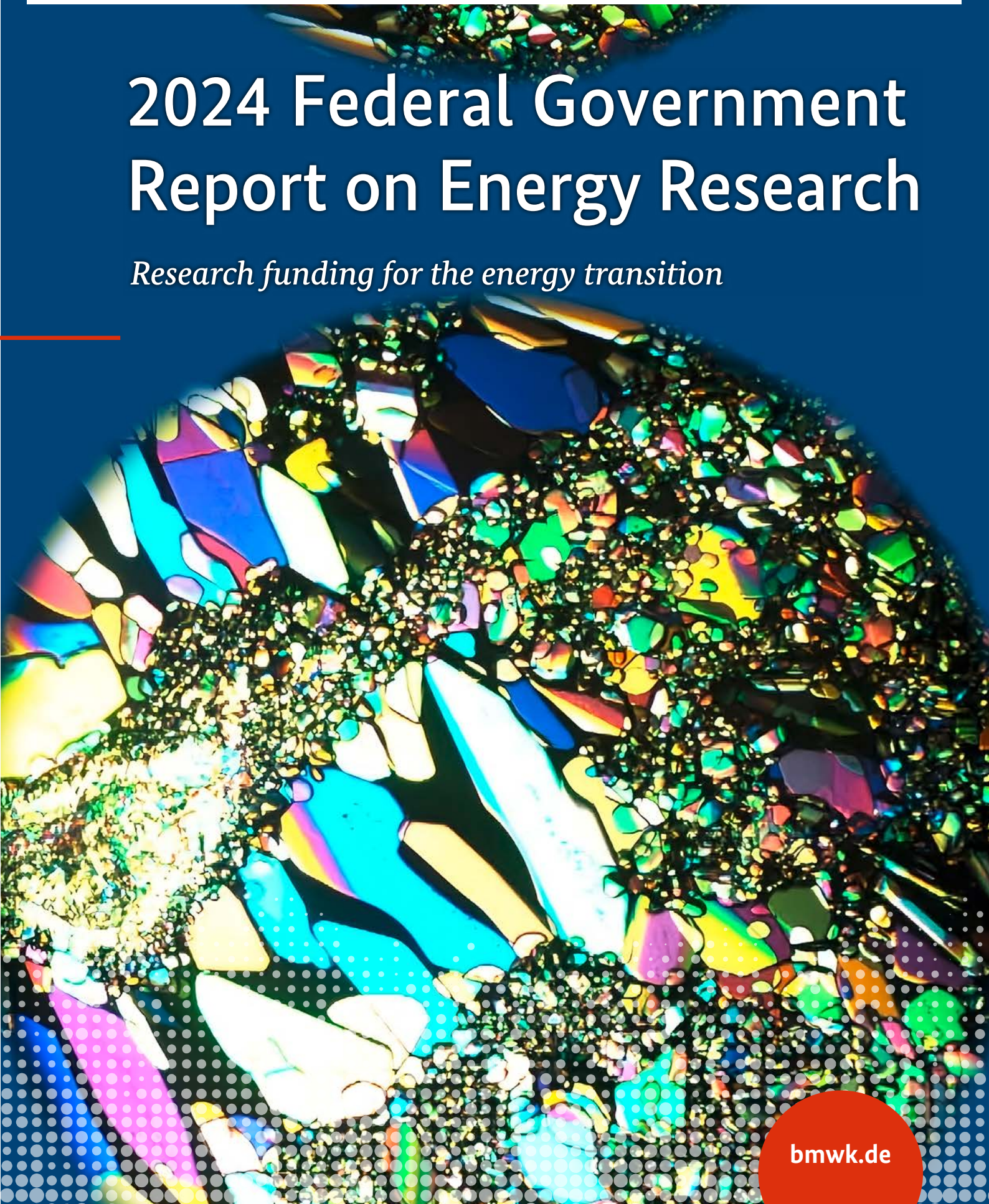
Federal Ministry
for Economic Affairs
and Climate Action

2024 Federal Government Report on Energy Research

Research funding for the energy transition



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Title: Compact energy storage systems are essential for electricity, heating and cooling if a high volume of energy is to be supplied by fluctuating renewable energy sources. In the partial crystallisation absorption refrigeration system research project (PAKS), scientists are developing a refrigeration system that works in much the same way as an absorption chiller. It is based on a closed absorption process that uses the combination of water/lithium bromide (LiBr) together with the cyclical crystallisation and redissolution of part of the aqueous LiBr solution. In contrast to conventional ice banks, the process enables a much higher energy density of approx. 250 kWh/m^3, resulting in a particularly compact storage system.

MORE DETAILS

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Content

1. Federal Government's Energy Research Policy

More powerful onshore and offshore wind turbines boost power generation from renewable sources.

The transformation of the energy system in Germany is in full swing. Much has already been achieved. Russia's war of aggression against Ukraine has given the transformation process of the energy system greater urgency. Not only does Germany's complex energy system need to become more climate-friendly and energy-efficient in terms of generation and consumption, it also needs to become geostrategically less dependent on fossil fuel imports such as crude oil and natural gas. The only way to achieve this is by diversifying energy imports, increasing the use of domestic renewable energy sources, leveraging efficiency potential and intelligently integrating material energy sources such as hydrogen and its derivatives. Innovations, new approaches and concepts are required. By implementing its progressive energy research programmes, the Federal Government is therefore supporting researchers in their efforts to identify solutions to meet this enormous challenge.

As a result, energy research continues to focus rigorously on the goals of the energy transition and – with a view to future developments – also to technologies needed subsequently. The funding policy is not only geared to a demand-oriented and reliable energy supply, but in particular also to climate-neutral energy generation. One of the priorities for research funding in 2023 was the development of solutions for the climate-neutral supply of heating and cooling.

Energy research and development facilitate the expansion of technological sovereignty. Apart consolidating a region's reputation as an attractive business destination, this also helps preserve and create jobs. Research is key to the energy transition and to future developments. It also provides a solid foundation for the society we wish to live in in the future. It gives rise, for example, to concepts as to how the public can actively participate in bringing about major structural changes. Increasing decentralised energy generation with opportunities for participation, like those presented by community wind farms, will strengthen the democratic participation of the public in the energy system. The energy transition is thus more than just a technological or structural transformation project. It has an impact at all levels. Research and development also pave the path for technologies such as those proposed in the "Fusion" programme to ensure a diversified energy sector in the future.

The aim of funding energy research is to ensure that research findings are put into practice as swiftly as possible. In this regard, the funding formats Living Labs of the Energy Transition of the Federal Ministry for Economic Affairs and Climate Action (BMWK) and the hydrogen flagship projects of the Federal Ministry of Education and Research (BMBF) play an important role and contribute directly in implementing the National Hydrogen Strategy of the Federal Government. Both project funding as an agile format and institutional funding, with their high level of reliability for researchers, contribute to the long-term success of the funding policy.

Geopolitical changes since the Russian invasion of Ukraine have made a resilient energy system and technological sovereignty a bigger priority. In addition, the Federal Government has set ambitious energy and climate policy targets. It was therefore necessary to introduce a new strategy for funding energy research (cf. section 1.2 Outlook for 2024: Strategic development, page 15).

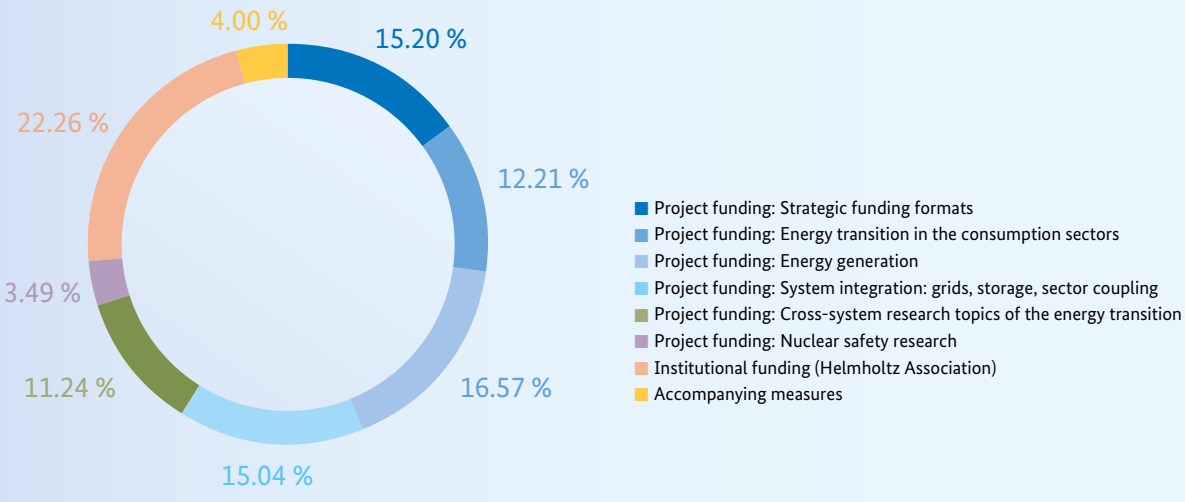
1.1 The Federal Government's 7th Energy Research Policy

1.1.1 Development in funding

Through public funding from tax revenue, the Federal Government supports research and development activities by companies, research institutions, universities and other organisations with respect to new technologies and applications for the energy transition.

In 2023, the Federal Government invested €1.461 billion in research and development funding – from basic research to applied research – as part of the 7th Energy Research Programme. That is a drop of 0.02% as against the previous year. This highlights the significance of energy research for a climate-friendly energy policy and maintaining supply security. The Federal Government invested €1.078 billion of the total funding for research and development in project funding, Funding was provided by the participating ministries for 7,570 pro-

Figure 1: Overview of funding in 2022 in the 7th Energy Research Programme
(Data cf. Table 1, p. 76)



jects. 1,796 new projects were approved. As research, development and demonstration of energy and efficiency technologies are primarily a task for the private sector, companies invested, by way of own funding, €368.58 million in innovative projects. In addition, the Federal Government invested €325.39 million in the scope of institutional funding in energy research by the Helmholtz Association.

1.1.2 Evaluations and performance reviews

Evaluations and performance reviews are valuable instruments to verify the efficient and effective use of tax revenues for funding measures. The relevant findings are incorporated into the financial, administrative, strategic and substantive design of future measures. Under the Federal Budget Code (section 7, BHO), the Federal Government is required to carry out performance reviews of all the measures implemented. Evaluations support performance reviews and are to be carried out independently by external third parties.

An independent evaluation to support performance reviews related to applied energy research of the 7th Energy Research Programme was started in 2021. It covers the funded projects of the Federal Ministry for Economic Affairs and Climate Action in accordance with the funding announcement for applied non-nuclear research under the 7th Energy Research Programme "Innovations for the Energy Transition" and analyses the effectiveness and economic efficiency of the funding formats in terms of the goals of the 7th Energy Research Programme. The first interim report was presented in September.

1.1.3 Governance

1.1.3.1 Coordination

The Federal Government provides funding for ambitious energy research projects aimed at supporting the development of innovations for the energy system. Since the 1970s, this funding has been provided in the form of regularly updated Energy Research Programmes that are always directed at the relevant requirements of the supply system, the economy and society and cover the complete innovation cycle from basic research to the testing of energy and efficiency technologies prior to their launch on the market.

The 7th Energy Research Programme is a joint programme of the Federal Ministries for Economic Affairs and Climate Action (BMWK), Education and Research (BMBF), Food and Agriculture (BMEL) as well as the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV). The Federal Ministry for Economic Affairs and Climate Action is responsible for the programmatic orientation of German energy research policy. With regard to funding applied energy research, the Federal Ministry for Economic Affairs and Climate Action published on 25 October 2023 the 8th Energy Research Programme for Applied Energy Research – Research Missions for the Energy Transition (cf. section 1.2.1, 8th Energy Research Programme for Applied Energy Research, page 16). In March 2024, the Federal Ministry of Education and Research, with a view to future developments involving fusion as a long-term perspective, published its new funding programme "Fusion 2040 – Research on the way to the fusion power plant" (cf. section 1.2.2 Funding programme Fusion 2040, page 17). The Federal Ministry of Education and Research continues its funding of the other energy-related topics in the scope of the Federal Government's 7th Energy Research Programme.

Project funding (cf. Chapter 2 Project funding, page 19) for energy research in non-technical areas is based on the level of innovation maturity and, in technical areas, on what is known as the technology readiness level (TRL) system. For each funded project, the technologies that are being researched are rated on a scale of 1 to 9 according to the intended level of scientific and technical maturity. In the scope of the 7th Energy Research Programme, the Federal Ministry of Education and Research funds application-oriented basic research projects that aim to reach a TRL of 1 to 3. The ministry also sup-

ports junior researchers, academic exchanges and scientific cooperation at EU level and with international partners. The Federal Ministry for Economic Affairs and Climate Action follows this up by supporting application-oriented research and development (TRL 3 to 7). The ministry also supports the Living Labs of the Energy Transition (up to TRL 9) and multilateral research cooperation. In the scope of the 7th Energy Research Programme, the Federal Ministry of Food and Agriculture is in charge of funding application-oriented research work in the field of bioenergy. This is supplemented by research funding provided by the Federal Ministry for Economic Affairs and Climate Action for the use of biogenic residue and waste materials for energy purposes. The Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection funds nuclear safety research in a broader sense, including research on the physical security of nuclear facilities, on methods and challenges for nuclear safeguards, nuclear waste management and radiation protection In the area of nuclear safety research, the Federal Ministry of Education and Research is funding applied basic research and young scientists.

Within the scope of institutional funding, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research are jointly responsible for the strategic orientation of energy research by the Helmholtz Association. In addition, the Federal Ministry for Economic Affairs and Climate Action is responsible for the institutional funding of the German Aerospace Center (DLR) while the Federal Ministry of Education and Research is responsible for institutional funding of the Helmholtz Centres (except for the DLR) (cf. Chapter 3 Institutional funding, p. 59).

The Federal Government is therefore banking on close cooperation between all the federal ministries involved in the Energy Research Programme, as well as the inclusion of all the other federal ministries and agencies which have energy-related mandates and responsibilities. This includes, for example, the Federal Ministry for Digital and Transport (BMDV) which is responsible for mobility and transport.

The Federal Government also relies on the advantages of the multi-level system for successful research funding. Thus, for example, the funding and coordination of energy research across Germany takes place both at Länder and federal level. Furthermore, the Federal Government also focuses on close European and international cooperation. Here, the Federal Ministry for Economic Affairs and Climate Action represents the Federal Republic of Germany in European and international bodies with regard to this policy field (cf. Chapter 4 European and international cooperation, p. 66).

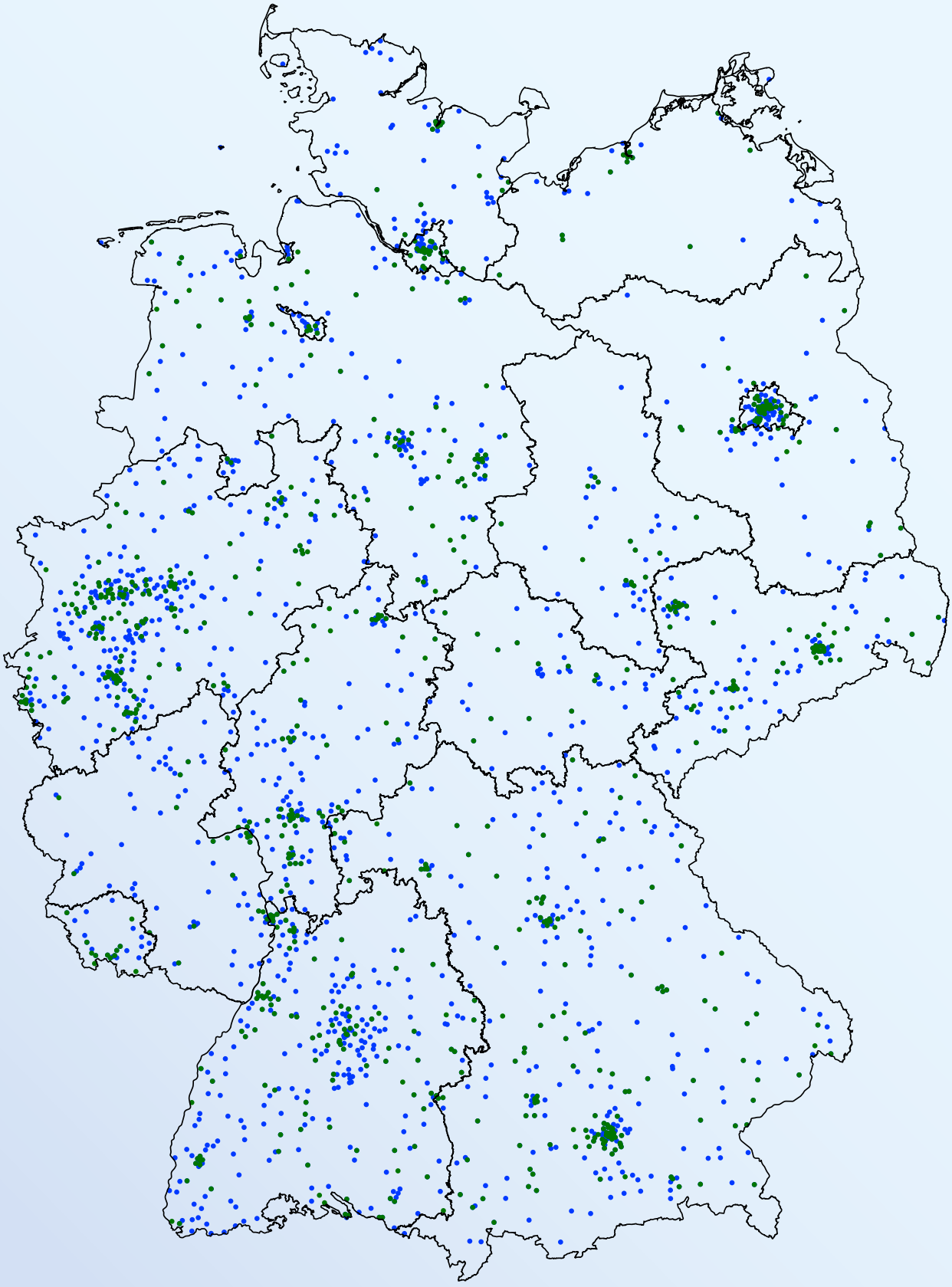
1.1.3.2 Stakeholders and networking

Climate change and various energy security issues impact all. These challenges can only be overcome by engaging in a dialogue and with the involvement of all relevant stakeholders. This is particularly true when it comes to research. After all, research brings out innovations, which in turn are the basis for future structures. None of this is possible without intensive networking and an open dialogue.

Energy research networks

Energy research networks (www.forschungsnetzwerke-energie.de) of the Federal Ministry for Economic Affairs and Climate Action create a network involving the scientific community, policymakers, planners and doers. These networks cover all important research topics for the energy transition and can be accessed by all experts. Through these networks, the Federal Ministry for Economic Affairs and Climate Action intends to intensify the interdisciplinary dialogue between all stakeholders. This is crucial for successful innovations. The energy research networks are therefore an invaluable instrument for the Federal Ministry for Economic Affairs and Climate Action to put research findings into practice, thereby accelerating the transfer process of the energy supply system. In self-organized teams and workshops, around 3,700 active members work closely in energy

Figure 2: Overview of the ongoing (blue) and newly approved (green) projects of non-nuclear energy research in Germany



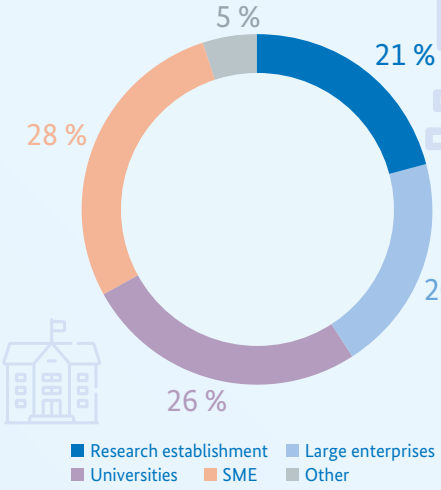
Source: GeoBasis-DE / BKG 2021 (data altered) / Geodata of the BKG for addresses of the implementing bodies from the BMBF profi-database / Projektträger Jülich

Figure 3: Energy research funding at a glance

€1.462 billion

total funding in the 7th Energy Research Programme in 2023 (preceding year: €1.311 billion)

Breakdown of funding for newly appropriated projects by category of beneficiary*



In 2023 the federation approved

1,796 new projects

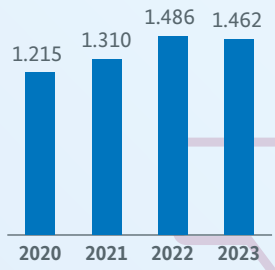
(preceding year: 1,661)

€1.078 billion

funding for projects in 2023

The Federal Government **funded**

7,365 projects in the 7th Research Programme in 2023



€368.58 million

Own funding from companies towards newly approved research and development projects in 2023 (preceding year: €390 million)

€164.63 million

funding for SMEs (*) for newly appropriated projects in 2023

* Based on the German definition of SME

research and other important fields of action. In 2023, the successful cooperation with the "Jugend forscht e. V." foundation was also continued.

The first symposium of the energy research networks was held in Berlin on 20 June 2023. Around 400 researchers attended the event which was officially opened by Federal Minister of Economic Affairs and Climate Action Dr. Robert Habeck. Following the welcome address and over the course of two days, the participants discussed pressing research-related issues that were key to the success of the energy transition.

Coordination platform for energy research

In order to facilitate the timely and targeted coordination of energy research and innovation measures implemented by various federal ministries, the platform for coordinating the energy research projects of the federal ministries was set up under the auspices of the Federal Ministry for Economic Affairs and Climate Action. Thanks to this platform, it is possible to coordinate planned measures and exploit synergies resulting from the collaboration between the involved parties. In addition, the Federal Government is engaged in a regular exchange on the most important energy research issues with the 16 Länder governments.

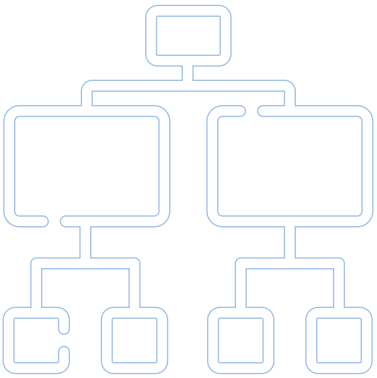
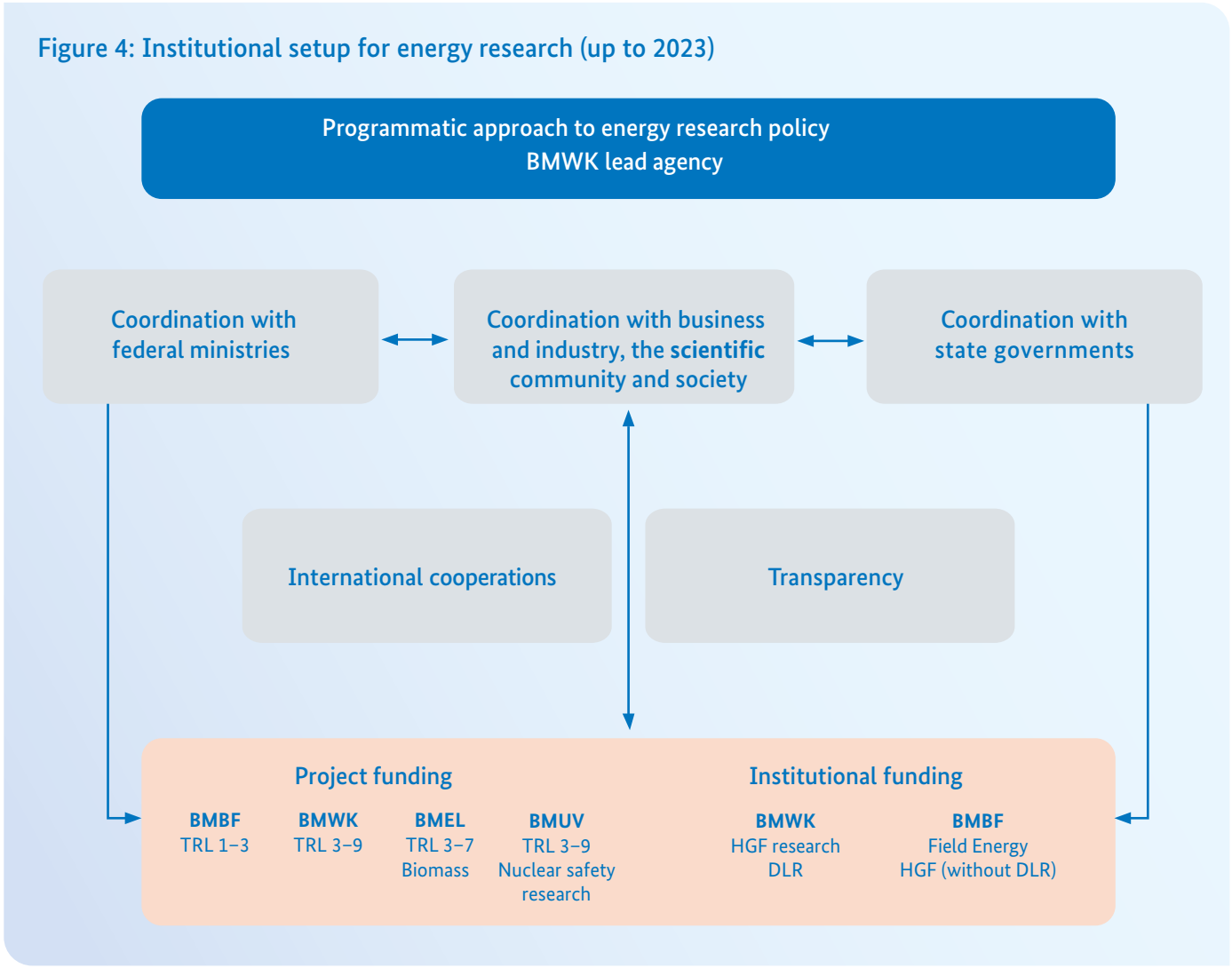


Figure 4: Institutional setup for energy research (up to 2023)



Germany continues expanding its district-heating networks to provide climate-friendly heating.

Research and Innovation Platform (R&I Platform)

The Research and Innovation Platform (R&I Platform) for the energy transition of the Federal Ministry for Economic Affairs and Climate Action was a forum for dialogue relating to energy research between federal and Länder policymakers, scientists, the business community, associations and the public. It served to facilitate dialogue on new approaches for forward-looking strategies, and to bring together research and practical applications in the energy sector. The platform also provided an overarching structure for the energy research networks.

Academies' "Energy Systems of the Future" project

The Academies' "Energy Systems of the Future" (ESYS) project pools the expertise of the German academies of science. Funded by the Federal Ministry of Education and Research, the initiative by acatech, the Leopoldina and the Union of Academies of Sciences and Humanities pools the know-how of various disciplines, categorises it and prepares it for the social and political debate on the energy transition in Germany. In the ESYS project, more than 160 experts are developing options for implementing a safe and affordable energy system. In 2023, for example, the ESYS project analysed scenarios and developed options for implementing solutions to make Germany climate-neutral, which options could offer investment incentives and reserve capacities for market integration of renewable energy and how a voluntary carbon market could contribute to climate protection. With regard to this and several other topics such as the expansion of hydrogen infrastructures or heat transition in cities, the Academies project has provided forums in which experts and the public can exchange their views.

1.1.3.3 Transparency and communications

Open and transparent communication of the goals and progress of energy research policy to the general public, researchers and practitioners is thus an important element of the Federal Government's energy research programmes. Using a wide range of formats, the Federal Government provides extensive information on the success, development trends, open research questions and existing challenges as we work towards a climate-friendly transformation and a resilient energy infrastructure.

The Federal Ministry for Economic Affairs and Climate Action's central website on applied energy

research www.energieforschung.de provides information on funding goals and structures as well as current funding opportunities. The ministry also uses this portal to report on the latest research priorities and findings. In addition, a specialist newsletter provides research and application experts news about the funding for applied energy research and funded projects. On the YouTube channel @energieforschung, Project Management Jülich (PtJ), on behalf of the ministry, provides information on the latest projects and events, elaborates on technologies, key topics and funding, and presents the people involved in the energy transition.

On behalf of the Federal Ministry for Economic Affairs and Climate Action, Project Management Jülich manages EnArgus (www.enargus.de), the central information system for energy research funding The EnArgus database provides a transparent overview of research projects in the energy sector that have been sponsored by the Federal Government through public funding since 1968. The website also provides information about technologies and specialist technical terminology. In addition, the figures for project funding cited in the Federal Report on Energy Research are set out in a transparent manner on EnArgus.

1.2 Outlook for 2024 Strategic development

As a strategic element of energy policy, energy research will be rigorously oriented to completing the energy transition and – with a view to future developments – also to technologies needed subsequently. The aim is to make Germany climate-neutral by 2045. This can only be accomplished by achieving the energy transition as swiftly as possible. To achieve the climate neutrality targets by 2030, 80% of the power consumption in Germany should be covered by renewable energy and 50% of the heat supply should be climate-neutral. Furthermore, the electrolysis output for the production of green hydrogen should rise to 10 gigawatts. Given increasingly shorter timeframes for reaching targets, the transfer of research findings to achieve the energy transition is becoming increasingly relevant in energy policy.

The upheavals in energy policies in 2022 following Russia's invasion of Ukraine have made one thing evident: The energy system should be less vulnerable to such developments in order to continue being reliable and resilient. To withstand any escalation in the wake of critical developments, meticulous planning in developing a resilient and digitally networked, highly complex energy system is a must.

15 April 2023 saw the end of nuclear energy for commercial power generation. Nuclear safety research is therefore no longer relevant to commercial power generation in Germany.

With regard to funding applied energy research, the Federal Ministry for Economic Affairs and Climate Action published on 25 October 2023 the 8th Energy Research Programme for Applied Energy Research – Research Missions for the Energy Transition. With regard to basic research in energy, the Federal Ministry of Education and Research, with a view to future developments involving fusion as a long-term perspective, published its new funding programme "Fusion 2040 – Research on the way to the fusion power plant". The Federal Government's 7th Energy Research Programme continues to apply for the basic research programme of the Federal Ministry of Education and Research.

New policy developments pertaining to the use of biomass for energy purposes are also ushering in changes in the energy research landscape. The energy research policy focuses on the utilisation of waste and residue materials for generating energy from biomass.

As a result of the policy developments outlined earlier, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection and th e Federal Ministry of Food and Agriculture will no longer be involved in energy research in the future.

Research projects play a key role in advancing digitalisation and making the electricity grid robust – a must for a resilient energy system of the future.

1.2.1 The Federal Ministry for Economic Affairs and Climate Action's 8th Energy Research Programme for Applied Energy Research

In order to achieve a secure, climate-neutral energy supply by 2045, innovative solutions are required for practical applications. Advanced technologies alone are not enough. We also need innovative processes, business models and services. With its "8th Energy Research Programme for Applied Energy Research – Research Missions for the Energy Transition", the Federal Ministry for Economic Affairs and Climate Action adopts a mission-oriented innovation policy and supports, for instance, companies and research institutions with respect to new technologies and applications for the energy transition. It stipulates the guidelines for applied energy research funding. The cross-sector and cross-disciplinary research funding focuses on specific, ambitious goals for each mission. The ministry published its programme on 25 October 2023. Funding is based on the funding announcement for applied energy research in the scope of the 8th Energy Research Programme adopted on 25 April 2024.

Mission-oriented innovation policy for practical solutions

A key objective of the Energy Research Programme is to achieve climate neutrality in the energy system. This can only be achieved if the proportion of renewable energy and climate-neutral energy sources continues to increase in all supply system sectors. At the same time, energy demand, the use of resources and, last but not least, CO_2 emissions must decrease. In order to accomplish this, various elements of the energy system – electricity grids, digitalisation, hydrogen technologies, sector coupling, and of course society itself – must be considered.

The focus of the "8th Energy Research Programme for Applied Energy Research" of the Federal Ministry for Economic Affairs and Climate Action is therefore to swiftly implement the research findings and innovations that contribute to the development of a climate-neutral, secure energy supply and put them into practice. This is why the programme focuses on applied energy research. The mission-oriented programme and a broad funding

approach covering the entire value chain should result in a wide range of commercially viable solutions for the transformation process in the energy sector. Through project funding as well as institutional support, the Federal Ministry for Economic Affairs and Climate Action supports researchers by way of short to mid-term projects.

The "8th Energy Research Programme for Applied Energy Research" of the Federal Ministry for Economic Affairs and Climate Action focuses on:

- Research for a resilient and efficient energy system in "Mission Energy System 2045"
- Research for a climate-neutral heating and cooling supply in "Mission Heat Transition 2045"
- Research for the conversion of the electricity supply to renewable energies in "Mission Electricity Transition 2045"
- Research for a sustainable hydrogen economy in "Mission Hydrogen 2030"
- The rapid transfer of research results into practice in "Mission Transfer"

1.2.2 The Federal Ministry of Education and Research's funding programme "Fusion 2040 – Research on the way to the fusion power plant"

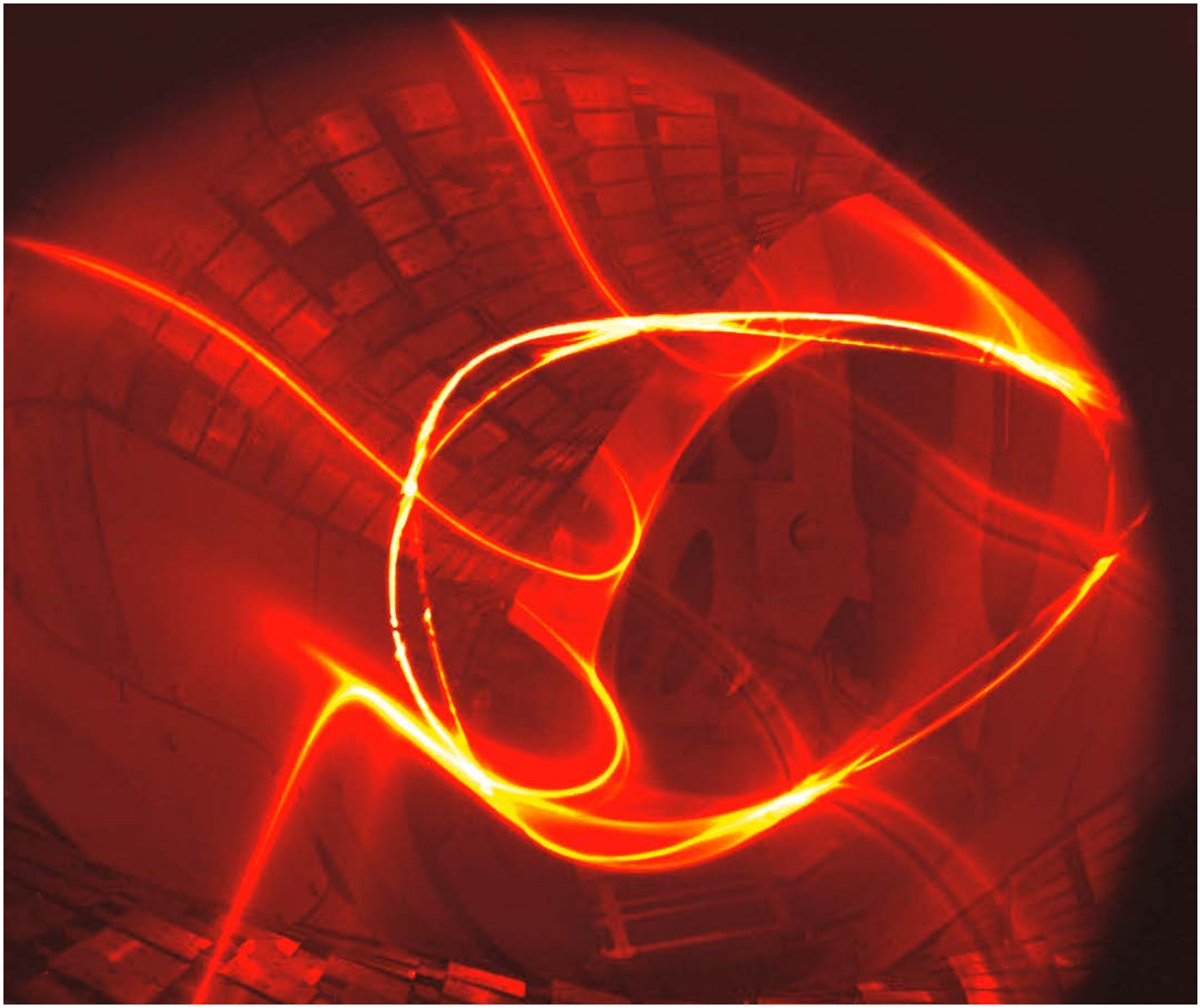
The global increase in electricity demand – according to latest studies, at least twofold between now and 2045 – and the energy transition, urgently needed for protecting the climate, require secure, affordable and CO_2-neutral power plant technologies capable of meeting baseload requirements. Fusion power plants, in conjunction with renewable energy, have the potential to cover the ever-rising power demands of the future.

Current research and development activities are focusing on two fundamentally different fusion technology concepts: the first involves laser fusion, in which particularly intense laser radiation ignites the fusion reaction; the second is magnetic confinement fusion, in which the hot fusion plasma is confined by magnetic fields. As of now, fusion research is gaining momentum across the world. This is also encouraged by recent scientific successes that have grabbed the attention of the public, such as the experiments at the National Ignition Facility (NIF) in the United States, where for the first time more fusion energy was released than the energy input into the system in the form of laser light. Notable successes in magnetic confinement fusion have also been achieved in the context of the two major research areas and leading device candidates, viz. tokamaks and stellarators.

More intensive research is, however, required before fusion energy can be used. This chiefly concerns the development of the technology maturity levels of the individual technologies (e.g. materials, tritium cycle, laser), some of which are still a long way from market readiness, but are in general more advanced in the field of magnetic fusion than in the field of laser fusion. The Federal Ministry of Education and Research is therefore committed to building a fusion ecosystem of industry, start-ups and the scientific community so that a fusion power plant can become a reality in Germany. The funding for this purpose is the Federal Ministry of Education and Research's "Position Paper on Fusion Research" presented by Federal Minister Stark-Watzinger on 22 June 2023. The paper outlines the main fields of action and possible strategic measures in magnetic and laser fusion research. Based on this, the Federal Ministry of Education and Research published the specialist programme "Fusion 2040 – Research on the way to the fusion power plant" in March 2024. The funding programme is aimed at all technologies and addresses both magnetic confinement and laser fusion.

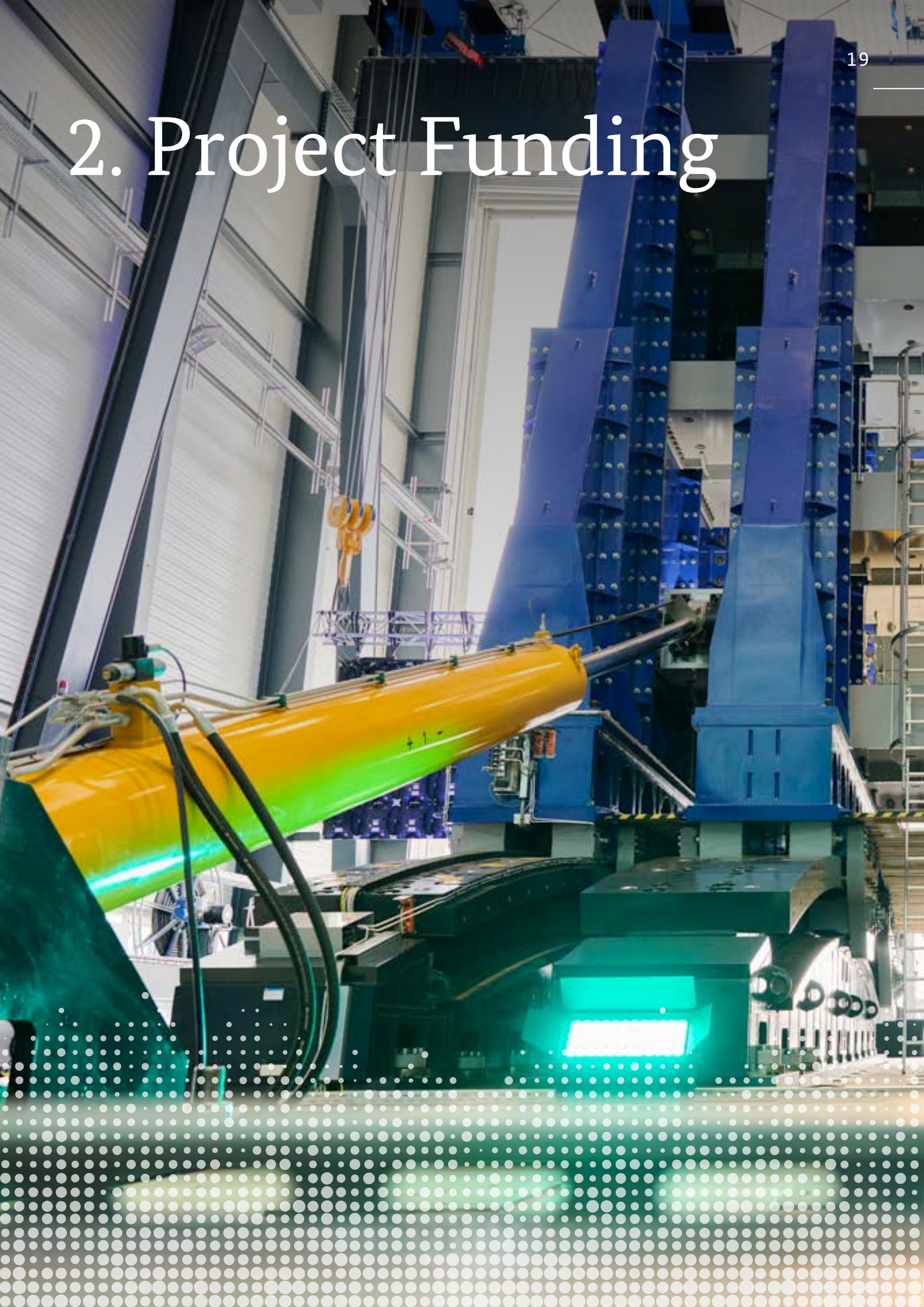
In order to achieve the goal of the funding programme, the construction of a fusion power plant, as quickly as possible, the measures are essentially based on application-oriented collaborative research in the form of a public-private partnership (PPP). This allows new findings from research studies to be applied at an early stage and the know-how to then be transferred to domestic industry for implementation. The conditions for fusion are already excellent in Germany, both among the scientific community and in industry. While OEMs will benefit considerably from the spillover effects of fusion research, the same applies thanks to the four of the 40 or so fusion start-ups worldwide that are now based in Germany.

The funding programme is in tune with the Federal Ministry of Education and Research's institutional funding, which is used to invest in research infrastructures for magnetic confinement fusion research (through the Max-Planck-Institute for Plasma Physics (IPP), Research Centre Jülich (FZJ) and the Karlsruhe Institute of Technology (KIT). In the long term, these investments will secure Germany's position as a global technology leader in magnetic confinement fusion, which is particularly evident in the development of stellarators.



Though a lot of research is still necessary: Fusion power plants, in conjunction with renewable energy, have the potential to cover the ever-rising power demands of the future.

2. Project Funding



2.1 Strategic funding formats

2.1.1 Living Labs of the Energy Transition

The Living Labs of the Energy Transition are a measure anchored by the Federal Ministry for Economic Affairs and Climate Action in the Energy Research Programme. Targeted support is given to projects which systematically trial innovations and research findings in a real-life environment and on an industrial scale. These projects make it possible to speed up the transfer of technology and innovation by closing the gap between research and practice in the energy sector: they are the dress rehearsal for the market launch. In this way, the Living Labs ofthe Energy Transition contribute to the success of the energy transition by paving the way for new technologies and new value creation.

The main objectives of the Living Labs ofthe Energy Transition are to make progress in the energy transition, contribute to climate neutrality and directly reduce greenhouse gas emissions. In the concept, the Federal Ministry for Economic Affairs and Climate Action emphasises the high practicality of the funding format.

Together with the RefLau and GeoSpeicherBerlin Living Labs of the Energy Transition, which were launched in 2023, the total of ongoing projects has gone up to thirteen.

- GeoSpeicherBerlin
- JenErgieReal
- Large heat pumps in district-heating networks (GWP)
- Darmstadt Energy Laboratory for Technologies in Application (DELTA)
- Wilhelmsburg Integrated Heat Transition (IW3)
- TransUrban.NRW
- SmartQuart – smart energy neighbourhoods

Living Labs of the Energy Transition in the field of “sector coupling and hydrogen technologies”:

- RefLau
- H2 Wyhlen
- Northern Germany Living Labs
- Bad Lauchstädt Energy Park
- H2Stahl
- WESTKÜSTE100

Important milestones were achieved in the living labs in 2023. In the GWP project, for instance, the world’s largest large-scale heat pump was integrated into a German district heating network and went into operation at the Mannheim site. The first high-pressure hydrogen pipeline in Germany was built in the SmartQuart living lab and approved by the technical monitoring association TÜV. In addition, the climate-friendly energy supply for the neighbourhoods participating in SmartQuart and the TransUrban.NRW living lab was started. Following the ground-breaking ceremony for the 30-megawatt electrolyser, significant milestones were achieved in the Bad Lauchstädt Energy Park living lab in June 2023 by converting the gas transport pipeline for the transport of hydrogen and installing what is known as a pig launching station or pig trap in late 2023.

The first transfer conference kicked off in April 2023. Representatives involved in the fields of hydrogen and sector coupling at the Living Labs of the Energy Transition convened at the event in Berlin. They receive scientific support from the Trans4Real project whose experts analyse and integrate the findings from the projects across the board. As such, the team was closely involved in organising the transfer conference. The scientific insights from the Living Labs of the Energy Transition will be used by Trans4Real to help build up a sustainable hydrogen economy in Germany and to integrate the gas into the energy system of the future.

The Living Labs of the Energy Transition that focus on energy-optimised neighbourhoods are supported by and benefit from the accompanying scientific for the Energiewendebauen initiative (in particular, Module III "Neighbourhood") headed by the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT.

Project funding

In the field of Living Labs of the Energy Transition, the Federal Ministry for Economic Affairs and Climate Action provided approximately €45.48 million in funding for 220 ongoing projects in 2023. The ministry also appropriated approximately €72.64 million in funding for 51 new research projects in this period (cf. Figure 5).

2.1.2 Hydrogen flagship projects

Regenerative or green hydrogen and its derivatives can make a major contribution to defossilising energy-intensive sectors. For example, hydrogen has the potential to make industrial processes and drive systems for heavy goods vehicles and aviation more climate-friendly. Hydrogen also serves as an important reservoir for storing energy. This is therefore a great opportunity for the energy system.

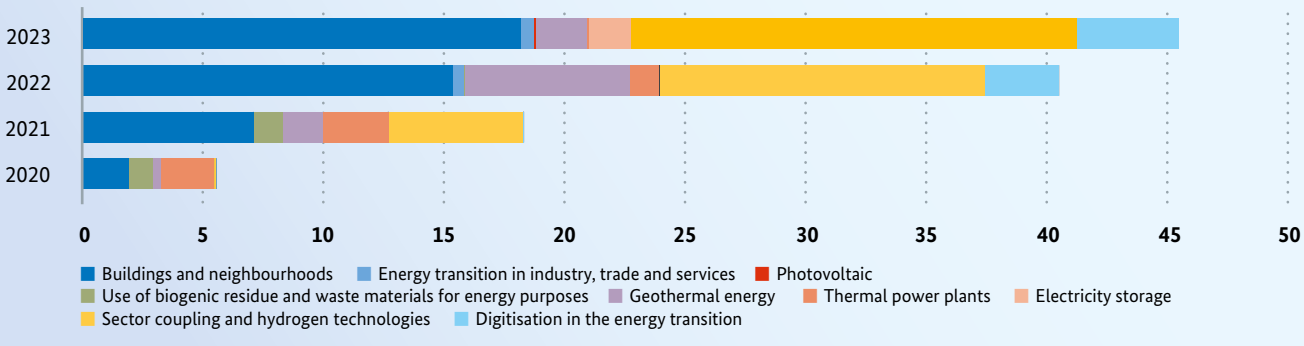
At present, there is still a lack of hydrogen produced from renewable sources to support the ramp-up of the hydrogen economy. Likewise, a suitable infrastructure for the distribution of hydrogen is not in place. By boosting the National Hydrogen Strategy, the Federal Government has thus committed itself to dealing with these and other challenges. A suitable import strategy for hydrogen and its derivatives will be adopted as soon as possible.

Funding priorities and scientific advances

The three hydrogen flagship projects of the Federal Ministry of Education and Research play an important role in achieving the goals of the National Hydrogen Strategy. More than 230 project partners in research and industry are collaborating to support the ramp-up of the hydrogen economy. Up until 2025, the projects will research the series production and scale-up of electrolysers (H_2Giga), offshore hydrogen production (H_2Mare) as well as hydrogen storage and transport technologies (TransHyDE).

For the series production and upscaling of electrolysers, the flagship project H_2Giga focuses on the development of three existing electrolysis technologies that are not yet ready for the mass production of hydrogen. The aim is to scale up these technologies and prepare them for industrial production. An initial model factory has already been set up to test various automated production steps. In addition, H2Giga aims to continue research into developing anion exchange (AEM) electrolysis. This technology has been successfully transferred to the megawatt scale for the first time worldwide.

Figure 5: Funding for the Living Labs of the Energy Transition in € million
(Data cf. Table 2, p. 76)

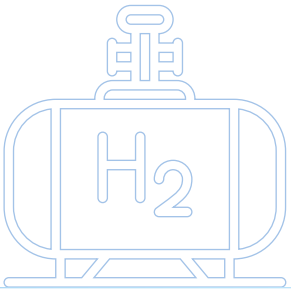


The H_2Mare flagship project is developing technologies that will facilitate the direct coupling of electrolysers and offshore wind turbines. This would help reduce the load on the electricity grid and save costs in the future. H_2Mare is also developing concepts for the offshore production of other power-to-X products. In addition to the technical and legal requirements, the flagship project is also focusing on the environmental impact and the participation of the public.

In order to transport hydrogen in large quantities in the future, a suitable infrastructure is a must. The flagship project TransHyDE is researching and demonstrating various alternatives for hydrogen transport and storage. The project also aims to assess the benefits and disadvantages of the individual alternatives. In particular, TransHyDE focuses on the transport and storage of gaseous and liquefied hydrogen as well as hydrogen in and ammonia or liquid organic hydrogen carriers (LOHCs). Furthermore, the flagship project is also examining the general regulatory framework. Since June 2023, a new consortium has been examining in particular the potential conversion of LNG terminals to hydrogen-based energy sources. The consortium is also examining the relevant criteria and planning measures for new terminal infrastructures. An initial analysis from TransHyDE has briefly highlighted that more terminals are needed than previously planned in order to meet the target import volumes.

Project funding

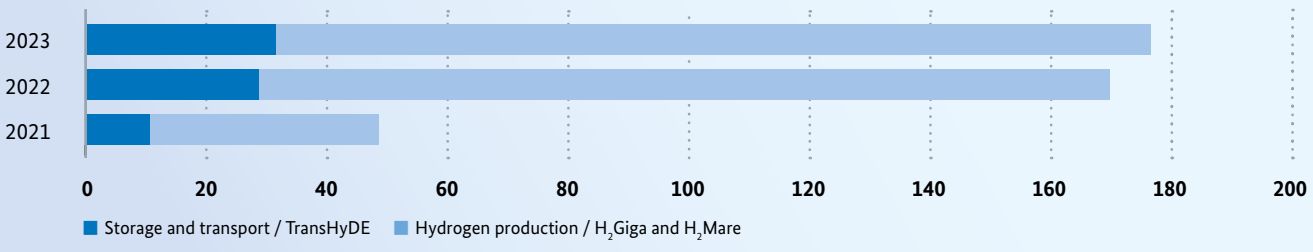
For hydrogen flagship projects, the Federal Ministry of Education and Research provided approximately €176.72 million in funding for 368 ongoing projects in 2023. In addition to this, the ministry appropriated approximately €43.21 million in funding for 37 new research projects in 2023 (cf. Figure 6).



"The flagship projects address the main challenges of the hydrogen ramp-up. With our work, we are laying the foundation for an important aspect of a climate-neutral future – making large quantities of green hydrogen available in the near future."

Coordinating teams of the three hydrogen flagship projects

Figure 6: Funding for hydrogen flagship projects in € million
(Data cf. Table 2, p. 76)



PROJECT ABSTRACT

Hydrogen flagship projects

Production, storage and transport of green hydrogen

Since 2021, three flagship projects of the Federal Ministry of Education and Research have been working on ramping up the hydrogen economy in Germany. H_2Giga focuses on enabling the serial manufacture and scaling up of electrolysers for hydrogen production. H_2Mare focuses on researching the offshore production of green hydrogen and its derivatives. TransHyDE focuses on developing storage and transport technologies.

H_2Giga, H_2Mare und TransHyDE, the three hydrogen flagship projects, are making significant progress in the hydrogen sector by laying the foundations for the series production of electrolysers, for the offshore production of green hydrogen, and for demonstrating hydrogen storage and transport technologies.

A combination of innovative materials, manufacturing processes and operational research are required for the production of high-performance electrolysers. H_2Giga has developed the first plant components for "giga factories" to enable the production of large-scale electrolysers and has launched a semi-automated sample production facility for electrolysis stacks. Moreover, the flagship project has also developed detailed recycling concepts to ensure that electrolysers become more cost-effective and environmentally friendly in the future. This includes all electrolysis technologies and key components. Another successful achievement is the development of a fluorine-free membrane material. As of now, it has been tested on a cellular scale for around 2000 hours and already matches the performance of tried-and-tested materials.

H_2Mare involved the construction of a test site to conduct tests, initially onshore and subsequently offshore, on the future combination of electrolysers and wind power plants. The aim is to demonstrate how electrolysers cope with fluctuating wind conditions. H_2Mare also boasts a highlight when it comes to public relations: an online game communicates the technologies and concepts that H_2Mare is developing.

The TransHyDE flagship project developed and set up the world's largest hydrogen calibration test rig. In Bavaria, the flagship project has also successfully converted an existing natural gas distribution grid for use with hydrogen. Ammonia is a promising solution for the transport of hydrogen. TransHyDE has developed a new catalytic converter that is designed to make the extraction of hydrogen from the carrier medium more efficient and consequently more cost-effective.

The close collaboration between scientists, researchers and the business community are instrumental in the successful achievements of the hydrogen flagship projects. The project partners jointly contribute to successful results and concepts that can be tested directly in practice.

Technology Readiness Level upon completion of the project: 3-7

Beneficiaries: more than 230 partners from the industry, business community and the public
Project funding by: Federal Ministry of Education and Research
Funding ID: 03HY101A-03HY132, 03HY200A-03HY210P, 03HY300A-303P
Appropriated funding: €759.55 million
Project duration: 2021 – 2025
Project description on EnArgus:

MORE DETAILS

2.2 Energy transition in the consumption sectors

2.2.1 Energy in buildings and neighbourhoods

More than a third of the total energy requirement in Germany goes in heating buildings and supplying hot water. Over 80% of the demand for heating is still covered by burning fossil fuels. In order to ensure the climate-neutral supply to and operation of buildings and neighbourhoods in the long term, it is imperative for us to step up the rate of modernisation and decarbonise heating and cooling supply. The Federal Climate Protection Act stipulates that emissions in the buildings sector must be limited to a maximum of 67 million tonnes of CO_2 equivalents by 2030. Efficiency measures, the transition to sustainable heating systems and the increased use of district heating through renewable energy sources are crucial in this regard.

Funding priorities and scientific advances

The aim of funding provided by the Federal Ministry for Economic Affairs and Climate Action is to research sophisticated and efficient energy supply systems that use renewable sources for modernisation activities as well as new constructions and to test these systems in practice. The funding supports solutions that are customised for specific locations but can also be applied to other locations. Research focuses chiefly on developing innovative materials and smart modernisation methods for buildings and neighbourhoods. This includes the automated monitoring of structural conditions as well as innovative and systemically designed energy supply solutions. Funded energy systems use on-site renewable energy, include storage and distribution systems and develop smart instrumentation and control engineering solutions to provide cooling, heating and electricity according to demand.

In the area of funding, the first half of the year focused chiefly on calls for funding climate-neutral heating and cooling projects. Particularly noteworthy in this context are the 24 approved micro-projects as they stand out from the existing concepts by virtue of their focus on the quick implementation of project results and short project durations. The practically relevant research projects cover current systemic and technological issues, such as heat systems planning, heat storage and heat pumps.

In 2023, the Federal Ministry of Education and Research continued activities already underway in the field of buildings and neighbourhoods.

Project funding

In the field of energy in buildings and neighbourhoods, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €87.09 million in funding for 1023 ongoing projects in 2023. Furthermore, the ministries also appropriated approximately €77.80 million in funding for 202 new research projects (cf. Figure 26).

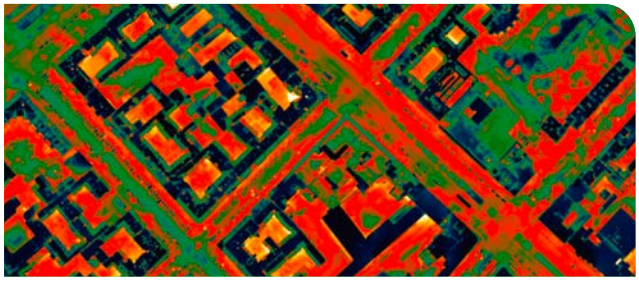
PROJECT ABSTRACT

ML4Heat

Tools for optimised operation of district heating networks based on machine-learning methods

The decarbonisation of energy generation is also having an impact on the district heating networks. Instead of a few large power plants, an increasing number of smaller regenerative heat sources are supplying the grid. For network operators, this means taking more variables into account for purposes of planning and expecting lower and unstable supply temperatures. Operators will therefore need more information in future in order to operate their systems efficiently. For instance: how will the heat capacity be distributed in the network? What changes can be anticipated in heating requirements? Based on these factors, operators can accordingly control and operate their networks. The relevant evaluations and analyses are delivered by AI tools developed by the scientists in the ML4Heat research project.

The software system provides information that network operators then use to plan and operate their heat production depending on the actual demand. Faults and failures in the district heating transfer stations are quickly detected and reported. This helps optimise energy efficiency in the heating supply. ML4Heat uses, for example, theoretical knowledge about the heat consumption of households and weather forecasts for its analyses. In order to obtain the necessary data, measuring stations and sensors need to be installed at various locations in the system.



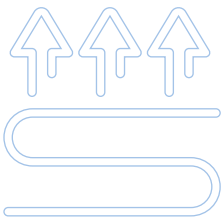
Researchers in the ML4Heat project investigate methods for the optimisation of district heating networks in Berlin.

In the pipeline network of the Neukölln district heating plant, which supplies around 40,000 households, the ML4Heat tools already offer considerable added value, for example for the reduction of peak loads. Preparation is currently underway to deploy these tools at utilities company Vattenfall Wärme Berlin which supplies heating energy to around 1.3 million households. In a subsequent project, the tools are also to be integrated at a municipal utilities company and an energy supplier.

Technology Readiness Level upon completion of the project: 7-8

Beneficiaries: Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB, and KT-Elektronik Klaucke und Partner GmbH
Project funding by: Federal Ministry for Economic Affairs and Climate Action (BMWK)
Funding ID: 03ET1668 A-B
Appropriated funding: approx. €1 million
Project duration: 2019 – 2022
Project description on EnArgus:

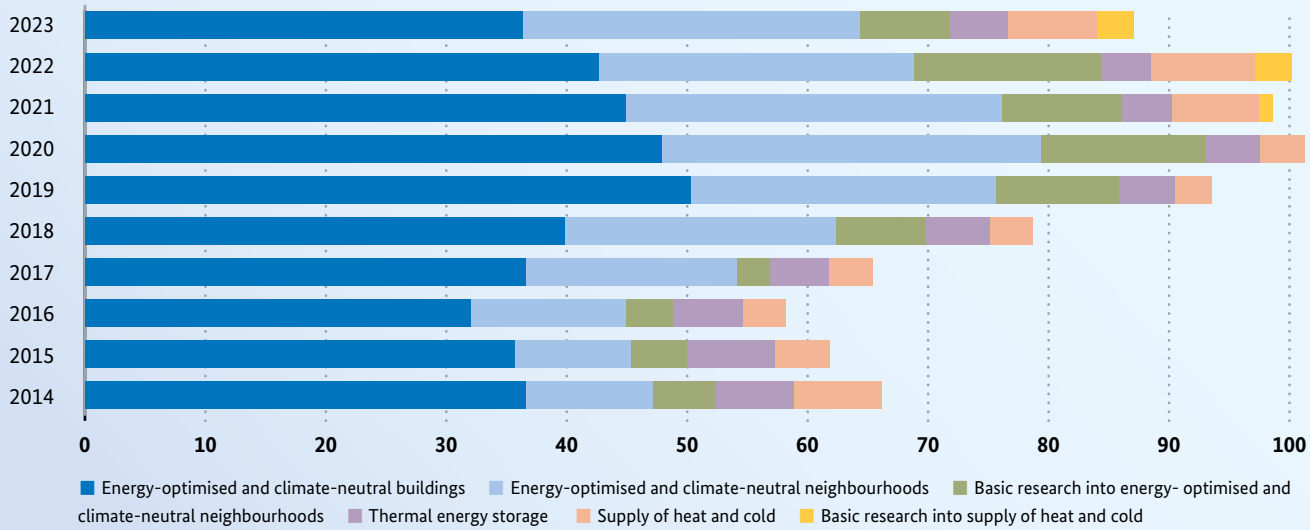
MORE DETAILS



"Our tools are designed to facilitate the commercial and energy optimisation of the network operation for existing infrastructure. District heating companies will reap the benefits almost immediately."

Dr. Thomas Bernard from Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB

Figure 7: Funding for buildings and neighbourhoods in € million
(Data cf. Table 3, p. 77)



2.2.2 Energy efficiency in industry, commerce, trade and services

Over a quarter of the energy consumed in Germany is used in industrial production. With a share of around 28% of the total energy consumption, the chemicals industry was the largest energy consumer in 2022. Following closely were the metal production and processing industry with around 23% and the coking and mineral oil processing industry with around 10%. Almost a third of energy consumption is accounted for by natural gas, which is used by industry for process heat, electricity generation and as a raw material.

Funding priorities and scientific advances

Industries including steel, chemicals, cement, aluminium, glass, ceramics and paper require a great deal of heating and cooling in their production processes. Waste heat is produced that can be further exploited and fed back into the process, thus reducing energy consumption in companies. Thermal process technology, for example, can provide innovative solutions for these energy-intensive processes. This technology has the potential to optimise energy efficiency, reduce CO_2 emissions, and integrate renewable energies in industrial processes. Heat research is now strongly represented in the Industry and Commerce research network. In 2023, two participating working groups were reorganised and a new one was included for heat and waste heat, thermal process technology, and heat pump and refrigeration technology. This helps researchers network more effectively and put research results into practice more quickly. This is also true for other research topics, such as the electrification of industry, more efficient manufacturing processes through new or optimised technologies, or cross-cutting topics such as artificial intelligence and digitalisation.

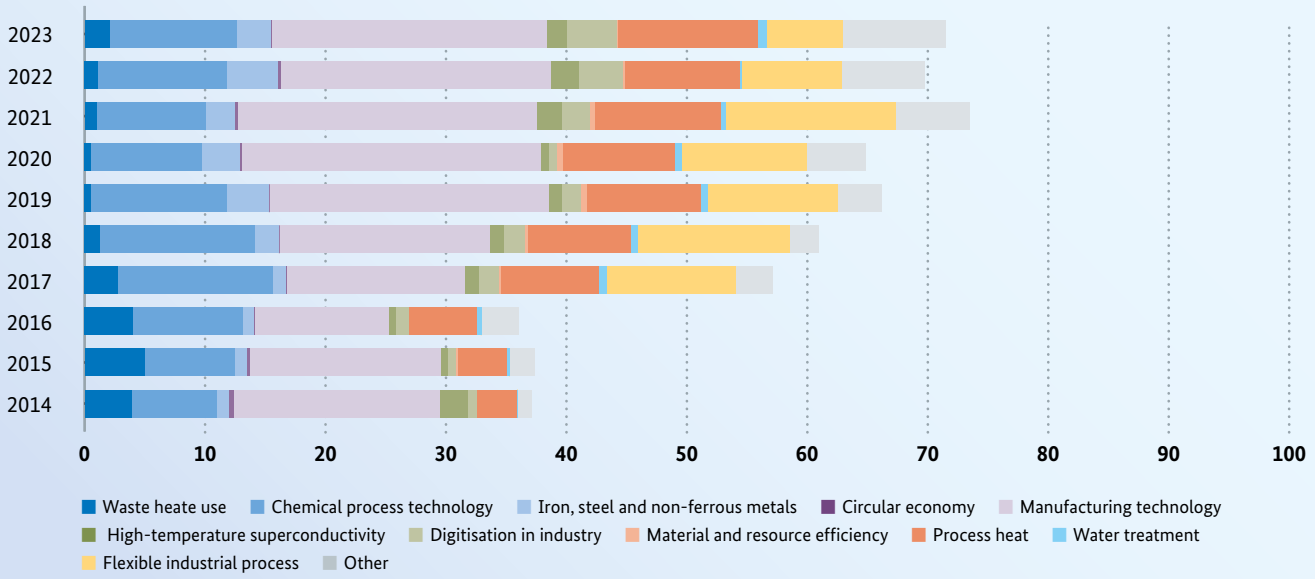
The Kopernikus project SynErgie, funded by the Federal Ministry of Education and Research, entered its third funding phase in 2023. A dual-fuel melting crucible furnace that can switch between gas and electricity as energy sources has gone into operation in a real-life environment. The project demonstrates how energy-intensive industry can adapt its electricity consumption to volatile, renewable electricity generation and what regulatory changes are necessary to implement the flexibility technologies devel-

oped. In this context, the focus is on the transfer of concepts, technologies and solutions for the energy-flexible factory from a laboratory and technical centre scale to an industrial and application scale. SynErgie is making a significant contribution to the energy transition and is therefore a flagship project of the Federal Government's digital strategy.

Project funding

In the field of energy efficiency in industry, commerce, trade and services, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €71.45 million in funding for 801 ongoing projects in 2023. In 2023, the ministries also appropriated approximately €106.40 million in funding for 251 new research projects (cf. Figure 8).

Figure 8: Funding for energy efficiency in industry, commerce, trade and services
(Data cf. Table 3, p. 77)



2.2.3 Interfaces between energy research and mobility and transport

At currently over two percent, the proportion of fully electric cars in Germany has more than tripled in the past two years. The increasing electrification of road transport and the rising share of renewable energies in the electricity mix are helping to decarbonise the transport sector. This also applies to the use of biofuels and the first applications involving hydrogen. Energy research is clearly making a relevant contribution to these developments.

Funding priorities and scientific advances

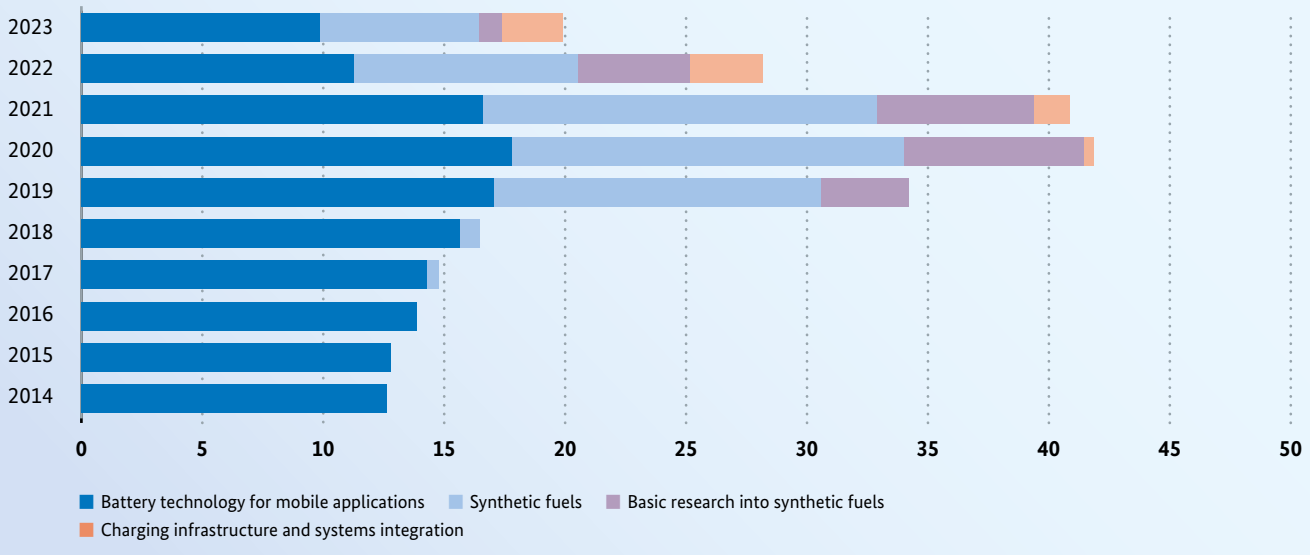
Research and development in the field of electric mobility covers all types of vehicles. This, for instance, provides the impetus for the further development, utilisation and recycling of batteries. Using electricity from renewable energies is often the most energy-efficient and economical option. Apart from this, hydrogen is yet another important building block as it also enables sector coupling between the electricity industry and transport. Green hydrogen can be produced both from water via electrolysis using renewable electricity and from biomass via thermochemical processes. This can be used directly in the mobility sector, for instance in fuel cell powertrains.

Additional process steps also make it possible to produce liquefied or gaseous fuel from hydrogen. The Federal Ministry for Economic Affairs and Climate Action is promoting research into these electricity-based fuels through its "Energy transition in the transport sector" initiative. Last year, it published its findings in a roadmap.

Project funding

In the field of the interface between energy research and mobility and transport, the Federal Ministry of Education and Research and the Federal Ministry for Economic Affairs and Climate Action provided approximately €19.92 million in funding for 177 ongoing projects in 2023. In addition to this, the ministry appropriated approximately €11.66 million in funding for 18 new research projects in 2023 (cf. Figure 9).

Figure 9: Funding for energy research on mobility and transport in € million
(Data cf. Table 3, p. 77)



PROJECT ABSTRACT

Third phase of the Kopernikus projects for the energy transition *(Ariadne, ENSURE, P2X, SynErgie)*

The Kopernikus projects are among the largest research initiatives for the energy transition. Their concept and structure were an absolute novelty at the time of inception: members of the business community, science and technology, and the civil society are working together on solutions with systemic relevance. With a focus on four key areas, they take a holistic approach to the energy transition: policy measures and the participation of society (Ariadne), the power grid of the future (ENSURE), the production of electricity-based fuels and chemical raw materials (P2X), and making industrial processes more flexible in order to adapt them to face fluctuations in electricity supply (SynErgie).

The duration of each project is ten years. The projects have now entered the third phase, which is dedicated to know-how transfer and to putting the technologies into practice. Ariadne uses tools such as the "Transformation Tracker" and studies to chart the general progress of the energy transition. A second participation process is also underway to integrate the diverse opinions of the public into the research. ENSURE focuses on a modular, highly flexible transfer of technologies for the power grids of the future. This implies visualising a power grid in conjunction with other energy sources and their infrastructure and not as a distinct, segregated entity. Following successful demonstrations, for example in low-iridium electrolysis, P2X focuses on electricity-based synthetic aviation fuels. Two satellite projects (each independent but networking closely with the P2X project) focus on polymers and chemicals as additional important power-to-X products. SynErgie demonstrates the potential of technology transfer in the model region of the city of Augsburg and its surrounding areas and how the energy flexibilisation of a group of companies integrated within a geographically delimited area can succeed. As a beacon of Germany's digital strategy, a major focus is on how the energy-flexible operation of production facilities can be implemented on a large scale using digital tools and management solutions.

Researches of the Kopernikus projects are involved in pioneering work for the energy transition: Fully integrating the civil society and members of the scientific and business communities paves the way for ushering in climate neutrality at a systemic level.

Technology Readiness Level nach Projektende: 7-8

Beneficiaries: Potsdam Institute for Climate Impact Research, Siemens, Karlsruhe Institute of Technology, University of Stuttgart and 134 other partners.
Project funding by: Federal Ministry of Education and Research
Appropriated funding: €110 million (Funding phase III)
Project duration: 2023 – 2027

"The Kopernikus projects play a crucial role in successfully shaping the energy transition – By pooling together a wide range of practical and research-based perspectives of partners from industry, NGOs, science and technology, we are in a position to illuminate viable paths to climate neutrality. Today more than ever, we need this integrative approach to reduce emissions across all sectors and put the energy supply on a new footing. To accomplish this enormous feat, new technologies are as vital as effective policy instruments and public backing."

Dr. Ottmar Edenhofer, Potsdam Institute for Climate Impact Research, Ariadne Project Management

2.3 Energy generation

2.3.1 Photovoltaics

The “Photovoltaic Strategy” published by the Federal Ministry for Economic Affairs and Climate Action in May 2023 is key to determining the prospects for the development of photovoltaics in Germany. The basis of the strategy is achieving the interim target of 215 gigawatts of installed photovoltaic (PV) capacity by 2030. This means that, within just a few years, the annual expansion of photovoltaics needs to increase threefold, from 7 gigawatts in 2022 to 22 gigawatts. In addition to facilitating PV installations – specifically in this context ground-mounted and rooftop systems, tenant electricity schemes, balcony power generator systems, grid connection and acceptance – the emphasis is also on advancing funding in research within the scope of the 8th Energy Research Programme.

Funding priorities and scientific advances

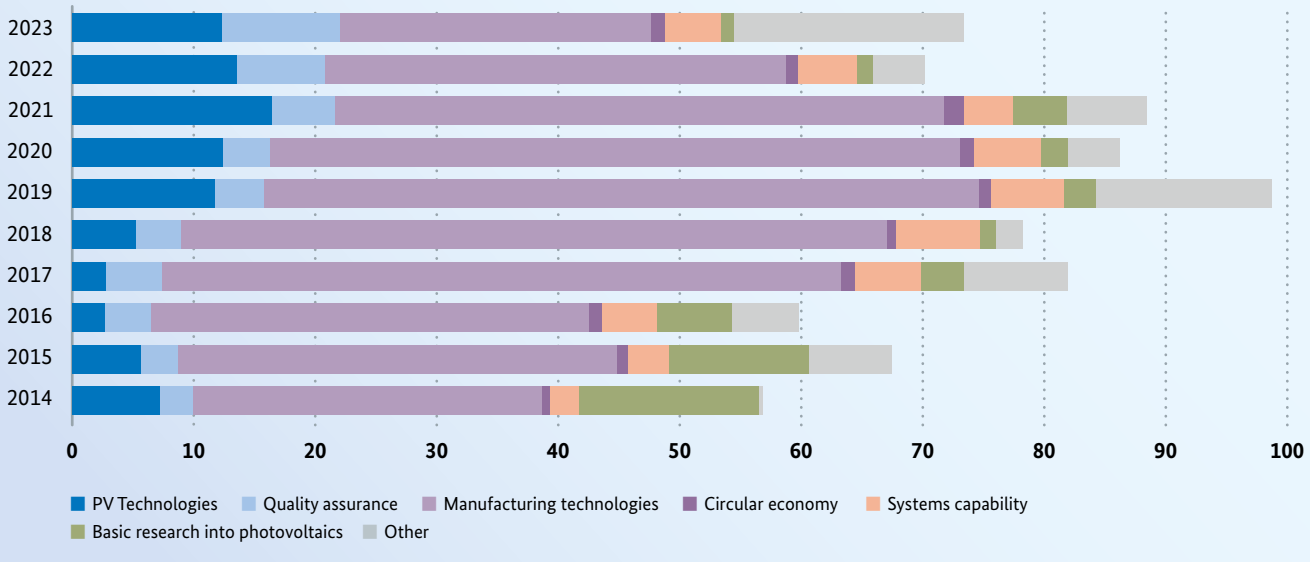
The rapid expansion of photovoltaics involves two major demands on research funding: on the one hand, further innovations are required in order to minimise the costs of restructuring the energy system. On the other hand, the objective is to secure supply chains and incentivise competitive European production.

As such, the focus continues to be on developing a new generation of tandem solar cells composed of silicon and perovskite sub-cells which, in the meantime, boast efficiencies of over 33%. To this end, institutions and the industry are collaborating closely in research projects. This concept is expected to be scaled up to industry standards in the near future and thus brought a step closer to going into production.

Apart from this, the consumption of resources is also becoming increasingly important. For a climate-neutral expansion of photovoltaics in the future, it is essential to introduce more resource-efficient processes along the entire value chain, avoid environmentally harmful materials, and implement comprehensive recycling measures.

Furthermore, one of the research priorities of funding by the Federal Ministry of Education and Research involves the analysis and optimisation of solar cells and the associated infrastructure in

Figure 10: Funding for photovoltaics in € million
(Data cf. Table 4, p. 78)



Africa. The relevant projects include, for example, yield analyses of photovoltaics with regard to food production, energy supply and electric mobility.

Project funding

In the field of photovoltaics, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €73.38 million in funding for 461 ongoing projects in 2023. In 2023, the ministries also appropriated approximately €65.90 million in funding for 93 new research projects (cf. Figure 10. p. 30).

2.3.2 Wind energy

No supply system based on renewable energy is complete without wind power: In 2023, wind power once again made the biggest contribution to electricity supply from renewable energy sources. At around 31.1%, wind power continues to be the most important energy source in the overall German electricity mix – ahead of fossil fuels such as lignite. Together, onshore and offshore plants produced just over 142 billion kilowatt hours of electricity, around 14% more than in the previous year. More new turbines were installed than in the previous year and the expansion has accelerated. The net output of onshore wind turbines connected to the grid increased by around 3 gigawatts (as against 2.1 gigawatts in 2022). New offshore wind turbines accounted for 258 megawatts.

Funding priorities and scientific advances

The Federal Ministry for Economic Affairs and Climate Action's funding projects are intended to making the use of wind energy – both onshore and offshore – more reliable, cost-effective and environmentally friendly. Research is possible in all phases of the service life of wind turbines: from turbine design, manufacture, assembly, operation and dismantling through to the recycling of the materials and components used. In addition to the turbine technology, the logistics, monitoring and maintenance of the turbines as well as strategies for operational management also need to be optimised.

Research projects funded by the Federal Ministry for Economic Affairs and Climate Action also focus on integrating the energy provided by wind farms into the system. Key aspects in this regard are, on the one hand, the grid-forming and grid-supporting properties of wind turbines. On the other hand, the energy requirement and energy supply should be dovetailed to the best possible extent, also in conjunction with other renewable energy sources and forms. Innovations with regard to supply security and resilience to internal and external disruptions are also supported.

The findings from wind energy research are intended to help accelerate the energy transition. It is therefore necessary to identify and eliminate existing obstacles, develop additional sites or utilise existing sites multiple times or upgrade them through repowering measures. Against this backdrop, issues such as noise, annoyance and adverse effects of wind turbines, and public acceptance play an important role. Innovations for nature and species conservation and the investigation of different forms of participation can provide potential solutions.

Offshore wind turbines generate a significantly greater and steadier power supply than their onshore counterparts. This potential must be exploited to produce hydrogen and its derivatives directly at sea using electricity from renewable energy. To this effect, electrolysers are coupled with wind turbines. For this to succeed, both the electrolyser and the wind turbine need to be fine-tuned. The Federal Ministry of Education and Research is funding two projects to achieve this. Project H_2Wind focuses on adapting electrolysers to the rough conditions at sea. Project OffgridWind focuses on the necessary adjustments to wind turbines. The direct coupling of wind turbines and electrolysers can minimise the costs of hydrogen production, since infrastructure costs can be signif-

icantly reduced when a connection to the power grid is not needed. In addition, the decoupling of electrolysis and the grid eases the burden on local grid structures. Another advantage of offshore hydrogen production compared to onshore production is that there are much larger potential areas for the generation of wind energy.

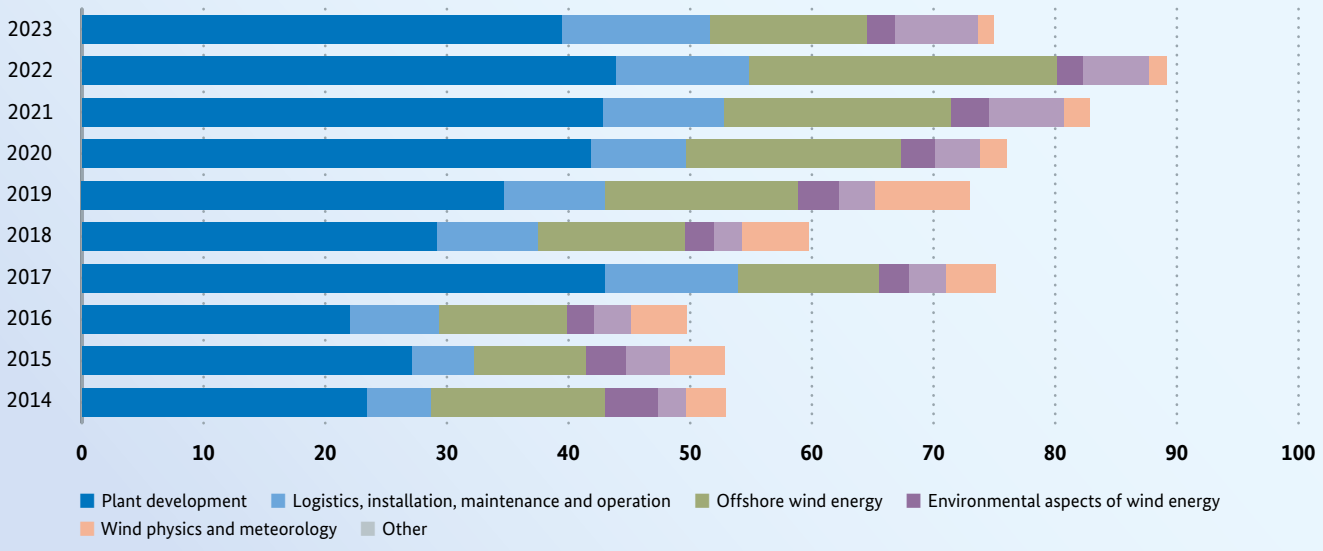
Project funding

In the field of wind power, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €74.97 million in funding for 471 ongoing projects in 2032. In 2023, the ministries also appropriated approximately €62.70 million in funding for 99 new research projects (cf. Figure 11).

2.3.3 Bioenergy

Despite the ongoing expansion of renewable energies such as solar and wind power, bioenergy still accounts for around two-thirds and thus the largest share of renewable energy in Germany. However, considering the limited biomass potential, non-biomass-based technologies, particularly electricity and hydrogen-based technologies, generally offer the most efficient long-term defossilisation options in the energy and industrial sectors. Currently, the generation of around 85% of renewable heat and also around 85% of sustainable fuels is still based on biomass. In the context of power generation, the share of wind and solar energy has increased significantly in recent years. Wind and solar energy must be prioritised in order to focus the use of the limited biomass potential in areas where these alternatives are not available or are not yet fully developed. Using biomass to generate energy can be meaningful, for example, where it is essential for the flexible, demand-based coverage of peak loads in the electricity supply (biogas/methane) or for the generation of high-temperature process heat in industry. The efficient utilisation of local and regional material cycles can also be a commercially viable application. The fermentation of liquid and solid manure – currently the only technically and commercially established solution for reducing methane emissions from farm fertilisers – therefore plays a particularly important role.

Figure 11: Funding for wind power in € million (Data cf. Table 4, p. 78)



Funding priorities and scientific advances

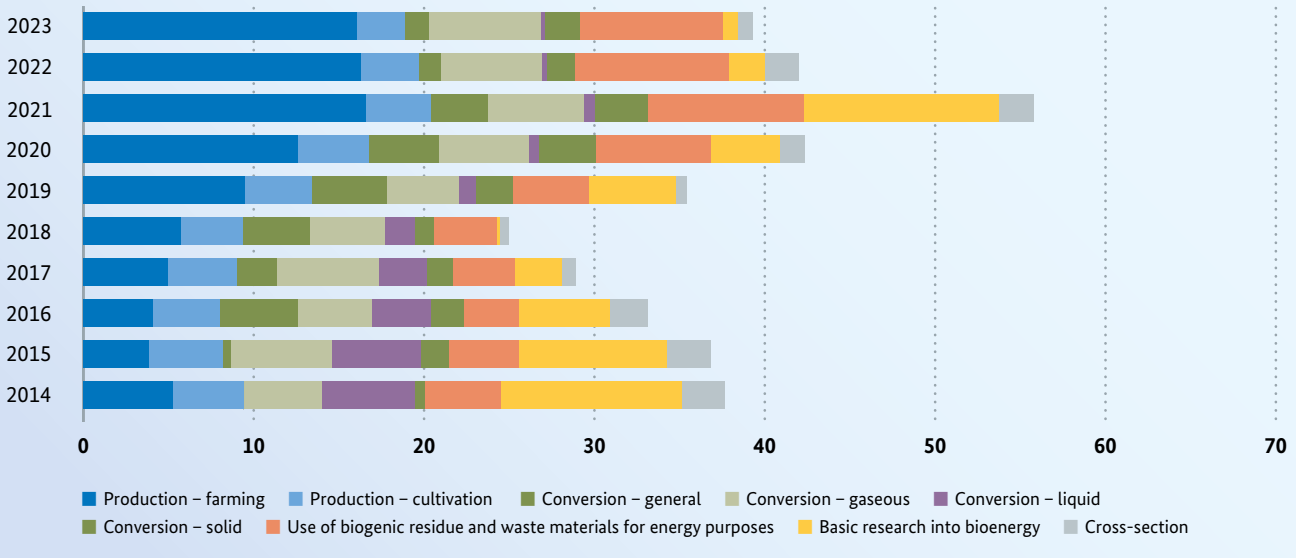
The Federal Ministry of Food and Agriculture funds research, development and demonstration projects in the field of bioenergy for various research priorities within the scope of the "Renewable Resources" funding programme. Various calls for funding have been launched in recent years to support these priorities and the first projects have now been successfully completed. Last year, for example, the funding projects from the calls "Intensifying agricultural residue and waste utilisation in biogas production" and "Making biogas production flexible" were completed. Projects from other calls, such as "The role of farm fertilisers in reducing emissions and generating energy" or "Clean combustion of solid biofuels in small-scale combustion systems with very low pollutant emissions", are ongoing with the participation of the funding recipients.

As of 1 January 2024, the new funding programme "Nachhaltige Erneuerbare Ressourcen" (sustainable renewable resources, FPNR 2024) has replaced the previous funding programme "Nachwachsende Rohstoffe" (renewable raw materials, FPNR 2015) of the Federal Ministry of Food and Agriculture.

FPNR 2024 aims to further develop a sustainable bioeconomy. To this effect, the sustainable extraction and utilisation of biomass from agriculture, forestry and waste management plays a key role. The programme aims on the one hand to promote the development of innovative, internationally competitive products made from renewable resources, as well as production processes and technologies, and, on the other, to support the development of concepts aimed at improving the sustainability of the bio-based economy. The funding programme is being implemented under the management of the Agency for Renewable Resources (Fachagentur Nachwachsende Rohstoffe e.V. – FNR).

In the funding priority "Use of biogenic residue and waste materials for energy purposes", the Federal Ministry for Economic Affairs and Climate Action is focusing on the development and testing of forward-looking technologies and process optimisations which allow for the efficient, economic and above all sustainable use of bioenergy. The main priority is on practical solutions that can serve as demonstration and pilot projects which support the flexible generation of electricity and heat from biomass, provide biofuel and use bio-

Figure 12: Funding for bioenergy in € million
(Data cf. Table 4, p. 78)

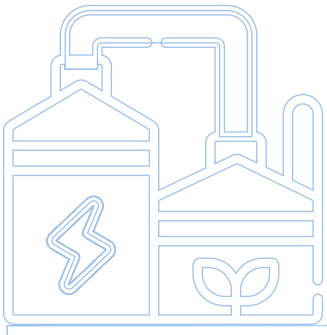


genic residues and waste. In addition to system integration, sector coupling and digitalisation, projects for biogenic hydrogen production are also attracting attention. In the context of heating applications, research focuses on solutions to decarbonise high-temperature processes. In the context of low-temperature applications, the focus is on developing innovative solutions for heating buildings and neighbourhoods as well as on heating grids, and developing concepts for coupling two or more different energy systems (for hybrid or multibrid systems) in the interaction between electricity, heat and mobility. This also involves the practical demonstration of carbon capture as well as the necessary application and utilisation options with BECCUS (bioenergy with carbon capture and storage or utilisation). The German Institute for Biomass Research (DBFZ) is providing scientific support for the funding priority and focuses on building networks and know-how transfer.

Funding by the Federal Ministry of Education and Research will shed light on the conversion of biogenic residues into green, ultrapure, climate-neutral biohydrogen. In addition to selecting suitable residue materials, the focus is on a stable, continuous, commercially viable and scalable separation of hydrogen from thermochemically produced synthesis gas.

Project funding

As part of its key focus on bioenergy, the Federal Government provided around €44.87 million to fund a total of 694 ongoing projects in 2023. The Federal Government also approved approximately €83.49 million in funding for 166 new research projects (cf. Figure 12, p. 33) in 2023.



“The use of co-products requires modifications to daily plant operations and often also technology. A certain period for breaking even and a higher workload should therefore be taken into account right from the beginning.”

Prof. Wilfried Zörner,
Ingolstadt Technical University

PROJECT ABSTRACT

LaRA

Use of biogenic residue and waste materials for energy purposes (LaRA) – developing engineering solutions for upgrading existing biogas plants and making them compatible for fibrous residues.

The aim of project LaRA is to develop practical and technical solutions that help create optimised process and plant engineering conditions for utilising fibrous residues such as hay, grass silage and farmyard manure in agricultural biogas plants Taking into account process, plant engineering and (socio-)economic factors, the concept was based on comprehensive investigations carried out at 15 composting facilities across Germany technical. The solutions and measures were compiled to provide optimised plant and site-specific engineering concepts which were presented as recommendations for action in a handout for plant operators.

This practical guide was published in early 2023 (cf.: https://www.carmen-ev.de/download/lara-leitfaden/) and includes:

- Presenting recommendations for action based on comprehensive, long-term investigations carried out at selected composting facilities,
- Identifying future-proof plant technology modifications based on reliable and practical data,
- Defining practical and marketable system concepts on the basis of tried-and-tested application models,
- Considering the economic impacts and prospects of increased co-product utilisation in agricultural biogas plants; comparing the additional costs and savings across the entire value chain,

The LaRA project has developed practical and technical solutions that have helped optimise process and plant engineering concepts for utilising hay, grass silage and farmyard manure to produce agricultural biogas.

- Taking into account various social aspects, such as regional integration and acceptance, local business relationships, and succession matters related to farms and businesses when assessing the potential transfer of different plant concepts.

Technology Readiness Level upon completion of the project: 9

Beneficiaries: Ingolstadt Technical University, Leibniz Institute for Agricultural Engineering and Bioeconomy e.V. (ATB), C.A.R.M.E.N. e.V.
Funding ID: 22042218, 2219NR158, 2219NR196
Appropriated funding: €600,000
Project duration: 2018 – 2022
Project description on EnArgus:

MORE DETAILS

MORE DETAILS

MORE DETAILS

2.3.4 Geothermal energy

Geothermal energy is a reliable source of energy. Currently available technologies mean that hydrothermal geothermal energy is an economically viable heat source on the German market. In contrast, it is rarely used to generate electricity.

Funding priorities and scientific advances

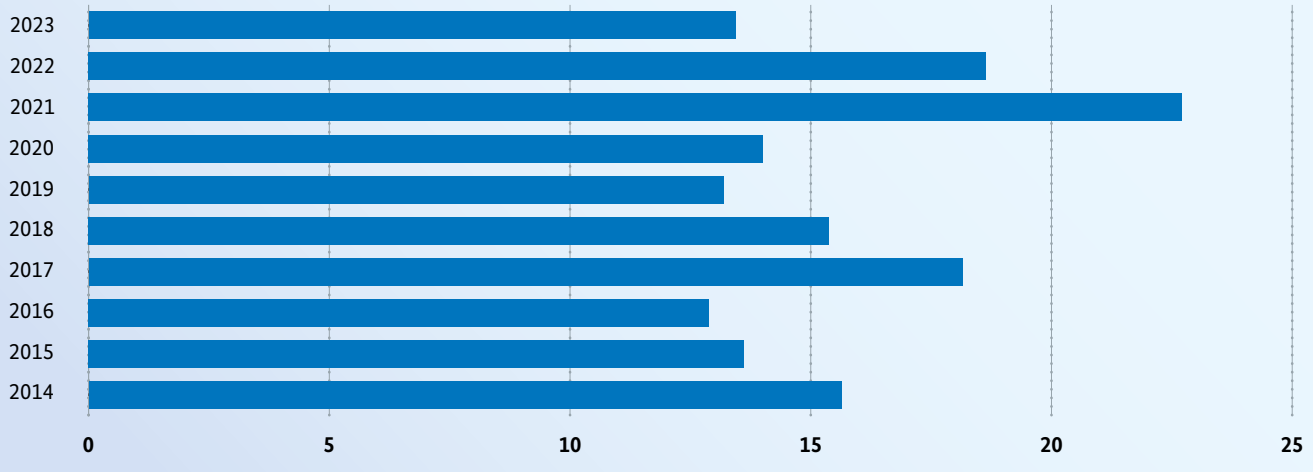
Geothermal energy is increasingly used to supply households, neighbourhoods and companies with heat and cold. In the field of deep geothermal energy, i.e. at depths in excess of 400 metres, the German Geothermal Association (BVG) states that currently 42 heating and power stations and combined heat and power plants with a total heating capacity of around 417 megawatts and an electrical capacity of approximately 46 megawatts are in operation in Germany. In the field of near-surface geothermal energy, i.e. at depths up to 400 metres, over 470,000 facilities have been installed – for example geothermal probes or collectors in conjunction with heat pumps. The total heating capacity of all facilities is roughly 4,400 megawatts.

In strategic terms, the use of geothermal energy for heating and cooling supply and the storage of heat is to be further expanded in Germany. Research projects to be funded under the 7th Energy Research Programme of the Federal Ministry for Economic Affairs and Climate Action are to help make geothermal heat rapidly deployable, reduce the costs and risks in development and use, and boost awareness and public acceptance of geothermal energy. The transfer of new technologies into practice is to be accelerated, with a focus on demonstration and pilot projects. In order to better exploit the potential of geothermal energy for the heat transition, the Federal Ministry for Economic Affairs and Climate Action has identified concrete measures in a key issues paper. At least 100 additional geothermal projects are to be initiated by 2030.

Project funding

In the field of geothermal energy, the Federal Ministry for Economic Affairs and Climate Action provided approximately €13.44 million in funding for 118 ongoing projects in 2023. In addition to this, the ministry also appropriated approximately €20.20 million in funding for 38 new research projects in 2023 (cf. Figure 13).

Figure 13: Funding for geothermal energy in € million
(Data cf. Table 4, p. 78)



2.3.5 Hydroelectric and marine power

Hydropower accounts for roughly 4% of Germany's electricity generation. It has a crucial advantage over wind and solar energy: Hydropower is largely unaffected by the weather, and, in general, is thus continuously available. However, almost all of the suitable sites for current technologies have been exhausted in Germany. Researchers are therefore aiming to use innovative technologies to boost the capacity of existing installations and to develop new sites. Research is also underway into how hydropower can help to improve the response to fluctuating energy demand. In the field of marine energy, funding is aimed at the development and demonstration of marine current turbines and wave energy converters.

Project funding

In the field of hydropower and marine energy, the Federal Ministry for Economic Affairs and Climate Action provided approximately €0.25 million in funding for five ongoing projects in 2023. In addition to this, the ministry also appropriated approximately €1.25 million in funding for two new research projects in 2023 (cf. Figure 14).

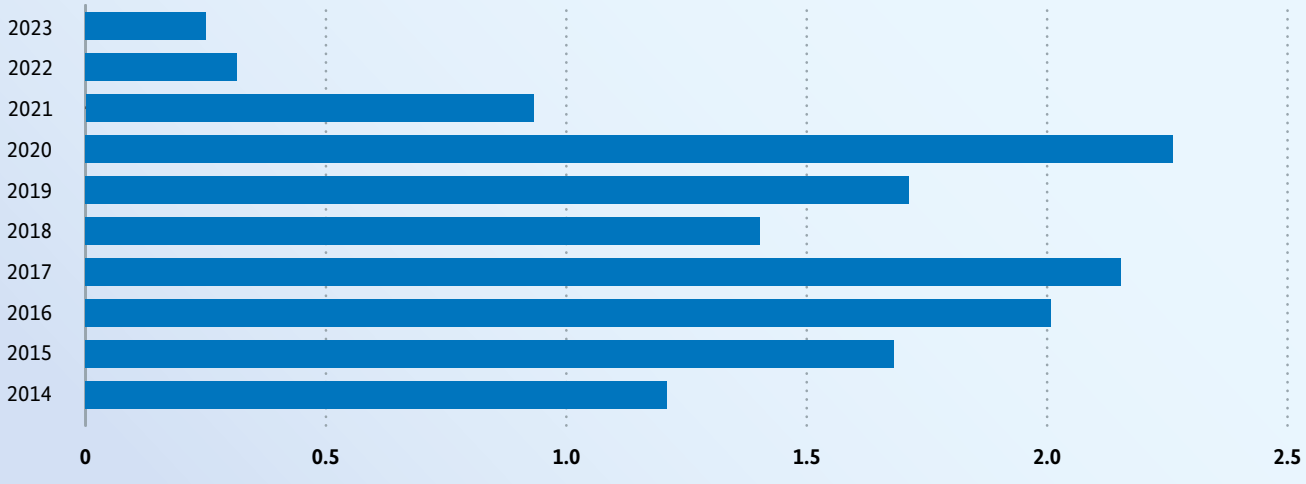
2.3.6 Thermal power plants

Thermal power plants are capable of supplying demand-based power when weather conditions impact renewable energy sources such that they cannot produce sufficient, if at all any, electricity. To ensure the efficient and low-emission operation of thermal power plants during the energy transition, fossil fuels are to be replaced gradually by hydrogen, synthetic gases or other alternative fuels.

Funding priorities and scientific advances

In contrast to hydrogen or alternative gases, natural gas has different combustion properties: for example, the temperatures generated during combustion, the flame speeds or the ignition delay times vary. Research contributes towards developing customised components, system concepts and operating processes – including for power-to-X-to-power processes. Scientists are also working on adapting the materials used – for example for turbine blade coatings – to the new fuels and increasing the efficiency of power plant processes.

Figure 14: Funding for hydropower and marine energy in € million
(Data cf. Table 4, p. 78)



Solar thermal power plants, on the other hand, produce electrical energy from concentrated solar power. This climate-friendly form of electricity generation will become even more important in countries like Spain, Morocco or the United Arab Emirates with many hours of sunshine. Due to the weather conditions, Germany only has model plants for research purposes. At the same time, it also possesses solid expertise in plant and mechanical engineering. This is to be further intensified for export purposes – for example with research work on receiver technologies and new heat transfer media such as molten salt.

Project funding

In the field of thermal power plants, the Federal Ministry for Economic Affairs and Energy provided approximately €35.26 million in funding for 358 ongoing projects in 2023. In addition to this, the ministry also appropriated approximately €29.58 million in funding for 58 new research projects in 2023 (cf. Figure 15).

2.4 System Integration

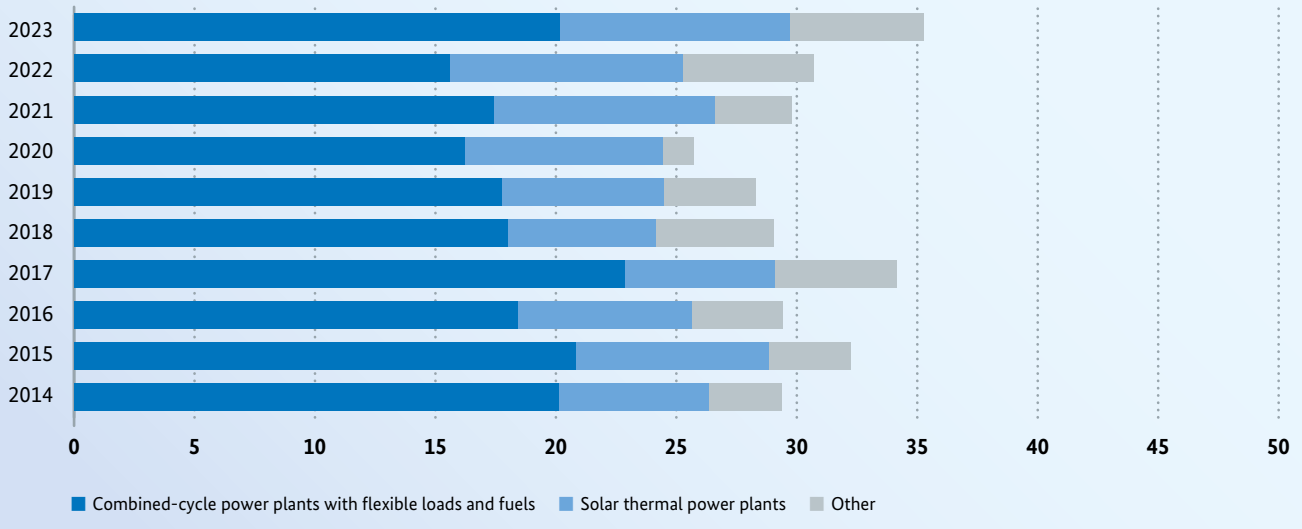
2.4.1 Electricity grids

In order to enable electricity grids to integrate the increasing volume of electricity generated from renewable sources, it is also necessary to increase their feed-in and transmission capacity. Merely adding lines is not enough to achieve this. Operators also need to digitalise the grids and develop them into smart grids.

Funding priorities and scientific advances

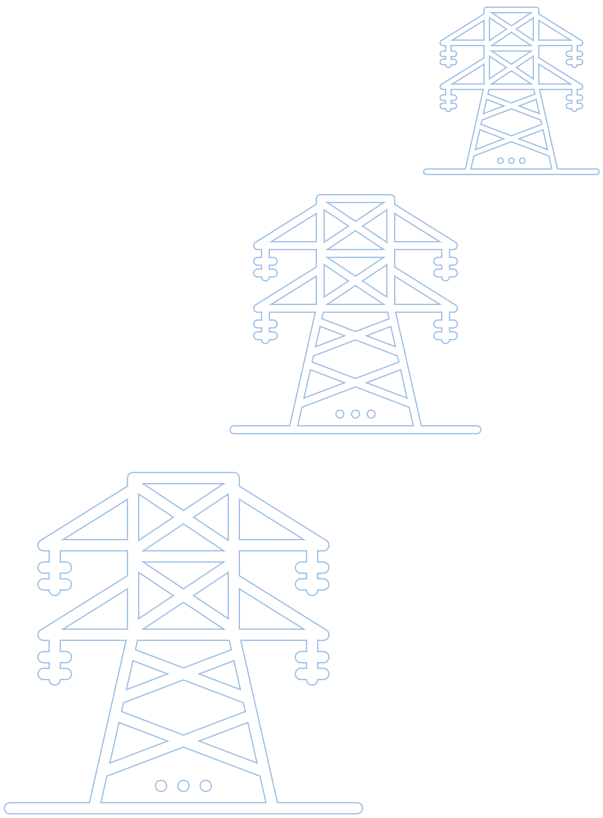
In May 2023, the Federal Ministry for Economic Affairs and Climate Action published the OptinetD funding call. The call is intended to push ahead with the modernisation of distribution grids at low and medium-voltage level. The first approved projects are scheduled to start in 2024. By addressing important aspects of grid stability, OptinetD supports the topics in the Federal Ministry for Economic Affairs and Climate Action's system stability roadmap. For example, the use of inverter-based systems such as photovoltaic or storage systems for feeding and supporting the grid as well as making

Figure 15: Funding for thermal power plants in € million
(Data cf. Table 4, p. 78)



the grids flexible. The objective of the funding is to allow for the higher utilisation of distribution grids, to develop system-supporting and grid-forming contributions, and to reduce costs for grid operators.

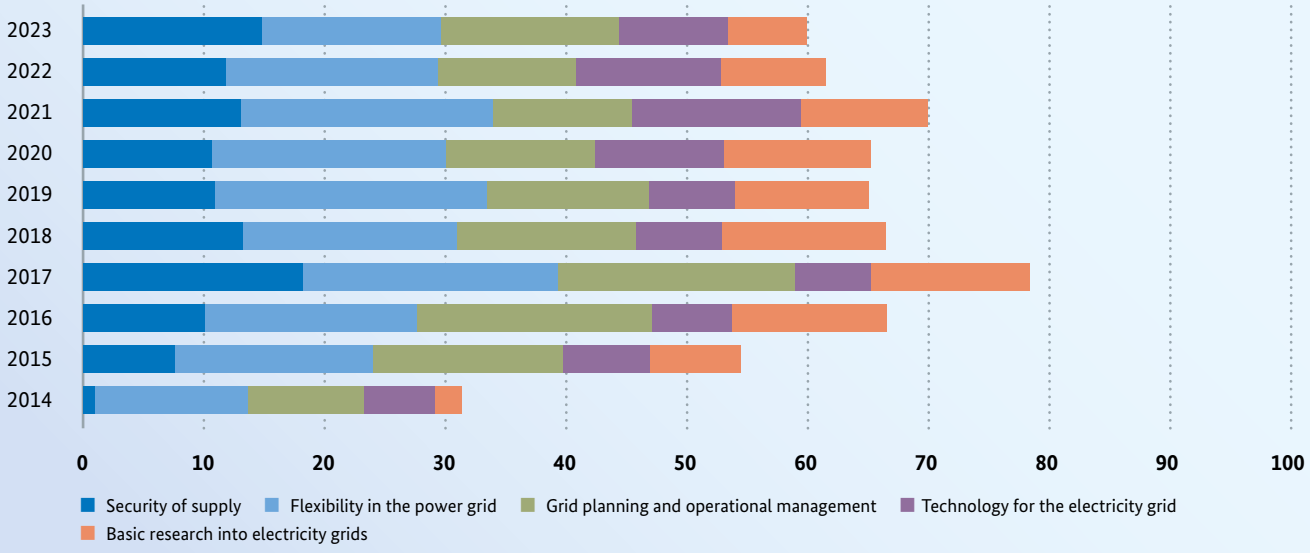
In 2023, the Federal Ministry of Education and Research's funding focused on the Kopernikus project ENSURE (new energy grid structures for the energy transition) and on the Flexible electrical grids research campus. Other consortia researched additional issues, such as resilient electricity grids or workplace design for grid control centres.



Project funding

In the field of power grids, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €59.78 million in funding for 582 ongoing projects in 2023. In 2023, the ministries also appropriated approximately €77.84 million in funding for 129 new research projects (cf. Figure 16).

Figure 16: Funding for electricity grids in € million
(Data cf. Table 5, p. 79)



PROJECT ABSTRACT

flexQgrid

Practice-oriented implementation of the quota-based grid light concept for flexibility in and from the distribution grid

Many customers of the distribution grid operator Netze BW would like to use photovoltaic systems to generate their own electricity. Not only do more and more households consume electricity, they also produce it themselves and feed it into the grid. This can lead to bottlenecks in the grid. How best to prevent such bottlenecks was investigated by the research team in the low-voltage grid in the sunny town of Freiamt in the Black Forest. To demonstrate the proper functioning of the technical solutions developed for the smart grid, the researchers conducted tests under actual operating conditions over a period of 17 months. To do so, the experts installed instrumentation, control and communication devices at the sites of 41 field test participants. They subsequently networked the integrated systems with each other. The research team was able to establish five main findings:

1. For efficient flexibility, it is necessary to standardise the interfaces between customer systems, energy management systems and smart metering systems.

2. The optimum interaction of a robust communication infrastructure and central and local systems is a must in order to ensure the reliable operation of a smart grid.

3. Advancing the current technical standards and regulations for smart metering systems will result in additional benefits for grid operators, customers and market participants.

4. Shortages could be successfully prevented and eliminated with the help of the grid light system.

5. Flexibility utilisation has great potential once grid customers accept that grid operators actively and intelligently control the energy management system in the event of any congestion. In many cases, the field test participants did not even notice a congestion. The research revealed: In the future, smart grids will play an important role in ensuring that grid operation remains economical and secure.

Project Manager Carmen Schantl

Technology Readiness Level upon completion of the project: 7

Beneficiaries: NetzeBW and seven other partners.
Project funding by: Federal Ministry for Economic Affairs and Climate Action (BMWK)
Funding ID: 03EI4002A-H
Appropriated funding: €5.2 million
Project duration: 2019 – 2023
Project description on EnArgus:

MORE DETAILS

„Our research is dealing with highly topical energy transition issues and I am delighted to say that we can now provide concrete answers. I hope that our findings can contribute to the ongoing discussions on congestion management and smart metering. I specifically have in mind, for example, the amendment of the Energy Industry Act and the Act on the Digitisation of the Energy Transition.“

Carmen Schantl, NetzeBW

2.4.2 Energy storage systems

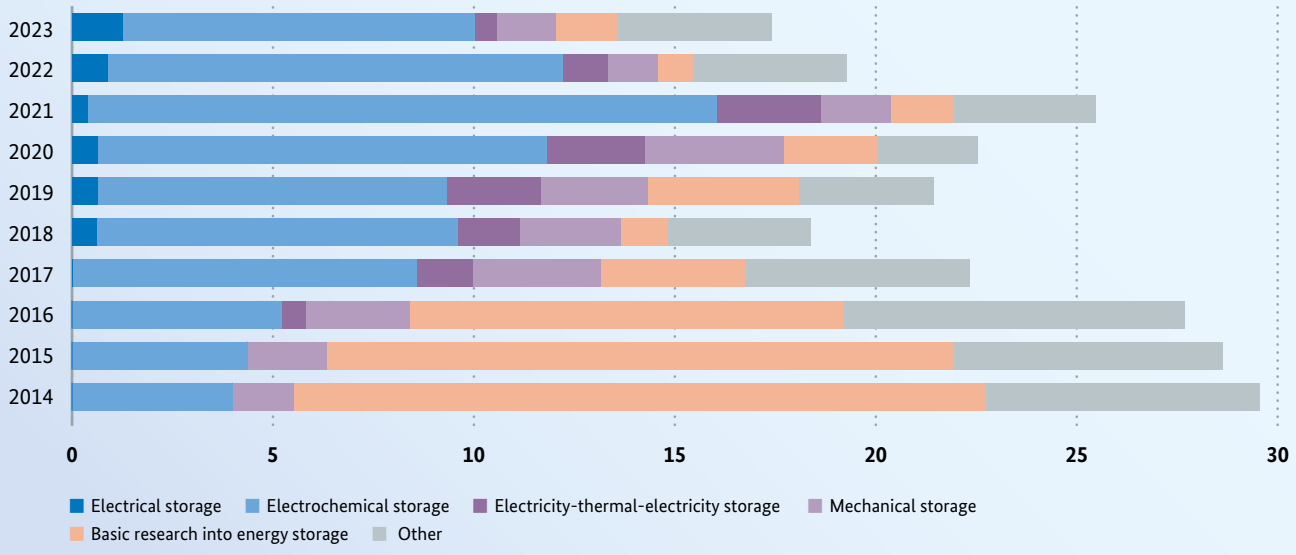
Depending on the weather, the generation of energy from renewable sources is subject to fluctuations. To keep the grid stable, electricity feed-in and consumption must always be well balanced. Reliable electricity storage makes this possible. Batteries store surplus energy temporarily and make it available again later.

Funding priorities and scientific advances

In December 2022, the Federal Ministry for Economic Affairs and Climate Action published the call for funding for "Innovative Materials for Optimised System Integration of Stationary Electricity Storage Systems (IMSES)". Following the selection process, the first projects kicked off in 2023. These include projects in which experts are working to further develop the cells and battery systems of electrochemical storage technologies for stationary applications. In particular, this involves the interaction between the individual battery components of lithium or sodium-ion batteries. With the two "Important Projects of Common European Interest" (IPCEI) in the field of batteries, the Federal Government has also been promoting the development of the value chain for sustainable battery production in Germany outside of the energy research programme since 2019. This was accompanied and supplemented in 2021 by the call for funding to support battery cell production, which was published with IPCEI funding but under the umbrella of the 7th Energy Research Programme, and in 2023 by the call for funding "Resilience and sustainability of the battery cell production ecosystem", for which project ideas could be submitted until November 2023. The Federal Ministry for Economic Affairs and Climate Action expects a swift transfer of technology and innovations so as to put the research findings into practice.

The Federal Ministry of Education and Research's funding for electricity storage focused on innovative battery materials and concepts in the context of materials research for the energy transition and Franco-German research cooperation. The WinZIB project consortium was declared the winner of a pilot competition for springboard innovations in the area of a globally applicable storage system. The project partners are developing an innovative, globally applicable zinc-ion battery system for initial demonstration purposes involving industrial production processes developed by the companies in the consortium.

Figure 17: Funding for energy storage systems in € million
(Data cf. Table 5, p. 79)



2.4.3 Sector coupling and hydrogen

As a climate-neutral energy carrier, hydrogen produced using electricity from renewable sources is an important building block for the energy system of the future. Hydrogen is versatile and can be used in a wide range of applications and thus support the decarbonisation of the entire system – in industry as a raw material, for fuel cell cars or synthetic fuels in the transport sector or as a storage medium for renewable energy required to generate electricity. Research in this funding priority contributes to the Federal Government's National Hydrogen Strategy.

Funding priorities and scientific advances

In the context of application-oriented research funding, the Federal Ministry for Economic Affairs and Climate Action supports projects that aim to advance the market ramp-up for the future generation, transport and use of hydrogen. In this way, innovations "Made in Germany" create local added value, skilled and sustainable jobs, and sales and export potential for German companies. The Federal Ministry for Economic Affairs and Climate Action's funding covers research into the production of hydrogen and its use in industrial processes, storage and transport in gas networks, and its use in road and rail transport. It also includes system analysis.

In the hydrogen research network supported by the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research, the event series "Wasserstand" was launched in 2023. At the online meetings, several experts report on key findings from their ongoing projects and discuss research-relevant subjects relating to hydrogen. In addition, the "Important Projects of Common European Interests" (IPCEIs) for hydrogen technologies and systems at European level and the International Hydrogen Projects at global level are supporting the market ramp-up.

Funding provided by the Federal Ministry of Education and Research focuses on the hydrogen flagship projects (see Section 2.1.2 Hydrogen flagship projects, page 21) as well as basic research into green hydrogen which addresses innovations along the entire value chain including systems studies. The Kopernikus project P2X on new production routes for the chemicals and primary industries based on green hydrogen entered its third phase in 2023. The Carbon2Chem cluster was equally successful with the production of chemical raw materials based on green hydrogen and CO_2 from industrial sources. The Federal Ministry of Education and Research is also funding research into sector coupling with hydrogen in several research platforms, including flexible industrial processes (WAVE-H2), an industrial port (hyBit) and the SEKO research infrastructure.

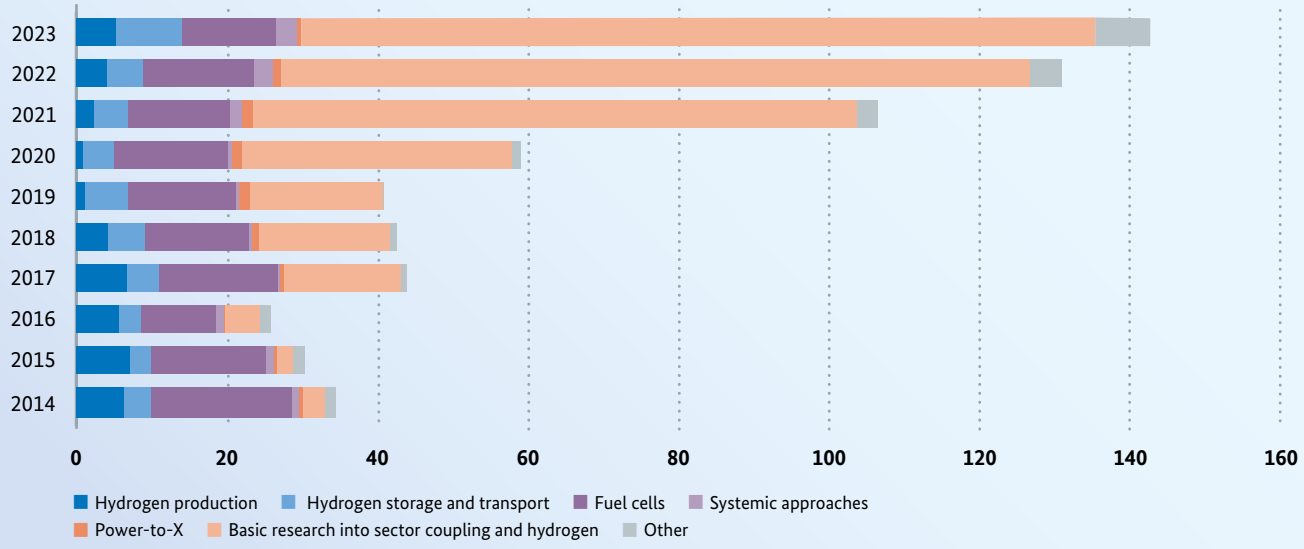
Project funding

In the field of sector coupling and hydrogen, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €142.62 million in funding for 671 ongoing projects in 2023. In 2023, the ministries also appropriated approximately €217.90 million in funding for 235 new research projects (cf. Figure 18, p. 43).

"We were able to demonstrate that electrochemical hydrogen recycling is possible under actual process conditions. Until recycling of hydrogen as a process gas becomes feasible in practice, we are focusing on sector coupling with fuel cell vehicles, among other things."

Nikolas Kraft and Konstantin Adaktylos-Surber,
Development Engineers,
centrotherm clean solutions

Figure 18: Funding for sector coupling and hydrogen in € million
(Data cf. Table 5, p. 79)



PROJECT ABSTRACT

EH2C

Hydrogen recycling by means of electrochemical compression

Hydrogen is used in the coating of components in the solar cell and semiconductor industry. Unused hydrogenous process waste gas is released into the atmosphere. To make the process sustainable, the EH_2C team has developed an innovative H_2 recycling system. The experts rely on the principle of electrochemical hydrogen purification (EHP) and electrochemical hydrogen compression (EHC) whereby it is possible to simultaneously separate and compress hydrogen from a gas mixture. Polymer electrolyte membranes are used for this purpose: A DC source provides the power. The objective of the team was to treat the hydrogen to the point where 75% of the unused gas could be reintroduced into the same process. This should help create a closed cycle. During the course of the project, the experts planned, built and successfully operated a stable and automated plant on an industrial scale. The consortium partners also carried out a risk analysis, integrated safety measures and issued a CE conformity marking. The consortium also carried out feasibility studies and discussed alternative options for utilisation. A permanent gas analysis is required for the actual reuse of hydrogen as a process gas. During the project, the team was unable to identify any relevant differences in the quality of the coatings prepared using fresh and recycled hydrogen.

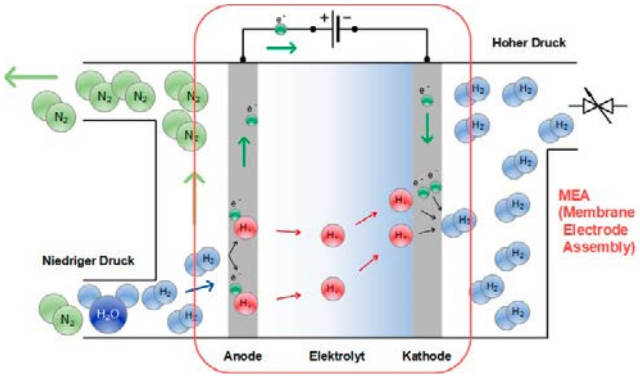


Diagram showing the Electrochemical hydrogen compression (EHC) principle developed by the project team.

Technology Readiness Level upon completion of the project: 5 – 6

Beneficiaries: centrotherm clean solutions and four other partners
Project funding by: Federal Ministry for Economic Affairs and Climate Action (BMWK)
Funding ID: 03EI3038A-E
Appropriated funding: €1.3 million
Project duration: 2021 – 2023
Project description on EnArgus:

MORE DETAILS

2.5 Cross-system research topics

2.5.1 Energy systems analysis

Energy systems analyses deliver model calculations, scenario analyses and techno-economic assessments. On the basis of these models, experts are in a position to determine how individual energy technologies or the energy system on the whole can be improved and, in addition, can also highlight favourable and adverse factors. These findings offer stakeholders in government, commerce and society scientifically sound assistance on the path to climate neutrality and present options for action, for example for the transition of industry or municipal heat planning.

Funding priorities and scientific advances

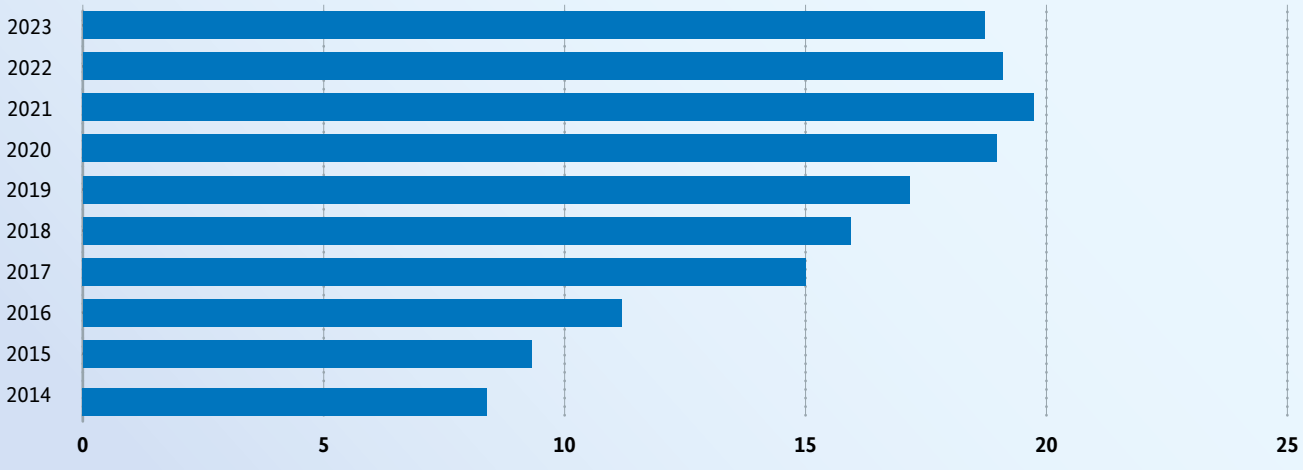
In the scope of the funding announcement for climate-neutral heating and cooling published in late 2022, the Federal Ministry for Economic Affairs and Climate Action approved six projects related to the funding priority "Systems Analysis". Four of these projects started in 2023 while the remaining two kicked off in early 2024. Among other things, the projects focus on modelling the systemic coupling of heating, cooling and power supply grids. Another priority is the systemic integration of measures.

The ministry organised an expert workshop in September 2023 in order to identify the specific research needs of the energy industry and consider them in future funding in the area of systems analysis. Experts from industry, the energy sector and consulting, aggregators such as associations and energy agencies, and stakeholders from the scientific community participated in the workshop. The experts provided the Federal Ministry for Economic Affairs and Climate Action with fresh ideas for research funding. These ideas help the ministry speed up the development of practical tools and methods and their transfer into practical applications.

Project funding

In the field of energy systems analysis, the Federal Ministry for Economic Affairs and Climate Action provided approximately €18.72 million in funding for 198 ongoing projects in 2023. In addition to this, the ministry appropriated approximately €18.80 million in funding for 48 new research projects in 2023 (cf. Figure 19).

Figure 19: Funding for energy systems analysis in € million
(Data cf. Table 6, p. 80)



PROJECT ABSTRACT

EMUSE

Energy cooperatives as multipliers for energy sufficiency

The energy transition faces the challenge of both completing the transition to renewable energies and minimising absolute primary energy consumption. Energy cooperatives play an outstanding role: not only do they promote environmentally friendly energy generation; they can also promote energy sufficiency in private households through targeted communication.

The communication toolkit for (citizen) energy cooperatives was developed as part of the project "Energy cooperatives as multipliers for energy sufficiency" (EMUSE). The toolkit is designed to support project teams step by step in the development of communication campaigns or events.

Project EMUSE investigated the extent to which energy cooperatives are already addressing the issue of sufficiency and which instruments they can use to promote a sufficiency-oriented lifestyle among their members. Energy cooperatives are the perfect partners for this purpose, as they enjoy particular trust as member organisations and stand for sustainable business practices. The project revealed that around one in six of over 500 energy cooperatives in Germany provide information on their website on topics such as energy saving and sufficiency. Interviews with members showed that a wide range of members are already aware and sensitised to the subject of sufficiency. In a design thinking process, energy cooperatives themselves developed communication projects on the subject of sufficiency. The team compiled implementation tips for various formats and prepared a toolkit that energy cooperatives can use to effectively raise awareness of sustainable behaviour among their target groups. During the "Energy transition plus – Shaping change together" action week, members of energy cooperatives were also able to spend a week learning and reflecting together on the topic of sufficiency and set themselves goals for a more sufficiency-oriented lifestyle.

Beneficiaries: Adelphi Research gemeinnützige GmbH and two other partners
Project funding by: Federal Ministry for Economic Affairs and Climate Action (BMWK)
Funding ID: 03EI5218A-C
Appropriated funding: €470,000
Project duration: 2021 – 2023
Project description on EnArgus:

MORE DETAILS

"The potential of sufficiency strategies – underrepresented in both research and practice – has hardly been exploited. In the energy transition dialogue, EMUSE plays a key role in fostering sufficiency."

Dr. Julia Fülling, Institut für ökologische Wirtschaftsforschung (IÖW)

2.5.2 Digitalisation of the energy transition

Regardless of whether for new energy technologies or the energy supply system as a whole, digitalisation offers promising opportunities. It can, for example, deliver solutions for decentralisation, flexibilisation and sector coupling.

Funding priorities and scientific advances

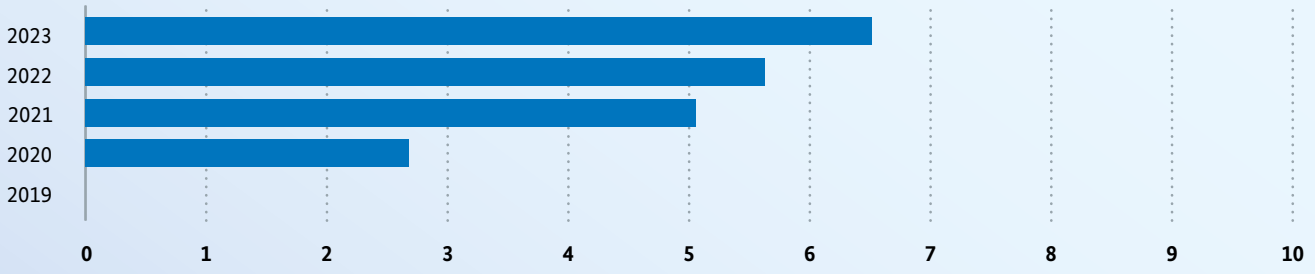
The Federal Ministry for Economic Affairs and Climate Action published the DigENet II call for funding in February 2023. Four projects were approved and all four were launched in the same year. The aim is to speed up the further development of smart meter gateways (SMGWs). The findings will be incorporated into the specifications of the Federal Office for Information Security. The energy data-X project was approved in October 2023. The project partners are involved in building a modern data space based on the Gaia-X architecture. The aim is to enable digital sovereignty for data exchange in Europe in the future. Data that is provided and managed in a decentralised process becomes virtually accessible by means of the federated data ecosystem.

Without digitalisation, a market ramp-up of the hydrogen economy is not feasible. The Federal Ministry of Education and Research is funding the HyPat project that focuses on digitalisation and the hydrogen economy. The research team is entrusted with preparing a digitally accessible global hydrogen potential atlas. The atlas identifies sustainable locations across the world for the green hydrogen economy of tomorrow. The H_2 regulatory sandbox in Burghausen, east of Munich, shows how digitalisation can be used to scale up technologies developed in research in order to make them marketable. The sandbox focuses on the production of hydrogen for the chemicals industry. A H_2-based power-to-methanol plant is envisaged to this effect. A digital twin simulates the upscaling to an industrial scale. It also gives users real-time feedback on the status of the plant. Additionally, there is the Kopernikus project SynErgie. It has been selected as a flagship project of the Federal Government's digital strategy. The core of the project is setting up an energy synchronisation platform that digitally connects the industry's electricity supply and demand.

Project funding

In the field of digitalisation of the energy transition, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €6.52 million in funding for 104 ongoing projects in 2023. In 2023, the ministries also appropriated approximately €8.63 million in funding for 15 new research projects (cf. Figure 20).

Figure 20: Funding for the digitalisation of the energy transition in € million
(Data cf. Table 6, p. 80)



2.5.3 Resource efficiency in the context of the energy transition

Using fewer resources is key to the energy transition. High resource consumption in Germany is directly linked to high energy consumption. In addition, the growing global demand for raw materials, which are becoming increasingly scarce and costly as a result, can jeopardise the energy transition.

Funding priorities and scientific advances

Energy research on resources in the context of the energy transition links the management of scarce raw materials with strategies to improve the efficient use of materials and the circular economy. Recycling quotas alone cannot yet cover a society's future demand for raw materials. Therefore, all resources circulating in the economic cycle must be protected, sustainably extracted and efficiently utilised.

This is why the Federal Ministry for Economic Affairs and Climate Action supports projects in which experts focus on analytical, conceptual, technical and commercial issues. In order to utilise resources more efficiently, it is important, for instance, to extend product lifetimes or generate less waste and lower emissions. One example for this type of project is ORka3D, which was launched in 2023. In this project, the goal of the research team is to find methods for reducing the sheet thickness of welded components and structures. In doing so, the experts aim to present solutions for reducing emissions and the high consumption of metal and energy in the metalworking industry. To achieve this, the research team, headed by the Fraunhofer Institute for Mechanics of Materials (IWM) in Freiburg im Breisgau, is developing a concept for an automated process to assess the service life of welded joints based on 3D scans.

Project funding

In the field of resource efficiency in the context of the energy transition, the Federal Ministry for Economic Affairs and Climate Action provided approximately €4.88 million in funding for 82 ongoing projects in 2023. In addition to this, the ministry appropriated approximately €9.07 million in funding for 40 new research projects in 2023 (cf. Figure 21).

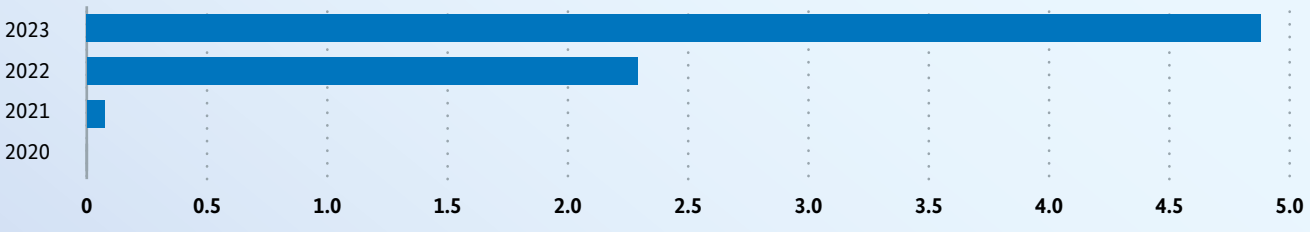
2.5.4 CO_2 technologies

CO_2 technologies present a tremendous potential for reducing carbon dioxide emissions (CO_2) – mainly in industries where it is not possible to prevent emissions. Research focuses on two areas: carbon capture and storage (CCS) and carbon capture and usage (CCU).

Funding priorities and scientific advances

The Federal Ministry of Education and Research and the Federal Ministry for Economic Affairs and Climate Action are funding research projects on the capture, storage and use of carbon dioxide.

Figure 21: Funding for resource efficiency in the context of the energy transition in € million
(Data cf. Table 6, p. 80)



The Carbon2Chem project funded by the Federal Ministry of Education and Research is collaborating with the steel, chemicals and energy industry to develop solutions for converting blast-furnace gases from steel production into feedstock for fuel, plastic or fertilisers. In this project, the blast-furnace gases are purified and, using green hydrogen, finally converted into a valuable input product such as methanol. Among other things, this input product can be used as a raw material in the chemicals industry. In the future, such solutions should also be applied to other CO_2 sources, such as lime works, thermal waste treatment plants or cement works.

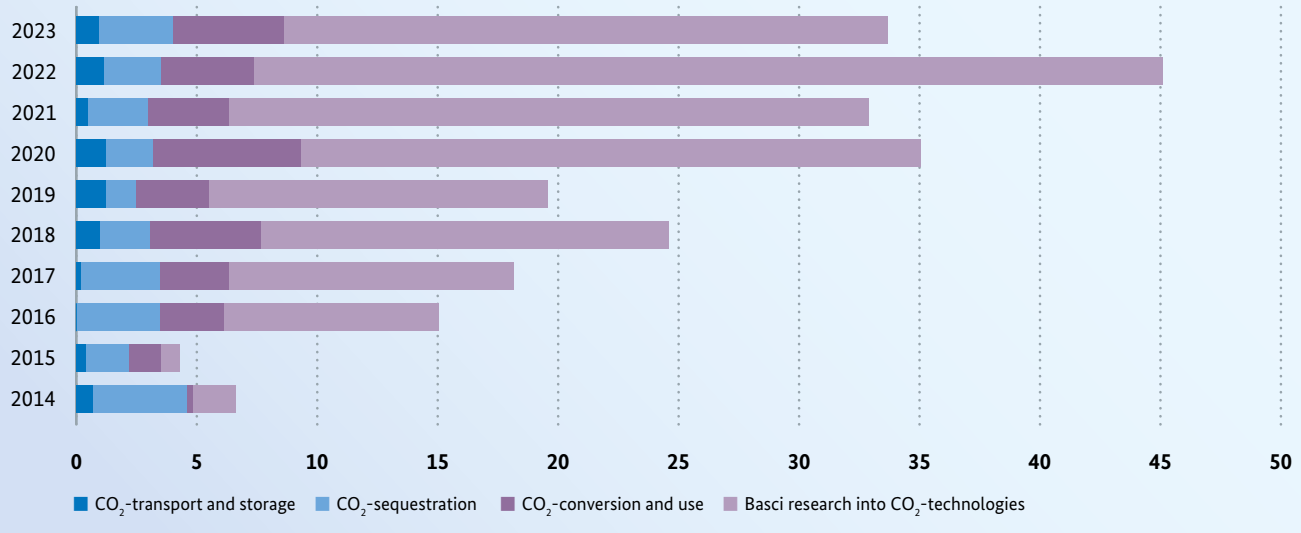
A meaningful utilisation concept and its integration into existing industries are crucial to the success of CCU. Underground storage facilities are crucial to CCS and ensuring the safety of these sites is a priority. Any leakage is a hazard for both the soil and groundwater. It therefore comes as no surprise that this is a major area of research.

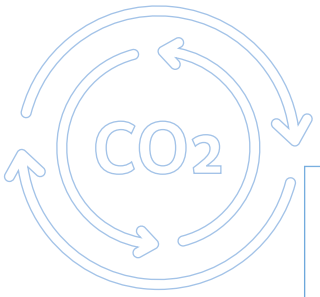
The Federal Ministry for Economic Affairs and Climate Action funds application-oriented research projects on the capture, storage and reuse of carbon dioxide. Experts from research institutions and companies are involved in many of these projects. The aim is to ensure the rapid transfer of results into practice, for example in the steel or cement industry. In these and a few other industries, process-related CO_2 emissions cannot yet be avoided. Carbon capture, utilisation and storage (CCUS) technologies can, however, generate substantial carbon cycles. The captured CO_2 can, for example, be used in the chemicals industry as a raw material, for battery production or for the production of synthetic fuels.

Project funding

In the field of CO_2 technologies, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €33.69 million in funding for 156 ongoing projects in 2023. In 2023, the ministries also appropriated approximately €10.09 million in funding for 21 new research projects (cf. Figure 22).

Figure 22: Funding for CO_2 technologies in € million
(Data cf. Table 6, p. 80)





"Thanks to the Carbon2Chem project, we are in a position to make the steel industry virtually climate-neutral."
Görge Deerberg, Fraunhofer UMSICHT

PROJECT ABSTRACT

Carbon2Chem (Phase II)
Utilisation of industrial waste gases for the production of chemicals

The Carbon2Chem project converts waste gases from steel production, known as smelting or blast-furnace gases, into commercially useful chemicals. The steel industry is one of the largest producers of carbon dioxide in Germany. Carbon2Chem Coordinator Görge Deerberg from the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT explains, "Hydrogen can help us achieve a significant reduction in emissions. We, however, need solutions for closing the carbon cycle and for the residual CO_2 which is unavoidable. That's when Carbon2Chem comes into the picture. Thanks to this project, we are en route to making steel production virtually climate-neutral."

To ensure the transfer of technology from research to practice as quickly as possible, researchers and the industry have been collaborating closely in Carbon2Chem since its inception. In the first project phase from 2016 to 2020, the consortium demonstrated that the Carbon2Chem approach works. To this end, an initial testing facility was set up at the thyssenkrupp steelworks. In the ongoing second test phase, the process is being validated for large-scale implementation. This involves, for example, testing the production of methanol from waste gases during operation. Methanol is a basic raw material in the chemicals industry and a potential climate-friendly fuel for shipping. Carbon2Chem is also testing methanol as a fuel for an innovative hybrid car. The Carbon2Chem approach can potentially be transferred to 50 steelworks in Europe. The project partners are also investigating its application in the lime, cement and waste incineration sectors. It is precisely in these industries that millions of tonnes of CO_2 are produced every year. As of now, it is quite unlikely that this can be avoided in the long term.

Bird's-eye view from 2018 of the Carbon2Chem® technology centre in Duisburg: Aimed at facilitating virtually climate-neutral steel manufacturing processes, the Carbon2Chem project explores how smelter gases from steel production can be converted into commercially useful chemicals.

Technology Readiness Level upon completion of the project: 7

Beneficiaries: Fraunhofer UMSICHT and 20 other partners
Project funding by: Federal Ministry of Education and Research
Funding ID: 03EW0003-9, 03EW0019
Appropriated funding: €63 million (Phase I, including preliminary study), €116 million (Phase II)
Project duration: Phase I: 2016 – 2020, Phase II: 2020 – 2024
Project description on EnArgus:

MORE DETAILS

2.5.5 Energy transition and society

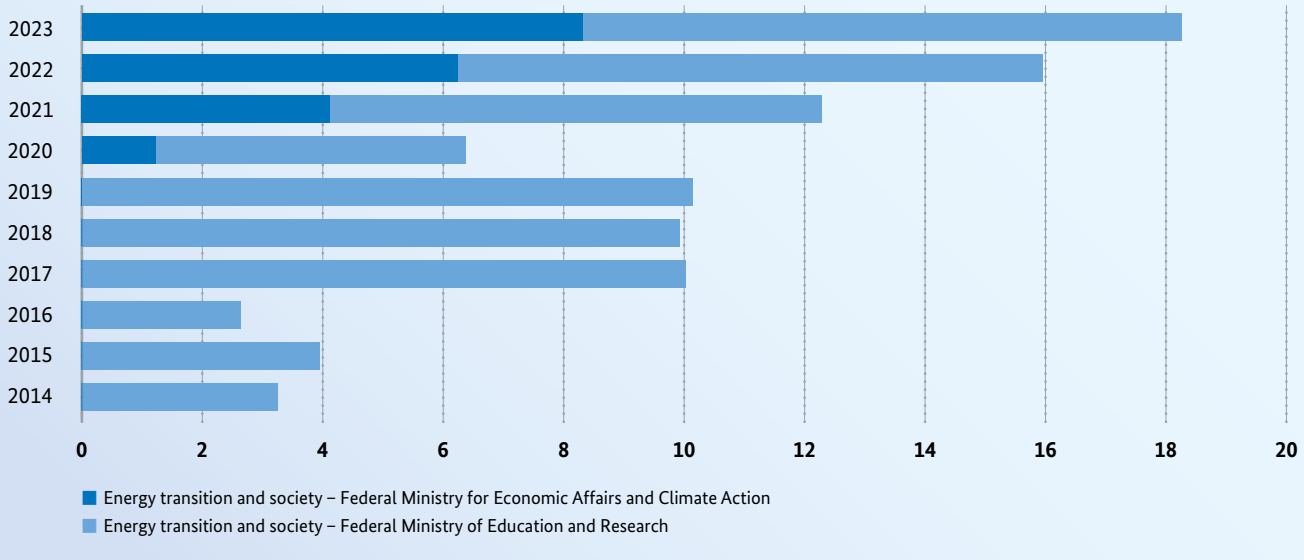
The energy transition is not exclusively a technological or economic transformation. Rather, it is a social endeavour involving citizens, administrative bodies, businesses and the government. As consumers and suppliers, stakeholders assume different roles in this process, while researchers analyse conflicting goals and interests and develop solutions.

Funding priorities and scientific advances

In early 2023, the Federal Ministry for Economic Affairs and Climate Action published a call for funding on social issues in the context of cross-system and cross-technology aspects for the success of the energy transition. In particular, the focus is on an interdisciplinary approach to developing a framework with regard to technical, commercial, social, institutional and legal aspects. The call for funding emphasises the importance of simulations, visualisations and communication strategies involving society, with a particular focus on addressing the younger generation. Research communication should include socio-economic analyses of the specific needs of individual regions undergoing structural change. In addition, the Federal Ministry for Economic Affairs and Climate Action is funding projects that explore effective forms of cooperation between institutional and public stakeholders in order to transfer the findings to other areas of action in the energy transition.

Since 2020, the Ariadne Kopernikus project funded by the Federal Ministry of Education and Research has been developing various decarbonisation scenarios and examining policy instruments in a systemic perspective in order to identify their potential effectiveness in achieving climate goals. Together with stakeholders from the government, the business community and society, the researchers are identifying useful strategies and measures for the energy transition and determining their acceptance among citizens. One of the priorities is to integrate the German energy transition into a European framework. In September 2023, Project Ariadne entered its next funding phase (27 partners and a funding volume of nearly €30 million) and has continued its research since. Through a systematic dialogue, Ariadne regularly includes new social trends in its ongoing research. Ariadne is also continuing its active collaboration with the

Figure 23: Funding for the energy transition and society in € million
(Data cf. Table 6, p. 80)



other Kopernikus projects funded by the Federal Ministry of Education and Research: ENSURE, SynErgie and P2X.

Project funding

In the field of the energy transition and society, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €18.27 million in funding for 205 ongoing projects in 2023. In 2023, the ministries also appropriated approximately €41.32 million in funding for 75 new research projects (cf. Figure 23, p. 51).

"Effective carbon pricing should be backed by accompanying measures to ensure public acceptance."
Dr. Ulrich Fahl, Universität Stuttgart

PROJEKT ABSTRACT

Carbon Price

Analysis of the short and long-term impacts of various carbon pricing models on society and the economy

How do we design a carbon pricing system that protects the climate, is economically viable, and is socially just and accepted by the public? How do we present something as complex as carbon pricing so that it is comprehensible to the general public? Researchers in the transdisciplinary research project Carbon Price focus on precisely these complex issues. They examined, for instance, the short and long-term impacts of different carbon pricing models on households, the energy system and the economy. At the same time, the researchers also took a closer look at factors that impact the acceptance of carbon pricing by society. To do so, they conducted several surveys. The researchers were supported by an advisory board comprising stakeholders from society and the economy who contributed to the research project with their expertise and know-how.

An important result: To gain the acceptance of the public, the benefits of carbon pricing for the energy transition and the climate must be communicated effectively such that it is clear and comprehensible. The research team has therefore produced several video clips and information brochures in the scope of the project. To find out more, visit the project website at https://www.co2-preis.info/.

What factors play a role in promoting public acceptance of the concept of carbon pricing? Researchers working for the CO_2 Preis Project have been taking a closer look.

Technology Readiness Level upon completion of the project: 9

Beneficiaries: University of Stuttgart and four other partners
Project funding by: Federal Ministry for Economic Affairs and Climate Action (BMWK)
Funding ID: 03EI5213A-E
Appropriated funding: €1.5 million
Project duration: 2020 – 2023
Project description on EnArgus:

MORE DETAILS

2.5.6 Materials research for the energy transition

Materials research is a strategically important area of research. After all, no progress is possible without a knowledge of materials. The Federal Ministry of Education and Research has been entrusted with funding projects in materials research. By funding a wide range of projects over several decades, the ministry has created ideal conditions for making breakthroughs in innovative materials. The goal: to be well equipped to face the challenges of the future, for example for the energy transition.

Funding priorities and scientific advances

The Federal Ministry of Education and Research funds projects in materials research across all research topics. As of today, the ministry is involved in more than 300 ongoing projects. Materials research for the hydrogen economy is of particular importance. The energy source of the future can help make industry, transport and heat supply climate-friendly. The Federal Ministry of Education and Research is funding 36 joint projects in basic hydrogen research. Aimed at the production, storage and transport of hydrogen, these projects focus on materials and key technologies for the next generation and beyond. Project H2Demo for instance has developed an innovative solar cell that uses sunlight directly to decompose water and aid hydrogen production. The Federal Ministry of Education and Research is also funding materials research in international cooperation programmes. The German-South African consortium CARE-O-SENE is optimising catalysts for the production of green kerosene. This is key to transforming the aviation industry and consequently achieving climate-neutrality. In 2023, a catalyst was produced and successfully tested on a semi-commercial scale at chemicals and energy company Sasol's site in South Africa.

Project funding

In the field of materials research for the energy transition, the Federal Ministry of Education and Research provided approximately €0.44 million in funding for one ongoing project in 2023 (cf. Figure 24).

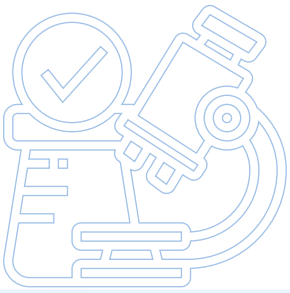
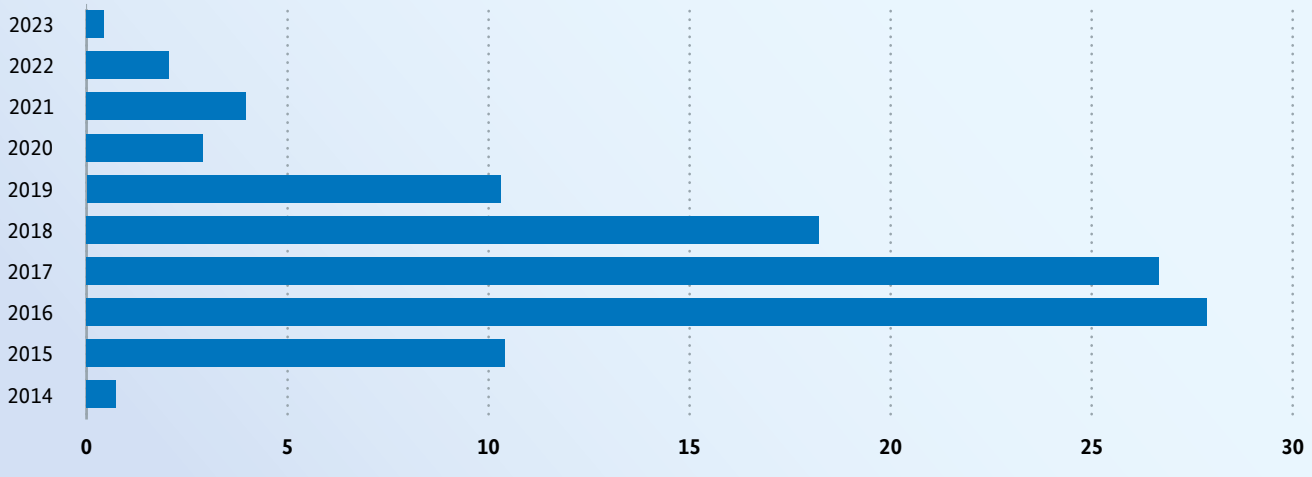


Figure 24: Funding for materials research for the energy transition in € million
(Data cf. Table 6, p. 80)



2.6 Nuclear safety research

2.6.1 Reactor safety research

The task of reactor safety research is to deepen our knowledge of the safety of nuclear power plants and research reactors both in Germany and abroad and to advance the state of the art in science and technology. Another focus is on competence building and promoting the development of future talent and young scientists in the area of reactor safety in Germany.

Funding priorities and scientific advances

Reactor safety research has its focus at both a domestic and international level. Funding is provided for research in the safety of new and existing reactors abroad. The aim is to establish independent safety assessments for such plants. Research is underway into the safety of components and structures, into transients, incidents and accidents, and into interactions between humans, technology and organisation as well as into probabilistic safety analyses. The involvement of German research work in international activities is of great significance and was consolidated by the involvement in outstanding multilateral research projects or by support for international cooperation programmes.

A key priority of funding was also on sustainable competence building and promoting the development of future talent and young scientists in the area of reactor safety. In the year under review, four projects from the funding initiative "Kompetenzerhalt in der Kerntechnik – KEK" on maintain-

Figure 25a: Funding for reactor safety research 2021 – 2023 in € million
(Data cf. Table 7b, p. 81)

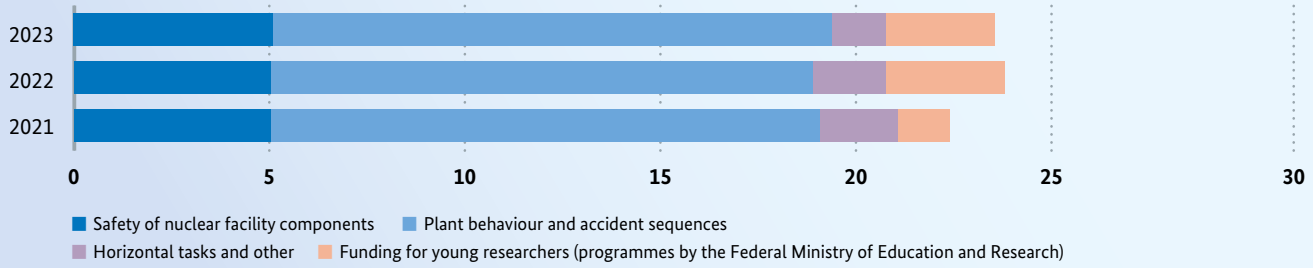
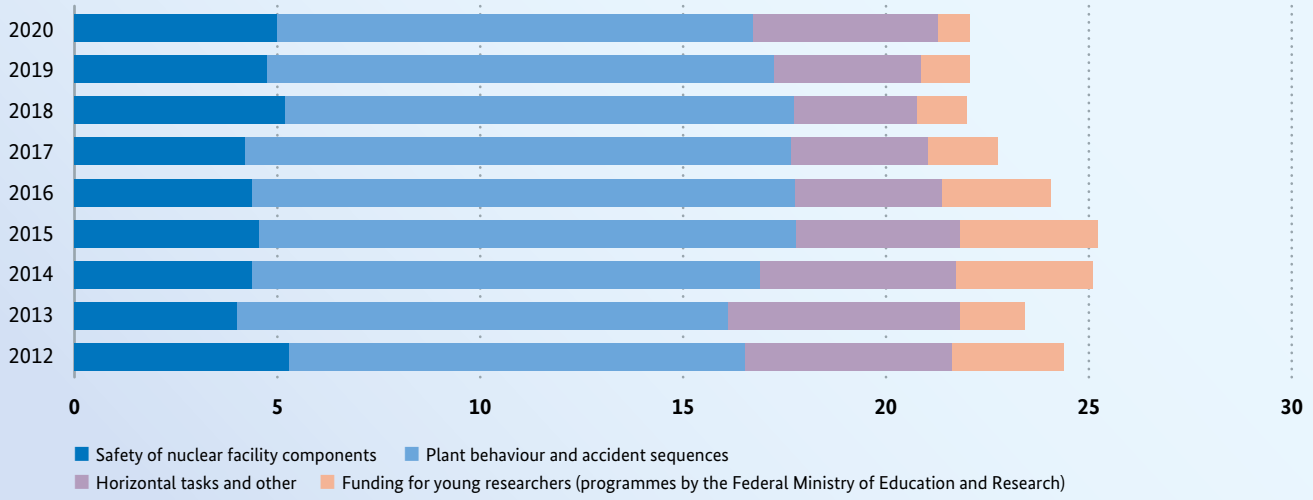


Figure 25b: Funding for reactor safety research 2012 – 2020 in € million
(Data cf. Table 7a, p. 81)



ing competence in nuclear technology were successfully completed. This also gave young scientists the opportunity to participate in training programmes and complete their doctorate in reactor safety research.

Project funding

Project funding in the field of nuclear safety research in 2023 was provided by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, and is supplemented by a Federal Ministry of Education and Research programme which supports young scientists. During this period, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection provided approximately €20.77 million in funding for 128 ongoing projects and appropriated funding of approximately €14.94 million for 26 new research projects. The Federal Ministry of Education and Research provided approximately €2.76 million in funding for 16 projects. This included four newly approved projects with €4.94 million in funding (cf. Figure 25a, p. 54).

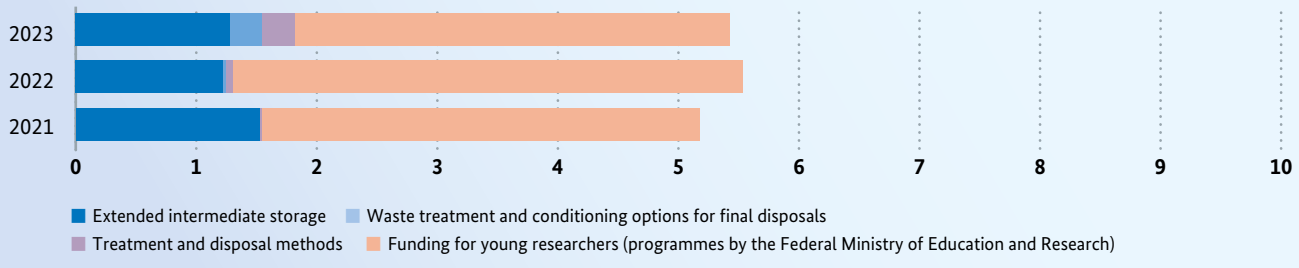
2.6.2 Research into extended intermediate storage and the treatment of highly radioactive waste

This research area aims to develop the scientific basis and insights into the intermediate storage of highly radioactive waste, as this storage will probably be needed for an extended period, as well as the treatment of the waste through to final disposal. It also aims to promote the development of skills and young scientists in this field in Germany.

Funding priorities and scientific advances

This research focuses on the state of the highly radioactive waste and containers stored, the effects of storage on their transport and handling capability, the protective effect of the structures over the extended lifetimes, and the (further) development of methods for assessing the safety of the interim storage facilities and the stored inventories. For this purpose, it is often possible to draw on findings from reactor safety research. This is the case both in developing methods for assessing the integrity of the stored fuel rods (project BREZL-2) and in developing monitoring concepts for interim storage buildings for anticipated extended storage times (joint project ZuMoBau-ZL). In order to optimally prepare the waste for final disposal, basic scientific knowledge of potential treatment and conditioning options is also being drawn up for the time after intermediate storage. Project Am-BALL which was launched in 2023 deals, for example, with the conditioning of volatile fission products for final storage and thus contributes to expanding the know-how in this field. In addition, developments abroad are being observed that could potentially impact the disposal of highly radioactive waste in Germany or in nearby foreign countries. Promoting young researchers and the development of skills are top priorities for waste management research and are strongly supported.

Figure 26: Funding for research into extended intermediate storage and the treatment of highly radioactive waste in € million (Data cf. Table 7b, p. 81)



Project funding

Project funding in the field of extended interim storage and for the treatment of highly radioactive waste in 2023 was provided by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, and is supplemented by a Federal Ministry of Education and Research programme which supports young scientists. During this period, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection provided approximately €1.82 million in funding for 15 ongoing projects and appropriated funding of approximately €2.36 million for five new research projects. The Federal Ministry of Education and Research provided approximately €3.61 million in funding for 28 projects. This included five newly approved projects with €3.48 million in funding (cf. Figure 26, p. 55).

2.6.3 Research into final disposal

The task of repository research is to provide and develop the scientific, technical and socio-technical basis for the safe final disposal of radioactive waste. It also aims to promote the development of specialist expertise and young scientists in order to effectively deal with current and future challenges.

Funding priorities and scientific advances

Research and development in safety verification, safety assessment, site selection and repository design continued in 2023. A particular focus is on identifying the safety-relevant processes in place in the repository system under consideration, their reciprocal effects and the impact on the entire system. Linking experimental data with modern simulation methods allows for a validated forecast of the repository system which subsequently helps support well-founded decisions in repository planning. In the future, this approach should create the basis for an adaptive system that also uses artificial intelligence (AI) methods. In 2023, international research was stepped up in European underground laboratories (Grimsel, Äspö, Mont Terri) as well as in international working groups and networks. Participation in activities of the OECD/NEA and the European Joint Programme EURAD offers researchers ideal opportunities for international networking. The integration of young scientists into research projects makes a significant contribution in Germany towards securing the level of competence and expanding our know-how in nuclear waste disposal.

Project funding

The project funding provided by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection is complemented by research funding provided by the Federal Ministry of Education and Research. The latter supports young scientists, thereby maintaining and promoting skills. In the field of final repositories, supplemented by the research into horizontal issues, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection provided approximately €12.4 million in funding for 104 ongoing projects in 2023. In addition to this, the ministry also appropriated approximately €4.2 million in funding for 10 new research projects in 2023 (cf. Figure 27a and Figure 27b, p. 57

Figure 27a: Funding for research into final repositories 2021 – 2023 in € million
(Data cf. Table 7b, p. 81)

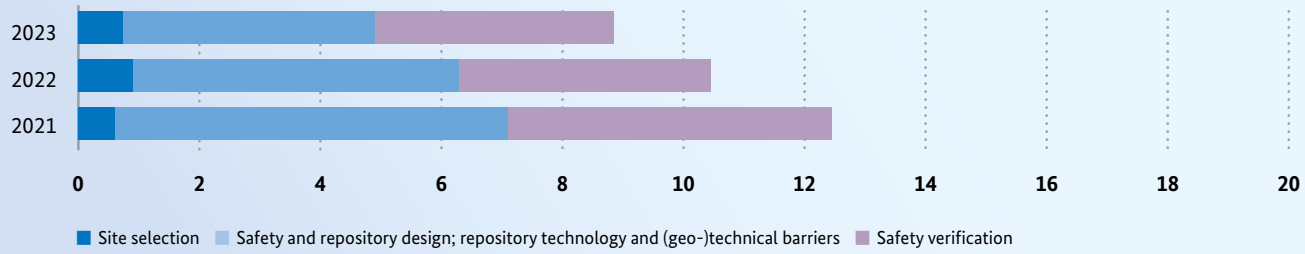
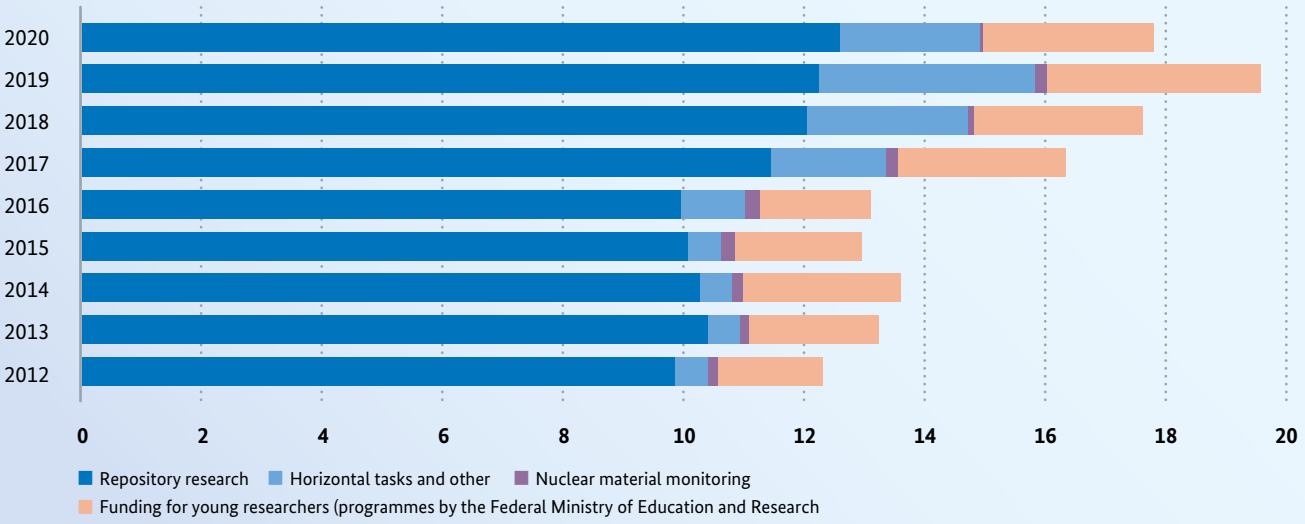


Figure 27b: Funding for nuclear waste repository and disposal research 2012-2020 in € million
(Data cf. Table 7a, p. 81)



2.6.4 Radiation research

During the reporting year 2023, the Federal Ministry of Education and Research continued to support collaborative research and individual projects on radiation research under its funding guidelines for nuclear safety research and radiation research within the scope of the 7th Energy Research Programme.

Funding priorities and scientific advances

The Federal Ministry of Education and Research funds projects on issues of radiobiology, radiation physics, and radioecology in application-oriented basic research. This helps build, develop and maintain scientific and technical competence while simultaneously advancing the state of the art in science and technology. In the interest of public welfare, Germany has to continue building on its expertise so that public authorities, industry, research and medicine can cope with the issues mentioned earlier. Within the scope of these projects, the Federal Ministry of Education and Research supported a total of approximately 130 young researchers during their training in 2023, which means that this funding priority was able to make a substantial contribution to the development and retention of expertise in radiation research in Germany. In particular, the newly

added focus of material-relevant radiation research was strengthened, creating the basis for socially explosive as well as scientifically highly relevant areas of application, such as radiological emergency preparedness. In its entirety, radiation research provides the scientific basis for assessing the health risks posed by radiation as well as the benefits for technical and medical progress.

The first KERNthemen conference, organised by the Federal Ministry of Education and Research, was held in 2023. KERNthemen has set up a platform that enables networking and exchange between scientists in the projects funded by the Federal Ministry of Education and Research in the individual fields of nuclear safety and radiation research and strengthens the scientific community in the future.

Project funding

In the field of radiation research, the Federal Ministry of Education and Research provided approximately €8.50 million in funding for 60 ongoing projects in 2023. In addition to this, the ministry also appropriated approximately €7.19 million in funding for 13 new research projects in 2023 (cf. Figure 28a).

Figure 28a: Funding for radiation research (by the Federal Ministry of Education and Research) in € million (Data cf. Table 7b, p. 81)

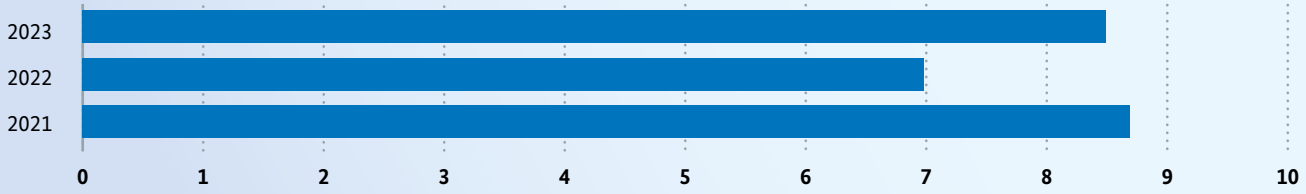
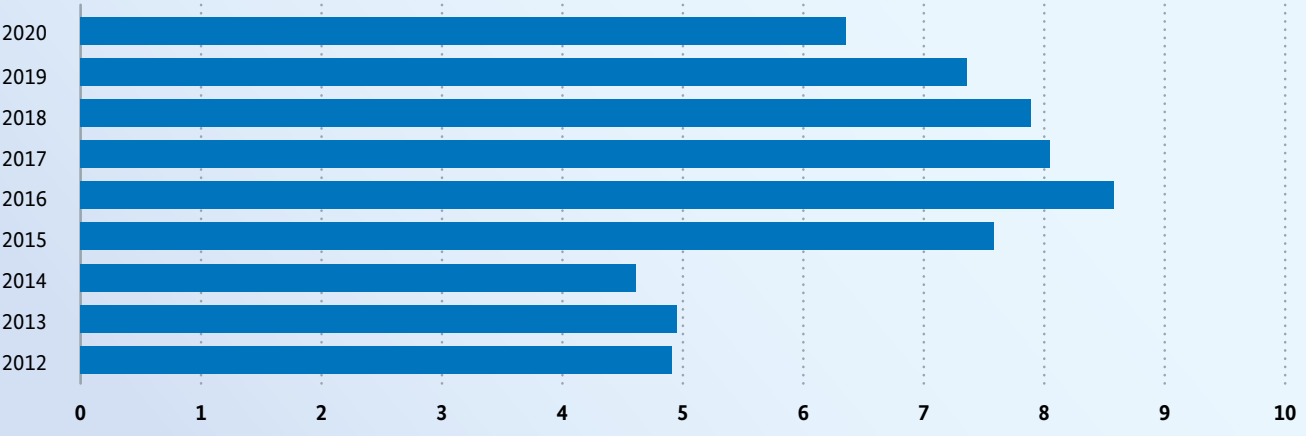
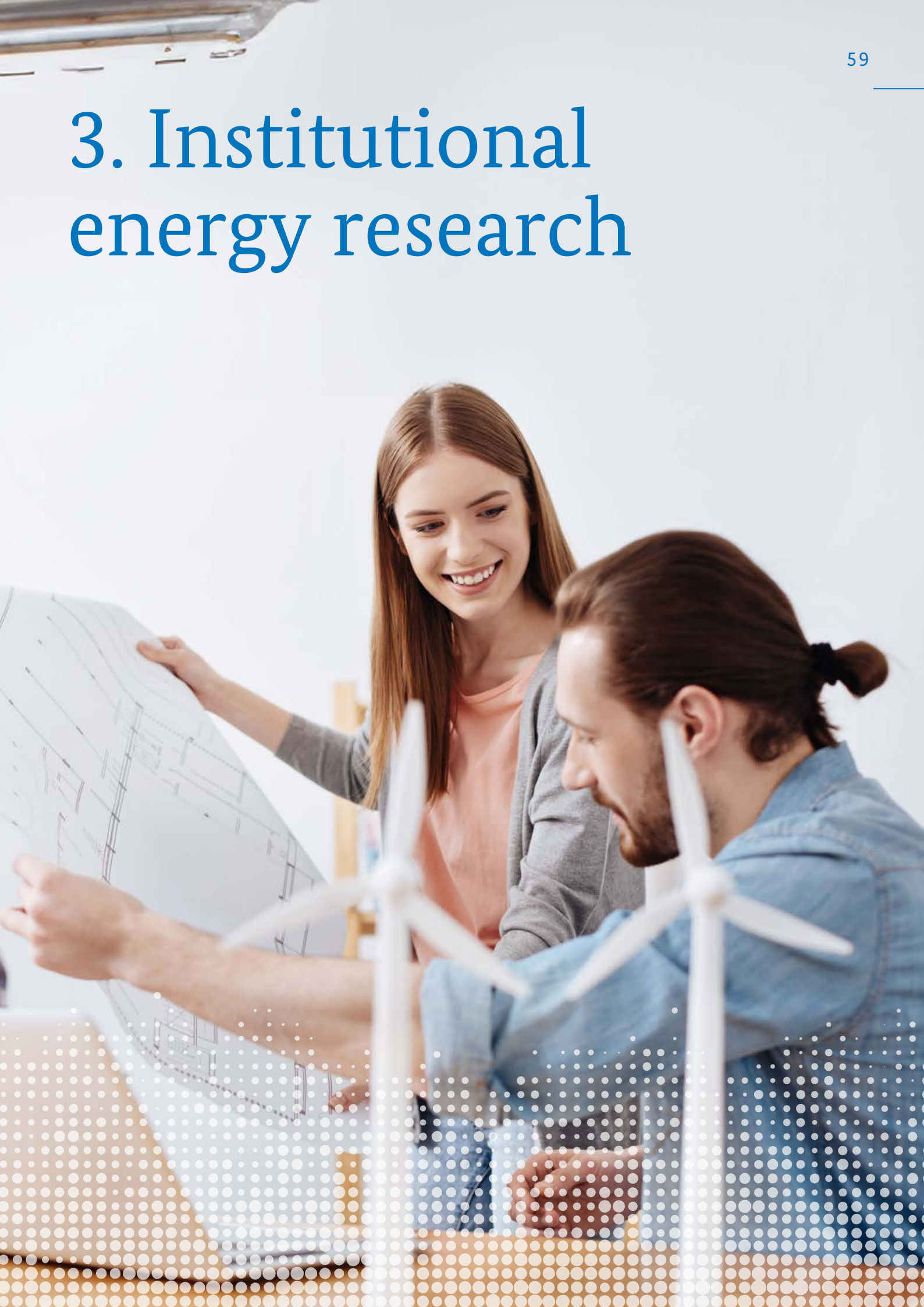


Figure 28b: Funding for radiation research (by the Federal Ministry of Education and Research) in € million (Data cf. Table 7b, p. 81)



3. Institutional energy research



Energy research by the Helmholtz Association

With research from basics to application, Helmholtz Energy is creating the scientific prerequisites for climate-neutral energy supply that is both economically and socially sustainable. In interdisciplinary programmes, the energy researchers are developing viable solutions for the energy transition in Germany and for the sustainable restructuring of energy supply worldwide. To this end, their activities focus on researching and developing innovative conversion, distribution and storage technologies. Taking into account all relevant energy conversion chains and future-proof technological options, Helmholtz Energy is developing holistic, cross-sectoral concepts and solutions for an energy system of the future.

Since 2021, Helmholtz Energy has continued its research for the energy transition with a scientific focus on four programmes within the framework of the fourth period of programme-oriented funding (POF IV):

The **"energy system design"** programme uses a holistic approach to research in order to build a sustainable energy system. In addition to the analysis of energy systems, a focus is also placed on their digitalisation and the development of system technologies.

The **"Materials and Technologies for the Energy Transition"** programme is dedicated to developing new technologies along the entire value chain – from the exploration and extraction of raw materials and the development of high-performance materials to the generation, conversion, storage and distribution and application of complementary energy sources such as electricity, biomass and hydrogen.

As part of European-coordinated and funded fusion research, the "Fusion" programme researches and develops the physical and technical foundations for the design and construction of fusion power plants.

The **"Nuclear Waste Management, Safety and Radiation Research"** programme deals with the essential issues of interim and final storage of radioactive waste, dismantling of nuclear facilities, safety of nuclear reactors and radiation protection.

The centres involved in research in POF IV are the German Aerospace Center (DLR), Research Centre Jülich (FZJ), Helmholtz-Zentrum Berlin für Materialien und Energie (HZB), Helmholtz-Zentrum Dresden-Rossendorf (HZDR) and Karlsruhe Institute of Technology (KIT), with the Max Planck Institute for Plasma Physics (IPP) as a scientifically associated centre.

Figure 29a: Funding for institutional energy research (PoF IV) 2021 – 2023 in € million
(Data cf. Table 8, p. 82)

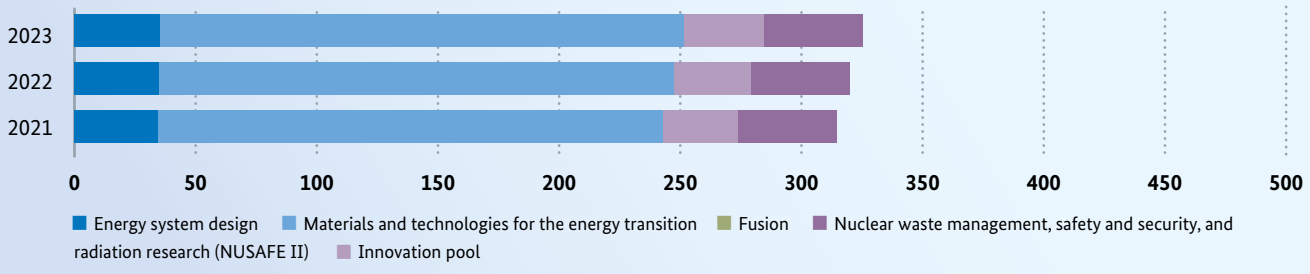
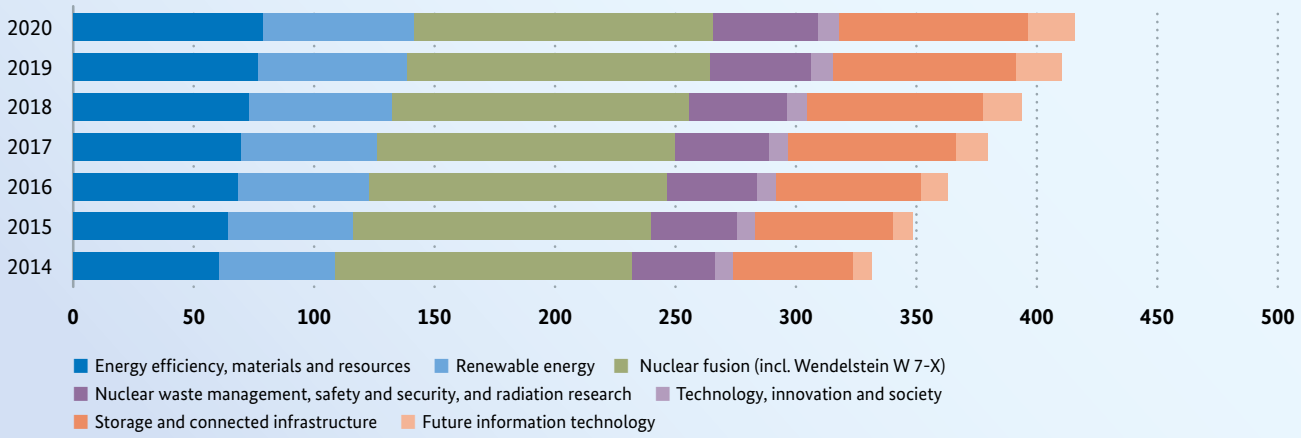


Figure 29b: Funding for institutional energy research (PoF IV) 2014 – 2020 in € million
(Data cf. Table 8, p. 82)



Selected highlights from Helmholtz Energy's research:

Recovering raw materials by means of recycling will play an increasingly important role in the future availability of raw materials and in the efficient use of resources to protect the climate and the environment. With numerous promising research projects, Helmholtz Energy is making a valuable contribution. A few highlights:

- Resource-efficient recycling of black mass from lithium-ion batteries by froth flotation, conducted at Helmholtz-Zentrum Dresden-Rossendorf (HZDR, also see project abstract on page 63).

- In collaboration with EnBW Energie Baden-Württemberg AG, the Karlsruhe Institute of Technology (KIT) has developed a low-cost, energy-efficient and environmentally friendly process for recovering up to 70% of the lithium from cathode materials used in a wide variety of lithium-ion batteries without the need for corrosive chemicals, high temperatures or prior sorting of the materials.

- Researchers at the Research Centre Jülich (FZJ) are working on advancing organic electronics with a circular approach. Organic electronics, in particular OLED technology, presents a promising approach to decarbonisation and resource efficiency. In order to make this technology sustainable and ensure its rapid growth, recycling plans, efficient manufacturing processes, environmentally friendly production methods, and due consideration to the entire product life cycle should be included from an early stage. These efforts are committed to making organic electronics environmentally friendly and thus ensuring a greener future.

- At the FZJ, researchers are testing innovative titanium-air batteries. Metal-air batteries use oxygen from the ambient air to generate electrical energy. Theoretically, higher energy densities can be realised than with conventional batteries. Researchers have successfully tested a titanium-air battery, although titanium has until now rarely been considered as an anode material.

Important milestones were achieved at Helmholtz-Zentrum Berlin (HZB) in their endeavour to make perovskite solar cells commercially available (see abstract on page 64).

The main objective of the German Aerospace Center (DLR) wind energy research farm, referred to as WiValdi, is to implement the highest scientific standards to study on-site the multi-disciplinary mechanisms and effects in a wind farm. WiValdi was opened in Krummendeich on 15 August 2023 (https://windenergy-researchfarm.com).

With the Technology Platform Power-to-Liquid Fuels (TPP), DLR plans to build a unique research and demonstration facility at the Leuna Chemical Complex in Saxony-Anhalt. Research and optimisation should focus on the entire chain of Power-to-Liquid (PtL) production – from electrolysis to fuel synthesis and processing to applications in various sectors – with the aim of achieving a production capacity of 10,000 t/a PtL fuels on a semi-industrial scale. TPP will support industry in developing scalable technologies and launching PtL fuels onto the market.

The JRODOS (Java-based Realtime Online DecisiOn Support System) programme system, which was developed under the leadership of KIT as part of the NUSAFE programme, supports authorities by providing suitable countermeasures for protecting the population and the environment and dealing with accidental releases from nuclear facilities. With the help of JRODOS, which is in operation in more than 40 countries across the world, KIT has been simulating scenarios for Ukrainian nuclear power plants on an hourly basis since April 2022 and has regularly been exchanging the findings with the Ukrainian authorities.

The X-point radiator (XPR) developed at the Max Planck Institute for Plasma Physics (IPP) offers a new approach for improved heat removal in tokamaks. This involves a cold, dense, strongly radiating volume within the enclosed plasma. For purposes of protecting the divertor, it is vital that the emitted radiation power of up to 90 percent is steady and can be controlled in real time.

PROJECT ABSTRACT

Resource-efficient recycling of black mass from lithium-ion batteries (LIBs) using innovative froth flotation

Recycling is a potential solution to bridging the gap between supply and demand of raw materials for lithium-ion batteries, but it continues to pose a complex technological challenge. At the Helmholtz Institute Freiberg for Resource Technology (HIF), a constituent part of the Helmholtz-Zentrum Dresden-Rossendorf (HZDR), various technologies for resource-efficient recycling of black mass were assessed. The technology that displayed the best resource efficiency – thermomechanical fragmentation followed by froth flotation as a separation process – led to excellent product yields of graphite and lithium metal oxides.

Froth flotation is an efficient, tried-and-tested process for separating valuable minerals from waste rock and tailings for particle sizes of around 10 to 200 micrometres. The process is based on the selective hydrophobic, i.e. water-repellent, properties of minerals and the ability of these particles to adhere to gas bubbles and form a froth which can then be removed. Therefore, surface properties as well as other particle properties such as size, shape and composition are essential separation characteristics for froth flotation. The introduction of a froth flotation stage enables the joint recovery of metals and graphite. Graphite usually makes up 15-25% of the battery weight. By recovering the graphite in addition to the 50% share of metals already recovered, recyclers can meet the EU material recycling target of 70% that will come into force in 2030.

The project is headed by Dr. Anna Vanderbruggen, an acclaimed researcher who completed her doctorate thesis at the Helmholtz Institute Freiberg for Resource Technology of the HZDR on the recycling of graphite from used lithium-ion batteries. In addition to her presentations at numerous conferences, Dr. Vanderbruggen is also involved in sharing her research on social media. Winning the prestigious EIT CHANGE Award in October 2022 for her pioneering work in graphite recycling has been one of the major milestones in her career. She also won the national preliminary round of the Falling Walls Lab competition in Berlin in 2021 and thus secured her participation in the international final.

Dr. Anna Vanderbruggen at the froth flotation separator for recycling graphite

Participating Helmholtz centres: Helmholtz Zentrum Dresden-Rossendorf (HZDR)
Participating programmes: Materials and Technologies for the Energy Transition (MTET)
Publications:

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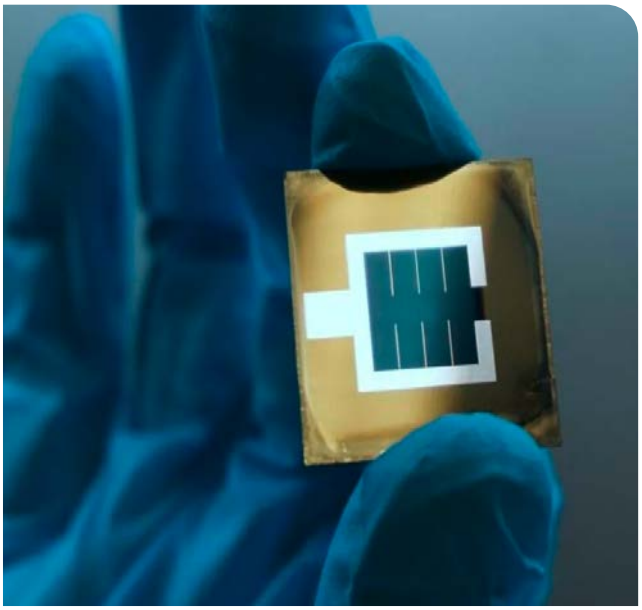
PROJECT ABSTRACT

Perovskite solar cells: Milestones en route to commercialisation

The Helmholtz Association's photovoltaics research team has been among the very best in the world over several years. Yet another world record of a tandem cell consisting of silicon and perovskite (as of April 2023) is testimony to this. The tandem cell, made entirely at the HZB, achieves an efficiency of 32.5%, a rate that is not even theoretically conceivable with conventional and globally prevailing silicon technology, which is why the findings have attracted a great deal of attention among the industry and scientists across the world. This was achieved thanks to a significantly improved perovskite compound and a sophisticated modification of the surface using a novel piperazinium iodide molecule. The research team expects to soon transfer this improvement which will aid in boosting domestic photovoltaic production.



The petrovskite-silicon tandem solar cell: the active area in the middle of the wafer is enclosed by the silver electrode.

Issues involving fatigue and the long-term stability of perovskite cells have so far been the major challenges that need to be overcome. The researchers at Helmholtz Energy have now achieved a significant improvement through a novel dipolar polymer compound which enabled the cell to retain 96% of its initial efficiency after one year of outdoor use (measured under accelerated test conditions).

The global leadership of photovoltaics research at Helmholtz Energy was also evidenced by the fact that five PV scientists are counted amongst Clarivate's most influential researchers in the world. At the European level, two researchers have received the prestigious "Consolidator Grants" of the European Research Council. Within the Helmholtz Association, photovoltaics research has gained a very high level of awareness and tremendous significance, thanks to the High Impact Award shared by four researchers.

Participating Helmholtz centres: Helmholtz-Zentrum Berlin (HZB), Research Centre Jülich (FZJ), Karlsruhe Institute of Technology (KIT)
Participating programmes: Materials and Technologies for the Energy Transition (MTET)

PROJECT ABSTRACT

Wendelstein 7-X

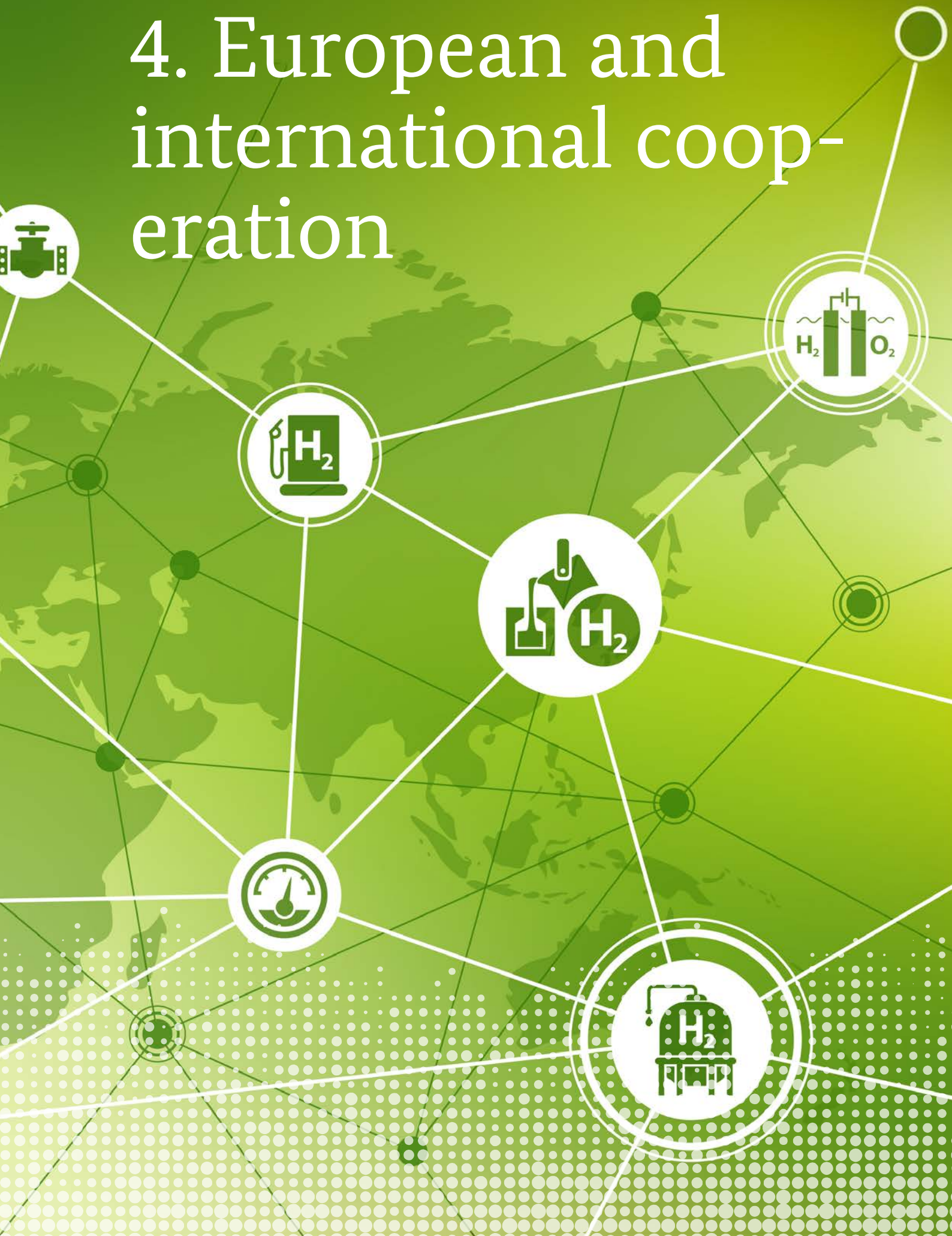
Magnetic confinement fusion (MCF) uses magnetic fields to enclose a gas mixture comprised of the hydrogen isotopes deuterium and tritium in a reactor and prevent the ensuing plasma from colliding with the reactor walls and particles and energy escaping the plasma (hence the term “magnetic confinement”). The confined plasma is heated to a temperature of several million degrees Celsius using a very powerful external heat source. This generates a fusion reaction based on the same principle that powers the sun, whereby the hydrogen isotopes fuse to form helium. Stellarators and tokamaks are the most common magnetic fusion reactors.

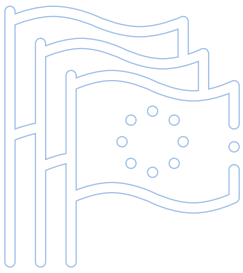
Built and operated by the Max Planck Institute for Plasma Physics (IPP), Wendelstein 7-X in Greifswald, Germany, is the largest and most advanced stellarator in the world. The purpose of this system is to demonstrate successful plasma confinement and consequently the suitability of this design for fusion power plants. In contrast to tokamaks systems, such as the large-scale international energy project ITER, stellarators facilitate continuous operation, an essential feature for operating a future fusion power plant at base load capacity.

The key component of Wendelstein 7-X is a toroid consisting of 50 superconducting magnetic coils, each around 3.5 meters high, which induce a magnetic field that ensures the hot plasma is confined. The special design of the coils is based on complex computer simulations. The vacuum vessel of the Wendelstein 7-X stellarator, or cryostat to be more precise, is 16 metres in diameter and 5 metres high.

The construction of Wendelstein 7-X began in 1997. The first operating phase commenced in 2015 and was completed in 2018. Subsequent upgrades included in particular the expansion of the heating system and equipping the wall elements with a water-cooling system. The second operating phase, which began in late 2022, reveals the success of the upgrades: In February 2023, an energy turnover of 1.3 gigajoules was achieved for the first time. The plasma discharge lasted more than eight minutes the plasma discharge lasted. The achievement of both these targets has set new records and is an important step towards making a fusion power plant reality. To use fusion for operating power plants, it is crucial to maintain the plasma for as long as possible and also be able to feed large amounts of power into the plasma and dissipate the heat generated.

4. European and international cooperation





4.1 European networking in energy research

As a member state of the EU, Germany is committed to achieving the EU's goals of becoming climate-neutral by 2050. Pursuing these goals also has an effect on domestic and European research funding strategies in the energy sector. International networking – identifying, creating and exploiting valuable synergies – is essential to ensure that appropriate measures are designed and implemented for the targeted and efficient funding of research, development and innovation programmes. International networking is also crucial in order to allow researchers to provide a prompt response customised to the requirements of European and international funding calls.

Consolidating Germany's position as a leading international research and business hub

With their successful involvement in European research, development and innovation projects, German research and industry stakeholders are playing an invaluable part in consolidating Germany's position as a leading international research and business hub.

To enable stakeholders from Germany to participate – both in terms of the specified programme goals and funding – in European projects in the energy sector, representatives from ministries and departments are actively involved in various committees at a conceptual and strategic level.

EU programme committees

Under the umbrella of "Horizon Europe", the EU's framework programme for research and innovation, Germany is involved in the programme committee for Cluster 5 (Climate, Energy and Mobility) and the Strategic Programme Committee.

For the EU framework programme, Germany played an active role in developing the upcoming funding strategy for the period from 2025 to 2027. In the next step, the programme committee of Cluster 5 will design the work programmes for this period such that they are closely integrated into the strategic plan.

Moreover, in the context of consultations at the corresponding national level, the funding goals of the national energy research programme can also be taken into account in the design of the work programmes and thus in the European collaborative research funding.

SET Plan and European partnerships

Together with stakeholders from industry and research as well as other EU member states, Germany is actively involved in shaping the EU research funding strategy in the energy sector in the Strategic Energy Technology Plan (SET Plan) where specific funding goals are drawn up and aligned with national programmes and the objectives of the EU framework programme. The objectives are revised where required based on technological developments and the current geopolitical situation. In addition, the SET Plan was revised in 2023 to include five cross-cutting themes: society's needs, circular economy, digitisation, workforce qualification and accelerating the market launch and deployment of green technologies.

Funding measures are being implemented since 2022 through multilateral research funding projects of the co-financed "Clean Energy Transition Partnership" (CETPartnership) and "Driving Urban Transition Partnership" (DUTP). Together with Germany, over 30 EU member states and other countries are involved in financing the calls. A major benefit for applicants: smaller consortia and a less cumbersome application process in contrast to Horizon Europe make the entry onto the European stage easier. Stakeholders in Germany are clearly very keen on this development. Partners from Germany took part in over half of the 320 applications in the first two CETPartnership calls

4.2 EU Research Framework Programme (Horizon Europe)

Horizon Europe is one of the world's largest research and innovation funding programmes initiated by the EU in a system of European and national funding programmes with common policy objectives. It focuses in particular on collaboration between universities, research communities and industry, including small and medium-sized enterprises, as well as citizens and their representatives. The programme aims to bridge the gap between regions, generations and local cultures and to shape Europe's future together.

The overarching mission of Cluster 5 "Climate, Energy and Mobility" is to accelerate the green and digital transition and consequently the transformation of business, industry and society with the aim of achieving climate neutrality in Europe by 2050. This includes the transition to greenhouse gas neutrality of the energy and mobility sector, whilst also boosting competitiveness, resilience and benefits to society.

The funding calls in Cluster 5 support the implementation of the 2015 Paris Agreement, the United Nations Sustainable Development Goals and the EU's political and strategic guidelines in the various energy sectors.

Against the backdrop of Russia's invasion of Ukraine, Cluster 5, in accordance with the REPowerEU priorities, is contributing towards reducing Europe's reliance on Russian fossil fuel imports. The funding activities under Cluster 5 encourage the diversification of European gas supplies, the electrification of the energy system and the conversion of energy-intensive industries.

German applicants successful in the field of energy in Horizon Europe

In 2022, roughly €833 million in funding was provided for a total of 129 collaborative projects. With a total of 216 participants, Germany is involved in 98 projects. This means that stakeholders from Germany were to be found in 76% of all collaborative projects in the energy sector of Horizon Europe, playing the responsible role of coordinator in seven of these projects (Figure 1). In total, German project participants were able to obtain approx. €134.5 million in funding. In other words, 16% of the total appropriated funding was allocated to projects in Germany. This places Germany in first place, ahead of Spain, Italy and France, in the context of the funding obtained in this programme area in 2022 (Figure 31, p. 69).

Figure 30: Number of project participants by country in the energy sector of Cluster 5 in 2022

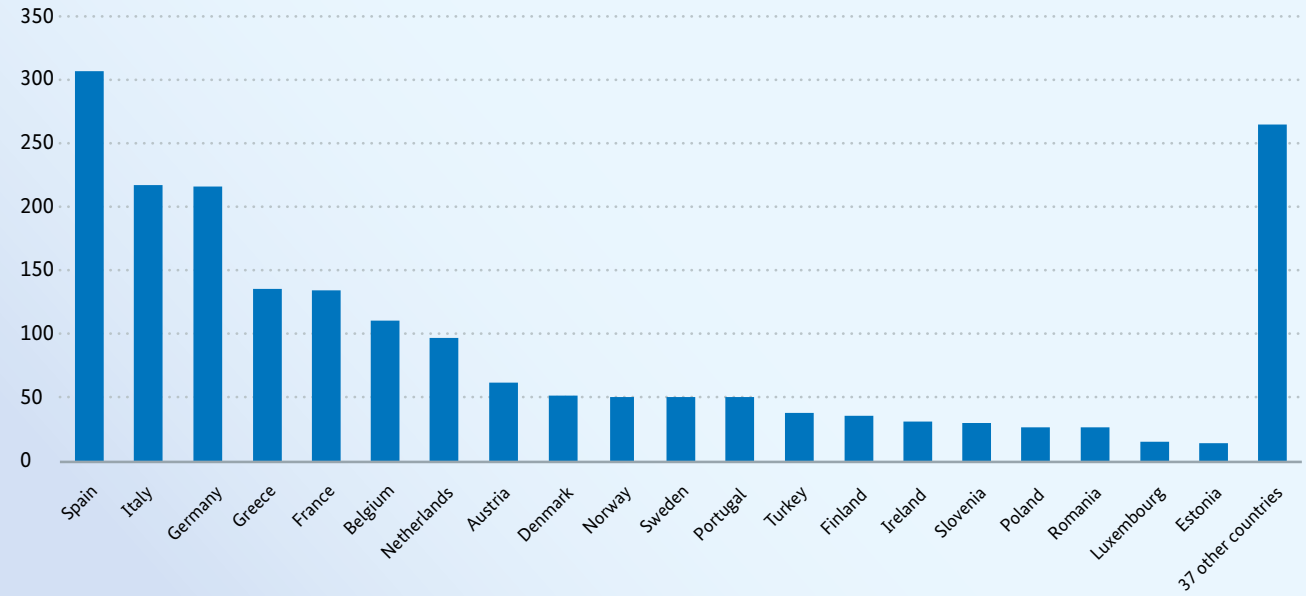
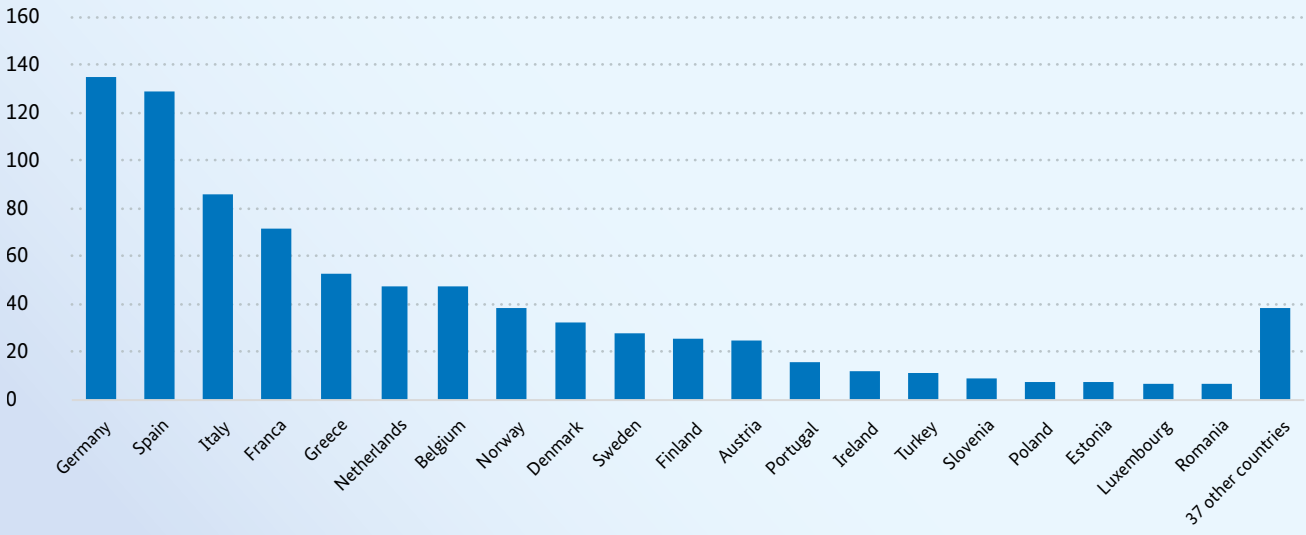


Figure 31: The first 20 recipients of EU funding in the energy sector of Cluster 5 in 2022

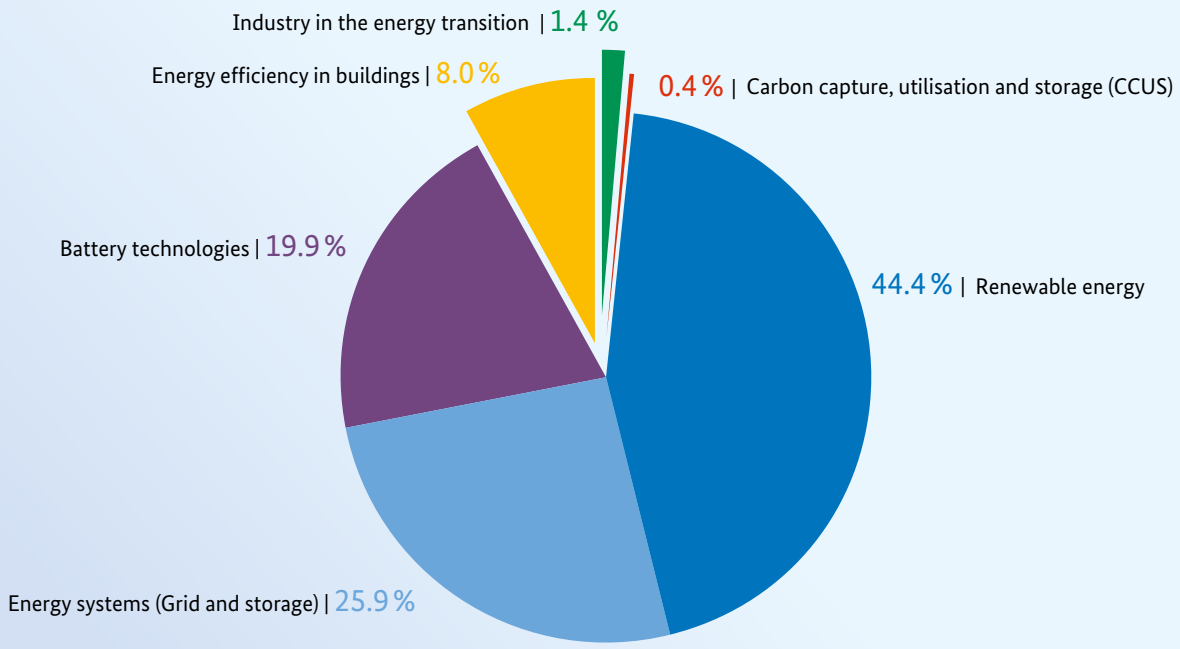


Priorities for energy research in Horizon Europe

40.7% of project participation by beneficiaries from Germany focused on renewable energy (global leadership in renewable energy) which takes into account both applied research and demonstration projects of renewables such as wind, solar, photovoltaics and geothermal energy as well as bioenergy and biofuels. This is also reflected in the breakdown of the funding received (Figure 3). The focus is clearly on research and demonstration projects in the following technology fields: renewable energies (44.4%), energy systems (25.9%), battery technologies (19.9%), energy efficiency in buildings (8.0%), industry in the energy transition (1.4%), and carbon capture, utilisation and storage (0.4%).

Funding priorities with a focus on technologies and innovations in the field of hydrogen are not included in the breakdown, as they are funded within the scope of the Clean Hydrogen institutionalised partnership. Likewise, other energy-related topics outside the programme area of Cluster 5 are not included in these breakdowns.

Figure 32: Prioritised topics by funding volume of German participation in the energy sector of Cluster 5 in 2022



4.3 International cooperation

The Federal Government is committed to energy research and prioritises international cooperation in both European and global organisations and initiatives.

International Energy Agency (IEA)

The International Energy Agency (IEA) is an independent organisation within the Organisation for Economic Co-operation and Development (OECD), and is committed to strengthening international cooperation in energy-related policies, technologies and economic affairs. The IEA is made up of 31 member countries, including Germany, and thirteen association countries. The Federal Government is represented by the Federal Ministry for Economic Affairs and Climate Action.

Research and development activities as well as strategic programmes in the field of energy technology are coordinated by the Committee on Energy Research and Technology (CERT). The goals of the energy research policy are implemented through the transnational Technology Collaboration Programmes (TCPs). Germany is currently involved in 24 of the 39 ongoing TCPs.

Mission Innovation (MI)

Mission Innovation (MI) is a global initiative that promotes the development and expansion of clean and cost-effective energy technologies and solutions worldwide, focusing in particular on increasing public and private investment.

In 2021, seven innovation missions were presented at the sixth ministerial meeting (MI-6) and the 26th UNFCCC Conference of the Parties (COP26):

- Green-Powered Future Mission
- Zero-Emission Shipping Mission
- Clean Hydrogen Mission
- Carbon Dioxide Removal Mission
- Urban Transition Mission
- Net-Zero Industries Mission
- Integrated Biorefineries Mission

Bilateral research cooperation

The Federal Government is also cooperating with other countries and regions at a bilateral level in the field of energy research.

Cooperation with France on sustainable energy supply for Europe

At an initiative by the Federal Ministry of Education and Research and the French Ministry of Research, nine research projects have been working on solutions for efficient, affordable and environmentally friendly energy supply since late 2019. The projects explore battery technologies, innovations for electricity grids and energy markets, the production of gases and chemicals from electricity from renewable sources, as well as fuel cells and private household energy supply with hydrogen. The bilateral cooperation was very successful despite the Coronavirus pandemic. In May 2023, all project teams convened for a final seminar and presented, among other things, latest developments in battery materials, an innovative CO_2 electrolyser and the laboratory setup for a hydrogen home.

German-Dutch research programme on green hydrogen and green chemistry

At the German-Dutch climate cabinet meeting on 4 October 2022, the Federal Ministry of Education and Research and the Federal Ministry for Economic Affairs and Climate Action, together with the Dutch Research Council, presented a joint call for funding: Electrochemical Materials and Processes for Green Hydrogen and Green Chemistry. The bilateral projects will pool the competencies of both countries in order to develop highly innovative and practical solutions and processes for green hydrogen and green chemistry. In December 2023, a total of six German-Dutch collaborative projects were approved. Four of these projects are in the Federal Ministry of Education and Research's area

of funding. The aim of these projects is to develop innovative components or processes for the production of hydrogen, methane or chemical raw materials on a renewable basis and involve partners along the entire innovation chain from research to industry to consumers.

European Green Hydrogen Research Agenda (SRIA)

The Strategic Research and Innovation Agenda (SRIA), a pilot project of the European Research Area, addresses the most important research questions relating to green hydrogen at the European level. A German-Italian workshop took place in October 2023 to further intensify bilateral collaboration. In this context, further research needs have been identified in various areas along the green hydrogen supply chain.

International collaborations are key to Germany's hydrogen strategy: research collaborations with Australia and other countries in Europe and Africa are vital as not all of the hydrogen required for the energy transition can be produced in Germany.

Partnerships with Africa on renewable energy and green hydrogen

The Federal Ministry of Education and Research is funding a large number of projects involving more than 30 African countries. In Burkina Faso, research is being carried out to determine the extent of yield reduction due to soiling of solar modules and to identify the countermeasures that can be implemented to prevent this. In Ghana, the Waste2Energy project is looking into how waste can be converted into energy and fertiliser. Researchers in Togo are setting up a large, certified biogas laboratory – the first of its kind in western Africa. In Nigeria, a study has been launched to investigate how sustainable fertilisers can be produced locally using green hydrogen and how this can reduce dependence on imports. The specialists of tomorrow are already being trained in the second round of the *International Master's Programme in Energy and Green Hydrogen*. South African and German research institutions and companies are working together to develop optimised catalysts required to produce CO_2-neutral aviation fuel on a commercial scale.

The five-year *Long-Term European African Partnership on Renewable Energy (LEAP-RE)* programme, co-funded by the European Commission, is building a long-term partnership between Europe and Africa on renewable energy research and innovation. German researchers are involved in 13 of the 31 selected projects.

PROJECT ABSTRACT

International cooperations with Australia and Namibia

Germany will have to import hydrogen from other countries. The Federal Government has set a target of generating 10 gigawatts of electrolysis capacity by 2030. The hydrogen produced, however, will barely cover 30-50% of Germany's needs. The Federal Ministry of Education and Research therefore entered into long-term international research collaboration projects at an early stage. Germany and Australia have been working closely to form a strategic hydrogen partnership since 2020. The HySupply feasibility study has shown that it is economically viable to produce hydrogen in Australia and export it to Germany. Based on this, the HyGATE funding initiative (German-Australian Hydrogen Innovation and Technology Incubator) was launched. Four joint projects were selected, out of which two began their work in 2023 itself.

Namibia too has sufficient land area and ample sources of solar and wind energy. The country therefore has great potential for the production and export of green hydrogen, which will be needed in Germany in the future. The Federal Ministry of Education and Research is currently funding three German-Namibian hydrogen projects with the aim of implementing hydrogen technologies in practice.

New technologies, and also sufficient local expertise, are needed for the generation and use of green hydrogen. Capacity building is therefore necessary to train local experts. The Youth for Green Hydrogen (Y4H2) scholarship programme aims to equip young Namibians with unique and relevant skills in alignment with the Green Hydrogen economy. Scholarships will be awarded in several calls to master's degree students as well as for technical and vocational education and training.

Moreover, the International Master's Programme in Energy and Green Hydrogen will also train 130 students from all 15 countries of the Economic Community of West African States (ECOWAS) in green hydrogen.

Technology Readiness Level upon completion of the project: 4 – 5

Beneficiaries: acatech – National Academy of Science and Engineering
Project funding by: Federal Ministry of Education and Research
Funding ID: 03EW0027
Appropriated funding: €1.7 million
Project duration: 2020 – 2023
Project description on EnArgus:

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"Our German-Australian consortium from science and industry has shown that supply chains for hydrogen, ammonia and other downstream products from Australia to Germany are technically and commercially possible in compliance with regulatory aspects. Our Australian partners are ready to make the energy sources available on a large scale to the German market. Implementation of such projects should, however, start immediately, if we are to succeed in making the hydrogen economy reality. It is important to think big and offer the industry a secure framework."

Prof. Dr. Robert Schlögl, HySupply Project Management and President of the Alexander von Humboldt Foundation

5. Research funding by the Länder

Since 2008, Project Management Jülich (PtJ) has undertaken an annual survey of spending by the Länder on research and development of innovative energy technologies on behalf of the Federal Ministry for Economic Affairs and Climate Action.

According to the survey conducted for 2022, total spending by the Länder amounted to €470.4 million, with project funding accounting for €265.5 million and institutional funding for €204.9 million.

As in the previous years, the focus in 2022 was once again on promoting technology in the field of "system integration and cross-system research topics", with funding by the Länder totalling €235 million. Priority was given to hydrogen technologies (€118.5 million) and energy storage technology (€45.5 million) as the most important instruments for coupling the sectors electricity, heating systems and mobility.

Research funding in "Energy transition in the consumption sectors" covers all energy efficiency measures and, at €128.3 million, overtook the amount allocated in the previous year. Boosted by research in electric mobility, the research area of "Energy efficiency in transport" was prominent, with grants of €58.5 million from the Länder.

Spending by the Länder on technology research and development in the area of "Energy generation" totalled €107.6 million in the survey year. The research areas of solar thermal and photovoltaics (€23.4 million), closely followed by wind energy (€20.9 million) benefited most in terms of the funding efforts.

With their remarkable funding of more than €470 million for non-nuclear energy research, the Länder are making a major contribution to the national energy transition process and to achieving the climate protection targets set forth by the Federal Government.

Alongside other Länder reports published to this date, the full version of the report on "Funding for non-nuclear energy research by the Länder in 2022" is available on the Federal Ministry for Economic Affairs and Climate Action's information website energieforschung.de.

6. Tables

6.1 Funding in the 7th Energy Research Programme of the Federal Government

Table 1 | Overview of topics in the Energy Research Programme of the Federal Government

Topic	Actual outlays in € million									
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Project funding	**487.65**	**525.44**	**536.28**	**659.45**	**635.25**	**703.66**	**750.59**	**945.17**	**1,111.98**	**1,077.83**
Strategic funding formats						-	5.53	66.93	210.65	222.20
Energy transition in the consumption sectors	115.89	112.04	108.08	137.28	156.04	193.92	208.03	212.92	198.11	178.46
Energy generation	198.95	209.86	191.67	244.49	212.36	255.36	252.60	288.39	257.01	242.16
System integration: grids, storage, sector coupling	95.22	113.30	119.79	144.44	127.15	127.11	146.61	201.69	211.39	219.80
Cross-system research topics for the Energy Transition	34.29	44.49	71.01	86.12	92.22	78.31	91.61	123.42	184.43	164.26
Nuclear safety research	43.29	45.74	45.73	47.13	47.48	48.98	46.21	51.82	50.39	50.96
Institutional funding (Helmholtz Association)	**331.60**	**348.69**	**362.81**	**379.63**	**393.75**	**410.29**	**415.78**	**314.42**	**319.85**	**325.39**
Accompanying measures	**28.14**	**34.72**	**35.03**	**28.20**	**25.76**	**34.47**	**50.16**	**51.38**	**54.53**	**58.50**
Total	**847.39**	**908.85**	**934.12**	**1,067.28**	**1,054.75**	**1,148.42**	**1,216.53**	**1,310.97**	**1,486.36**	**1,461.72**

Table 2 | Disbursements of project funding in the area “Strategic funding formats: Regulatory Sandboxes for the Energy Transition and hydrogen flagship”

Funding topic	Actual outlays in € million					Number of projects		Total funding in € million
	2019	2020	2021	2022	2023	ongoing in 2023	new in 2023	appropriated in 2023
Living Labs of the Energy Transition	**-**	**5.53**	**18.29**	**40.50**	**45.48**	**220**	**51**	**72.64**
Energy-optimised and climate-neutral buildings	-	0.14	1.22	1.31	1.38	9	4	12.15
Energy-optimised and climate-neutral neighbourhoods	-	1.70	5.06	8.69	10.00	44	-	-
Supply of heat and cold	-	0.06	0.80	5.33	6.78	17	1	0.70
Energy transition in industry, commerce, trade and services	-	-	-	0.46	0.58	3	3	5.68
Photovoltaics	-	-	-	-	0.07	4	4	2.69
Use of biogenic residue and waste materials for energy purposes	-	1.01	1.22	0.05	0.03	-	-	-
Geothermal energy	-	0.35	1.66	6.87	2.08	11	1	0.81
Thermal power plants	-	2.17	2.72	1.20	0.11	1	-	-
Electricity grids	-	-	-	-	-	-	9	13.80
Energy storage systems	-	-	-	0.00	1.73	12	4	13.08
Hydrogen production	-	0.11	5.04	11.63	15.51	53	-	-
Fuel cells	-	-	-	-	0.34	7	3	7.52
Systemic approaches	-	-	0.54	1.89	2.65	23	-	-
Digitalisation in the Energy Transition	-	-	0.04	3.05	4.21	36	22	16.20
Hydrogen flagship projects	**-**	**-**	**48.64**	**170.14**	**176.72**	**368**	**37**	**43.21**
Storage and transport/TransHyDE	-	-	10.71	28.72	31.34	124	19	21.36
Hydrogen production/H_2Giga and H_2Mare	-	-	37.93	141.43	145.38	244	18	21.86
Total	**-**	**5.53**	**66.93**	**210.65**	**222.20**	**588**	**88**	**115.86**

Table 3 | Disbursements of project funding in the area of "Energy Transition in the consumption sectors"

Funding topic	Actual outlays in € million										Number of projects		Total funding in € million
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	ongoing in 2023	new in 2023	appropri-ated in 2023
Energy transition in buildings and neighbour-hoods	**66.11**	**61.85**	**58.21**	**65.38**	**78.63**	**93.51**	**101.27**	**98.57**	**100.16**	**87.09**	**1,023**	**202**	**77.80**
Energy-optimised and climate-neutral buildings	36.55	35.64	32.00	36.57	39.78	50.24	47.86	44.90	42.60	36.34	487	89	32.57
Energy-optimised and climate-neutral neighbour-hoods	10.59	9.65	12.94	17.57	22.52	25.35	31.51	31.24	26.20	27.98	309	71	28.62
Basic research into energy-optimised and climate-neutral neighbourhoods	5.19	4.65	3.88	2.73	7.50	10.22	13.63	9.92	15.53	7.49	63	-	-
Thermal energy storage	6.51	7.33	5.75	4.84	5.33	4.65	4.52	4.19	4.17	4.78	45	12	3.54
Supply of heat and cold	7.27	4.59	3.64	3.67	3.51	3.06	3.74	7.15	8.56	7.40	116	30	13.08
Basic research into supply of heat and cold	-	-	-	-	-	-	-	1.17	3.09	3.08	3	-	-
Energy transition in industry, commerce, trade and services	**37.17**	**37.39**	**36.00**	**57.12**	**60.92**	**66.20**	**64.88**	**73.49**	**69.80**	**71.45**	**801**	**251**	**106.40**
Waste heat use	3.88	4.98	4.03	2.78	1.26	0.55	0.56	0.98	1.11	2.07	29	11	7.33
Chemical process technology	7.13	7.49	9.11	12.83	12.83	11.22	9.21	9.12	10.64	10.54	107	38	16.43
Iron, steel and non-ferrous metals	0.98	0.97	0.86	1.09	2.07	3.56	3.15	2.36	4.25	2.82	38	11	4.63
Circular economy	0.34	0.32	0.12	0.03	-	-	0.16	0.29	0.29	0.10	6	-	-
Manufacturing technology	17.13	15.82	11.09	14.82	17.49	23.19	24.80	24.75	22.40	22.84	246	30	8.82
High-temperature super-conductivity	2.37	0.53	0.62	1.18	1.15	1.07	0.70	2.15	2.33	1.61	12	-	-
Digitalisation in industry	0.70	0.74	1.07	1.59	1.69	1.61	0.66	2.30	3.70	4.21	25	3	0.92
Material and resource efficiency	0.07	0.09	0.01	0.18	0.28	0.49	0.43	0.37	0.15	0.03	-	-	-
Process heat	3.29	4.14	5.65	8.15	8.58	9.45	9.36	10.51	9.49	11.65	115	49	19.61
Water treatment	0.04	0.18	0.35	0.72	0.58	0.57	0.51	0.41	0.20	0.78	13	5	2.43
Flexible industrial processes	-	-	-	10.70	12.54	10.80	10.43	14.05	8.37	6.25	107	66	28.82
Other	1.24	2.12	3.07	3.03	2.44	3.67	4.93	6.19	6.89	8.55	103	38	17.40
Energy transition in the transport sector	**12.61**	**12.80**	**13.87**	**14.78**	**16.49**	**34.21**	**41.87**	**40.85**	**28.16**	**19.92**	**177**	**18**	**11.66**
Battery technology for mobile applications	12.61	12.80	13.87	14.28	15.63	17.06	17.80	16.59	11.25	9.88	107	13	6.79
Synthetic fuels	-	-	-	0.50	0.86	13.51	16.19	16.29	9.28	6.57	46	5	4.87
Basic research into synthetic fuels	-	-	-	-	-	3.64	7.44	6.49	4.61	0.91	4	-	-
Charging infrastructure and systems integration	-	-	-	-	-	-	0.44	1.48	3.02	2.56	20	-	-
Total	**115.89**	**112.04**	**108.08**	**137.28**	**156.04**	**193.92**	**208.03**	**212.92**	**198.11**	**178.46**	**2,001**	**471**	**195.86**

Table 4 | Disbursements of project funding in the area of "energy generation"

Funding topic	Actual outlays in € million										Number of projects		Total funding in € million
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	ongoing in 2023	new in 2023	appropri-ated in 2023
Photovoltaics	**56.83**	**67.41**	**59.78**	**81.90**	**78.24**	**98.69**	**86.19**	**88.39**	**70.14**	**73.38**	**461**	**93**	**65.90**
PV technologies	7.22	5.64	2.65	2.75	5.24	11.75	12.40	16.40	13.55	12.28	90	12	7.07
Quality assurance	2.65	3.07	3.79	4.60	3.65	3.97	3.83	5.24	7.25	9.73	92	26	10.73
Manufacturing technologies	28.77	36.05	36.10	55.93	58.11	58.86	56.81	50.05	37.90	25.64	176	36	22.45
Circular economy	0.63	0.91	0.99	1.14	0.82	1.01	1.16	1.72	1.05	1.13	10	5	1.56
Systems capability	2.40	3.40	4.57	5.41	6.85	5.99	5.50	4.00	4.79	4.59	48	5	2.93
Basic research into photo-voltaics	14.83	11.59	6.17	3.51	1.33	2.69	2.27	4.39	1.34	1.07	6	-	-
Other	0.34	6.75	5.51	8.56	2.24	14.41	4.23	6.60	4.27	18.93	39	9	21.15
Wind energy	**52.88**	**52.85**	**49.68**	**75.11**	**59.73**	**72.95**	**76.06**	**82.87**	**89.19**	**74.97**	**471**	**99**	**62.70**
Plant development	23.40	27.09	21.99	42.92	29.13	34.69	41.82	42.79	43.85	39.44	190	49	38.87
Logistics, installation, maintenance and operation	5.25	5.18	7.38	11.00	8.34	8.30	7.83	9.96	10.97	12.14	122	12	7.84
Offshore wind energy	14.34	9.19	10.45	11.56	12.03	15.88	17.61	18.67	25.31	12.94	73	12	4.80
Environmental aspects of wind energy	4.31	3.23	2.25	2.48	2.42	3.34	2.83	3.08	2.13	2.25	24	5	1.54
Wind physics and meteorology	2.34	3.63	3.03	3.06	2.33	2.96	3.70	6.18	5.45	6.84	43	13	7.08
Other	3.24	4.53	4.58	4.08	5.49	7.79	2.26	2.18	1.48	1.36	19	8	2.58
Bioenergy	**43.00**	**42.10**	**37.88**	**33.03**	**28.54**	**40.52**	**48.37**	**63.72**	**48.00**	**44.87**	**694**	**166**	**83.49**
Production – farming	5.98	4.43	4.69	5.70	6.52	10.86	14.39	18.97	18.59	18.36	223	51	53.91
Production – cultivation	4.77	4.92	4.49	4.58	4.20	4.44	4.78	4.35	3.90	3.19	54	13	3.98
Conversion – general	-	0.53	5.22	2.73	4.46	5.03	4.64	3.76	1.53	1.63	25	5	2.14
Conversion – gaseous	5.27	6.84	4.92	6.79	5.04	4.88	6.05	6.46	6.72	7.50	124	36	10.79
Conversion – liquid	6.19	5.92	3.97	3.21	1.98	1.12	0.68	0.78	0.39	0.26	7	2	0.52
Conversion – solid	0.73	1.92	2.23	1.77	1.34	2.43	3.85	3.49	1.83	2.39	34	3	0.76
Use of biogenic residue and waste materials for energy purposes	5.06	4.69	3.66	4.17	4.20	5.12	7.71	10.48	10.39	9.53	209	56	11.37
Basic research into bioenergy	12.16	9.89	6.17	3.13	0.22	5.83	4.63	13.13	2.37	1.07	8	-	-
Cross-section	2.85	2.97	2.53	0.94	0.59	0.80	1.65	2.29	2.28	0.95	10	-	-
Thermal power plants	**29.39**	**32.22**	**29.44**	**34.14**	**29.05**	**28.30**	**25.72**	**29.77**	**30.72**	**35.26**	**358**	**58**	**29.58**
Combined-cycle power plants with flexible loads and fuels	20.12	20.82	18.42	22.87	18.01	17.74	16.22	17.41	15.59	20.15	215	38	22.22
Solar thermal power plants	6.23	8.01	7.21	6.20	6.13	6.75	8.19	9.19	9.71	9.58	101	5	2.10
Other	3.04	3.39	3.81	5.07	4.90	3.80	1.31	3.17	5.43	5.53	42	15	5.26
Geothermal energy	**15.64**	**13.61**	**12.89**	**18.15**	**15.38**	**13.19**	**14.01**	**22.71**	**18.64**	**13.44**	**118**	**38**	**20.20**
Hydroelectric and marine power	**1.21**	**1.68**	**2.01**	**2.15**	**1.40**	**1.71**	**2.26**	**0.93**	**0.31**	**0.25**	**5**	**2**	**1.25**
Total	**198.95**	**209.86**	**191.67**	**244.49**	**212.36**	**255.36**	**252.60**	**288.39**	**257.01**	**242.16**	**2,107**	**456**	**263.13**

Table 5 | Disbursements of project funding in the area of "system integration: grids, storage, sector coupling"

Funding topic	Actual outlays in € million										Number of projects		Total funding in € million
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	ongoing in 2023	new in 2023	appropri-ated in 2023
Electricity grids	**31.24**	**54.32**	**66.32**	**78.14**	**66.24**	**64.85**	**65.05**	**69.75**	**61.28**	**59.78**	**582**	**129**	**77.84**
Security of supply	2.23	7.50	12.75	13.10	13.51	11.02	12.11	10.52	8.67	6.51	65	12	5.26
Flexibility in the power grid	5.88	7.21	6.60	6.30	7.13	7.14	10.71	13.88	11.90	9.06	120	10	4.90
Grid planning and operati-onal management	9.53	15.65	19.45	19.56	14.74	13.35	12.29	11.54	11.43	14.65	149	48	22.53
Technology for the electri-city grid	12.64	16.39	17.52	21.07	17.71	22.50	19.36	20.83	17.50	14.81	186	34	15.05
Basic research into electri-city grids	0.96	7.57	10.01	18.11	13.15	10.85	10.58	12.97	11.78	14.74	62	25	30.11
Electricity storage	**29.57**	**28.63**	**27.69**	**22.35**	**18.37**	**21.43**	**22.53**	**25.47**	**19.28**	**17.40**	**167**	**31**	**18.10**
Electrical storage	-	-	-	0.02	0.61	0.63	0.63	0.39	0.89	1.25	11	2	1.59
Electrochemical storage	3.99	4.36	5.22	8.54	8.99	8.68	11.19	15.64	11.32	8.78	88	18	8.84
Electricity-thermal-electri-city storage	-	-	0.58	1.39	1.54	2.36	2.42	2.60	1.12	0.52	4	-	-
Mechanical storage	1.53	1.97	2.60	3.19	2.53	2.65	3.48	1.76	1.24	1.49	10	-	-
Basic research into energy storage	17.21	15.61	10.79	3.60	1.17	3.77	2.30	1.56	0.88	1.51	9	-	-
Other	6.84	6.70	8.50	5.59	3.54	3.34	2.52	3.53	3.83	3.84	45	11	7.68
Sector coupling and hydro-gen technologies	**34.41**	**30.35**	**25.77**	**43.95**	**42.53**	**40.82**	**59.02**	**106.47**	**130.83**	**142.62**	**671**	**235**	**217.90**
Hydrogen production	6.35	7.17	5.70	6.66	4.21	1.13	0.86	2.36	4.06	5.27	77	32	16.13
Hydrogen storage and transport	3.46	2.76	2.85	4.36	4.90	5.73	4.10	4.50	4.74	8.66	100	13	6.17
Fuel cells	18.82	15.23	10.04	15.67	13.81	14.31	15.17	13.48	14.81	12.57	118	39	19.23
Systemic approaches	0.96	1.12	0.99	0.32	0.33	0.46	0.43	1.60	2.41	2.79	19	9	2.40
Power-to-X	0.40	0.39	0.19	0.62	1.06	1.33	1.35	1.58	1.11	0.58	3	-	-
Basic research into sector coupling and hydrogen	3.04	2.10	4.63	15.53	17.36	17.78	35.99	80.12	99.54	105.44	287	101	157.16
Other	1.39	1.58	1.37	0.79	0.85	0.08	1.13	2.83	4.16	7.31	67	41	16.81
Total	**95.22**	**113.30**	**119.79**	**144.44**	**127.15**	**127.11**	**146.61**	**201.69**	**211.39**	**219.80**	**1,420**	**395**	**313.83**

Table 6 | Disbursements of project funding in the area of "cross-system research topics for the Energy Transition"

Funding topic	Actual outlays in € million										Number of projects		Total funding in € million
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	ongoing in 2023	new in 2023	appropri-ated in in 2023
Energy systems analysis	**8.39**	**9.32**	**11.18**	**15.01**	**15.94**	**17.16**	**18.97**	**19.74**	**19.09**	**18.72**	**198**	**48**	**18.80**
Digitalisation in the energy transition	**-**	**-**	**-**	**-**	**-**	**-**	**2.68**	**5.06**	**5.63**	**6.52**	**104**	**15**	**8.63**
Resource efficiency in the context of the energy tran-sition	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0.07**	**2.29**	**4.88**	**82**	**40**	**9.07**
CO_2 technologies	**6.60**	**4.28**	**15.06**	**18.15**	**24.58**	**19.57**	**35.05**	**32.87**	**45.09**	**33.69**	**156**	**21**	**10.09**
CO_2 transport and storage	0.67	0.38	-	0.18	0.96	1.23	1.22	0.49	1.14	0.94	7	2	1.54
CO_2 sequestration	3.90	1.80	3.46	3.30	2.11	1.23	1.95	2.48	2.36	3.07	47	16	7.36
CO_2 conversion and use	0.27	1.30	2.64	2.83	4.61	3.04	6.15	3.35	3.88	4.60	61	2	0.91
Basic research into CO_2 technologies	1.76	0.79	8.95	11.84	16.90	14.08	25.74	26.54	37.71	25.08	41	1	0.28
Collective industrial research programme cooperation	**-**	**-**	**0.05**	**2.52**	**4.22**	**5.47**	**4.90**	**5.71**	**4.64**	**3.89**	**46**	**14**	**6.86**
Energy transition and society	**3.25**	**3.95**	**2.64**	**10.02**	**9.93**	**10.15**	**6.37**	**12.28**	**15.95**	**18.27**	**205**	**75**	**41.32**
Energy transition and society – applied energy research	-	-	-	-	-	0.00	1.23	4.12	6.23	8.31	153	48	11.44
Basic research into energy transition and society	3.25	3.95	2.64	10.02	9.93	10.14	5.14	8.16	9.72	9.95	52	27	29.88
Materials research	**0.72**	**10.41**	**27.87**	**26.68**	**18.21**	**10.30**	**2.90**	**3.96**	**2.05**	**0.44**	**1**	**-**	**-**
Basic research into the energy-related use of subsurfaces	**4.22**	**3.69**	**3.59**	**1.81**	**2.02**	**1.36**	**2.35**	**3.55**	**14.88**	**8.43**	**103**	**26**	**9.88**
Technology-neutral fund-ing with an international focus	**1.03**	**2.00**	**0.65**	**0.28**	**2.11**	**3.88**	**11.73**	**24.46**	**60.00**	**27.41**	**104**	**15**	**14.26**
Other basic research	**10.07**	**10.84**	**9.96**	**11.64**	**15.22**	**10.42**	**6.64**	**15.70**	**11.57**	**23.15**	**15**	**-**	**-**
Accompanying funding for IPCEI battery cell research	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**3.24**	**18.87**	**87**	**68**	**39.08**
Total	**34.29**	**44.49**	**71.01**	**86.12**	**92.22**	**78.31**	**91.61**	**123.42**	**184.43**	**164.26**	**1,101**	**322**	**158.00**

Table 7a | Disbursements of project funding in the area of "nuclear safety research" until 2020

Funding topic[1]	Actual outlays in € million								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
Nuclear waste repository and disposal research	**12.30**	**13.23**	**13.58**	**12.95**	**13.09**	**16.33**	**17.61**	**19.57**	**17.79**
Repository research	9.84	10.39	10.25	10.06	9.94	11.43	12.02	12.23	12.58
Horizontal tasks and other	0.54	0.53	0.53	0.54	1.06	1.90	2.69	3.57	2.31
Nuclear material monitoring	0.18	0.15	0.19	0.24	0.26	0.21	0.09	0.22	0.05
Funding for young researchers (Research Ministry programmes)	1.74	2.17	2.61	2.11	1.83	2.78	2.81	3.54	2.85
Reactor safety research	**24.38**	**23.43**	**25.10**	**25.22**	**24.06**	**22.76**	**21.98**	**22.05**	**22.06**
Safety of nuclear facility components	5.28	4.01	4.38	4.55	4.38	4.20	5.19	4.75	4.98
Plant behaviour and accident sequences	11.25	12.09	12.51	13.22	13.37	13.46	12.52	12.47	11.72
Horizontal tasks and other	5.08	5.72	4.81	4.05	3.63	3.37	3.04	3.63	4.56
Funding for young researchers (Research Ministry programmes)	2.77	1.62	3.39	3.39	2.68	1.73	1.23	1.19	0.79
Radiation research (Research Ministry)	**4.91**	**4.95**	**4.61**	**7.58**	**8.58**	**8.05**	**7.89**	**7.36**	**6.36**
Total	**41.59**	**41.61**	**43.29**	**45.74**	**45.73**	**47.13**	**47.48**	**48.98**	**46.21**

1 Reorientation of funding from 2021

Table 7b | Disbursements of project funding in the area of "nuclear safety research" from 2021

Funding topic				Number of projects		Total funding in € million
	2021	2022	2023	ongoing in 2023	new in 2023	appropriated in in 2023
Reactor safety research	**22.39**	**23.80**	**23.53**	**144**	**30**	**19.88**
Examining and assessing the safety of components and structures	5.03	5.03	5.09	51	11	6.56
Detection methods to manage transients, incidents and accidents	14.04	13.88	14.27	62	9	6.55
Human-technology interaction and probabilistic safety analyses	2.01	1.86	1.41	15	6	1.83
Funding for young researchers (Research Ministry programmes)	1.32	3.03	2.76	16	4	4.94
Research into extended intermediate storage and the treatment of highly radioactive waste	**5.18**	**5.53**	**5.43**	**43**	**10**	**5.85**
Extended intermediate storage	1.52	1.22	1.28	11	4	1.53
Waste treatment and conditioning options for final disposal	-	0.02	0.26	2	1	0.83
Treatment and disposal methods	0.02	0.07	0.28	2	-	-
Funding for young researchers (Research Ministry programmes)	3.64	4.22	3.61	28	5	3.48
Repository research	**12.44**	**10.46**	**8.84**	**90**	**9**	**3.75**
Site selection	0.60	0.90	0.74	7	-	-
Safety and repository design; repository technology and (geo-)technical barriers	6.49	5.38	4.16	43	9	3.75
Safety verification	5.36	4.17	3.94	40	-	-
Funding for young researchers (Research Ministry programmes)	-	-	-	-	-	-
Research on cross-cutting issues	**3.12**	**3.63**	**4.67**	**16**	**2**	**2.52**
Knowledge and skills management	1.05	1.26	1.12	2	1	2.05
Socio-technical issues	1.82	2.37	2.33	10	-	-
Nuclear material monitoring (safeguards)	0.25	-	1.22	4	1	0.47
Funding for young researchers (Research Ministry programmes)	-	-	-	-	-	-
Radiation research (Research Ministry)	**8.69**	**6.98**	**8.49**	**60**	**13**	**7.19**
Total	**51.82**	**50.39**	**50.96**	**353**	**64**	**39.19**

Table 8 | Institutional support

Funding topic	Actual outlays in € million									
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
PoF III	**331.60**	**348.69**	**362.81**	**379.63**	**393.75**	**410.29**	**415.78**			
Energy efficiency, materials and resources	60.49	64.12	68.43	69.45	73.00	76.67	78.60			
Renewable energy	47.84	51.91	54.37	56.73	59.09	61.51	62.94			
Nuclear fusion (incl. Wendelstein W 7-X)	123.51	123.51	123.51	123.51	123.51	126.00	78.23			
Nuclear waste management, safety and security, and radiation research	34.62	35.76	37.27	38.84	40.47	42.16	19.63			
Technology, innovation and society	7.11	7.65	7.95	8.25	8.54	8.84	9.00			
Storage and connected infrastructure	49.93	57.12	60.47	69.61	72.86	76.21	43.32			
Future information technology	8.11	8.62	10.81	13.24	16.28	18.90	124.07			
PoF IV								**314.42**	**319.85**	**325.39**
Energy system design								34.60	34.89	35.19
Materials and technologies for the energy transition								208.09	212.13	216.25
Fusion								31.28	32.03	32.79
Nuclear waste management, safety and security, and radiation research (NUSAFE II)								38.46	38.81	39.16
Total[1]	**331.60**	**348.69**	**362.81**	**379.63**	**393.75**	**410.29**	**415.78**	**314.42**	**319.85**	**325.39**

1 The total for 2021 does not correspond to the total of individual items. The total includes an extra €2 million for an innovation pool.

Table 9a | Overview of the Federal Government's Energy Research Programme by chapter and title in the federal budget

Topic Chapter/title[1]	Respon-sible Ministry[2]	Chapter heading[1]	Title heading[1]	Actual outlays in € million 2020	2021	2022	2023
Project funding and accompanying measures				**800.75**	**996.55**	**1,166.51**	**1,136.33**
0903/68301	BMWK	Energy and sustainability	Energy research	535.03	572.61	530.94	509.81
0901/68601[3]	BMWK	Innovation, technology and new mobility	Industrial research for companies		3.85	4.28	3.86
0903/68602[6]	BMUV	Energy and sustainability	Safety research for nuclear facilities	38.33	40.33		
0903/68608[3]	BMWK	Energy and sustainability	Living Labs of the Energy Transition[5)]		18.64	43.66	53.63
0904/89602[7]	BMBF	Globalisation opportunities	Hydrogen Strategy, global trade and foreign markets – international cooperation on the hydrogen market			7.28	14.28
1005/68611 & 1005/89311	BMEL	Sustainability, research and innovation	Grants to promote research, development and demonstration projects in the field of regenerative raw materials and to promote national projects of sustainable forest management & Grants to promote research, development and demonstration projects in the field of regenerative raw materials (investments)	37.83	42.11	35.17	29.46
1605/54401[6]	BMUV	Nuclear safety and radiation protection	Research, studies and related projects			38.33	38.28
3004/68541	BMBF	Research for innovation, high-tech strategy	"Energy technologies and efficient energy use, green hydrogen – research and development projects"	117.77	185.84	201.61	178.16
3004/68541	BMBF	Research for innovation, high-tech strategy	Funding for young researchers, nuclear safety research	10.68	14.32	14.93	15.68
3004/68542[3]	BMBF	Research for innovation, high-tech strategy	Environmental technology, resources and georesearch		3.55	14.88	8.43
6092/68304	BMWK	Climate and Transformation Fund	Measures for developing electric mobility	14.64	15.37	14.34	13.07
6092/68502	BMBF	Climate and Transformation Fund	Application-oriented basic research into green hydrogen	29.42	99.79	245.92	226.84
6092/68616[3]	BMWK	Climate and Transformation Fund	Prevention and use of CO_2 in basic industries		0.11	2.83	6.45
6092/68618 & 6092/68621[7]	BMEL	Climate and Transformation Fund	Grants to promote measures for the use of fertilisers for energy purposes and for reducing emissions from fertiliser management & Grants to promote measures for protecting peatland soil and reducing the use of peat			1.82	3.98
6092/68626[4]	BMWK	Energy and Climate Fund	Living Labs of the Energy Transition [5)]	17.04			
6092/89203[3]	BMWK	Climate and Transformation Fund	Implementation of the National Hydrogen Strategy		0.01	7.29	15.53
6092/89304[3]	BMWK	Climate and Transformation Fund	Industrial manufacturing for mobile and stationary energy storage		0.00	3.24	18.87
Institutional funding (Helmholtz Association)				**415.78**	**314.42**	**319.85**	**325.39**
0901/68531 & 0901/89431	BMWK	Innovation, technology and new mobility	"German Aerospace Center – operation & German Aerospace Center – investment"	30.99	48.54	49.62	50.71
3004/68570 & 3004/89470	BMBF	Research for innovation, high-tech strategy	"HGF centres – operation & HGF centres – investment"	384.79	265.88	270.24	274.68
Total				**1,216.53**	**1,310.97**	**1,486.36**	**1,461.72**

1 2022 federal budget or, where titles expire, last year of use
2 Responsibility in line with organisational decree of Federal Chancellor of 8 December 2021, where title expired, current responsible ministry is cited
3 New from 1 January 2021
4 Expired from 1 January 2021
5 Funding incl. existing funding stipulations for the Living Labs were moved from 2021 into federal budget chapter 0903 title 68608.
6 Change in responsibility from the Federal Ministries for Economic Affairs and Climate Action to the Federal Ministry for the Environment, Nature
7 New from 1 January 2022

Table 9b | Overview of the Federal Government's Energy Research Programme by ministry

Ministry[1]	Actual outlays in € million			
Topic	2020	2021	2022	2023
Federal Ministry for Economic Affairs and Climate Action	**597.71**	**659.14**	**656.19**	**671.93**
Project funding and accompanying measures	566.72	610.59	606.57	621.22
Institutional funding (German Aerospace Center)	30.99	48.54	49.62	50.71
Federal Ministry of Food and Agriculture	**37.83**	**42.11**	**36.99**	**33.45**
Project funding and accompanying measures	37.83	42.11	36.99	33.45
Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection	**38.33**	**40.33**	**38.33**	**38.28**
Project funding and accompanying measures	38.33	40.33	38.33	38.28
Federal Ministry of Education and Research	**542.66**	**569.39**	**754.85**	**718.07**
Project funding and accompanying measures	157.87	303.51	484.61	443.38
Institutional funding (Helmholtz Association excl. German Aerospace Center)	384.79	265.88	270.24	274.68
Total	**1,216.53**	**1,310.97**	**1,486.36**	**1,461.72**

1 Responsibility in line with organisational decree of Federal Chancellor of 8 December 2021, where title expired, current responsible ministry is cited

6.2 Funding for energy research by the Länder

Table 10 | Spending on non-nuclear energy research by Land 2014-2022 in € million [1]

Land	2014	2015	2016	2017	2018	2019	2020	2021	2022
Baden-Württemberg	44.37	52.22	48.77	44.10	38.30	63.62	78.66	67.98	74.71
Bavaria	85.61	89.98	96.34	54.15	59.26	40.05	76.49	71.01	80.75
Berlin	4.70	3.63	2.94	3.89	4.36	4.62	11.86	3.48	3.11
Brandenburg	4.40	3.54	4.05	2.20	1.22	0.19	2.24	1.39	1.78
Bremen	1.99	2.08	2.10	1.35	2.22	1.75	3.94	17.30	13.94
Hamburg	14.91	16.12	15.64	17.29	16.81	16.63	16.87	17.11	18.61
Hesse	3.48	5.17	9.11	9.95	14.93	13.96	16.22	11.14	47.34
Mecklenburg-Western Pomerania [2)]	13.02	1.50	-	-	-	-	-	14.77	-
Lower Saxony	38.57	19.78	18.21	17.15	14.22	19.40	87.86	135.62	141.87
North Rhine-Westphalia	28.99	40.14	17.24	79.08	28.84	42.34	43.76	37.90	35.71
Rhineland-Palatinate	2.37	2.51	1.95	4.00	4.39	0.90	3.05	1.64	2.18
Saarland	1.56	0.98	1.42	2.77	1.53	1.52	1.06	1.28	1.13
Saxony	1.01	20.89	21.78	26.04	22.66	27.29	28.46	28.54	27.86
Saxony-Anhalt	4.62	1.53	0.89	9.45	1.94	2.71	3.94	6.52	0.69
Schleswig-Holstein	5.15	5.97	4.76	6.76	6.65	6.44	9.28	10.38	10.10
Thuringia	1.81	0.95	3.42	3.50	2.70	2.68	3.69	4.57	10.66
Total	**256.56**	**266.99**	**248.63**	**281.68**	**220.04**	**244.12**	**387.37**	**430.64**	**470.43**

1 See 2023 Federal Report on Energy Research for data from 2008.
2 Data from 2022 not available at the time of publication on 14 May 2024

Table 11 | Spending on non-nuclear energy research by Land by research topic in 2008-2017[1] in € million

Funding topic	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Biomass	21,48	7,79	15,90	18,73	18,71	22,44	20,56	21,53	11,78	13,05
Fuel cells/hydrogen	9,47	10,86	15,14	8,11	5,40	12,29	9,82	11,46	12,83	13,73
CO_2 storage	-	0,11	0,24	0,07	0,21	-	0,02	2,77	0,02	0,20
Energy savings	24,86	32,19	23,74	31,66	51,35	45,58	34,73	46,10	49,27	42,00
General energy research	22,21	40,20	12,97	14,96	21,01	72,81	61,73	73,03	69,02	118,87
Energy systems, modelling	4,48	12,02	7,87	2,46	5,37	4,53	4,33	3,13	3,33	3,35
Renewables (in genera)	14,45	13,38	18,09	28,28	35,83	13,50	15,34	15,96	11,94	21,61
Geothermal energy	1,27	8,41	8,86	11,27	12,52	8,43	8,09	2,09	4,70	3,53
Power station technology/ CCS	5,09	3,87	4,84	6,09	11,35	7,12	4,25	5,52	3,78	2,68
Photovoltaics	18,12	22,17	19,62	20,84	26,95	21,85	21,31	24,81	27,34	13,19
Wind energy	5,89	6,12	8,26	11,61	14,48	18,60	27,29	12,25	3,97	4,93
Electric mobility/ energy storage/grids	1,55	4,02	21,58	20,31	49,61					
Electric mobility						54,19	22,54	15,88	20,73	21,43
Energy storage						25,84	24,16	28,12	26,34	18,32
Grids						4,58	2,40	4,33	3,60	4,81
Total	**128,87**	**161,14**	**157,11**	**174,39**	**252,78**	**311,74**	**256,56**	**266,99**	**248,63**	**281,68**

1 Continued from 2018 with different classification, cf. Table 12

Table 12 | Spending on non-nuclear energy research by Land by research topic based on the IEA technology classification[1] from 2018

Group number[1]	Funding topic	Actual outlays in € million				
		2018	2019	2020	2021	2022
11	Energy efficiency in industry, trade and commerce	24.04	17.00	36.39	35.91	40.81
12	Energy efficiency in buildings and neighbourhoods	16.97	13.62	12.68	9.69	9.00
13	Energy efficiency in transport (incl. electric mobility)	29.39	43.72	50.63	55.71	58.55
14	Other energy efficiency measures	22.10	16.55	19.26	15.29	19.97
2	Thermal power plants/CO2 technologies	4.40	5.63	6.31	6.63	5.65
31	Renewable energy – solar thermal and PV	18.39	17.49	36.11	28.22	23.40
32	Renewable energy – wind energy	6.82	5.64	24.85	18.46	20.89
33	Renewable energy – marine energy	0.40	0.36	3.34	2.87	2.84
34	Renewable energy – bioenergy	10.86	9.54	21.96	13.74	15.54
35	Renewable energy – geothermal energy	6.55	5.74	9.79	10.15	14.67
36	Renewable energy – hydropower	0.95	0.44	3.42	5.10	8.56
37	Other sources of renewable energy	19.48	19.92	20.03	42.67	16.04
51	Hydrogen technologies	12.94	9.92	36.13	97.55	118.46
52	Fuel cells	6.49	10.47	20.70	18.44	29.47
62	Grids (electricity transmission and distribution)	6.43	11.06	9.12	9.92	21.39
63	Energy storage technologies	26.42	38.85	54.67	42.31	45.46
71	Energy system analysis/modelling	7.39	18.18	22.01	17.99	19.74
	Total	**220.04**	**244.12**	**387.37**	**430.64**	**470.43**

1 IEA technology classification, cf. https://www.iea.org/data-and-statistics/data-product/energy-technology-rd-and-d-budget-database-2#documentation