
Research funding for the energy transition

Research funding for the energy transition
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1. Research funding for the energy transition
1.1 The 7th Energy Research Programme of the Federal Government

1.1.1 Energy research in the shadow of the COVID-19 pandemic

The year 2020 was overshadowed by the COVID-19 pandemic. The restrictions required to stop the spread of the pandemic required research work to be replanned and the approach to be adjusted in some cases. Overall, flexibility and creativity made it possible to press ahead with research for the energy transition even in this exceptional year. Results of energy research have also been put to productive use in the context of the COVID-19 pandemic. Findings from projects on highly efficient heat insulation and thermal storage technology, for example, are beneficial when organising the transport of vaccines at very low temperatures. Energy research infrastructures in the field of ventilation technology have also been applied to COVID-19 research. This underlines the value of research and science for society, the applications of which are often not foreseeable.

Making available a broad range of solution options is also essential with regard to climate change, and this is the objective of research funding in the context of the 7th Energy Research Programme. Despite the current focus on the COVID-19 pandemic, it remains vital not to lose sight of the central long-term objectives of research for the energy transformation: to prepare the climate-neutral energy system of the future and in so doing to secure a reliable and affordable energy supply. Particularly for the Federal Republic of Germany as an industrial location, meeting this challenge is of key importance for long-term economic progress and prosperity in society.

Since as early as the 1970s, the Federal Government has been funding the development of new technologies and applications for a modern energy supply in its ongoing Energy Research Programmes. This funding included renewable energy technologies early on and laid the foundation for their success. The 7th Energy Research Programme, which has been under way since 2018, is aimed at comprehensively funding technical and non-technical innovations for the energy transition. Its main focus is on quickly getting innovations out of laboratories, testing rooms and the minds of scientists into energy-sector practice and society.

The adoption of a National Hydrogen Strategy in June 2020 further boosts the cross-sectoral energy transition. Research and development on hydrogen (H2) as an energy source is making a key contribution to achieving the National Hydrogen Strategy’s ambitious objectives. Initial energy research measures to implement the strategy started in 2020.

1.1.2 Development in funding

The 7th Energy Research Programme underlines the major significance of R&D for the success of the energy transition. Through public funding, the Federal Government supports extensive research activities by companies, research establishments, higher education institutions and other organisations in their endeavours to contribute to the success of the energy transition. At the same time, the structure for awarding funding underlines that the research, development and demonstration (RD&D) of energy and efficiency technologies is primarily a task for the private sector.

In 2020, the Federation invested €1.216 billion in energy research, an increase of approximately six percent compared with the previous year. Of that amount, project funding accounted for €750.62 million. In 2020, the Federal Ministries supported a total of 5,980 ongoing projects from tax revenues and approved 1,590 new projects. In the field of non-nuclear energy research, companies contribute co-payments totalling €303.6 mil-
1.1.3 Evaluations and performance review

Evaluations and performance reviews are valuable instruments to verify the efficient and effective use of tax revenues for funding measures. They also enable conclusions to be drawn for designing future measures with regard to their financial, administrative, strategic and contents-based orientation. Under the Federal Budget Code, the Federal Government has an obligation to carry out performance reviews of all the measures implemented. These are done by the ministries concerned. Evaluations support the performance reviews by the Federal Government and are carried out by external third parties.

An ongoing evaluation of the 7th Energy Research Programme was prepared in 2020 relating to the funding for applied energy research in line with the rules on state aid. Scheduled to start in 2021, its purpose is to look at the funding measures of the Federal Ministry for Economic Affairs and Energy in accordance with the funding announcement “Applied non-nuclear research funding in the 7th Energy Research Programme ‘Innovations for the Energy Transition’” and the Funding Guidelines on Living Labs for the Energy Transition. This ongoing evaluation is intended to verify the effectiveness of the funding formats in relation to the objectives of the 7th Energy Research Programme. The evaluation includes an economic efficiency assessment. The effects of funding on the different target groups will also be examined.
Figure 2: Overview of the ongoing (blue) and newly approved (green) projects of non-nuclear energy research in Germany

Source: GeoBasis-DE / BKG 2020 (data altered) / Geodata of the BKG for addresses of the implementing bodies from the BMBF profi-database / Projektträger Jülich
1. RESEARCH FUNDING FOR THE ENERGY TRANSITION

**€1.216 billion**

Total funding in the 7th Energy Research Programme in 2020 (previous year €1.148 billion)

In 2020 the Federation approved **1,590 new projects** (previous year 1,662)

The Federal Government funded **5,980 projects** in the 7th Energy Research Programme in 2020 (previous year 5,903)

**€303.6 million**

Funding from companies towards newly approved research and development projects in 2020 (non-nuclear energy research)

**€122.5 million**

Funding for SMEs for non-nuclear energy research projects newly approved in 2020 (based on German SME definition)

**Figure 3: Energy research funding at a glance**

**44 percent**

Rise in funding compared to 2014 and 6 percent rise compared to 2019

**Beneficiaries of newly approved projects in 2020 in percent**

- Research institutions: 25%
- Universities: 30%
- Large enterprises: 24%
- SME: 14%
- Other: 7%

**Disbursements in € million**

<table>
<thead>
<tr>
<th>Year</th>
<th>Disbursements</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>847</td>
</tr>
<tr>
<td>2015</td>
<td>909</td>
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<td>2019</td>
<td>1,148</td>
</tr>
<tr>
<td>2020</td>
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1.2 Structures of energy research policy

1.2.1 Asks of the federal ministries

The 7th Energy Research Programme is being implemented by the Federal Ministry for Economic Affairs and Energy (BMWi), the Federal Ministry of Education and Research (BMBF) and the Federal Ministry of Food and Agriculture (BMLF). The Federal Ministry for Economic Affairs and Energy is responsible for the programmatic orientation of energy research policy and represents the Federal Republic of Germany in European and international bodies working on energy research policy. The ambitious programme is based on an interministerial, thematically oriented structure and enhances the use of synergies in thematically oriented collaborations. It is subdivided into project funding and institutional funding.

The division of responsibilities for the project funding is in line with the concept of the technology readiness level (TRL) of the technologies and applications being researched. The TRL places the scientific and technical status of a technology on a scale from 1 to 9. The Federal Ministry of Education and Research funds application-oriented basic research projects that lay the foundation for future innovations. These correspond to TRLs 1 to 3. Also, the ministry supports young scientists, academic exchange and scientific cooperation at EU and international level via an intranet platform provided by Project Management Jülich. The Federal Ministry for Economic Affairs and Energy is responsible for funding applied R&D and Living Labs for the Energy Transition (TRLs 3 to 9), and has taken charge of the project funding of multilateral research collaborations at EU and international level. The Federal Ministry of Food and Agriculture funds applied research work on the energy use of biomass.

In the area of institutional funding, the Research and the Economic Affairs Ministries are jointly responsible for the strategic orientation of energy research by the Helmholtz Association. The Federal Ministry for Economic Affairs and Energy is responsible for the institutional funding of the German Aerospace Center (DLR), while the Federal Ministry of Education and Research is responsible for the institutional funding of the other participating Helmholtz Centres.

1.2.2 Coordination of energy research funding

The energy transition is a major task for society as a whole, and the combined effect of all measures and instruments is crucial to its success. For this reason, close coordination with the federal ministries responsible for heavily energy-dependent portfolios is particularly important. They include, for example, the Federal Ministry of Transport and Digital Infrastructure (BMVI), responsible for the energy-dependent portfolios of mobility and transport, and also cooperation with the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), responsible for climate protection. Close exchange is also essential beyond the federal level, particularly with the Länder and municipalities, but also with the energy sector, associations, and organisations representing society.

1.2.3 Networking at national level

Dialogue, exchange and networking are particularly crucial for the energy transition in all its complexity in order to bring together the many elements, development trajectories and dynamics of this major societal project.

Research and Innovation Platform (R&I Platform)

In the field of energy research, the Federal Ministry for Economic Affairs and Energy established the Energy Transition Research and Innovation Platform (R&I Platform), a forum for dialogue between policymakers, the business and scientific communities, and civil society. The platform facilitates dialogue on current developments in energy research and a discussion of new approaches for future strategies, as well as the dovetailing of research and
1. RESEARCH FUNDING FOR THE ENERGY TRANSITION

Programmatic approach to energy research policy

**BMWi lead agency**

Coordination with federal ministries

Coordination Platform for Energy Research Policy

Coordination with business and industry, the scientific community and society

Energy Transition Research and Innovation Platform

Coordination with state governments

Federal and State Government Dialogue on Energy Research Policy

International cooperation

EU, IEA, Mission Innovation, National Contact Point for Energy

Transparency

EnArgus information system, Federal Government Report on Energy Research

Project funding

- **BMBF**
  - TRL 1–3

- **BMWi**
  - TRL 3–9

- **BMEL**
  - TRL 3–7
  - Biomass

Institutional funding

- **BMWi**
  - HGF Research
  - DLR

- **BMBF**
  - Field Energy
  - HGF (without DLR)

Figure 4: Institutional setup for energy research
energy-sector practice. The members generally convene at an annual plenary session. The 8th meeting took place in February 2020. The platform also provides an overarching structure for the energy research networks, bringing them together and coordinating them. As well as hosting the R&I Platform, the Federal Ministry for Economic Affairs and Energy, as lead ministry for the energy transition, also discusses energy research questions with representatives of the 16 Land governments in regular talks between the Federation and the Länder.

Energy research networks

The energy research networks represent the broad research scene in the field of energy research in Germany and have established themselves as dialogue-oriented forums for exchange between research, politics, and industry. An important interface between research, practice and politics, they are supported by the Federal Ministry for Economic Affairs and Energy.

At present, there are nine research networks, focusing on the topics of bioenergy, construction for the energy transition (buildings and neighbourhoods), energy systems analysis, renewable energy, flexible energy conversion, industry and commerce, electricity grids, start-ups and hydrogen. The members jointly develop ideas to help translate research findings into energy-sector practice. The philosophy behind the networks is self-organised exchange in the form of joint events, webinars, working groups and opinion polls. They also offer the opportunity to address energy policy problems and participate in finding solutions.

The latest research network, devoted to hydrogen technology, took up its work in September 2020. The research network takes a broad thematic approach to supporting the Federal Government’s National Hydrogen Strategy (see Chapter 1.2.5, page 17). In autumn 2020, the network’s more than 1,000 members participated in the consultation process to prepare a call by the Federal Ministry for Economic Affairs and Energy for funding applications relating to hydrogen technologies, which the ministry published in December 2020.

Furthermore, within the energy research networks that had already been established, many activities also took place in the various working groups in 2020. Increasingly, such activities are also taking place across networks, thereby promoting cross-sector and cross-technology dialogue as a central component of networked energy research. In December 2020, for example, the networks on construction for the energy transition and bioenergy held a joint digital expert conference on the systematic integration of bioenergy and other renewable energy sources in buildings and neighbourhoods. Due to the COVID-19 pandemic, this exchange has largely shifted into digital space, but the members have been able to continue to deepen their cooperation, not least via an intranet platform provided by Project Management Jülich.

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 German Academy of Sciences Leopoldina and the Union of the Academies provide impulses for the debate on the challenges and opportunities of the German energy transition. In the ESYS project, more than 120 experts are developing options for action to implement a secure, affordable and sustainable energy supply. Thus, in 2020, opinions concerning the energy transition in Europe, central and decentralised elements in the energy system, energy source pricing, and efficient and effective grid bottleneck management were prepared and put up for discussion.
1.2.4 Living Labs for the Energy Transition

Living labs are becoming increasingly important as testing rooms for new developments and technologies in Germany as a hub of innovation. That applies also and particularly to the restructuring of the energy supply. By means of Living Labs for the Energy Transition, the Federal Ministry for Economic Affairs and Energy therefore anchored a strong funding instrument in the 7th Energy Research Programme to help innovations make the leap from lab to real life. They close the gap between the triad of basic research, applied research and energy-sector practice, transferring findings from laboratory research to practical applications. Only if new technologies and systems can make this leap can they ultimately contribute to the success of the energy transition. Living Labs for the Energy Transition provide blueprints to make this possible within a defined framework.

The year 2000 saw the launch of four Living Labs for the Energy Transition. Back in January, work began on SmartQuart, which in December 2019 was the first Living Lab for the Energy Transition to receive approval from the Federal Ministry for Economic Affairs and Energy. The project involves smart, energy-optimised neighbourhoods and aims to achieve a climate-neutral energy supply in three selected model regions. The aim of the IW3 project Integrated HeatTransition Wilhelmsburg, a real-world laboratory launched in August 2020, is to demonstrate that a reliable and affordable heat supply can be achieved using renewable energy. Since August 2020, the Living Lab “WESTKÜSTE 100” (see project abstract, page 16) has been dedicated to using hydrogen from wind turbines to make companies’ industrial processes more environmentally friendly. Finally, the Living Lab TransUrban.NRW addresses structural change in coal-mining regions of North Rhine-Westphalia. In the long-term, the partners are aiming to replace the traditional, partly coal-based district heating by low-carbon heating and cooling in four neighbourhoods.

In spring 2020, the Federal Ministry for Economic Affairs and Energy launched an ideas competition for scientific transfer research into Living Labs for the Energy Transition, focusing on sector coupling and hydrogen technologies. The aim is overarching evidence synthesis, focusing on systems analysis
1. RESEARCH FUNDING FOR THE ENERGY TRANSITION

WESTKÜSTE100 – Supply-chain-oriented energy transition meets decarbonisation of industry

WESTKÜSTE100 is a Living Lab for the Energy Transition of the Federal Ministry for Economic Affairs and Energy. The living lab and other projects under the ENTREE100 initiative are intended to establish a blueprint for a climate-friendly business location and an integrated energy transition. As well as cross-industry sector coupling, WESTKÜSTE100 is also looking at industrial decarbonisation.

The team aims to model and scale a regional industrial-scale hydrogen economy and has selected the western coast of Schleswig-Holstein to do so. This region has many wind turbines and offers suitable geological storage options. WESTKÜSTE100 aims to use wind energy to generate green hydrogen, thereby making local companies’ industrial processes more environmentally friendly. To this end, the research alliance is installing a 30-megawatt electrolysis plant, aiming to gain valuable insights for the next scaling step from its operation, maintenance, control and grid-friendliness. Additionally, there is a model grid to transport the hydrogen from intermediate storage via a hydrogen pipeline to an off-motorway service area and Heide’s public utilities. There, the hydrogen is fed into the existing natural gas grid for the heat supply. In addition, a feasibility study is to evaluate the use of unavoidable CO2 from regional cement production for the manufacture of climate-friendly aviation fuel at a refinery. The consortium is also drawing up operational and business models and recommendations for the further development of the regulatory framework. Studies of socio-economic parameters will also be carried out to increase the acceptance of hydrogen.

Beneficiaries: Raffinerie Heide GmbH and nine other partners
Funding ID: 03EWR009A-L
Estimated funding: €30 million
Project duration: 2020 – 2025
work. Innovations from Living Labs for the Energy Transition are to gain faster market entry by evaluating findings across projects. A total of eleven consortia have applied. The transfer research will begin in spring 2021.

1.2.5 Research for the innovative leaps of tomorrow

The energy transition is a long-term task. Basic research is therefore just as important as supporting the market uptake and application of technologies with a high level of maturity. Basic research lays the foundation for the innovations of tomorrow and beyond.

The funding by the Federal Ministry of Education and Research is consistently oriented to linking basic research with the challenges of industry, thereby accelerating the process from research idea to marketable innovation. The Kopernikus projects on energy transition are exemplary of this approach. In concerted action by research, the private sector and civil society, four major long-term projects are working on the key areas of the energy transition. In the Copernicus Ariadne Project (see project abstract in Chapter 2.4.5 Energy transition and society, page 57), which was launched in 2020, the initiative is further developing social science energy research and systemic energy research.

1.2.6 Transparency and communications

The energy transformation penetrates all areas of social interaction, from public infrastructure to everyday professional life and citizens’ private living environments. Responsible energy policy not only has the task of helping innovations on their way to becoming practical applications through research funding, but also of supporting the development of these new technologies, systems and solutions through transparent research communications. In this way, research communications support the practical application of innovations through providing the scientific community and energy industry with the relevant specialist information, while at the same time providing the general public with comprehensive information on current research questions, progress and development trends.

The website [www.energieforschung.de](http://www.energieforschung.de), implemented by Project Management Jülich on behalf of the Federal Ministry for Economic Affairs and Energy, is a central source of information on the objectives, structure and key issues of energy research policy and current funding opportunities. Four specialist portals, also implemented by Project Management Jülich, provide in-depth insights into project funding and research projects in the individual funding priorities.

EnArgus ([www.enargus.de](http://www.enargus.de)) is the central information system on the subject of energy research funding. The web-based portal gives an overview of the research projects in the field of energy which receive public funding from the Federal Government and provides information on technologies and specialist terminology. Since November 2020, EnArgus has also been available in English.
2. Project funding
2. PROJECT FUNDING

2.1 Energy transition in the consumption sectors

2.1.1 Energy in buildings and neighbourhoods

Under the Federal Climate Change Act (Bundes- Klimaschutzgesetz, KSG), which was adopted in 2019, only 70 million tonnes of CO₂ may be emitted by the building sector in the year 2030. That represents a reduction of 67 percent in comparison with 1990. The target of climate neutrality is to be reached by 2050. Building sector emissions are caused by the combustion of the fossil fuels oil and natural gas to provide room heating and hot water. The Federal Climate Change Act allocates greenhouse gas emissions from electrical power applications in buildings (electric heating, pumps etc.) and from the heat network supply to the energy sector.

For energy research, the long-term goal of climate neutrality in all sectors is the crucial benchmark. That means that solutions have to be found not only to do without fossil fuels in buildings, but also to avoid emissions arising when constructing buildings and manufacturing building technologies (grey energy). In 2050, the supply of buildings and neighbourhoods with energy using heat and power grids and climate-neutral energy sources must be emission-free. The less energy required, the easier that will be. Overall, a holistic approach is being taken that includes social and societal aspects.

Funding priorities and scientific advances

When developing technologies and concepts in the building and neighbourhood sector, users’ needs are always taken into consideration. At building level, optimised restoration and modernisation measures and the further development of construction materials and building technology play an important role. Individual buildings and ensembles are analysed, as well as interfaces with neighbouring buildings and the neighbourhood.

Systematic interaction of buildings, neighbourhoods and energy infrastructure is gaining importance. Buildings and neighbourhoods comprise a growing share of the needs-based, decentralised supply of heating, cooling and electricity. Appropriate grids and energy management infrastructure

Figure 5: Funding for energy efficiency in buildings, neighbourhoods and urban areas in € million (Data cf. Table 2, p. 87)
are needed so that local and district heating can be delivered in an energy-efficient manner. Smart, digital solutions play an important role in current research funding.

January 2020 saw the start of research work by SmartQuart, the first Living Lab for the Energy Transition. A decentralised, sustainable and economic energy supply will be implemented within and between neighbourhoods at three sites featuring different structures. To this end, the key local stakeholders are being brought together, from residents to energy suppliers and local technology providers.

TransUrban.NRW, the second Living Lab for the Energy Transition, was launched in May 2020. The aim of the project is to replace the traditional, partly coal-based district heating by a more climate-friendly infrastructure. In each case, the results can be transferred to locations in Germany with similar structures.

In its City of the Future Flagship Initiative and its many funding activities, the Federal Ministry of Education and Research is supporting municipalities in very practical ways to shape sustainable change constructively and effectively, with energy topics playing a key role. A project initiated in 2020, for example, extends the geographic scope of the predecessor project’s planning basis for an urban logistics tool while forging ahead with practical implementation of the results obtained so far.

“Solar-powered Buildings/Energy-efficient Cities”, an initiative jointly funded by the Economic Affairs and Research Ministries, addresses many topics of relevance to the energy transition in urban areas, for example the use of locally produced green hydrogen as a neighbourhood energy store.

Project funding

In the field of energy in buildings and neighbourhoods, the Economic Affairs and Research Ministries provided approximately €103.16 million in funding for 948 ongoing projects in 2020. In addition, the ministries approved approximately €127.16 million in funding for 220 new research projects in 2020 (cf. figure 5).
ODH@Jülich – Open data based planning tools for cross-sector energy supply in the neighbourhoods using open, integrated ICT ecosystems

The energy transition is creating increasingly meshed infrastructures in the energy, heat and mobility sectors. The exchange of energy between them offers many opportunities for the sustainable, carbon dioxide-neutral reconstruction of the energy system, and thus also for neighbourhood heat generation. As a neutral platform, the Open District Hub (ODH) makes a valuable contribution in this area by promoting exchange and cooperation between companies from the energy and housing sectors and research. Its objective is to join forces to promote the smart supply of neighbourhoods with locally-generated, renewable energy, which requires comprehensive models and modern tools for the operation of technical installations. Linking the sectors creates a complex system with strong interactions and feedback. The ODH@Jülich project is developing a planning and simulation tool for this system that is open to all users, integrates all sectors, and facilitates decisions on supply system investments. Through its publicly accessible platform, the project provides support to actors such as the Open District Hub to make the energy transition a success in neighbourhoods.

**Beneficiaries:** Fraunhofer Society for the Promotion of Applied Research with six institutes  
**Funding ID:** 03SF0608  
**Estimated funding:** €7.5 million  
**Project duration:** 2020 – 2025
2. PROJECT FUNDING

**Arkol – Development of architecturally highly integrated façade collectors with heat pipes**

A research consortium headed by the Fraunhofer Institute for Solar Energy Systems ISE has developed two types of solar collectors that can be integrated into transparent and opaque building envelopes. As a result, façade areas can now be better utilised to generate heat. The solar thermal venetian blinds can serve both to supply heat and to provide sun protection. They are installed between panes of glass, for example in double façades. The heat is transported via heat pipes. This is also the case in the second development, solar thermal strip collectors. The collectors are mounted on a rear-ventilated curtain façade. The technology, in combination with the “dry” thermal coupling of the heat pipe, enables the strip collectors to be supplied in varying lengths and to be positioned on the substructure using a stepless connector system. The development of the solar thermal venetian blinds received recognition from the International Energy Agency (IEA) as one of the best Today in the Lab - Tomorrow in Energy? projects. The follow-up project DESTINI started in 2020. It will further develop the solar thermal venetian blinds. A follow-up project on the strip collector is being planned.

**Beneficiaries:** Fraunhofer Institute for Solar Energy Systems ISE and four other partners  
**Funding ID:** 032857 A–C  
**Estimated funding:** €2.1 million  
**Project duration:** 2016 – 2020

**WPUQ – Energy-Efficient Cities (EnEff:Stadt) project: Wind-solar-heat pump neighbourhood-heat pumps operated using renewable energy to minimise primary energy needs**

Use of primary energy can be cut by more than half using compression heating pumps for neighbourhood heating. The prerequisite for this is that the deployment of the neighbourhood facilities is optimally controlled. On the basis of two neighbourhoods near Hameln and Augsburg, the researchers are aiming to show that this is possible. As large a share as possible of the electric energy required to drive the heat pumps is to come from renewable energy sources. Such sources include local photovoltaic systems placed on individual buildings, and wind turbines. Prediction models are to be used to match users’ needs and the supply of renewable energy as economically as possible. Directed by the Institute for Solar Energy Research, researchers are examining which operational strategies could enable optimal values to be attained. At the end of the project, the researchers will provide a practical planning aid to support experts in planning and operating existing and new neighbourhoods using heat pump energy.

**Beneficiaries:** Institute for Solar Energy Research and three other partners  
**Funding ID:** 03ET1444A-D  
**Estimated funding:** €1.3 million  
**Project duration:** 2017 – 2021
2. PROJECT FUNDING

2.1.2 Energy efficiency in industry, commerce, trade and services

In Germany, the industrial sector accounts for around one-third of final energy consumption. Trade, commerce and services use around 15 percent, approximately half of final energy consumption. Germany’s energy requirements are largely met by natural gas, electricity and oil, as well as coal in the industrial sector. Electricity in particular is assuming an ever more important role as more industrial processes are electrified. Depending on the region, increasing use is also being made of renewable energy. Industry reduced its energy consumption by four percent in 2019 in comparison with previous years.

Funding priorities and scientific advances

Process heat accounts for approximately two-thirds of industry’s energy needs, while mechanical energy used for machine and motor operation accounts for a further quarter. Much of the energy used here is lost in the form of waste heat. Companies and scientists therefore have the task of developing energy-efficient solutions. They can harness the waste energy produced for other industrial processes and for heating, for example, or energetically optimise a process while maintaining product quality.

This may involve individual plants or machine components, but primarily it involves entire value chains, from the raw material to the finished product. Good planning is important, with the help of research. Ideally, flexible and digitally networked processes help companies to save costs and become more competitive. If the industrial sector can increase its energy efficiency and make greater use of new energy sources, such as waste heat, power from renewable energy sources and green hydrogen, it will contribute to a climate-neutral future.

To achieve this objective, policymakers are supporting diverse research topics in the industrial sector. These include waste heat and industrial heat storage units, chemical process technology, the carbon circular economy, iron and steel, manufacturing technology, high-temperature superconductivity, artificial intelligence and sensor technology,

Figure 6: Funding for energy efficiency in industry, commerce, trade and services in € million
(Data cf. Table 2, p. 87)
material and resource efficiency, tribology (friction, lubrication, wear-and-tear), heating and cooling technologies, and water technologies.

The Federal Ministry of Education and Research is funding the SynErgie consortium as part of its funding initiative Kopernikus Projects for the Energy Transition. The consortium demonstrates how industry can compensate for fluctuations in renewable energy generation by adapting its production processes’ power consumption. It also shows short-term and long-term options for changing the regulatory system to promote flexible energy consumption in the design of the energy market. In 2020, the project published an online tool enabling companies to quickly and simply establish their potential for energy-flexible production.

Project funding

In the field of industry, commerce, trade and services, the Economic Affairs and Research Ministries provided approximately €64.88 million in funding for 706 ongoing projects in 2020. In addition, the ministries approved approximately €67.77 million in funding for 134 new research projects in 2020 (cf. figure 6).

**PROJECT ABSTRACT**

**MPS – Modular production lines for specialty chemicals**

In the MPS research project, scientists are developing a modular and intelligently-networked overall system for the production of specialty chemicals as a model project on a realistic scale and under real conditions. The project is part of the ENPRO research initiative and applies the results of previous laboratory research projects within a production environment. Partial solutions for modular production, such as those achieved in ESIMEM, Mi2Pro, Skampi, TeiA and ORCA, are being applied to the pioneering Darmstadt plant for the chemicals factory of the future and are being successfully integrated. Using a modular production plant, products currently produced in batch processes can be converted to continuous operation with potential energy savings of approximately 30 percent in comparison with current state-of-the-art technology. Modular plants can simply integrate cutting-edge technologies into existing processes to achieve the greatest possible efficiency and quality in product manufacturing. The objective of this research and development is to increase energy efficiency under market conditions and accelerate process and production plant development by means of reusable standard modules.

**Beneficiary:** MERCK KGaA  
**Funding ID:** 03EN2059A  
**Estimated funding:** €3.45 million  
**Project duration:** 2020 – 2023
2. PROJECT FUNDING

2.1.3 Interfaces between energy research and mobility and transport

The share of renewable energy sources in the transport sector is still less than six percent. Diverse solutions are required to make progress in this area – in individual and heavy goods transport, over long and short distances by road, sea and air. As traffic volume continues to increase, a whole range of innovative drive technologies are needed to promote decarbonisation: electromobility, hydrogen/fuel cell technology, electricity-based fuels and biofuels. The different options supplement one another in this process. While electromobility is at a clear advantage, particularly for cars, hydrogen and alternative fuels are a suitable decarbonisation solution for shipping, heavy goods traffic and aviation, according to the latest research findings.

Funding priorities and scientific advances

Hydrogen plays a key role in alternative drive technologies and also in technologies using synthetic electricity-based fuels. Green hydrogen can be produced by water electrolysis using wind and solar energy or by means of thermochemical processes. In further steps, hydrogen can be used to produce liquid or gaseous fuels.

In the “Energy transition in the transport sector” initiative funded by the Federal Ministry for Economic Affairs and Energy, 15 technical research associations focus on the production and use of such electricity-based fuels. This is a cross-programme measure. Depending on the research priority, the Federal Ministry for Economic Affairs and Energy funds projects either within the framework of the 7th Energy Research Programme of the

ENKRIST – Energy savings resulting from improved carbide and nitride semiconductor crystal production

Switching transformers enable complex functions in areas ranging from industry to household appliances, for example in smart motors and wireless charging devices. Novel circuit breakers are deposited on substrates made from particularly suitable wide-bandgap (WBG) semiconductors. Based on gallium nitride (GaN) and silicon carbide (SiC), they have fewer defects than other semiconductors, enabling higher switching frequencies and operating temperatures. They are robust in tough environments and offer high breakthrough voltages. Growing crystals for WBG semiconductors is very energy and cost-intensive as all the processes involved are carried out at high temperatures. The ENKRIST research project has optimised the process chains’ energy performance, improved quality and increased the length of the crystals. In the SiC crystal-growing process, ENKRIST has succeeded in doubling the length and yield of high-quality crystals as well as reducing energy consumption by 37 percent. In the case of GaN crystals, the energy expenditure was reduced to approximately ten percent of the baseline value. This enables the costs of substrate to be significantly reduced. The improved crystals have been demonstrated and will now realise their great energy-saving potential in new, innovative, high-performances construction elements.

Beneficiaries: Fraunhofer Institute for Integrated Systems and Device Technology IISB and three other partners

Funding ID: 03ET1398A-D

Estimated funding: €3.12 million

Project duration: 2016 – 2020
Federal Government, the “New vehicle and systems technologies” programme, or the ministry’s Maritime Research Programme. In the activities accompanying this funding initiative, the Federal Ministry of Education and Research is funding the measure “Sustainable mobility through synthetic fuels” (NAMOSYN), which is also part of the Federal Government’s Climate Action Programme. Mid-way through the initiative, the research alliances presented their intermediary results at the status conference in 2020 (see project abstract MethQuest). And together with the technically oriented projects, the associated accompanying research has developed methods that could enable comparison of the potential production costs of different prospective fuels.

As well as electricity-based fuels, biofuels also offer options for sustainable mobility. In 2020, the first five projects funded by the Federal Ministry for Economic Affairs and Energy took up their work in this area. The PyroMar project, for example, focuses on possibilities for a maritime energy transition (see project abstract, page 36).

The ministry’s approach of providing systemic and also market-oriented funding is not only helping to make the transport sector more energy-efficient, climate and environmentally compatible, but is also helping to harness new, regenerative energy sources, thereby reducing dependence on fossil fuels.

Electromobility offers the potential to transfer the successful decarbonisation of the electricity sector to the transport sector. Researchers in the field of battery technology are focusing primarily on battery material with a view to improving batteries’ energy density, lifetime and price-performance ratio. Another issue is grid-friendliness. In the future, bidirectional charging possibilities could stabilise the power grid. Similarly, stationary fuel cells can provide electricity and heat as required, and can enable freight and long-haul vehicles to be powered by climate-neutral green hydrogen. Other major research topics are environmental compatibility, resilient value chains, more flexible production processes, subsequent use and recycling.
The National Innovation Programme on Hydrogen and Fuel Cell Technology (NIP) and the research activities of the Federal Ministry of Transport and Digital Infrastructure into alternative drive technologies and fuels provide key impetus in the mobility sector (see Chapter 5.1, page 82).

Project funding

In the field of energy research at the interface of mobility and transport, the Research and Economic Affairs Ministries provided approximately €41.87 million in funding for 303 ongoing projects in 2020. In addition, the ministries approved approximately €24.57 million in funding for 60 new research projects in 2020 (cf. figure 7, page 27).

**PROJECT ABSTRACT**

**MethQuest – Methane-based fuels from renewable energy sources for mobile and stationary applications**

Methane-based fuels produced from renewable energy sources (power-to-gas) can help reduce CO2 and pollutant emissions. They can be used in CHP plants, flexible gas power stations and, in compressed or liquefied form, for car, truck and shipping traffic. The MethQuest project is developing and optimising production processes and engine concepts for this purpose. The team anticipates findings for proton exchange membrane (PEM), high-temperature and seawater electrolysis, the provision of CO2 and methanisation. The partners are also examining optimised engines for renewable fuels in cars, ships and for power generation, and are developing solutions for coupling electricity, gas and heat infrastructures, taking the inland port of Karlsruhe as a case study. They also aim to understand the climate impact and economic and ecological benefit of introducing renewable methane on a large scale. Key interfaces and synergies will be comprehensively analysed, also with regard to efficiency, cost and medium and long-term transformation processes. To this end, the team is extensively coupling different partial models of the German energy system. By taking an interdisciplinary, holistic approach, the team’s overall aim is to make technological progress along the value chain, from carbon-neutral gas production and the required infrastructure to the final application.

**Beneficiaries:** MTU Friedrichshafen and the DVGW Research Centre at the Engler-Bunte-Institute at Karlsruhe Institute of Technology (KIT) and 27 other partners

**Funding ID:** 03EIV041A-I; 19I18010A-G; 03EIV043A-B; 03EIV044A-E; 03EIV045A-F; 03EIV046A-D

**Estimated funding:** €18 million

**Project duration:** 2018 – 2021
DaLion - 4.0 – Data mining as a basis for cyber-physical systems in the production of lithium-ion battery cells

The DaLion - 4.0 project models battery cell production in cyber-physical systems. In the DaLion predecessor project, researchers analysed large amounts of target data and parameters relating to battery cell production. They are now using these to develop a “digital twin”. Huge amounts of data obtained using modern sensors and data mining converge in a data warehouse. They allow analysis of costs, environmental impact and other product features. Using novel measurement technology not only enables diverse processes to be controlled; extensive data acquisition (and models derived from it, in some cases automatically) enables specific process improvements to be deduced, simulated in a digital twin and immediately applied to actual production. That has already been demonstrated by the project partners from the scientific community and industry at the Battery Lab Braunschweig (BLB). In future, this will make cell production significantly more flexible and will further optimise it from environmental and cost points of view, a major step towards Industry 4.0.

Beneficiaries: Technische Universität Braunschweig – Battery Lab Braunschweig (BLB) and six other partners
Funding ID: 03ETE017A-G
Estimated funding: €5.6 million
Project duration: 2019 – 2021

DEKADE German-Canadian Fuel Cell Cooperation – Low-platinum catalyst systems, electrodes and membrane-electrode units for fuel cell drive

To be viable on the market, fuel cell drives must be able to compete with combustion engines, particularly in terms of cost and durability. Estimates indicate that the cost of series-relevant quantities of fuel cell stacks is largely determined by their precious metal or platinum content. Platinum is used in PEM fuel cell catalysts. Platinum-free catalysts do exist, but they do not have the desired performance and stability and are thus currently unsuitable for the automotive industry.

In the DEKADE research project “Diagnosis and Development of Components for Automotive Fuel Cells”, which is being coordinated by the Fraunhofer Institute for Solar Energy Systems ISE, scientists have been developing innovative low-platinum catalyst systems, electrodes and membrane-electrode units since 2017. They are also devising a model to describe membrane-electrode units. In 2020, the Fraunhofer ISE won the f-cell award in the Research & Development category. The prize distinguished the work of the DEKADE cooperation on the development of flat-bed screen printing as an industrially scalable manufacturing process for fuel cell electrodes.

Beneficiaries: Fraunhofer Institute for Solar Energy Systems ISE and two other partners
Funding ID: 03SF0544
Estimated funding: €4.2 million
Project duration: 2017 – 2020

In order to be viable on the market, fuel cell drives must be able to compete with combustion engines long-term, particularly in terms of cost and durability.
2.2 Energy generation

2.2.1 Photovoltaics

In energy generation, photovoltaics is increasingly becoming a supporting pillar of the energy transition. This is reflected in the increasing expansion figures forecast by the International Energy Agency (IEA). The IEA presented its current World Energy Outlook in October 2020. According to the outlook, renewable energy sources, primarily photovoltaics, will contribute a total of 80 percent of energy needs by 2030. The report explains this by quoting the falling energy generation costs of photovoltaics. These costs are often lower than the cost of generating power at new coal and gas power plants.

Funding priorities and scientific advances

The energy research networks set up by the Federal Ministry for Economic Affairs and Energy have established themselves as a platform for dialogue between research, politics and industry. In December 2020, in the context of dynamic market development, members of the Renewable Energy Research Network launched a consultation process on photovoltaics to identify current research needs in this area. The basic aim is to improve the integration of photovoltaics in energy systems through R&D projects and to further reduce electricity generation costs.

A focus of research needs is on technological innovations in the area of new materials, such as perovskite, and new structures, such as tandem cells or selective contacts. Global champions have established their development and have set up pilot production facilities in Germany. A relatively new material in solar cell technology, perovskites are undergoing rapid development. In early 2020, teams of scientists at the Helmholtz Centre Berlin (HZB) developed a tandem solar cell from perovskite and silicon that achieves an efficiency rate of 29.15 percent, setting a new world record for this cell structure.

Innovations are also anticipated in manufacturing technologies in the years ahead, which will reach the production stage through plant construction. This will be achieved by digitalisation and Industry 4.0 concepts, with new process technologies also

Figure 8: Funding for photovoltaics in € million (Data cf. Table 3, p. 88)
playing a key role. These include kerfless wafering technology, an alternative wafer manufacturing technique. In comparison with conventional wafer production, this technique uses less energy while producing less waste. The newly developed kerfless wafers can thus be produced at high quality and low cost. Finally, the consultation process will also underline the significance of the topics of quality assurance, sector coupling, system integration and circular economy for photovoltaics.

Building-integrated photovoltaics (featuring solar modules on building façades) and electromobility (with solar modules on electric vehicles) are relevant growth areas. Also in the field of floating PV power plants, research projects are being intensified that enable solar energy to be generated, for example in converted areas such as former open-cast mining lakes.

Project funding
In the field of photovoltaics, the Economic Affairs and Research Ministries provided approximately €86.19 million in funding for 485 ongoing projects in 2020. In addition, the ministries approved approximately €65.70 million in funding for 116 new research projects in 2020 (cf. figure 8).

### PROJECT ABSTRACT

**P³T – Perovskite-POLO-PERC tandem solar cells and modules**

Tandem solar cells – in contrast to the majority of solar cells in commercial use today – consist of two subcells with different, light-absorbing layers arranged on top of one another. These absorber layers combine different semiconductor materials that absorb different wavelength ranges of the entering sunlight in the stacked arrangement of tandem cells. As a result, tandem solar cells use the sunlight spectrum more efficiently, and, in theory, achieve higher levels of efficiency. This is what P³T is about. In this research project, the research team is aiming to develop highly-efficient, large-area perovskite-silicon tandem solar cells. Based on established PERC silicon solar cell technology, these tandem solar cells are to be developed as a drop-in upgrade and integrated into demonstration modules. Within the project, work will be done in key fields of research with a view to achieving the industry maturity of perovskite-silicon tandem solar cell modules. In early 2020, the Helmholtz Zentrum Berlin developed a tandem solar cell made of perovskite and silicon that converts 29.15 percent of the incident light into electrical energy, a new record.

**Beneficiaries:** Helmholtz-Zentrum Berlin für Materialien und Energie and five other partners  
**Funding ID:** 03EE1017A-G  
**Estimated funding:** €3.6 million  
**Project duration:** 2019 – 2022
Wind energy plays a key role in making the energy transition a success. It accounts for the largest share of electricity generation from renewables and, in 2020, was used to produce significantly more power than in the preceding year, setting another annual record. Specifically, electricity generation from wind energy reached a new record level of approximately 131 terawatt hours (TWh) in 2020. This compares with approximately 126 TWh in the previous year. Thus, wind energy generation increased by four percent compared with the previous year. The record in February was particularly remarkable. At 20 TWh, the previous record of March 2019 (15.5 TWh) was significantly surpassed.

Funding priorities and scientific advances

The aim of research funding is to further reduce the cost of producing electricity from wind energy and to increase the reliability of the turbines. The funding is to help ensure that future generations of wind turbines become more efficient, more reliable and produce a higher number of full-load hours.

Alongside the turbines’ location, turbine engineering is also a key factor that determines their cost. When designing wind turbines, it is particularly important to take a holistic approach. Right from the design phase, it is crucial to take into account what the total costs of production, construction, operation, dismantling and recycling will be and

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**Standard building-integrated photovoltaics (BIPV) system – Development of standardised BIPV construction elements with integrated system technology**

Building-integrated photovoltaics (BIPV) generates electricity without the need for additional space and is at the same time an aesthetically appealing element of the building envelope. Such systems promote the social acceptance of photovoltaics since the use of structures that already exist or would be built in urban spaces in any case not only avoids land sealing, but also offers solar energy generation close to the point of use.

The team of researchers working on the standard BIPV system project are pursuing two goals. Firstly, plug & power BIPV building elements are being developed with integrated electric systems technology that can be cost-effectively manufactured, simply included in construction planning, and easily installed in the building envelope. Secondly, a study is being carried out on the potential of BIPV for solar energy use. This analysis classifies the areas on existing buildings in Germany that are technically and economically suitable for BIPV use, comprising areas on the roofs and façades of residential, commercial and industrial buildings. The current project takes up findings of the predecessor project Standard BIPV, in which analysis of BIPV area potential began and standardised lightweight PV modules were designed.

**Beneficiaries:** Fraunhofer Institute for Solar Energy Systems ISE and six other partners

**Funding ID:** 03EE1061A-G

**Estimated funding:** €2.1 million

**Project duration:** 2020 – 2023

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2.2.2 Wind energy

Wind energy plays a key role in making the energy transition a success. It accounts for the largest share of electricity generation from renewables and, in 2020, was used to produce significantly more power than in the preceding year, setting another annual record. Specifically, electricity generation from wind energy reached a new record level of approximately 131 terawatt hours (TWh) in 2020. This compares with approximately 126 TWh in the previous year. Thus, wind energy generation increased by four percent compared with the previous year. The record in February was particularly remarkable. At 20 TWh, the previous record of March 2019 (15.5 TWh) was significantly surpassed.
how the wind turbines/wind farms can be integrated into the electricity grid. Wind turbines and wind farms need to be operated flexibly using smart technology. Advanced operation management strategies can improve the yield or extend the turbines’ service life. If forecasts are made more accurate, electricity generation can be predicted with greater precision, helping to ensure the security of supply.

The number of easily accessible windy sites for further expansion of wind energy is declining. This is why wind turbines are increasingly being erected in complex terrain. It is therefore vital to use suitable methods to select potential sites and to explore these sites over a considerable period of time using the most economical methods possible.

As modern wind turbines become increasingly larger, more and more construction elements are reaching the limits of their material strength. It is therefore vital to use new materials in order to reduce weight or increase reliability etc., so that wind turbines can be made and operated efficiently and at low cost. At the same time, increasing attention is being given to questions of closed-loop recyclability.

When it comes to the operation of offshore wind farms, logistics and maintenance represent major challenges. The accessibility of the turbines is the key to their economic efficiency, since offshore wind turbines are very difficult and expensive to reach in the event of malfunction. This is why it is important to have innovative grid connection and logistics concepts in place that take into account plant accessibility, the transportation of personnel and material, pooling concepts, and operation and maintenance plans.

**Project funding**

In the field of wind energy, the Federal Ministry for Economic Affairs and Energy provided approximately €76.06 million in funding for a total of 488 ongoing projects in 2020. In addition, the ministry approved approximately €65.32 million in funding for 99 new research projects in 2020 (cf. figure 9).
2. PROJECT FUNDING

X-Wakes – How offshore wind farms change wind conditions

In the X-Wakes research project, scientists are investigating how wind conditions in the German Bight change when large-scale offshore wind farms are built. As the energy supply increasingly shifts towards renewable energy sources, harnessing offshore wind energy is becoming more important. Offshore winds are steadier and smoother than onshore winds. There is only limited space available, however, which is why wind farms are usually set up in clusters. Such clusters can comprise several hundred wind turbines. Wakes with low wind speeds and considerable turbulence develop in the wind shadow behind the turbines. As a result, turbines towards the back generate less energy and are more strongly affected by turbulence.

The researchers use a wide range of different methods for their investigations: fixed measurement equipment on the wind turbines, on the FINO1 research platform and on converter stations continuously transfer meteorological data, and a research aircraft selectively recollects them. The extent of the wakes is analysed on a large scale with the aid of satellite-based data. The measured data are used to improve and further develop models for planning offshore wind farms. The research outcomes from the project are to help optimise wind farms which are currently being constructed and make planning easier for new ones. In future, offshore wind turbines can then be appropriately positioned and operated to be able to achieve the optimum wind energy yield.

Beneficiaries: Fraunhofer Institute for Wind Energy Systems IWES and six other partners
Funding ID: 03EE3008A-G
Estimated funding: €3.4 million
Project duration: 2019 – 2022

A research aircraft provides high-resolution meteorological data which can be used to precisely analyse the wind conditions in offshore wind farms.
2. PROJECT FUNDING

2.2.3 Bioenergy

Bioenergy can be used flexibly and, in particular, is available irrespective of the weather conditions, time of day, or time of year. It therefore continues to play an indispensable role in the renewable energy sector. It currently accounts for nearly two-thirds of the total production of renewable energy in Germany, which is due in particular to its extensive use in the transport and heating sectors, where it has shares of 90 percent and 86 percent respectively. Nevertheless, biomass accounts for only 7.6 percent of the total primary energy supply. Research funding can make an important contribution to ensuring that the continuous potential of bioenergy is utilised in an efficient manner and in a way that serves the energy system as a whole.

Funding priorities and scientific advances

The German Biomass Research Centre (DBFZ) has been making key contributions to research since 2008. The Centre conducts applied R&D on the use of energy carriers and integrated materials as regenerative raw materials in the bioeconomy. In this work, it places a special focus on the use of innovative technologies and on the economic and environmental effects of the materials being studied. One of the objectives in this work is to increase the contribution that biomass makes to the energy system by developing sustainable bioenergy strategies, evaluating biomass utilisation concepts and investigating the efficiency and sustainability of biomass use. In addition, the Centre is developing various processes to convert biomass as a raw material into biofuels and chemical sources of bioenergy. It is also carrying out noteworthy work in the field of smart biomass heating technologies (SmartBiomassHeat) and on the catalytic reduction of emissions in combustion equipment for gaseous, liquid and solid bioenergy carriers using solid catalysts.

The Federal Government has included the use of biogenic residual and waste materials as energy sources in its Energy Research Programme since

SeeOff – Development of strategies for efficient decommissioning of offshore wind farms

In the coming years, more than 15 offshore wind farms in the North and Baltic Seas will be decommissioned following 20 to 25 years of operations. For wind farms in the German Exclusive Economic Zone, the Federal Maritime and Hydrographic Agency lays down decommissioning concepts already at the time when the wind parks are approved. This presents wind farm operators with a major challenge. Currently, experience of decommissioning is almost entirely lacking. Techniques and procedures for dismantling, logistics and recycling components need to be devised.

Scientists in the “SeeOff” research project are developing various decommissioning scenarios. These are to help wind farm operators to make a realistic estimate of the costs. The researchers will also evaluate environmental and occupational safety aspects as well as the social acceptance of the various decommissioning options. The results will be drawn up in a handbook giving recommendations for action.

Beneficiaries: University of Applied Sciences Bremen and three other partners
Funding ID: 0324322A-D
Estimated funding: €1.1 million
Project duration: 2018 – 2021
2. PROJECT FUNDING

2018. The Federal Ministry for Economic Affairs and Energy places its funding priority in the field of bioenergy in this research area. The focus is on R&D into cutting-edge technologies and process optimisation, facilitating the efficient, economical and sustainable use of bioenergy and contributing to supply security. To this end, the ministry supports practical solutions with demonstration and pilot projects that help to expand the flexibility of energy and heat generation from biomass. Other aspects include system integration, sector coupling, digitalisation and successfully combining facilities and concepts for harnessing renewable energy sources. In particular, biomass by-products and waste potential should be tapped in order to improve the sustainable use of energy in the (combined) heat and power and transport sectors. The recipients of funding include traditional research institutions but also in particular small and medium-sized enterprises aiming at the market uptake of particular technologies.

Project funding

In the field of bioenergy, the Federal Government provided approximately €49.38 million in funding for a total of 707 ongoing projects in 2020. In addition, the ministries approved approximately €45.47 million in funding for 179 new research projects in 2020 (cf. figure 10).

PROJECT ABSTRACT

PyroMar – Environmentally friendly marine fuels for shipping from biogenic blending components

Ships emit large amounts of the harmful substances sulphur dioxide and carbon dioxide into the environment. Their share of global CO2 emissions is about three percent, which equals the overall CO2 emissions of Germany. To reduce emissions, more sustainable forms of diesel and heavy fuel oil are required. These include drop-in fuels based on sustainable biogenic raw materials. The PyroMar project aims to achieve this reduction in emissions by means of new technologies to produce biogenic blending components. The greatest challenges it is facing are scaling up production to manufacture the required quantities of fuel, and the cost-intensive production process. Previously unused biomass, such as straw, autumn leaves, landscape hay or shrub cuttings serve as raw materials. During the first project phase, the researchers succeeded in mapping the entire process chain for the production of bio-based blending components. The team will go on to produce blend variants with conventional shipping fuels and will test them on a single-cylinder engine test stand. The project partners will also carry out ecological and economic sustainability assessments and analyse biomass potential, sales markets and legal framework conditions as well as approaches for transfer to private sector practice.

Beneficiaries: Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT and two other partners
Funding ID: 03EI5412A-C
Estimated funding: €1.3 million
Project duration: 2020–2022
Figure 10: Funding for bioenergy in € million  
(Data cf. Table 3, p. 88)

**PROJECT ABSTRACT**

**Waste2Energy project in Ghana – From municipal waste to green energy**

In Ghana, more than 12,000 tonnes of municipal waste are disposed of without any controls every day. The decomposition of waste from the household waste sector generates gases accounting for approximately a quarter of Ghana’s overall greenhouse gas emissions. In the Waste2Energy project, Ghanaian and German researchers demonstrate how waste lying around in the street can be transformed cleanly into energy and raw materials. In a hybrid photovoltaic biogas pyrolysis plant, waste is converted into energy using green energy from the sun and various decomposition processes. A special feature of these processes is that they generate energy while reducing carbon dioxide emissions. In addition, nutrients are retrieved, which can be used by farmers in the surrounding villages as fertiliser. The demonstration plant (400 kW) reduces carbon dioxide emissions by 4,000 tonnes each year and creates 50 jobs. In the future, it is conceivable that there could be as many as ten large plants in Ghana alone, providing jobs for approximately 1,000 people. That would help to improve living conditions, providing Ghana with cleaner air and streets, and prospects of work and prosperity.

**Beneficiaries:** University of Rostock and four other partners  
**Funding ID:** 03SF0591  
**Estimated funding:** €5.9 million  
**Project duration:** 2020 – 2023
2.2.4 Geothermal energy

Geothermal energy is a reliable source of energy. Current technologies enable hydrothermal geothermal energy to provide heat commercially. According to the German Geothermal Association (BVG), 40 heat and power plants as well as combined heat and power plants are currently in operation in Germany. In the field of near-surface geothermal energy, around 400,000 systems are installed.

Funding priorities have been placed on the use of geothermal heating and cooling applications and on seasonal heat storage. Research projects will contribute to reducing costs and risks, creating storage facilities and increasing awareness and acceptance of geothermal energy. There will be a focus on demonstration and pilot projects which can speed up the transfer of new technologies to practice.

Project funding

In the field of geothermal energy, the Economic Affairs Ministry provided approximately €14.36 million in funding for 106 ongoing projects in 2020. In addition, the ministry approved approximately €40.95 million in funding for 41 new research projects in 2020 (cf. figure 11).

OPTIBIOSY – Examination of the potential and development of an optimisation model for biogas plants in the context of the future electricity system

Biogas plants are a cornerstone of the energy transition and the renewable energy supply. Power from biogas is generally available continuously, regardless of the time of day or the time of year, but is comparatively expensive. In order to compensate for fluctuations in the availability of other renewable energy sources (wind, solar), balance energy supply and demand, and guarantee a secure and stable energy supply, so-called system services are required. They include voltage and frequency stability, residual load supply and reactive power. In principle, biogas can provide these system services if plant performance is precisely tailored to this and to fluctuating needs.

The collaborative project Optiobiosy being carried out with two higher education institutions in eastern Bavaria aims to use biogas facilities to improve system stability and energy efficiency. First, the potential of biogas to provide various system services within the future energy system will be presented, and an analysis and evaluation made of the possible system services to be provided by biogas and the technical conditions they require, taking into account the size of plants and network integration in each case. This leads to deductions concerning the required design of engine technology and process and plant engineering and a description of the necessary economic framework conditions.

Beneficiaries: East Bavarian Technical University of Regensburg and University of Applied Sciences Amberg-Weiden

Funding IDs: 22405016, 2241041, 22410517

Estimated funding: €710,000

Project duration: 2018 – 2021
GEOmaRE – Optimised control and installation technology with sustainable reservoir management for deep geothermal heating projects in the Munich region

As part of its heating vision, Munich’s municipal utilities are increasingly using deep geothermal energy for climate-neutral energy generation. An efficient, regenerative, area-wide supply of district heating for the Bavarian metropolis of Munich requires both an appropriate heating infrastructure and sustainable reservoir management.

The research project GEOmaRe will provide scientific and technical assistance for conceptual and development work to achieve an envisaged 400 megawatts of geothermal heating. As well as overarching questions on heat availability and utilisation in the municipal heat networks, the partners will be looking at above-ground and underground aspects of decentralised geothermal heating in two partial projects. The aim is to allow careful reservoir management and economic heat generation.

On the one hand, project teams will develop innovative control and regulation technology enabling the efficient networking of decentralised geothermal and other existing plants. On the other hand, the collection and evaluation of extensive geophysical, geological and hydrochemical data will create the quantitative and qualitative basis for sustainable, safe heat generation. Questions relating to drilling technology, especially the testing of exploratory technology, complete the project spectrum.

Beneficiaries: SWM Services and the Leibniz Institute for Applied Geophysics (LIAG)
Funding ID: 0324332A-B
Estimated funding: €3.1 million
Project duration: 2018 – 2021
2.2.5 Hydroelectric and marine power

As a constantly available source of renewable energy, hydropower is long established in the German energy system. Its share of total energy generation in Germany is just under 3.5 percent. Based on use of the technologies available today, however, suitable locations for hydropower generation have virtually all been exhausted.

Research projects therefore contribute to developing technologies to increase the output of existing plants, to react to fluctuating energy needs, and to improve ecological compatibility.

In the field of marine power, funding is also being provided for 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 Energy provided approximately €2.26 million in funding for ten ongoing projects in 2020 (cf. figure 11, page 39).

2.2.6 Thermal power plants

Thermal power plants are likely to play an important role in the climate-neutral energy system of the future. In this area, energy research contributes to opening up further options, also for existing infrastructures. It is also important to adapt the existing infrastructure to a new energy landscape involving many different many actors.
Funding priorities and scientific advances

The Federal Ministry for Economic Affairs and Energy supports projects that investigate how large energy stores can be integrated into the power plant park. These facilities can be used to temporarily store electricity from renewable energy sources that is not immediately needed by converting it into green hydrogen or heat using power-to-x technologies, for example. If needed, the energy stored could be used to generate electricity again. Funding is also being provided for research projects on solar thermal power plant processes and components. In Germany, there is insufficient direct solar irradiance for this technology to be used to generate electricity. However, German companies successfully export solar technology “made in Germany”.

Project funding

In the field of thermal power plants, the Federal Ministry for Economic Affairs and Energy provided approximately €27.90 million in funding for 375 ongoing projects in 2020. In addition, the ministry approved approximately €38.30 million in funding for 83 new research projects in 2020 (cf. figure 12).

PROJECT ABSTRACT

VeNiTe – Thermal power plants – development of procedures for thermal storage in nitrate salts for increased temperatures and enhanced product life

For some years, solar power plants in sunny regions of the world have generally used molten-salt storage for the intermediate storage of excess heat in large tanks at a temperature of around 550 degrees Celsius. Higher temperatures would further enhance power plants’ effectiveness. There is a need for further research in this area, however. This is because at temperatures above 600 degrees Celsius, the salt reacts more strongly with gases in thermal storage. This can lead to increased corrosion of the storage components. The VeNiTe team of researchers therefore aims to modify the composition of the gases coming into contact with the salt to prevent excessive corrosion. By taking this approach, solar salt can be used long-term at operating temperatures of more than 600 degrees Celsius. The technology is to be demonstrated in practice using 100 kilogrammes of salt in the first instance, and then conceptually planned to power-plant scale. Although the sun is not sufficiently intense for this type of energy generation in Germany, this technology has export potential. It can also be used in these latitudes, for example in thermal storage power plants and to store process heat in industrial enterprises.

Beneficiaries: German Aerospace Center (DLR) and two other partners
Funding ID: 03EE5043A-C
Estimated funding: €1.2 million
Project duration: 2020 – 2023
2.3 System integration

2.3.1 Electricity grids

Previously, electricity grids were set up to bring energy from central large power stations to end consumers. Meanwhile, so-called prosumers are producing and consuming electricity decentrally in many places across Germany. The distance electricity is transported has also increased because a great deal of electricity is generated at the windy coast and transmitted to the major centres of consumption in the west and south. Electricity grids must also react flexibly to the fact that the generation of renewable energy fluctuates due to its dependence on weather conditions. All this requires optimised operation of the electricity grids. Maintaining the security and affordability of the electricity supply contributes to Germany’s competitiveness as a business location.

Funding priorities and scientific advances

The Federal Ministry for Economic Affairs and Energy supports making operating materials and components more efficient and more cost-effective. There is also a need for research in the area of smart grid operations management. The aim is to achieve reliable multilevel grid control. The call for funding applications “Optimised network operation in transmission and distribution networks (OptiNet I)” was therefore addressed at grid operators in order to use the opportunities of improved (multilevel) cooperation. Another research topic is the question of how grids can be flexibly adapted to fluctuations in generation and consumption while still maintaining stable frequency and voltage. Improved monitoring of grids, a critical infrastructure, is also important to ensure that they are resilient and secure. In case of a power outage, viable concepts are required for restoring the system.
rapidly afterwards. In addition, the Federal Ministry for Economic Affairs and Energy has several funding priorities in the targeted digitalisation of the energy system using information and communications technologies, artificial intelligence and machine learning methods. The Federal Ministry for Economic Affairs and Energy participated in the transnational Joint Call 2020 (MICall20) on digital transformation for green energy transition of the European Joint Programming Platform (ERA-Net) Smart Energy Systems and the global initiative Mission Innovation.

Another initiative with these research priorities is the funding programme “Smart Energy Showcases – Digital Agenda for the Energy Transition” (SIN-TEG) (see Chapter 5.1, Federal Government activities beyond the Energy Research Programme, page 82).

The Kopernikus projects funded by the Federal Ministry of Education and Research are a research initiative for the energy transition. One of these projects, “New Energy Grid Structures for the Energy Transition” (ENSURE), is taking a comprehensive and forward-looking approach to developing options for the energy grid of the future. In 2020, the project presented a comprehensive study participatively prepared with all major stakeholders with various options for the energy system of 2030 and conclusions for appropriate development of the grid structure. The study concluded that various possible development paths would make a better and faster contribution to decarbonising the energy sector than the current Grid Development Plan.

Project funding

In the field of power grids, the Economic Affairs and Research Ministries provided approximately €65.05 million in funding for 517 ongoing projects in 2020. In addition, the ministries approved approximately €81.85 million in funding for 145 new research projects in 2020 (cf. figure 13).

**PROJECT ABSTRACT**

In the future, an innovative battery inverter will provide a readily available and modular alternating current network with grid-forming and backup functions.

**LEITNING – Power converters for robust and reliable energy supply by integrating ‘green’ generators**

A new kind of battery inverter will be researched and tested by a consortium of partners in the LEITNING project. It is to provide a readily available and modular alternating current network with grid-forming and backup functions. Guaranteeing smooth interaction with renewable energy plants presents a challenge.

The project will lead to huge material, weight and cost savings in comparison with the inverter systems commercially available today. In the process, cross-technology research will be conducted in the fields of inverter systems, semiconductor technology, passive construction elements and system integration. Consideration is being given to extending this integration, using a hybrid inverter to connect photovoltaic generators, fuel cells and other energy sources. The planned high mass-power-density of the inverter combined with its low weight are the key to opening up new areas of application for the simple and flexible integration of renewable energy sources. The project also contributes to reaching the CO₂ reduction targets.

**Beneficiaries:** Infineon Technologies and five other partners

**Funding ID:** 03EI6030A-F

**Estimated funding:** €3.5 million

**Project duration:** 2020 – 2024
2.3.2 Energy storage systems

Energy storage systems have an important role to play in the energy system of the future. Their main purpose is to store energy from renewable sources and make it available at a later time. That may be necessary, for example, when the wind is not blowing or the sun is not shining, i.e., when electricity cannot be generated or is in high demand. In addition, storage systems prevent the loss of excess energy at times when the weather conditions make it possible to generate large amounts of eco-energy. Up to now, particularly in windy conditions, wind turbines have had to be turned off because there is insufficient grid capacity to take up and transport the electricity. Thus, energy storage systems could have a balancing effect and stabilise the grid. Sector coupling – connecting supplies in the electricity, heating and transport sectors – could open up new fields of application for energy storage systems in the future. Instead of oil or gas tanks, energy storage systems could be installed in residential buildings, which are charged when large amounts of electricity are available. Experts in R&D are working continuously to improve the performance and cost-effectiveness of storage systems, enabling their potential to be tapped even more effectively.

Funding priorities and scientific advances

The Federal Ministry for Economic Affairs and Energy provides funding for research into various storage technologies: electrothermal storage systems (batteries, including redox flow batteries), SuperCaps (electrical storage devices), mechanical storage systems (compressed air and gas, pumped and flywheel storage systems) and high-temperature heat storage systems for electricity storage (Carnot batteries). Researchers are constantly working to improve materials and components as well as to optimise production, standardisation and operational processes. Experts use digital technologies to ensure optimal integration of storage systems into the energy system. In connection with this, the ministry is also providing funding for research teams to explore related issues, such as cell chemistry, and to test their findings in practical field tests, using demonstration plants, for example, and within the framework of the Living Labs for the Energy Transition (see Chapter 1.2.4, page 15).

The Federal Ministry of Education and Research has initiated the development of a “world storage” system for domestic use in its “pilot competition for breakthrough innovations”. This system should at least equal the performance of available systems at significantly lower costs. The prerequisite for funding is the major scientific and technological advance to be anticipated (“breakthrough innovation”). The aim is to develop decentralised storage solutions, particularly for rural regions, for example in Sub-Saharan Africa and the Indian subcontinent. Since June 2020, the researchers submitting five particularly suitable concepts have been framing their solutions in more concrete terms over a period of one year. Approaches range from various different new battery technologies to an innovative systemic concept.

Project funding

In the field of electricity storage, the Federal Ministry for Economic Affairs and Energy and the Federal Ministry of Education and Research provided approximately €22.53 million in funding for 214 ongoing projects in 2020. In addition, the ministries approved approximately €25.55 million in funding for 50 new research projects in 2020 (cf. figure 14).
2. PROJECT FUNDING

Figure 14: Funding for storage in € million
(Data cf. Table 4, p. 89)

DEMIKS – Decentralised energy storage using integrated rotational kinetic energy mass storage

Kinetic flywheel storage is an energy-storage method that has been in use in engineering for centuries. When used for short-term energy storage, mechanical storage systems (also called rotational kinetic energy storage), where a flywheel accelerates and energy is stored in the form of rotational energy, have low losses in comparison with other energy storage systems. They allow a comparatively large number of charging/discharging cycles and have short reaction times, as well as having the advantage of being practically site-independent and environmentally compatible throughout the entire product life cycle. One project objective is to develop rotational kinetic energy storage that can be installed right next to a wind turbine where the energy is being generated. That reduces transmission losses, and the storage device can be connected with a decentralised transmission grid that already exists. This project is breaking new ground in the area of single-rotor rotational kinetic energy storage, with an envisaged mechanical rotational kinetic energy storage capacity of 500 kilowatt hours and an electric charging and discharging performance of 500 kilowatts. Previous rotational kinetic energy storage systems had a storage capacity of around 100 kilowatt hours, a significantly lower capacity in comparison. Thus, the project is making completely new demands on the storage system and its components.

Beneficiaries: Technical University of Dresden and five other partners
Funding ID: 03ET6102A-F
Estimated funding: €2.8 million
Project duration: 2016 – 2021
ReserveBatt – System services for secure operation of the energy supply service: Active power reserve with maximum performance batteries and VISMA stack inverters

To ensure that the energy system is always stable and the frequency is even, exactly the same amount of electricity has been fed into the system as the amount being used. Therefore, transmission grid operators must compensate for imbalances immediately. To do so, they require an active power reserve as a kind of system service.

To date, this has been provided first and foremost by conventional power plants. Since these will gradually be removed from the grid in the wake of the energy transition, a shift to alternative suppliers of system services is required, such as energy storage systems.

The aim of the project team is to design and develop a demonstrator that produces an active power reserve. It contains a so-called stack inverter, which connects a lithium ion high-performance battery with the supply grid and controls the energy flow between the two systems. In the course of field tests, the team carried out research on the demonstrator in Goslar as part of the public distribution grid in practice. Their objective was to gain meaningful results and be able to make recommendations for the intended later field of application. That means that the experts are developing and evaluating utilisation possibilities and possible business models for providing system services.

Beneficiaries: Energy Research Center of the Clausthal University of Technology and six other partners
Funding ID: 03ET6123A-G
Estimated funding: €5.3 million
Project duration: 2017 – 2021
2.3.3 Sector coupling and hydrogen

Sector coupling aims to introduce renewably generated electricity into sectors that have not yet been fully electrified. These include green electricity for heating and cooling as well as operating energy for the transport sector and process energy for industry. To date, the main energy sources used in industrial production, transport and the heating market have been fossil fuels such as oil, natural gas and coal. Hydrogen is regarded as a multitalent for decarbonising these sectors and making them CO2-neutral. Surplus energy from wind and PV plants can be transformed into hydrogen using electrolysers. The hydrogen can then be used directly for energy or material applications, for example in steel production or the chemicals industry. Hydrogen is also an important component of alternative power-based fuels used in transport and aviation.

Funding priorities and scientific advances

The National Hydrogen Strategy, published in 2020, aims at the sustainable reduction of CO2 emissions in the transport, heating and industrial sectors. To achieve this, hydrogen technologies need to be made economically viable and the conditions need to be created for hydrogen to be widely used in the energy system. That requires innovative technologies for the production, transport, storage and use of hydrogen as a source of energy. It is also necessary to develop a stable and secure hydrogen infrastructure and to integrate it into the existing energy system.

Important research topics are generating green hydrogen using electrolysis or biochemical processes, and processing the raw material to make synthetic fuels or downstream products that facilitate storability and transportability. Research
should also be carried out into repurposing existing gas grids, blending hydrogen into the natural gas grid, and developing non-grid-bound transport methods. In the area of use, the focus lies on further developing fuel cells and using hydrogen in refineries and in the raw material and steel industries. Research also needs to be done in the areas of plant and component standardisation, transport and pipeline systems, monitoring and security technologies and hydrogen product certification. Furthermore, the technologies need to be examined and evaluated with respect to their possible impact on social acceptance, the labour market and the national economy. To meet these challenges, the Research and Economic Affairs Ministries launched large-scale research initiatives in 2020.

In the context of its initiative to boost hydrogen technologies, the Federal Ministry for Economic Affairs and Energy called on industrial and business enterprises to accelerate the transfer of technology to practical applications.

The call for funding applications “Hydrogen Republic of Germany” by the Federal Ministry of Education and Research, published in June 2020, is aimed firstly at industry-led flagship projects on central and urgent fields of hydrogen innovations. Three large-scale research and technology platforms on the subjects of the serial production of electrolysers, offshore hydrogen production and hydrogen transport solutions involving a total of around 350 partners were planned and appraised in 2020. The projects will commence work in spring 2021. Secondly, the call for funding applications addresses basic research along the entire hydrogen value chain (production, storage, transport and use, including reconversion). The focus is on materials research and possible key technologies for the next generation and beyond.

In 2020, the Federal Ministry of Education and Research also launched the Atlas of Green Hydrogen Generation Potentials for Africa, a project to explore the potential of green hydrogen production in West and Southern Africa (see project abstract H2 Atlas Africa, page 49).

**Project funding**

In the field of sector coupling and hydrogen technologies, the Federal Ministry for Economic Affairs and Energy and the Federal Ministry of Education and Research provided approximately €59.13 million in funding for 269 ongoing projects in 2020. In addition, the ministries approved approximately €151.16 million in funding for 95 new research projects in 2020 (cf. figure 15, page 47).
2. PROJECT FUNDING

PROJECT ABSTRACT

The H₂Atlas is a guide to the potential for implementing a green hydrogen-based economy in Africa.


Germany will be dependent on importing sustainably generated hydrogen, as domestic generation alone is far from being able to meet hydrogen needs. The Federal Ministry of Education and Research is therefore relying on strategic partnerships with Africa, where there are sufficient undeveloped spaces not only to cover local energy needs, but also to be able to export energy in the form of green hydrogen. H₂Atlas Africa is to evaluate the potential of producing and exporting green hydrogen and examine how its generation can support Africa’s sustainable development. Researchers in more than 30 countries are analysing a range of topics including available renewable energy and water resources, usable areas, the cost-efficiency of hydrogen production, local energy needs and energy infrastructure, and social and political conditions. The results will be presented on an interactive map, showing investors which locations are suitable for developing a green hydrogen infrastructure. Pilot projects will then examine how the production, export and sale of green hydrogen can be realised in an economically efficient way.

**Beneficiaries:** Research Centre Jülich and two other partners  
**Funding ID:** 03EW0001  
**Estimated funding:** €5.9 million  
**Project duration:** 2020 – 2022

PROJECT ABSTRACT

In the bioreactor, microorganisms convert carbon dioxide and hydrogen into speciality chemicals (chemical synthesis).

**Rheticus – Establishment and validation of a fully-continuous modular basic technology platform for the production of specialty chemicals**

One of the central questions of the energy transition is how to make good use of volatile renewable power and intelligently store its energy. The answer of the Rheticus project is to produce valuable specialty chemicals from carbon dioxide and electricity from renewable sources with the aid of bacteria. At the test facility which opened at Evonik’s site in Marl on 23 September 2020, the two participating companies are showing how carbon dioxide can be used as an industrial-scale raw material in the chemicals sector. A special feature of the plant is its modular structure. The two modules – the electrolyser and the fermenter – are designed as separate units. That enables the size of plants to be scaled and adapted to local circumstances as required. The development of additional modules also gives unprecedented flexibility with regard to the sources of raw materials and the products obtained. Rheticus thus shows the great potential for sector coupling that arises from integrating the energy and the chemicals sectors.

**Beneficiaries:** Evonik and Siemens  
**Funding ID:** 03SF0548A-B and 03SF0574A-B  
**Estimated funding:** €6.4 million  
**Project duration:** 2017 – 2021
Portal Green – Development of power-to-gas guidelines for the integration of renewable energy

Power-to-gas plants are an important cornerstone for the integration of renewable energy sources into the energy system. The authorisation procedures and operating standards for such installations are complex and sometimes confusing. Moreover, the possible scope for interpretation of the applicable laws and regulations is used in different ways by the competent authorities and can lead to different regional approaches. This makes the processes difficult for plant planners and operators to calculate and leads to effort and delays. Portal Green’s partners have therefore developed guidelines on the technical and planning permission requirements for constructing and operating power-to-gas facilities. These aim to support operators and representatives of public authorities in planning, approving and operating power-to-gas plants. The guidelines were completed at the end of 2020. The research consortium has made them available to interested parties to download free of charge. The document explains the process, the documents required and the preliminary examinations in the respective approval process. It also considers specific issues that may arise when connecting different branches of use. These include feeding hydrogen or methane into the existing gas grid, supplying hydrogen filling stations, reconversion and industrial use.

Beneficiaries: Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) and three other partners
Funding ID: 03ET6135A-D
Estimated funding: €1.3 million
Project duration: 2018 – 2020
2.4 Cross-system research topics

2.4.1 Energy systems analysis

Energy system models give an insight into the relationships between providers and users, show the interactions between technologies and sectors and highlight potential development paths. Their success is based on selecting the right variables, database, tools and methods to achieve a high degree of realism.

Funding priorities and scientific advances

Systems analysis models provide decision-makers with a planning resource for designing tomorrow’s energy world. Thus, transferring system-analytical research to energy-sector practice, for example by including consideration of industrial applications, plays a key role in project funding. In addition, Open Science, Open Data, Open Source and Open Access are to be used to achieve, transparent, comprehensible and comparable results. There is also a focus on interdisciplinary approaches that include all the relevant technical, economic, ecological, energy-policy and social factors. The ministry also supports projects that pursue the continuous development of tools and methods, such as standardised interfaces, so models can be connected (across sectors).

In order to enhance international collaboration, the Federal Ministry for Economic Affairs and Energy issued a call for funding applications in April 2020 for German scientific evaluation of the Energy Technology Systems Analysis Programme (ETSAP), the International Energy Agency’s technology collaboration programme (TCP) on systems analysis.

Project funding

In the field of energy systems analysis, the Federal Ministry for Economic Affairs and Energy provided approximately €18.97 million in funding for 216 ongoing projects in 2020. In addition, the ministry approved approximately €15.13 million in funding for 34 new research projects in 2020 (cf. figure 16).
UNSEEN – Evaluation of uncertainties in linear energy system optimisation models using neural networks

Supply security depends on stable energy systems. That applies also and particularly when there are fluctuations due to grid bottlenecks or power station outages. To be prepared for such deviations, the UNSEEN research team is developing a process to simulate and evaluate a large number of model-based scenarios (including extreme situations). The scientists’ central approach is to use high-performance computing systems to analyse a large number of highly-complex model-based energy scenarios, using machine learning methods to train neural networks. Ultimately, the reliability of the results of energy systems analysis can be improved by applying parameter variations and increasing the complexity of the models. For all this to succeed, however, reducing the computing times of models presents a major challenge. In this area, UNSEEN builds on the research work conducted in the predecessor project BEAM-ME. It achieved considerable success in reducing the computing times of complex energy system optimisation models. The partners are aiming to consistently continue this work, firstly to calculate millions of scenarios within relatively short periods of time, and secondly to further develop solution algorithms in a purposeful way.

Beneficiaries: German Aerospace Center (DLR) and five other partners
Funding ID: 03EI1004A-F
Estimated funding: €2.9 million
Project duration: 2019 – 2022

HySupply – German-Australian feasibility study of hydrogen produced from renewables

The project aims to investigate for the first time the feasibility of the entire value chain for renewable hydrogen between two industrialised countries, Germany and Australia, as part of a comprehensive study. Together with a consortium of Australian partners, the existing barriers and obstacles to the establishment of a global value chain for hydrogen will be identified and tangible options for the implementation of supply relations between the two countries described. The study will examine economic and business aspects, scientific and technical aspects, as well as regulatory, legal and logistical conditions. The feasibility study will be carried out jointly by German and Australian partners with the involvement of stakeholder project groups so that the insights gained can be speedily applied to specific implementation projects. The project lays the foundation for a long-term German-

Beneficiary: acatech – National Academy of Science and Engineering
Funding ID: 03EW0027
Estimated funding: €1.7 million
Project duration: 2020 – 2022

A German delegation views an ammonia-to-hydrogen cracking facility at CSIRO in Clayton, Australia.

Australian hydrogen partnership, addressing a central aim of the National Hydrogen Strategy.
2.4.2 Digitalisation of the energy transition

Digital applications and services play a key role in networking, decentralisation and added flexibility in the energy system and for the efficient use of energy and resources. Intelligent information and communications technology (ICT) is thus a key component of tomorrow’s energy infrastructure.

Funding priorities and scientific advances

Digitalisation is a horizontal issue in many energy research funding projects. Furthermore, IT networking often works across systems and technologies, for example in connection with efficiency in the energy supply or in sector coupling. In addition, digitalisation in the energy sector results in new markets, new business models and innovative smart services. At the same time, however, that makes the energy system more complex and more dependent. That gives rise to new questions regarding system security and reliability. In order to efficiently tap the potential of digitalisation for the energy system, the Federal Ministry for Economic Affairs and Energy is funding this set of issues as a separate research priority for the energy transition. Digitalisation is also an important horizontal issue in the context of the application-oriented basic research funded by the Federal Ministry of Education and Research. In 2020, as well as modelling complex energy systems, various projects developed digital marketplaces, for example for local energy trading or services relating to energy-efficient construction measures. Using augmented reality to improve the presentation of energy-related data for planners and citizens is another subject of research.

In December 2020, the ERA-Net Digitalisation of Energy Systems (EnerDigit) of the EU Joint Programming Platform Smart Energy Systems and the global initiative Mission Innovation published the call for funding applications Digital Transformation for Green Energy Transition (MICall20). This measure is intended to fund the development of new concepts and solutions in the area of information and communications technologies.

Project funding

In the field of digitalisation of the energy transition, the Economic Affairs and Research Ministries provided approximately €2.68 million in funding for 34 ongoing projects in 2020. In addition, the ministries approved approximately €8.22 million in funding for 22 new research projects in 2020 (cf. figure 17).

Figure 17: Funding for digitalisation in the energy transition in € million (Data cf. Table 5, p. 90)
2.4.3 Resource efficiency for the energy transition

The responsible use of resources is an important horizontal issue of the 7th Energy Research Programme. “Resources” means the totality of all natural resources and artificially created goods in the economic cycle that are used to manufacture products and provide services. They include raw materials, intermediate products and products at the end of an economic exploitation phase, but also energy sources. The supplementary circular economy concept enhances resource efficiency by making products into resources again after use. In this context, resource efficiency in combination with a circular economy predominantly considers flows of goods not only in material terms, but also in terms of energy.

In the autumn, in preparation for a call for funding applications on resource efficiency and circular economy for 2021 by the Federal Ministry for Economic Affairs and Energy, Project Management Jülich carried out a poll on behalf of the ministry. It asked company representatives, research institutions, the energy industry and energy-intensive sectors about the need for R&D in this area. In addition, the Federal Government is ensuring appropriate consideration of aspects of resource efficiency in funding energy research.
2.4.4 CO₂ technologies (including Carbon2Chem)

In industrial processes where carbon dioxide (CO₂) emissions cannot be prevented, CO₂ can be separated to prevent its release into the atmosphere. One approach of research into CO₂ technologies explores the use of CO₂ as a raw material. CO₂ serves as a source of carbon that can be used to make new products. If such products are durable, thereby sequestering CO₂ long-term, it could enable emission-intensive industrial processes to be made sustainable.

Funding priorities and scientific advances

Approaches to carbon capture and utilisation (CCU) and carbon capture and storage (CCS) are central to this research area, which is being funded by the Economics and Research Ministries. Several different processes for sequestering or scrubbing carbon dioxide from industrial exhaust fumes are available. The Federal Ministry for Economic Affairs and Energy provides funding for projects seeking to make these more efficient and economically viable. The gas, which damages the climate, can also be captured directly from the atmosphere, for example, by technical means in specially-developed direct air capture facilities such as those in the NECOC project (see project abstract, page 57) or in the Kopernikus project P2X. Growing biomass can also permanently remove CO₂ from the atmosphere (negative emissions).

By no means the least important objective for researchers and developers is to help to establish a well-functioning circular economy where CO₂ is recycled, thus achieving net zero carbon dioxide emissions into the atmosphere. A first step in this direction is the Carbon2Chem project by the Federal Ministry of Education and Research. In this project, the blast-furnace gases generated during steel production are used as feed materials for chemical production, thereby reducing the all-natural CO₂ emissions from steel production.

The Federal Ministry for Economic Affairs and Energy funds application-oriented research projects which will further develop the diverse technologies for the capture, transport, storage and use of CO₂. December 2020 saw publication of the call for funding applications Carbon Capture and Utilisation (CCU) in the Raw Materials Industry. This

Figure 18: Funding for CO₂ technologies in € million
(Data cf. Table 5, p. 90)
The Carbon2Chem project explores how blast-furnace gases can be used to manufacture valuable precursors for fuels, plastics or fertilisers. Launched in 2020, the second phase of Carbon2Chem will validate the processes developed for industrial implementation and assess the transfer of the technology to the emissions-intensive processes of lime production and waste incineration. The project follows on seamlessly from the first phase, which has been funded since 2016, in which the scientific foundations were laid. In the Carbon2Chem project, leading industrial enterprises, together with the Max Planck Society, the Fraunhofer Society and universities, are conducting research into globally applicable solutions for transforming emissions into basic chemicals. In the Technikum, a specially established facility in the steel-producing city of Duisburg, the development work can be carried out under real-life conditions. In addition, complex modelling and analysis will achieve the ecological and economic optimisation of the integrated systems and look at options for supplying green hydrogen in the required quantities.

**Beneficiaries:** thyssenkrupp, Max Planck Society, Fraunhofer Society for the Promotion of Applied Research and ten other partners  
**Funding ID:** 03EW0003A-03EW0009C  
**Estimated funding:** €78.5 million  
**Project duration:** 2020 – 2024
2. PROJECT FUNDING

2.4.5 Energy transition and society

The energy transition influences the living environment of all citizens at many different levels. The Federal Government has therefore anchored research on social aspects as a cross-technology funding priority in its 7th Energy Research Programme.

Funding priorities and scientific advances

Fifteen research projects were launched in 2020 in the area of energy transition and society from the first call for funding applications by the Federal Ministry for Economic Affairs and Energy. They are devoted to socio-technological energy transition research. Subjects that were strongly addressed included “Acceptance and participation in the transformation process”, “Technology design and technology impact assessment” and “Socio-economic effects of financial participation opportunities”. In September 2020, the Federal Ministry for Economic Affairs and Energy published a second call for funding applications for this research priority. The focus of these cross-system and cross-technology projects is to be placed on subjects such as labour market changes induced by the energy transition or socio-economic aspects of structural change. In addition, research teams could submit outlines on research into acceptance of digitalisation or project ideas for communication and visualisation strategies with a view to the intensive participation of social actors.

PROJECT ABSTRACT

NECOC – Creating negative emissions by converting CO₂ contained in ambient air into carbon black that can be used as a resource in industry and O₂

In this project, an absolutely innovative process is being developed for reducing the concentration of carbon dioxide in the atmosphere. The Karlsruhe Institute of Technology is aiming to achieve this by developing an innovative, decentrally usable facility as a container system. CO₂ is filtered out of the atmosphere and goes through a number of steps in a process to convert it into a valuable raw material for high-tech applications. The resulting carbon black can be used in industry, for example in the electronics, printing and construction sectors. So far, carbon black has been produced mainly from fossil petroleum.

Specifically, the scientists plan to do the following:

The first step is to filter carbon dioxide out from the air using the direct air capture process. Together with hydrogen, it is then converted into methane and water in a microstructured reactor. The methane produced serves as a carbon carrier in the downstream process and is passed into a bubble reactor filled with liquid tin. In the ascending methane bubbles, a pyrolysis reaction takes place, by means of which methane is decomposed into its constituents. These are, on the one hand, hydrogen, which is directly fed back to methanation and, on the other hand, carbon black.

Beneficiaries: Karlsruhe Institute of Technology (KIT) and two other partners
Funding ID: 03EE5009A-C
Estimated funding: €1.5 million
Project duration: 2019 – 2022
The Kopernikus project Ariadne, which was launched by the Federal Ministry of Education and Research in 2020, is examining political instruments, social acceptance and the achievement of climate neutrality within a systemic perspective (see project description). In addition, social aspects are being examined, also in the context of a large number of projects on mobility, the urban energy transition and structural change in the wake of the phase-out of coal-fired power generation in combination with other factors.

Project funding

In the field of energy transition and society, the Economic Affairs and Research Ministries provided approximately €6.37 million in funding for 76 ongoing projects in 2020. In addition, the ministries approved approximately €39.06 million in funding for 69 new research projects in 2020 (cf. figure 19).

**PROJECT ABSTRACT**

**Kopernikus-Project Ariadne – Evidence-based assessment for designing the German energy transition**

The Kopernikus project Ariadne, which was launched in 2020, is drawing up options for designing energy transition policies in such a way that the climate protection goals are achieved and the instruments are socially accepted. In systemic analyses, long-term strategies are being examined for the transition to a greenhouse-gas-neutral energy system, taking into account the specific challenges, for example of transport, heating, industry and the development and integration of renewable energy sources. In addition, Ariadne is analysing political instruments and approaches to governance for the energy transition. A structured dialogue process with decision-makers, stakeholders and citizens will draw up options enabling politics to be designed in a way that makes the climate protection goals achievable. For example, values and norms of citizens selected at random relating to the energy supply and mobility will be recorded. The results will be collected in Green and White Papers in a multimedia process. The Green Paper will describe the options. The White Paper will contain evaluations drawn up in a joint learning process involving decision-makers, the scientific community and stakeholders.

**Beneficiaries:** Potsdam Institute for Climate Impact Research (PIK) and 23 partners  
**Funding ID:** 03SFK5A-Y0  
**Estimated funding:** €29.5 million  
**Project duration:** 2020 – 2023
Figure 19: Funding for Energy transition and society in € million
(Data cf. Table 5, p. 90)

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**PROJECT ABSTRACT**

**Benefits – Accelerating the energy transition through the financial participation of municipal and private stakeholders**

The success of the energy transition depends not least on the extent to which the restructuring of the energy supply is supported and shaped by society. That includes financial commitment, for example in the form of sustainable investments.

The research project Benefits is therefore examining the ways in which citizens and municipalities have been able to invest in energy transition projects to date and where the opportunities and obstacles lie. The team will initially be analysing the current situation regarding the possibilities for financial participation and is viewing the legal conditions applying to them. The focus is also on the question of the effectiveness of such investments by citizens or municipalities and whether and how they accelerate the progress of the energy transition. Building on that, the team aims to join forces with economic and civil society actors to draw up scientifically sound strategies to attract more people and municipalities to make financial investments. In the course of the Benefits project, the scientists will be looking specifically at the regions of Baden-Württemberg, Mecklenburg-Western Pomerania, Lower Saxony and the Saarland. The project will also take up ideas from the European Union’s Clean Energy Package.

**Beneficiaries:** ECOLOG Institute for Social-Ecological Research and Education and three other partners

**Funding ID:** 03EI5203 A–C, E

**Estimated funding:** €830,000

**Project duration:** 2020 – 2022
2.4.6 Materials research for the energy transition

Basic research to develop innovative materials to meet the needs of a sustainable energy supply are of major strategic significance for the energy transition.

Funding priorities and scientific advances

The Federal Ministry of Education and Research takes a thematically open approach to material research – from energy generation and storage to efficiency enhancement. The wide range of the projects conducted in 2020 included the development of new materials for optimising PEM fuel cells and electrochemical energy storage systems, innovative insulation material for buildings, promising high-performance materials for photovoltaics and solar hydrogen generation, as well as innovative materials for gas turbines. Two projects in the area of photovoltaics once again set efficiency records in their development of innovative materials, and researchers involved received awards. A group of young scientists successfully developed new highly-active catalysts for PEM fuel cells that save on costly platinum and make the technology more cost-effective.

Project funding

In the field of materials research for the energy transition, the Federal Ministry of Education and Research provided approximately €2.90 million in funding for 21 ongoing projects in 2020 (cf. figure 20).

**PROJECT ABSTRACT**

**ECat-PEMFC group of young scientists – Active and stable low-platinum electrode catalysts for low-temperature polymer electrolyte membrane fuel cells**

Polymer electrolyte fuel cells are a promising technology for environmentally compatible and clean energy conversion. It uses hydrogen and oxygen to convert chemical energy into electrical energy. Fuel cells are regarded as efficient and versatile, and can be used, for example, to power vehicles or for domestic energy. Producing them requires rare and expensive materials, such as platinum as a catalyst, which impedes broad market uptake. The ECat-PEMFC group of young scientists are developing catalysts for fuel cells which are lower in platinum and therefore more cost-effective while still being efficient and robust. In experiments with test cells, the group of young scientists demonstrated a reduction in the platinum required amounting to at least 20 percent. That means that a pile of 80 cells can now provide the same performance previously achieved by a pile of 100 cells. That not only means saving approximately 1–2 grammes of platinum, but also other expensive materials for the electrodes and bipolar plates.

**Beneficiary:** Technische Universität Braunschweig  
**Funding ID:** 03SF0539  
**Estimated funding:** €2.2 million  
**Project duration:** 2016–2021
2.5 Nuclear safety research

2.5.1 Reactor safety research

A key task for those conducting research on the safety of nuclear energy is to use R&D to make nuclear power plants (NPPs) as safe as possible, both in Germany and abroad and to promote the development of competence and young scientists in the area of nuclear safety in Germany.

Funding priorities and scientific advances

The focal topics of safety-related research not only include observations of existing plants in Germany and abroad but also safety research into new reactors and plant concepts under development internationally, where the safety concept differs from that of plants operated in Germany. Funding priorities are placed on examining and assessing the safety of components and structures and on detection methods to manage transients, incidents and accidents. Funding is also provided for studies of possible safety-related consequences of extending the service life of nuclear power plants, which is currently being discussed and implemented internationally. The PolySafe project was one of the projects on this subject to be completed during the reporting period (see project abstract, page 62).

The involvement of German research work in international activities has been stepped up further, particularly through commitments in the multilateral research projects of the OECD/NEA. Germany participated in five new projects in 2020 and is organising one of them itself (THEMIS).

Project funding

The lead responsibility for project funding in the field of nuclear safety research rests with the Federal Ministry for Economic Affairs and Energy. This funding is supplemented by a Federal Ministry of Education and Research programme which supports young scientists. In the field of reactor safety research, the Economic Affairs Ministry provided approximately €21.27 million in funding for 137 ongoing projects in 2020. The Federal Ministry of Education and Research provided €0.79 million in funding for five projects. In addition, the Federal Ministry for Economic Affairs and Energy approved approximately €24.37 million in funding for 46 new research projects in 2020 (cf. figure 21).

Figure 20: Funding for materials research for the energy transition in € million
(Data cf. Table 5, p. 90)
The PolySafe project aims to develop a nondestructive method for characterising and monitoring the ageing condition of cables. This is crucial for extending the lifetime of nuclear power plants, which are currently under discussion globally, especially in Germany and its neighbours. The project focuses on the condition and remaining service life of safety-related components, particularly cables, which are exposed to various loads like increased temperature, radiation, pressure, or vibrations.

Within the context of the PolySafe project, ultrasonic and terahertz technologies have been developed and validated using artificially-aged cables. These technologies are capable of detecting ageing phenomena in practical applications. The work is attracting significant interest internationally, and the Fraunhofer Institute for Nondestructive Testing is currently contributing its expertise in terahertz spectroscopy to the TeaM Cables project, part of the European research programme Horizon 2020, which examines the ageing of cables in the context of nuclear plant management.

**Beneficiaries:** Fraunhofer Institute for Nondestructive Testing IZFP and Materials Testing Institute (MPA) University of Stuttgart

**Funding ID:** 1501567A and B

**Estimated funding:** €920,000

**Project duration:** 2018–2020
2.5.2 Disposal and final repository research

A key task is to create the scientific and technical basis for final repository concepts in crystalline, rock salt and clay rock, the possible host rocks.

Funding priorities and scientific advances

In the context of application-oriented basic research, the focus is on studies of the behaviour of the repository system in the possible host rocks. They include research work on the release of radionuclides, the effectiveness of the barrier system and the monitoring system; others set out plans for the development of technologies for transporting nuclear waste and putting it into the final repository. Finally, there are projects studying the impact that foreseeably longer interim storage periods compared with original plans will have on the waste and the containers. Research is also being conducted in the context of international cooperation, enabling studies to be carried out in underground laboratories. This enables technologies and methods to be tested and system-specific knowledge to be gained. This also leads to enhanced process understanding, which is required to make safety assessments. Projects dealing with socio-technical questions relating to nuclear waste disposal round off the research portfolio. Continuous research funding contributes substantially to the development of competence and young scientists in the field of nuclear waste disposal in Germany.

Project funding

The project funding provided by the Federal Ministry for Economic Affairs and Energy is complemented by the research funding provided by the Federal Ministry of Education and Research. The latter provides targeted support for young scientists, thereby maintaining competence. In the field of nuclear waste disposal and repository research, the Economic Affairs Ministry provided approximately €14.9 million in funding for 126 ongoing projects in 2020. The Federal Ministry of Education and Research provided €2.85 million in support for young scientists across 35 projects. In addition, the Federal Ministry for Economic Affairs and Energy approved approximately €10.1 million in funding for 29 new research projects in 2020. (cf. figure 22).

Figure 22: Funding for Disposal and final repository research and radiation research in € million (Data cf. Table 6, p. 91)
Sandwich-HP – Vertical hydraulic sandwich sealing

Scientists in the Sandwich HP project are examining the performance of shaft seals for the final storage of highly radioactive waste at the Mont Terri rock laboratory near St-Ursanne in Switzerland. A large-scale in-situ experiment is being conducted on a vertical hydraulic sealing system. The in-situ experiment is being supplemented by laboratory tests and model simulations. Sandwich HP is a consortium project with the participation of associated international partners.

The sandwich system developed at the Karlsruhe Institute of Technology consists of alternating layers of high-density bentonite segments and hydraulically controlled equipotential layers. In the Sandwich HP project, sealing systems of this kind will be installed in two vertical experimental shafts with a diameter of 1.18 meters and a depth of 10 or 12 meters. The sealing systems are saturated with synthetic Opalinus Clay pore water via compression chambers deep in the shaft supplied via drill holes. The shafts and the surrounding mountains are intensively used for monitoring. The aims of the experiment are to demonstrate the installation technology, to examine the saturation process, to qualify the measurement and monitoring technology and to evaluate the effectiveness of the sandwich sealing system.

**Beneficiaries:** Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) and two other partners

**Funding ID:** 02E11799A-C

**Estimated funding:** €4.4 million

**Project duration:** 2019 – 2023
2.5.3 Radiation research

During the reporting year 2020, the Federal Ministry of Education and Research continued to support collaborative research and projects on radiation research under its funding guidelines for nuclear safety research and radiation research and the 7th Energy Research Programme.

Funding priorities and scientific advances

The Federal Ministry of Education and Research funds projects on radiobiological, radiation medicine, epidemiological and radioecological questions in the field of basic research. This serves to further develop science and technology, thereby making a substantial contribution to building, developing and maintaining scientific and technical competence. Germany continues to require expertise in the above-mentioned areas in public authorities, industry, research and medicine. With these projects, the Federal Ministry of Education and Research supported approximately 150 young scientists during their training, which means that this funding priority was able to make a substantial contribution to building and retaining expertise in the field of radiation research in Germany. The research conducted as part of the projects resulted in numerous publications in high-ranking and highly renowned scientific journals. Some projects contributed to the success of the National Decade Against Cancer with their research findings.

Project funding

46 individual projects were funded in 2020. They were organised in 13 collaborative and two individual programmes. In the reporting period, research projects in the field of radiation research were supported by funding from the Federal Ministry of Education and Research totalling around €6.4 million (see figure 22, page 63).
3. Institutional energy research
3.1 Energy research by the Helmholtz Association

Institutionally-funded research institutions make a major contribution to energy research in Germany. Yet clear categorisation of institutionally-funded research work in the field of energy research presents a challenge. That is because basic research in other areas, such as materials research, promotes progress in the field of energy research, just as it promotes progress on many other scientific topics as well. Work in the research field “Energy” at the Helmholtz Association of German Research Centres (HGF) can be clearly categorised as energy research due to its programme-based funding. That is why the HGF’s research field “Energy” is part of the 7th Energy Research Programme, unlike thematically-related research work by other research organisations such as the Fraunhofer Society, the Leibniz Association or the Max Planck Society, which is equally significant for energy research in Germany.

The third period of programme-oriented funding (POF III) at the HGF in the research field “Energy” was concluded in 2020. From 2021, the HGF will continue its research for the energy transition in new programmatic structures within the framework of the fourth period of programme-oriented funding (POF IV). The research will be organised in four programmes in future. “Energy System Design” is a central programme that pools expertise in the fields of systems analysis, social sciences and economics. This holistic approach will help to shape the energy system of the future. As well as energy systems analysis, digitalisation in the context of energy systems is another focal area. The programme was prepared through the work of Energy System 2050 (ES2050), the joint initiative of the Helmholtz Association’s Research Field Energy in POF III, which presented its results at a conference in September 2020.

The strategic further development of the HGF’s energy research is also to be supported by means of a Helmholtz Energy Transition Roadmap. The “Materials and Technologies for the Energy Transition” programme is the largest programme. It addresses a wide range of materials and technologies for energy generation, conversion and storage as well as for energy and resource efficiency. The “Nuclear Waste Management, Safety and Radiation Research” (NUSAFe) and Fusion programmes will continue their work. The Max Planck Institute for Plasma Physics (IPP) terminated its association status with the HGF at the end of 2020 because the association had led to duplicate structures and considerable additional effort in reporting and in the evaluation procedure. Nothing will change with regard to the IPP’s ongoing close scientific cooperation with the HGF in the field of fusion research, however. In future, the institutional funding of the IPP will no longer be categorised in the statistics as part of the Energy Research Programme (see Chapter 3.2 Fusion research).

The Helmholtz Centre for Environmental Research (UFZ) in Leipzig and the German Research Centre for Geosciences in Potsdam (GFZ) are no longer involved in the research field “Energy” in POF IV. Cross-disciplinary cooperation on relevant topics, such as bioeconomics, geothermal energy and nuclear repository research, will be continued, however. The centres involved in the research field “Energy” in POF IV are the Research Centre Jülich (FZJ), the Karlsruhe Institute of Technology (KIT), the Helmholtz-Zentrum Berlin (HZB), the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) and the German Aerospace Center (DLR). With the exception of the DLR, which receives institutional funding from the Federal Ministry for Economic Affairs and Energy, institutional funding for the Helmholtz Centres will be provided by the Federal Ministry of Education and Research.
Examples of activities in the HGF research field “Energy”

The Helmholtz-Zentrum Berlin (HZB) and two Max Planck institutes – the Fritz Haber Institute (FHI) and the Institute for Chemical Energy Conversion (CEC) – are building a catalysis research platform named CatLab to achieve leaps of innovation in hydrogen research. The European BIG-MAP initiative, in which KIT and FZJ with their scientists are key participants, has been successful in its aim to significantly shorten the time it takes to develop new, high-performance batteries. This was achieved by pooling the expertise of 34 institutions in 15 countries. For the researchers at the GFZ, former natural gas facilities under Berlin’s Grunewald forest offered a unique opportunity. Using old boreholes, tests are being conducted to discover whether the shell limestone rock layer 500 meters above the facility is suitable for use as a heat and cold storage system – and thus for supplying sustainable energy to the growing metropolitan area. As well as the work of the Helmholtz Centre for Environmental Research (UFZ) on solar fuels (see project description), its research on drop-in fuels from dairy wastewater have been stepped up to pilot-plant scale using electro-biotechnological procedures. Unique research infrastructures for the development of liquid metal batteries have been set up at the HZDR. Such batteries have the potential to store large quantities of renewable energy cost-effectively. In a consortium with European partners, this concept is now to be developed to application maturity in an EU-funded project. Progress has been made in the COSIMA project at the Helmholtz Institute Erlangen-Nuremberg, which belongs to the FZJ. This project involves the automatic inspection of PV facilities from the air using drones. In the HiFlex project, the DLR shows how solar energy can be used for industrial processes, specifically in a pilot plant near a pasta factory in Italy. Interdisciplinary research cooperation is also of major significance at the DLR, for example in developing fuel cell aircraft using hydrogen that could fly with zero emissions.

Figure 23 shows the funding deployed in the research field ‘Energy’.

Figure 23: Funding for institutional energy research in € million
(Data cf. Table 7, p. 91)
Institutional Energy Research

**Bio-H2 – Biotechnical hydrogen production for decentralised applications**

Work is focusing on seeking robust procedures suitable for everyday use to generate hydrogen from water and CO₂ by means of natural photosynthesis using cyanobacteria.

A research highlight to date is the continuous generation of hydrogen by cyanobacterial mats powered by solar energy. These communities of a soil bacterium and a cyanobacterium grow in very thin tubes as catalytic biofilms. This new technical ecosystem overcomes two major hurdles. In previous photobio-reactors, bacterial growth density and the amount of light reaching the bacteria were insufficient to generate hydrogen.

In another first, electrons from the photosynthesis of cyanobacteria were put to direct electrochemical use for hydrogen production. This process, called biophotovoltaics, generates power from light energy. This could become increasingly interesting in the future because it is calculated to supply more energy than traditional water electrolysis due to its low electrode overvoltage. Moreover, no explosive gas mixtures are formed and no critical raw materials are needed.

**Beneficiary:** Helmholtz Centre for Environmental Research GmbH – UFZ, Department Solar Materials (SOM)

**Estimated funding:** €1.7 million per year (2020)

**Project duration:** ongoing since 2014
3.2 Fusion research

Research into how energy can be generated from fusion is aimed at tapping a non-fossil, reliable and affordable source of energy in the long term. In view of the global rise in energy demand, the Federal Government believes it is necessary to explore a broad range of options for the future energy supply. Fusion research is contributing to long-term, application-oriented basic research. Like other basic research activities, the purpose of fusion research is, not least, to gain understanding. The Federal Government therefore supports German fusion research by means of institutional funding. The three fusion research centres, the Max Planck Institute for Plasma Physics (IPP), Karlsruhe Institute of Technology (KIT) and the Research Centre Jülich (FZJ), are engaging in a close exchange and are making important contributions to national and international fusion research. With its outstanding scientific expertise in the field of fusion research, Germany also has a global responsibility to advance the understanding of high-temperature plasmas and fusion processes, and to make this expertise available to the world. Even if it becomes possible to apply this research, fusion energy is unlikely to be available until after 2050.

The leading position of German fusion research is highlighted not least by the world records achieved in 2018 in the ongoing experimental operation of the unique Wendelstein 7-X fusion facility in Greifswald, e.g. with plasmas maintained for up to 100 seconds.
4. European and international cooperation
4.1 European networking in energy research

The Federal Government is also committed to funding energy research at European level. The overarching political context under European Commission President Ursula von der Leyen is the European Green Deal, which aims to make Europe the first climate-neutral continent by 2050.

The energy policy goals of the European Green Deal are taken up in the European Strategic Energy Technology Plan (SET Plan). The European Commission’s SET Plan sets out a strategic concept within the European Energy Union with a long-term agenda to overcome innovation bottlenecks, from research to the market uptake of innovative energy technologies. Since 2008, it has been drawing up a strategic framework for funding European energy research into non-nuclear energy topics and is regularly aligned with the EU’s energy and climate targets. In 2020, the Federal Ministry for Economic Affairs and Energy organised the 14th SET Plan Conference “Making the SET Plan fit for the EU Green Recovery” in the context of the German Presidency of the Council of the European Union. The online event was attended by top-level international participants.

ERA-Net Cofund is one of the actions to receive funding to implement the SET Plan Strategy. Within the framework of the Horizon 2020 funding programme, EU and associated countries set up partnerships with the EU, each addressing a specific issue, to strategically coordinate EU and national programmes. In 2020, there were a number of calls for funding applications, for example in the fields of capturing and storing CO2 and geothermal energy. Projects with German participation were among those selected for funding. These included projects in two European Research Area Networks (ERA-Nets) on solar energy. Eight projects in this area with German participation are to receive funding. In addition, the first projects in the first joint call for funding applications by the ERA-Net Smart Energy System and the global initiative Mission Innovation took up their work. And EnerDigit, a new ERA-Net, was launched. The first call within this European Research Area Network was published in December.

In the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), an institutionalised public-private partnership on fuel cells and hydrogen, the latest call in 2020 comprised a volume of €93 million for 24 research topics in the fields of transport, energy and horizontal issues. Preparations are currently under way for the continuation of the European Partnership for clean hydrogen from 2021, part of the Horizon European programme. It is to focus on the production of green hydrogen and the requisite infrastructure.

**Contribution to the European Joint Programme on Radioactive Waste Management (EURAD)**

Germany is involved in the European Joint Programme on Radioactive Waste Management (EURAD) through the participation of representatives of scientific institutions, operators of the federal company for radioactive waste disposal (BGE) and the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), an organisation providing scientific and technical expertise. EURAD serves to implement a joint programme of research and knowledge management activities, bringing together and complementing EU Member State nuclear waste disposal programmes. Its R&D activities are concerned with demonstrating the robustness of disposal concepts, improving understanding of basic processes and maintaining scientific excellence. These activities are complemented by studies on methodological and strategic challenges as well as on knowledge management.
4.2 European Union Research Framework Programme (Horizon 2020)

Horizon 2020, the biggest EU Research and Innovation programme ever, ended at the end of 2020. With a total budget of nearly €80 billion, funding has been provided for projects over the last seven years, from basic and applied research to demonstration projects. The programme’s aim was to promote a knowledge and innovation-based society and a competitive economy throughout the EU while also contributing to more sustainable development.

In the field of energy research, the focus was on calls for project funding applications to develop technologies and systems for a low-carbon, resource-efficient and climate-neutral energy supply.

Horizon Europe succeeds Horizon 2020 and is already on the starting blocks. With its new funding programme for research and innovation, the European Commission is aiming to continue the success story of Horizon 2020 and further fund and strengthen scientific, technological, economic and social progress in Europe through research and innovation. The new programme runs from 2021 to 2027.

Horizon Europe brings together energy issues in Cluster 5 – Climate, Energy and Mobility – with the aim of reducing greenhouse gas emissions and environmental pollution in the energy and transport sectors and increasing competitiveness, resilience and the benefit for society. The cross-sectoral activities within the cluster aim to support implementation of the Paris Climate Agreement, the European Green Deal, the European Economic Recovery Plan and other EU priorities in the areas of climate, energy and mobility. In addition, they aim to contribute to economic recovery following the COVID-19 pandemic by means of the European Recovery Plan.

German applicants successful in the field of energy in Horizon 2020

During the period under review, 2014 to 2019, German actors were involved to an outstanding extent in consortium projects in the energy sector. In the core areas of the work programme Secure, Clean and Efficient Energy, funding amounting to approximately €3.53 billion was approved by Horizon 2020 in the first six years for a total of 751 consortium projects. 1,069 project participants from Germany took part in 470 projects, receiving total funding of approximately €459 million. That equates to roughly 13 percent of the funding approved (cf. figure 24, page 76) The project coordinators of 103 of the 751 projects approved are based in Germany. Approximately 40 percent of the German beneficiaries are from research establishments and higher education institutions. 47 percent are from the private sector, and the remaining 13 percent are from public-sector and other institutions. The share of applicants from Germany to receive project funding is especially high in the technology field of renewables (approx. 37 percent), followed by project participation in the fields of energy systems (approx. 15 percent) and consumers and the public sector (approx. eight percent).
Figure 24: Beneficiaries and funding in the core field of energy research under Horizon 2020 in the period 2014–2019 by country

- **Germany**: €500, Number of beneficiaries: 1,400
- **Spain**: €450, Number of beneficiaries: 1,200
- **UK**: €400, Number of beneficiaries: 1,000
- **Italy**: €350, Number of beneficiaries: 800
- **France**: €300, Number of beneficiaries: 600
- **Netherlands**: €250, Number of beneficiaries: 400
- **Belgium**: €200, Number of beneficiaries: 200
- **Denmark**: €150, Number of beneficiaries: 100
- **Norway**: €100, Number of beneficiaries: 50
- **Sweden**: €50, Number of beneficiaries: 20
- **Finland**: €0, Number of beneficiaries: 1

**Figure 25: Funding under Horizon 2020 in the core area of energy research to beneficiaries from Germany by field (2014–2019)**

- **Renewable energy**: 43.3%
- **IKT/Digitalisation of the energy transition**: 0.8%
- **Cross-sector and horizontal aspects**: 1.0%
- **Financial instruments/investments in renewables**: 1.5%
- **Energy efficiency in buildings**: 2.2%
- **Industry, services and products**: 2.2%
- **Socio-economic research**: 3.5%
- **European Research Area**: 3.2%
- **Consumers and the public sector**: 4.0%
- **Decarbonisation in the use of fossil fuels**: 8.5%
- **Smart city projects**: 8.6%
- **Energy systems (grids and storage systems)**: 19.2%
4. EUROPEAN AND INTERNATIONAL COOPERATION

4.3 International cooperation

In addition to the European level, the Federal Government is also engaged in networking and commitments world-wide.

International Energy Agency (IEA)

The International Energy Agency (IEA) is a central organisation of international cooperation in the energy sector. Its focus in the field of technology and innovation lies on R&D, demonstration and the dissemination of innovative technologies. The IEA unites 30 member states, including the Federal Republic of Germany under the auspices of the Federal Ministry for Economic Affairs and Energy, and eight associated partner states.

The Committee on Energy Research and Technology (CERT) coordinates world-wide energy research activities within the IEA. CERT also supports the participation of German research partners in the international research programmes. The specific cooperation on energy research takes place within multilateral technology initiatives, the Technology Collaboration Programmes, or TCPs for short. TCPs are the IEA’s main instrument for implementing its technology programme with the aim of helping to establish a sustainable, secure and affordable global energy supply system. Collaboration in TCPs is open to all IEA member states as well as interested partners from other countries. Germany is involved in 21 of the total of 38 ongoing TCPs. Within these initiatives, research institutions and private-sector companies have the possibility to engage in cross-border cooperation in all technological fields of non-nuclear energy research as well as in the field of nuclear fusion.

Priorities for energy research in Horizon 2020

Figure 25 shows the distribution of funding to beneficiaries from Germany in the period from 2014 to 2019 broken down by research field.

The figures show that there was a strong focus (43.3 percent) on research and demonstration projects in the technology field of renewables. This field is followed by energy systems – grids and storage (19.2 percent) and Smart City projects (8.6 percent). “Hydrogen” and “fuel cells” do not feature in the figure, as they receive funding from the Fuel Cells and Hydrogen Joint Undertaking – a public-private partnership. In addition, other energy-relevant fields are receiving funding under Horizon 2020, but in other sections, such as materials research and production technologies.
Mission Innovation

Mission Innovation is a global intergovernmental initiative working to develop clean energy technologies and solutions and make them widely available and affordable. Its 25 members (24 countries and the European Union) are aiming to achieve this through a boost in public-sector investment and increased private-sector engagement in this area. It also aims to increase international collaboration and raise awareness of the potential of energy innovations to promote the transformation of supply systems.

Mission Innovation was set up in 2015 in the context of the 21st Conference of the Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC), initially for five years. At the virtual ministerial meeting (MI-5) held in September 2020, the member states agreed to develop a second phase of MI. This will start at the next ministerial meeting (MI-6) in early June 2021. Missions on particularly relevant topics are to be the key content of the second phase, where international cooperation is likely to lead to outstanding added value. In addition, an Innovation Platform is to be developed to further promote international cooperation and an exchange of knowledge.

As part of the Mission Innovation, Germany is focussing on the inherently global issue of hydrogen. It has therefore been involved in two Innovation Challenges in particular, addressing the subjects of hydrogen and converting sunlight. As part of the Converting Sunlight Innovation Challenge, an international roadmap was published, the result of the first phase. The Hydrogen Innovation Challenge has published online information on a platform on so-called Hydrogen Valleys (www.h2v.eu). Germany has also taken part in other activities within the context of the Mission Innovation, for example in the area of electricity grids (see Chapter 2.3.1, page 42).

International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)

The IPHE is an association of 22 partners consisting of member countries and the European Commission. Its mission is to support and promote the commercialisation of hydrogen and fuel cell technologies. To this end, activities in different sectors and departments are internationally pooled and coordinated. Since the IPHE was established, the Federal Government has been involved in this global forum.
4.4 Bilateral research cooperation

As well as networking in the context of European and international institutions and organisations, the Federal Government is also cooperating with other countries at bilateral level in the field of energy research.

Bilateral cooperation in the field of application-oriented basic research

The Federal Ministry of Education and Research funds bilateral research cooperation with selected partner countries in order to support transformation towards a sustainable energy sector and to build up expertise on both sides through an exchange of knowledge. An example is the Client II funding initiative in which the Federal Ministry of Education and Research is promoting demand-oriented research collaborations with selected emerging and developing countries. Funding is provided to develop innovative and sustainable energy solutions which will help to address concrete challenges in the African partner countries. Another example is the project “H2Atlas - Atlas of Green Hydrogen Generation Potentials for Africa”, which explores in detail the potential of green hydrogen production in West and Southern Africa (see project abstract page 49). Within Europe, too, however, research collaborations, for example with France, play a major role in providing Europe with a sustainable energy supply. Cross-border alliances of scientists and businesses are working on projects to deliver solutions in the fields of “converting and storing energy from renewable sources” and “smart grids”. In addition, the Federal Ministry of Education and Research is funding project groups of outstanding international scientists in the field of energy and climate research at German institutions in the Franco-German programme entitled “Make Our Planet Great Again”.

Contribution to bilateral cooperation in the field of nuclear waste disposal

World-wide cooperation in the field of nuclear disposal takes place on the basis of bilateral agreements between the Federal Ministry for Economic Affairs and Energy and foreign repository organisations, through international agreements and on the basis of research cooperation between foreign research centres and German institutions. Contracts currently exist between the Federal Ministry for Economic Affairs and Energy and ROSATOM (RUS), Nagra (CH), SKB (S), Andra (F), Surao (CZ), DOE (USA) and CNNC (CHN).

German scientists are taking part in international research programmes on this subject and are collaborating on projects, some of which are conducted in underground laboratories abroad.

The experience and results will thus be made available for German interests with the following aims:

- to extend knowledge of the characteristics/material properties of the respective host rocks,
- to extend and deepen understanding of the behaviour of the overall system and the processes occurring within it and
- to test and develop techniques and methods for different applications.
5. Other energy-related research activities
5. OTHER ENERGY-RELATED RESEARCH ACTIVITIES
5.1 Federal Government activities beyond the Energy Research Programme

The Federal Government also funds and supports R&D into energy technologies beyond the 7th Energy Research Programme through selected special programmes.

**SINTEG Smart Energy Showcases – Digital Agenda for the Energy Transition**

Between 2016 and the beginning of 2021, experts developed and demonstrated blueprints for the smart energy supply of the future in selected model regions within the framework of the funding programme “Smart Energy Showcases – Digital Agenda for the Energy Transition (SINTEG)”. In the five so-called showcases, more than 300 partners from the energy sector, industry and research, as well as the municipalities, districts and the Länder are working on scalable blueprint solutions for a secure, affordable, and environmentally compatible energy supply involving high proportions of power from renewables. The programme placed a major focus on building smart networks linking up the electricity supply and demand sides, and on the use of innovative grid technology and operating strategies. In addition, recommendations were made on the basis of the practical experience gained in the model regions on how the legal framework could be further developed in the future. SINTEG is regarded as a forerunner of the Living Labs for the Energy Transition. After four years of successful work, the participating teams of researchers presented their results at a final conference at the end of October 2020. That is now to be followed by an evaluation of the model solutions and recommendations for action from the five showcases in a cross-showcase synthesis of the results. This is due to be completed in 2022.

**National Innovation Programme on Hydrogen and Fuel Cell Technology (NIP)**

The National Innovation Programme on Hydrogen and Fuel Cell Technology (NIP) aims to prepare technologies for the market in the context of the current guidelines for research, development and innovation, and to establish an industry in Germany that can compete internationally. Following the first successful phase from 2007 to 2016, competitive hydrogen and fuel cell technologies are to be established in the transport sector and the energy market during the programme’s second phase (NIP 2), which ends in 2026. The Federal Ministry of Transport and Digital Infrastructure is providing an annual funding volume of approximately €80 million to this end. The Transport Ministry is already funding vehicle procurement (including cars, buses, small aircraft, refuse collection vehicles and short-haul passenger trains) and refuelling infrastructure on the basis of funding guidelines for R&D and for activation of the market in the field of hydrogen and fuel cell technology. Work is currently under way on funding guidelines open to all technologies, in particular for trains, buses and utility vehicles with batteries and fuel cells. Hydrogen generation plants for transport applications are already receiving funding. Work is currently under way to draw up new, independent funding guidelines for the funding of generation plants. The Federal Ministry for Economic Affairs and Energy is funding NIP technologies within the framework of the Energy Research Programme.

**Research on alternative drive technologies and fuels**

To achieve the climate protection targets, the energy used in transport must move step by step towards being based on climate-friendly alternative fuels by 2050, particularly more renewables. The Federal Ministry of Transport and Digital Infrastructure is conducting research into both electricity-based fuels and advanced biofuels, for example. Within the framework of the Energy and
Climate Fund, a funding volume of €450 million is available to the Federal Ministry of Transport and Digital Infrastructure for application-oriented pilot and demonstration projects and innovation clusters for the period from 2020 – 2023. The strategic research framework of the Federal Ministry of Transport and Digital Infrastructure covers a wide variety of research activities, demonstrating the fluid boundaries between energy research and mobility research. The strategic research framework defines “Alternative drive technologies and fuels” as an important research priority that is essentially devoted to the question of how alternative drive systems and fuels can be implemented step by step to achieve the climate protection targets in the transport sector, taking into consideration the associated supply infrastructure in the transport sector.

Research within the framework of the electromobility funding guidelines

The electromobility funding guidelines of 14 December 2020 focus on developing municipal and commercial electromobility concepts, providing investment grants for conversion to battery-run electric vehicle fleets and, in particular, R&D projects contributing to climate-friendly mobility and an efficient transport infrastructure. The aim of funding is to establish alternative technologies in the transport sector and to make these more energy-efficient, climate-friendly and environmentally compatible in order to press ahead with the energy transition in the transport sector. A cross-technology and mode-neutral approach can be taken to examining open research questions in collaborative projects. For example, the project aims to develop an environmentally-friendly, customer-friendly and extensive high-power charging (HPC) system that can be connected to available low-voltage networks with grid-friendly functions in urban areas. The aim is to close the gap between the two defined locations, the hotspots (motorway service stations) and the destination. Another aim is to develop a standards-compatible, fast-charging inductive charging system, for example for city logistics. User-friendly charging options can increase the attractiveness and acceptance of electromobility, and thus also the number of electric vehicles in the medium term. Field studies are being conducted into bidirectionally chargeable, regenerative electric vehicles to test the feed-in of energy into power grids (vehicle-to-grid, V2G) and buildings (vehicle-to-home, V2H and vehicle-to-building, V2B). The aim is to develop and realise innovative, economical and sustainable solutions for using electric vehicle batteries.

Funding Programme Model Project Heat Network Systems 4.0

With its funding programme “Model Project Heat Network Systems 4.0”, the Federal Ministry for Economic Affairs and Energy supports model projects for the innovative supply of climate-friendly neighbourhood and district heating using fourth-generation heat network systems. These feature low temperature levels, a proportion of energy from renewable sources of between 50 and 100 percent and generally large heat accumulators for seasonal use.

The programme has existed since 1 July 2017 and was updated at the end 2019.

Specifically, the measure provides for basic funding amounting to 30 percent plus performance-related bonuses (10 percent in each case), and for a climate-friendly and particularly cost-effective grid-connected heat supply using heat networks with a high proportion of renewable energy and waste heat (at least 50 percent). Under this programme, the ministry is also funding heat accumulators and measures relating to the heating grid distribution system. In addition, funding is also provided for the preparation of feasibility studies, network construction, and acquisition and information measures.
From 2021, the programme will be supplemented by a so-called basic programme, which will be adapted to the special circumstances in older existing networks. The aim is to gradually decarbonise existing high-temperature, fossil-fuel-fired networks over a longer period. This process will be implemented by gradually replacing fossil heat generators as part of a long-term transformation plan of the heat grid operator.

5.2 Research funding by the Länder

Since 2008, Project Management Jülich (PtJ) has undertaken an annual survey of the spending by the Länder on non-nuclear energy research on behalf of the Economic Affairs Ministry. According to the current survey (2019), project and institutional funding expenditures of the Länder amounted to a total of more than €244.1 million, with project funding accounting for €135.1 million and institutional funding accounting for €109 million.

As in previous years, funding energy efficiency measures were also the cross-sector funding priority and the supporting pillar of the national energy research policy in 2019. The technology-specific research priority of the Länder was in the area of energy efficiency in the transport sector (€43.7 million). This includes funding for electromobility. This is the funding priority in Baden-Württemberg (€21.7 million) due to the local automotive industry. Research into energy efficiency in the industrial sector, trade and commerce was also funded by the Länder (€17 million in total), especially Saxony (€8.2 million).

The Länder earmarked €13.6 million in funding for research into energy efficiency in buildings and neighbourhoods, with Baden-Württemberg making the largest contribution at €3.4 million.

Technological research funding for systems integration and sector coupling amounted to €88.5 million in 2019, a considerable increase on the previous year. In this connection, special mention must be made of the increase in funding in the
fields of energy storage (€38.9 million euro) and power grids (€11.1 million). While Baden-Württemberg plays a pioneering role in energy storage research, providing funding of €14.3 million, North Rhine-Westphalia in particular has devoted itself to developing reliable smart grids (€4.1 million).

The Länder also stepped up their funding for fuel cell technologies (€10.5 million). In 2019, as has been the case for many years, this research area again received the largest amount of financial support from North Rhine-Westphalia (€4.4 million). At the same time, research funding for hydrogen technologies, which is recorded separately, amounted to a total of €9.9 million. Bavaria leads in this area, providing funding of €4.1 million.

Research funding for regenerative energy amounted to a total of €64.8 million, slightly down on previous years. As in previous years, solar thermal energy and PV is the most important field, receiving €17.5 million in funding. The largest amount of funding is provided in Bavaria and North Rhine-Westphalia, at €4.3 million each. €9.5 million was provided in funding for bioenergy technology, slightly less than the previous year's level. Bavaria in particular is pressing ahead with this technology (€5.4 million). Funding for wind energy research, too, is slightly down on 2018 at €5.6 million. It receives the largest amount of funding in Hamburg and Bremen, due to their location (€1.6 million each).

The increasing level of research activities by the Länder in the field of thermal power plants/CO2 technologies amounted to €5.6 million in 2019. North Rhine-Westphalia in particular earmarked €3.8 million for research into these topics.

As energy supply structures become increasingly complex, a holistic systemic view needs to be taken and valid future scenarios modelled. To meet these demands, the volume of funding for the horizontal research topic Energy Systems Analysis and Modelling rose substantially in 2019, receiving total funding of €18.2 million. North Rhine-Westphalia makes the most significant contribution to research in this field, with €6.5 million.

Alongside all other Länder reports published to this date, the full version of the report on 'Funding for non-nuclear energy research by the Länder in 2019' [in German] can be accessed on the above-mentioned website of Project Management Jülich (PtJ).
### 6. Tables

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

Table 1 | Overview

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<td>0.03</td>
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<td>11.09</td>
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<td>0.07</td>
<td>0.09</td>
<td>0.01</td>
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<td>0.72</td>
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<td>Flexible industrial processes</td>
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<td>Total</td>
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<td>117.63</td>
<td>115.89</td>
<td>112.04</td>
<td>108.08</td>
<td>137.28</td>
<td>156.04</td>
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Table 3 | Disbursements of project funding in the area of “energy generation”

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<tr>
<th>Funding topic</th>
<th>Disbursements in € million</th>
<th>Number of projects</th>
<th>Total funding in € million</th>
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<td>Photovoltaics</td>
<td>66.74</td>
<td>62.73</td>
<td>56.83</td>
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<td>PV technologies</td>
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<td>9.88</td>
<td>7.22</td>
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<td>Quality assurance</td>
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<td>2.80</td>
<td>2.65</td>
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<tr>
<td>Manufacturing technologies</td>
<td>31.33</td>
<td>32.49</td>
<td>28.77</td>
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<tr>
<td>Circular economy</td>
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<td>0.85</td>
<td>0.63</td>
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<td>Systems capability</td>
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<td>2.40</td>
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<td>Basic research into photovoltaics</td>
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<td>14.49</td>
<td>14.83</td>
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<tr>
<td>Other</td>
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<td>0.34</td>
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<td>Wind energy</td>
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<td>52.88</td>
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<td>Wind farm development</td>
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<td>Logistics, installation, maintenance</td>
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<td>7.38</td>
<td>5.25</td>
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<tr>
<td>and operation</td>
<td></td>
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<td>Offshore wind energy</td>
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<td>Production – breeding</td>
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<td>4.77</td>
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<td>Conversion – gaseous</td>
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<td>Conversion – liquid</td>
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<td>Conversion – solid</td>
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<td>materials for energy purposes</td>
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<tr>
<td>Basic research into bioenergy</td>
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<td>Solar thermal power plants</td>
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Table 4 | Disbursements of project funding in the area of “systems integration: Grids, storage, sector coupling”

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### Table 7 | Institutional funding

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Table 8 | 7th Energy Research Programme of the Federal Government

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6.2 Funding for energy research by the Länder

Table 9 | Spending by Länder on non-nuclear energy research

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Table 10 | Spending by the Länder on non-nuclear energy research by topic in 2018 and 2019 in line with new technology classification*

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</tr>
<tr>
<td>Renewable energy – solar thermal and PV</td>
<td>18.39</td>
</tr>
<tr>
<td>Renewable energy – wind energy</td>
<td>6.82</td>
</tr>
<tr>
<td>Energy efficiency in transport (including electromobility)</td>
<td>29.39</td>
</tr>
<tr>
<td>Energy storage technologies</td>
<td>26.42</td>
</tr>
<tr>
<td>Grids (electricity transmission and distribution)</td>
<td>6.43</td>
</tr>
<tr>
<td>Energy efficiency in buildings and neighbourhoods</td>
<td>16.97</td>
</tr>
<tr>
<td>Energy efficiency in industry, trade and commerce</td>
<td>24.04</td>
</tr>
<tr>
<td>Renewable energy – hydropower</td>
<td>0.95</td>
</tr>
<tr>
<td>Renewable energy – marine energy</td>
<td>0.40</td>
</tr>
<tr>
<td>Other sources of renewable energy</td>
<td>19.48</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>220.04</strong></td>
</tr>
</tbody>
</table>

* The technology classification corresponds to the definition of funding topics of the International Energy Agency (IEA)