry 4.0 tools. The storage and use of data will enable new services and digital marketplaces that interlink different material and component cycles.

By the end of its term in 2028, the programme will also have implemented the fields of action "data-oriented value creation" and "resilient value creation". As a learning programme, it identifies early signals of change in value creation systems, which the BMBF will take into account in further fields of action. The task of research will be to develop new business models in each field of action, to increase resource efficiency and to integrate socio-technical innovations into processes. Industry 4.0 technologies will remain a central element in order to exploit the digital networking of all value creation processes.

Further information:
zukunft-der-wertschoepfung.de

3.3.4 Civil security

Civil security research is another area of application-oriented, technology-neutral and cross-cutting innovation and transfer funding. Living in security and freedom is a basic need of all people. To ensure Germany's unrestricted ability to act in the field of civil security, security solutions must be based on digital and industrial key technologies that the state can control with sovereignty. It is important to recognise and avoid critical dependencies in good time in order to be able to counter threats effectively. This applies to the entire range of civil security research applications, from civil protection, security of supply and hybrid threats to the fight against crime.

The Federal Government's 2024–2029 framework programme "Research for civil security – working together for a safe life within a resilient society" will create the basis for a resilient society. The aim and objective is to develop socio-technical security solutions to strengthen the security of the state and society in the future as well as their capacity to act. To this end, technologies that are important for ensuring civil security in the future are considered in order to create an important foundation for the targeted and needs-based design of technological sovereignty.

Further information:
sifo.de/sifo/en/home/home_node.html

3.4 Solving cross-cutting issues

FITS2030 initially formulates action mandates until 2030. The framework programme is more than the sum of its technology-specific research funding programmes and its innovation funding. More than in the past, the BMBF wants to promote research contributions for cross-technology cross-cutting issues and develop practical solutions. In doing so, FITS2030 adds significant value for the relevant thematic programmes. At the same time, it ensures that research and innovation for technological sovereignty will be networked, future-oriented and effective by 2030.

The cross-cutting tasks address overarching issues of technological sovereignty that play a role in many key technologies and applications. They are a connecting element between the individual key technologies and are essential for their funding success. The BMBF will therefore promote and organise the exchange between the technology-specific programmes on the following cross-cutting topics, thus enabling and accelerating the transfer of functioning solutions to other technologies.

3.4.1 Promoting environmental and climate compatibility

A climate-neutral economy cannot be achieved without a broad base of key technologies. Those who consistently consider the recyclability of materials and products and organise a circular economy conserve resources and protect the environment, reduce dependence on economically and politically fragile supply chains and create markets for future-oriented products, processes and services. This requires technological solutions as well as economic and social innovations, the research and development of which should be integrated into the individual thematic programmes or taken into account in the BMBF's Research for Sustainability strategy (FONA).

For example, the BMBF's material hub initiative "Ressourcensouveränität durch Materialinnovationen" (Resource Sovereignty through Material Innovations, MaterialNeutral) addresses the topics of process efficiency, sustainable use of raw materials and resource conservation. An accompanying project ("MANTRA") is supporting the development of a metric system to measure and evaluate the project results in terms of the sustainability effects achieved. It is intended that the set of indicators developed in the MANTRA project will be made available to other technology funding areas following positive validation.

In the framework programme "Research and Innovation for Technological Sovereignty" (FITS2030), strong research funding of key technologies comes together with the consideration of cross-technology transfer and cross-cutting issues.

Figure 5: Matrix structure of the framework programme Research and Innovation for Technological Sovereignty (FITS2030)

In the future, all funding programmes for key technologies will also integrate environmental and climate-related funding objectives. In the course of the project, funding recipients will be required to demonstrate the environmental and climate protection contribution of a new technological solution compared to a reference solution that is to be replaced.[22] In addition, the results of climate and environmental impact analyses are used to prepare, accompany and, if necessary, modify the funding of technology.

3.4.2 Securing skilled workers and young scientists

Germany's technological performance is shaped at all levels of academia and in professional practice by brilliant minds and personalities. As a result of demographic change, initiatives to secure the next generation of scientists and to expand the supply of skilled workers will continue to be pushed to the top of the political agenda in the coming years. In particular, this approach involves strengthening STEM subjects in early, school, extracurricular, vocational and academic education.

22 publica-rest.fraunhofer.de/server/api/core/bitstreams/299039bd-78f5-42dd-8c08-8b8d486ac58b/content

In order to increase digital and technological sovereignty, digital skills need to be developed more strongly as a basis for the critical and self-determined use of technologies as well as their design. In this context, promoting digital teaching and learning is particularly important in order to equip all of tomorrow's skilled workers with the necessary skills. Furthermore, developing and expanding data skills is essential to further developing and using key technologies. To this end, the BMBF is systematically promoting measures to network stakeholders, provide information, data and tools to increase data literacy among the population and establish a data culture.

As part of the STEM Action Plan 2.0, the aim is to spark enthusiasm for a professional or academic career in the STEM fields along the entire education chain. This includes funding for the Kinder forschen (Little Scientists) foundation, the #MINTmagie (STEM magic) communication campaign, competitions for schoolchildren and young people such as Jugend forscht (a youth science competition), and the nationwide MINTvernetzt (STEM network) networking centre. The MINT-Campus offers stakeholders in STEM fields free further and continuing education opportunities. In addition, the BMBF is expanding cooperative, extracurricular STEM programmes for children and young people nationwide by funding regional STEM clusters. MINTvernetzt and the Alliance for Women in STEM have developed #empowerGirl, a platform for internships for girls in STEM professions.

The Federal Government's 2022 skilled labour strategy is intended, among other things, to improve training and continuing education in future-oriented occupations in order to cope with urgent developments (digitalisation, decarbonisation and demographic change). In the National Further Training Strategy, the Federal Government, federal states, social partners and the Federal Employment Agency (BA) are working together in partnership to strengthen people's economic and social participation and to support companies in shaping structural change.

Universities should offer their students and doctoral candidates practice-oriented modules that promote entrepreneurial thinking (science entrepreneurship) at an early stage, alongside their studies. In particular, the BMBF's collaborative funding programme gives participating companies and other stakeholders the opportunity to offer internships to students in relevant subjects and to explore opportunities for later recruitment. In addition, the BMBF supports universities throughout Germany in their digital transformation process with a variety of information, advice and training services, ensures that current developments and possible applications are visible and promotes the testing of innovative solutions in teaching and learning.

Another approach taken by the stakeholders involved in FITS2030 is to specifically address students, including international students at German universities, with the aim of employing them after graduation. The Campus Initiative for International Talents of the German Academic Exchange Service (DAAD) will support international students, who are known to disproportionately study STEM subjects in Germany[23], in successfully completing their studies and starting their careers in the coming years. The new law on the immigration of skilled workers creates better immigration and settlement opportunities for foreign skilled workers with academic and professional qualifications, which the stakeholders involved in FITS2030 should make intensive use of.

Supporting young scientists is an important part of the BMBF's funding, particularly in the area of digital technologies and key technologies. In the funding programmes for AI, quantum technologies, materials research and battery research, the BMBF specifically promotes the development of research groups at universities and research institutions. Successful measures for recruiting young talent should be continued and expanded to include further technology areas. The BMBF wants to use the knowledge and ideas of particularly promising young researchers who have received funding – Future FITS Makers – and bring them into a cross-technology and future-oriented dialogue. In addition, the BMBF will encourage German research institutes to participate in technology-related "Skills Academies" at the EU level.

23 **Wissenschaft weltoffen 2024 kompakt. Data and facts on the internationality of studies and research in Germany (wissenschaft-weltoffen.de)**

3.4.3 Strategically shaping European and international cooperation

The EU's research and innovation policy cooperation aims to increase the global market share of German and European products, reduce unilateral dependencies on third countries, and strengthen the economic growth and resilience of industry and the economy in Germany and the EU.

That is why the BMBF is committed to strengthening Europe's technological sovereignty at various levels in the European Research Area and in national implementation. As part of the National Action Plan for the European Research Area, we want to mutually strengthen national and European R&I-driven missions, coordinate the application of new technologies at the European level and implement joint European research priorities. The BMBF is already committed to ensuring that the tenth EU Framework Programme for Research and Innovation (FP10), which starts in 2028, focuses on securing the EU's long-term technological sovereignty and strengthens key technologies. Collaborations with non-EU countries are to be strategically expanded in FP10. Based on the guiding principle of being "as open as possible, as closed as necessary", care must be taken to ensure that measures to ensure research security in FP10 are proportionate to the risks and dangers.

In the context of EUREKA, the BMBF is committed to ensuring that future projects lasting until the end of this decade develop substantial research and innovation contributions that strengthen the EU's technological sovereignty. EUREKA clusters play a special role in technological sovereignty: These are industry-driven, long-term industrial partnerships in strategically important technological fields, managed as public–private partnerships. The aim is to secure Germany and Europe as a research and innovation hub in the global competitive landscape. The aim is to increase the innovative strength of Germany and Europe through international cooperation and to strengthen technological leadership and technological sovereignty in future fields and key technologies.

To develop knowledge bases, bilateral research and innovation cooperation between Germany and third countries should also be expanded. In the future, a risk-conscious approach must be taken to research security aspects (see **Box 10**). In addition, multilateral forums should be used to shape and strengthen technology policy cooperation. Examples include the G7, the G20 and the OECD, as well as targeted participation in international standardisation bodies for key technologies. The leaders of the thematic research funding programmes will also explore how they can better integrate the key technological

expertise of prizewinners and scholarship holders of the Alexander von Humboldt Foundation (AvH) and the DAAD into the implementation and further development of their measures in the future, and how they can recruit these talents.

Box 10: Research security when cooperating with third countries

The concept of technological sovereignty does not have the aim of national isolation or autarky. German science continues to need international cooperation, especially with partners that share our values. However, following the guiding principle of "as open as possible, as closed as necessary", the risks of international research cooperation must be addressed, especially in times of increasing geopolitical tensions. Instead of decoupling, a differentiated approach that is both interest-driven and risk-conscious is therefore required. The prerequisites for targeted European, bilateral and multilateral activities with partners are that they

- allow cooperation in line with our values and on an equal footing,
- are conducive to the goal of technological sovereignty and
- lead us to expect reciprocal added value from the cooperation due to the complementary nature of the partners' skills and technologies.

In particular, unwanted outflow of technology knowledge should be prevented with a view to possible military or intelligence use by third countries. BMBF-funded projects and institutions in particular must also analyse the opportunities and risks of specific bilateral research collaborations in detail, and where appropriate also use advice and support services, and then make a considered decision in line with their own responsibility. Particularly in times when international competition for key technologies is setting the course for the future, the BMBF is committed to strengthening synergies between civil and military research within Germany and the EU. In this way, military applications may benefit from civil research results just as civil applications may benefit from military research results.

3.4.4 Helping to shape standardisation

In the design of key technologies, norms and standards play an important role. Where norms and standards are lacking, frictions and costs arise or only market access is limited to a niche. Legal regulations with measurement, testing and evaluation requirements for safety and sustainability must be continuously adapted in line with the state of the art. Taking into account current research results is of fundamental importance for high-quality standard setting.[24] Standardisation must therefore be anchored in the research and development process.

At the same time, standardisation that accompanies development offers an effective lever for scaling up and commercialising innovations more quickly, while also taking into account technological solutions that result from the research and development work of German stakeholders. This is associated with opportunities to implement important technology policy requirements such as the safeguarding of civil liberties, consumer and data protection or climate protection and recyclability in technological development paths.

In order to increase the impact of development-related standardisation in the innovation process, the close exchange with the Federal Ministry for Economic Affairs and Climate Action (BMWK), which is responsible for this area, and relevant partners such as the German Institute for Standardisation (DIN) is to be continued.

24 See European Commission (2024), Directorate-General for Research and Innovation, Blind, K., Baldan, F., Tardos, G., et al., European standardisation panel survey: final report, data.europa.eu/doi/10.2777/643814

In addition, the BMBF is raising awareness among universities and providers of initial and continuing vocational education and training of the need to integrate modules on standardisation into their curricula in order to ensure a pool of experienced experts. Master's students, doctoral students and master craftsmen apprentices in STEM fields are particularly relevant target groups here.

The BMBF will promote the stronger integration of science itself in development-related standardisation processes at the national, European and international level. Corresponding activities by researchers from universities and non-university research institutions should be classified as funding objectives, as eligible for funding and as utilisation successes throughout the funding process.

4. Operational implementation

FITS2030 is initially set up to run until 2030 and provides the strategic and communicative umbrella for the wide range of measures described in the previous chapters. It will be further developed and implemented through the technology-specific programmes with their current and future funding announcements, as well as through institutional research funding. The budget of the framework programme essentially corresponds to the budgets of the technology-specific funding programmes.

As a "learning" framework programme, FITS2030 is subject to continuous monitoring and is to be evaluated at the end of its term. This evaluation will primarily focus on the cross-cutting topics and strategic objectives, but not on the technology goals of individual thematic funding programmes. This will also assess the extent to which the FITS2030 measures have contributed to relevant indicators of the Future Research and Innovation Strategy (see also **Chapters 3.3** and **4.1**).

4.1 Establishing technological sovereignty as a guiding theme for thematic research funding programmes

Thematic research funding programmes formulate specific research and innovation policy goals, define a roadmap for achieving them and continuously monitor progress. On the one hand, this requires a definition of the capabilities necessary for sovereignty in the respective key technology. These range from research capabilities, an adequate system for transferring research results into application, and the training and further education of the necessary skilled workers, to capabilities in areas such as standardisation, production or supply chain management.

The specific areas, as well as the current and desired level of capability, should be determined with an evidence-based approach using suitable indicators. Such indicators are usually determined on a technology-specific basis. Examples include, in addition to classic research and innovation policy indicators (publications, patents, level of industrial R&I investment), the number of new students and graduates, for example in quantum technologies, the degree of diffusion of a technology, such as AI in companies, the world market share, for example in the production of the latest generation of microchips, or participation in standardisation bodies, for example in the field of modern and future communication systems.

Suitable measures and instruments are to be defined for the technology-specific roadmaps. The regulatory framework should also be reviewed and, if necessary, adapted, for example with regard to remuneration models for attracting the necessary skilled workers or with a view to ensuring compliance with existing and foreseeable regulatory frameworks, for example in materials research. In addition, the cooperation and division of labour at the European level in the thematic programmes must also be considered. For instance, infrastructures for calculating large AI models are often better financed and operated jointly, so that they do not have to be provided by Germany alone. Similarly, access to computer infrastructures operated at the level of EU member states or regions should be facilitated, particularly for small and medium-sized enterprises (SMEs).

The BMBF is continuously reviewing how the application, selection and approval procedures can be simplified and accelerated. The reporting requirements should also be as lean and focused as possible. In addition to completely new funding institutions such as SPRIND and DATI, the BMBF's programme funding is also reviewed. In implementing Mission 4 of the Federal Government's Future Research and Innovation Strategy, these measures should also help to ensure that, by 2030, the approval processes for research and development projects will be streamlined and accelerated overall.

4.2 Synergising institutional and project-based funding

Technologies developed in other BMBF funding programmes and in institutional funding also contribute to digital and technological sovereignty. For example, materials research benefits from the unique opportunities for analysing and characterising materials at large research infrastructure facilities that are funded in the Exploration of Universe and Matter (ErUM) framework programme.

To ensure that non-university research organisations contribute more efficiently to technological sovereignty, the work of the Max Planck Society (MPG), the Helmholtz Association (HGF), the Fraunhofer Society (FhG) and the Leibniz Association (WGL) is to be more closely interlinked and coordinated than before within the framework of their institutional missions and project funding. The goals are to optimise the division of labour, to develop priorities and to enhance the cooperation between these actors, as well as to align the research organisations' strategic focus with the goal of technological sovereignty in order to achieve the greatest possible leverage.

Box 11: National prioritisation process for research infrastructures (Forschungsinfrastrukturen, FIS)

Research infrastructures play a key role in the performance, innovative strength and international competitiveness of the German and European science and business location. They contribute significantly to scientific progress, the development of cutting-edge technologies, the training of specialists and the development of solutions for major societal challenges. With a decision in favour of a research infrastructure, long-term investment decisions are made that tie up considerable public funds. In order to evaluate the planning for possible new, extensive infrastructure projects according to a uniform, fair and transparent procedure, the BMBF is conducting a procedure for prioritising extensive research infrastructures as a successor to the FIS roadmap process. The aim is to have prioritisation procedures at regular intervals so that potential projects for new research infrastructures can be continuously and promptly evaluated.

This interlinked cooperation can be achieved, on the one hand, through the BMBF's involvement in the steering and supervisory committees of non-university research organisations and relevant research institutes. On the other hand, the participation of researchers and representatives of research organisations in advisory and review bodies of the BMBF's thematic research funding programmes and in the Council for Technological Sovereignty is intended to promote the reciprocal flow of knowledge and insights. In order to take account of interdependencies between key technologies and to avoid blind spots, the BMBF will also strengthen their networking.

4.3 Discourse in society and the FITS Forum

As a guiding principle for policy, technological sovereignty requires the development and dissemination of knowledge, the establishment of frameworks and the mobilisation of resources. This calls for a debate that the BMBF will continue and intensify with relevant stakeholders.

The biennial FITS Forum will be one of the central instruments for the exchange of expertise. As a contribution to science communication, the forum will offer participants in the framework programme and its technology-specific funding programmes the opportunity to present promising research and development results, thus helping to strengthen the idea of technological sovereignty. Furthermore, the FITS Forum will promote the exchange between the technology-specific programmes on cross-cutting topics, thus enabling and accelerating the transfer of functioning solutions to other technologies.

The aim is for stakeholders from science, industry, administration and civil society to discuss and evaluate how Germany and Europe can maintain technological sovereignty and in which areas it must be expanded. The Council for Technological Sovereignty and the Future FITS Makers are to play an active role in this. In addition, the aim is to open dialogue on the opportunities and risks of key technologies and their application, as well as the necessary legal framework, on the basis of scientifically and empirically sound findings, as recommended by the OECD, for example[25]. At the same time, the FITS Forum is intended to help network the relevant stakeholders from the participating thematic programmes on key technologies and technology-neutral innovation funding.

25 OECD Framework for Anticipatory Governance of Emerging Technologies (2024)

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