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2020 Federal Report on Energy Research

Research funding for the energy transition

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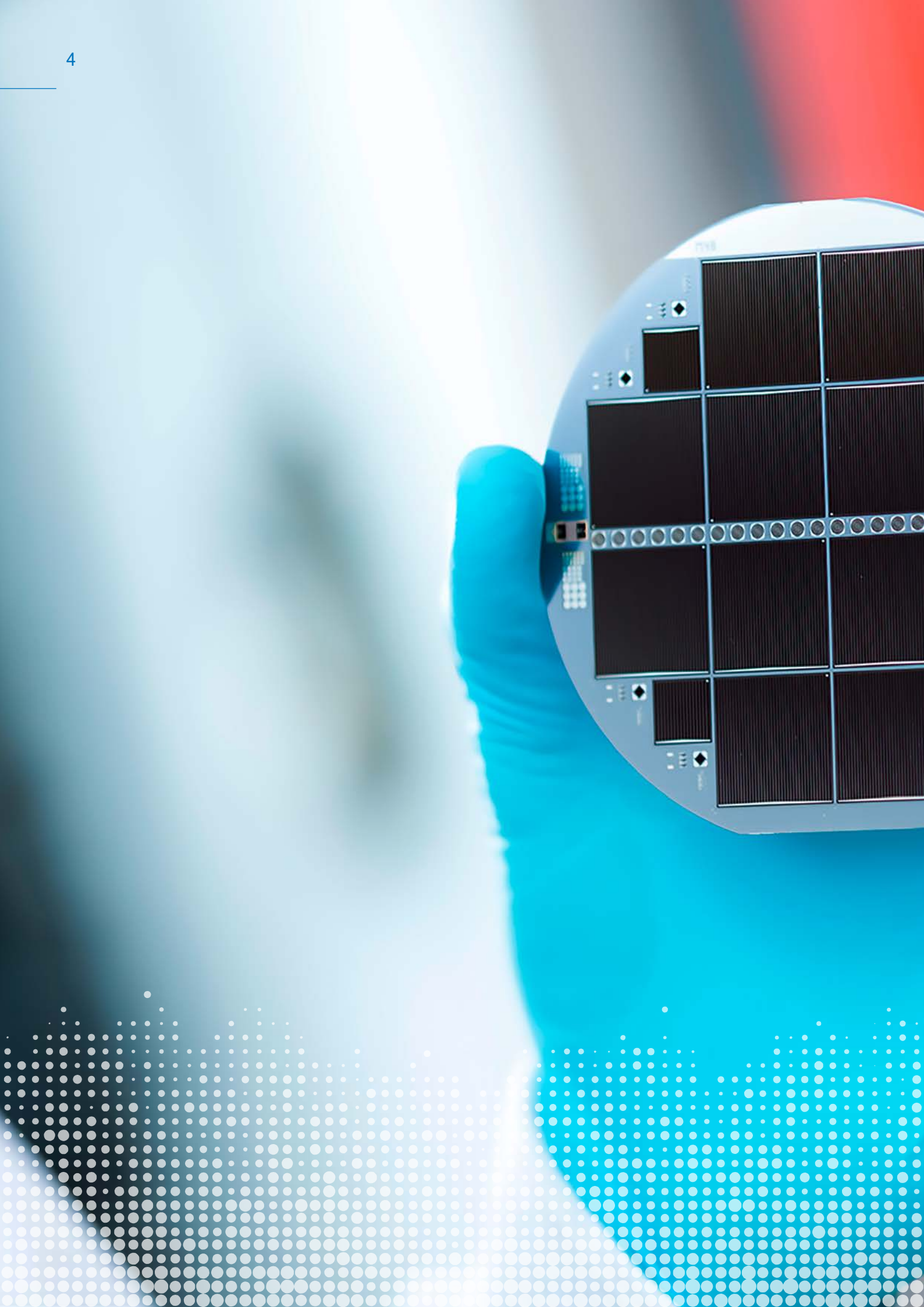


1. Research funding for the energy transition

1.1 The 7th Energy Research Programme of the Federal Government

1.1.1 Objectives and measures

Research and development forms the basis for tomorrow's new, cheap, market-ready energy and efficiency technologies. In its energy transition policies, the Federal Government has committed to challenging national, European and international energy and climate targets. The proportion of renewable energy needs to increase further in all consumption sectors, not least in view of the goal of attaining greenhouse gas (GHG) neutrality in 2050. The decision was taken in the 2030 Climate Action Programme to significantly step up the expansion of renewable energy and to have renewables cover 65 percent of electricity consumption by 2030. At the same time, consumption must be reduced by means of efficiency measures. In addition, the supply infrastructure is to be expanded further and to be even better networked and synchronised. This results in a great need for advances in technology and forward-looking innovations, which will make a success of the deep-reaching restructuring of the energy system. Energy research is therefore a strategic element of energy policy and helps to make the German economy more resilient.

In the 7th Energy Research Programme, the Federal Government has comprehensively oriented the funding for energy research to the needs of the energy transition and placed a focus on the swifter transfer of innovations into practice. Energy research promotion is thus an important measure to implement the energy transition and to mitigate climate change. In the 2030 Climate Action Programme, the Federal Government has therefore confirmed that energy research must be boosted. Due to the long run-up periods from research to broad-based application, it is necessary – in view of the 2050 target date – to foster application-based energy research and to dovetail it closely with further measures (and particularly the Regulatory Sandboxes for the Energy Transition).

Energy research also plays an important role in the 2050 Energy Efficiency Strategy. There are good reasons why, in the 7th Energy Research Programme, the energy transition in the consumption sectors is mentioned first, in line with the "efficiency first" principle.

Green hydrogen is to become an important element of Germany's decarbonisation strategy. The decarbonisation strategy aims to avoid the use of fossil carbon-based fuels. To this end, the entire value chain (technologies, components, generation, storage, infrastructure and logistics) must be developed further in order to make green hydrogen available and usable at a low cost. The Federal Government's Hydrogen Strategy is intended to help expand the pioneering role of German firms in the field of climate-neutral hydrogen technologies, to establish new value chains for the German economy, to attain the climate targets, and to trigger positive developments in developing and emerging economies. As a strategic element in Germany's energy and industrial policy, research plays a central part in the attainment of these goals. By deploying long-term research and innovation funding that covers the entire hydrogen value chain – from storage, transport and distribution all the way to its use – the Federal Government aims to make progress on these key-enabling technologies for the energy transition.

Strong partnerships between companies and research establishments have proven their worth as a central instrument to promote energy research in Germany. In such collaborative projects, consideration is given from the outset to which research questions are particularly relevant to the practical implementation of the energy transition; at the same time, the participation of the business community means that the transfer of the innovations can take place whilst the project is still ongoing. In order to speed up the transfer of innovations even further, the Federal Ministry for Economic Affairs and Energy (BMWi) launched the Regulatory Sandboxes for the Energy Transition last year, establishing them as a new pillar of energy research (see Chapter 1.2.4). The Ministry's energy research networks and the communication of research also aim to accelerate the transfer of innovation (see Chapter 1.2.3). In the funding area covered by the Federal Ministry of Education and Research (BMBF), the Kopernikus projects are a central instrument for application-oriented basic research.

1.1.2 Development in funding

The Federal Government's 7th Energy Research Programme has set ambitious targets so that innovations can drive the energy transition forward. Whilst the private sector is primarily responsible for research, development and the demonstration of energy and efficiency technologies, public research funding aims to support not only basic research, but also applied research, technological advances and innovations by companies, research establishments and higher education institutions. Moreover, public-sector funding makes an important contribution towards measures to mitigate risks affecting the whole of society, thus enabling scientific work to pursue bold ideas for innovations.

Under the 7th Energy Research Programme, the Federal Government intends to make funds available totalling around €6.4 billion in the 2018–2022 period. This means that energy research is being given an additional boost compared with the 6th Energy Research Programme. In 2019, the Federal Government invested €1.15 billion in energy research. This represents an increase of about 9 percent compared with the previous year. Around €704 million of this went towards project funding, and around €410 million took the form of institutional funding. The Federal Government is thus underlining the indispensable contribution made by research and development to the energy transition and climate change mitigation.

1.1.3 Evaluations and performance review

When the Federal Government implements a policy action such as the Energy Research Programme, taxpayers' money is used. In such cases, national rules require a review to ensure that the public's money is being used efficiently. Under European rules, the effects on competition and trade between Member States must be investigated.

Evaluations offer wide-ranging possibilities for this, and therefore play an important role in ensuring that the funding policy for energy research is efficient and compliant with European rules. Also, the publication of the findings from evaluations leads to greater transparency for the general public. At the same time, evaluations provide valuable pointers for the design of future funding measures, in terms both of the strategic and substantive orientation, and of administrative procedures.

An on-going evaluation of the 7th Energy Research Programme is being prepared, relating to applied energy research in line with the rules on State aid. Specifically, all of the funding measures of the Federal Ministry for Economic Affairs relating to applied non-nuclear research within the 7th Energy Research Programme are to be evaluated in accordance with the call for proposals "Applied non-nuclear research funding in the 7th Energy Research Programme 'Innovations for the Energy Transition'". This on-going evaluation is therefore intended not only to verify the effectiveness of the aforementioned funding measures against the background of the 7th Energy Research Programme, but also to consider the economic viability of the attainment of the goals. Here, the study is to consider the impact of the funding on various target groups.

Figure 1: Overview of funding in 2019 in the 7th Energy Research Programme
(data cf. Table 1, p. 73)

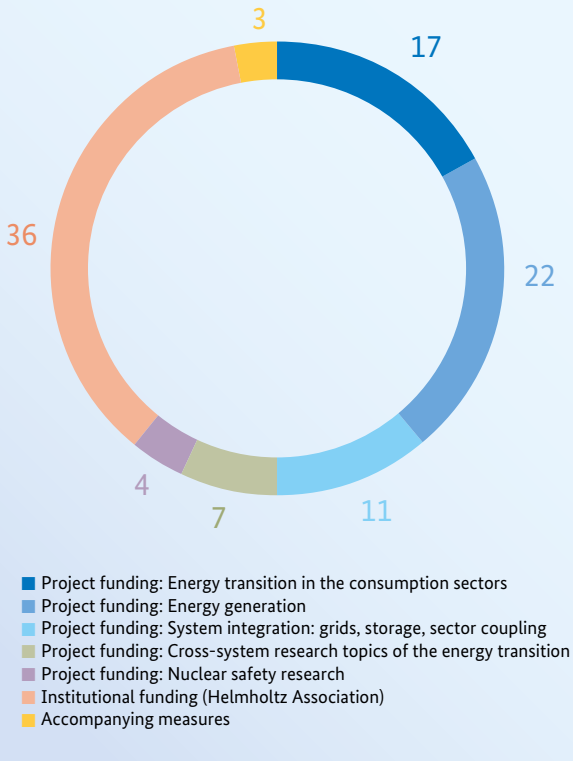
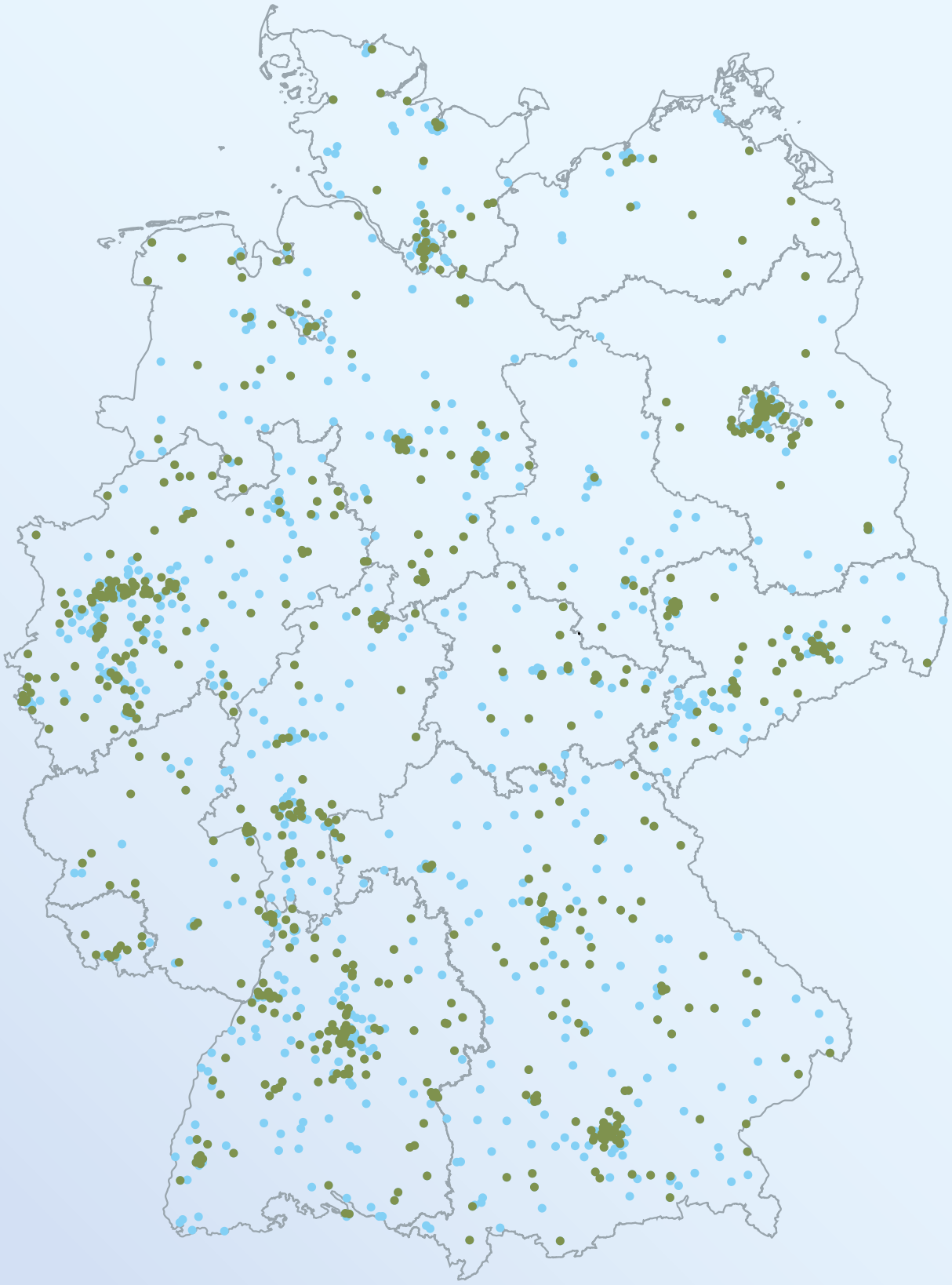


Figure 2: Overview of the ongoing (blue) and newly approved (green) projects of non-nuclear energy research in Germany



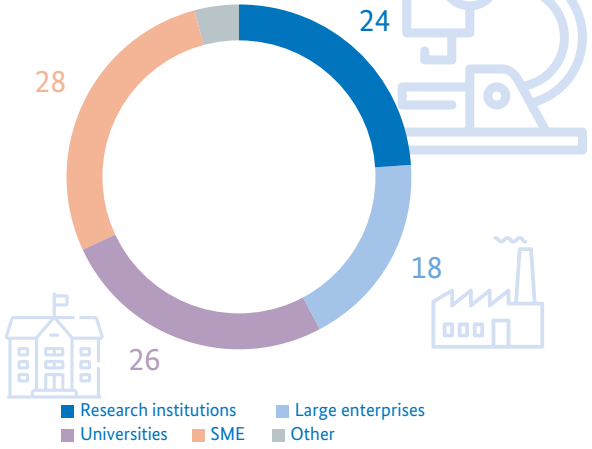
Source: GeoBasis-DE / BKG 2019 (data altered) / Geodata of the BKG for addresses of the implementing bodies from the BMBF profi-database / Projektträger Jülich

Figure 3: Energy research funding at a glance

€1.148 billion

Total funding in the 7th Energy Research Programme in 2019

Beneficiaries of newly approved projects in 2019 in percent



In 2019, the Federation approved

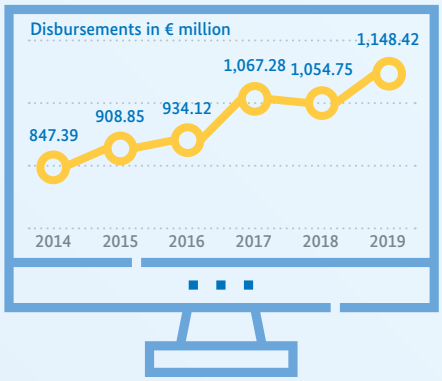
1,622

new projects

The Federal Government funded

5,903

projects in the 7th Energy Research Programme in 2019



25 percent

Rise in funding compared to 2014 and 9 percent rise compared to 2018

€279.3 million

Funding from companies towards newly approved research and development projects in 2019 (non-nuclear energy research)

€97.3 million

Funding for SMEs for non-nuclear energy research projects newly approved in 2019 (based on German SME definition)

1.2 Structures of energy research policy

1.2.1 Tasks of the federal ministries

The Federal Government's 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 (BMEL). It is based on an inter-ministerial, thematically oriented structure. The Federal Ministry for Economic Affairs and Energy is responsible for the programmatic orientation of energy research policy, and thus has the lead responsibility for the Energy Research Programme. Further to this, the Federal Ministry for Economic Affairs and Energy represents the Federal Republic in European and international bodies working on energy research policy.

The division of responsibilities for the project funding is in line with the concept of the technology readiness level (TRL) of the subjects and technologies 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 projects of application-oriented basic research. These correspond to TRLs 1 to 3. Also, the ministry funds young scientists, academic exchanges and scientific cooperation at EU level and with international partners. The Federal Ministry for Economic Affairs and Energy is responsible for applied research and development and for the Regulatory Sandboxes for the Energy Transition (TRLs 3 to 9). It also provides project funding for multilateral research cooperation. The Federal Ministry of Food and Agriculture, in contrast, focuses on applied research in the field of biomass utilisation for energy purposes.

Furthermore, the Federal Government provides institutional funding. Together with the Federal Ministry of Education and Research, the Federal Ministry for Economic Affairs and Energy is responsible for the strategic orientation of the Research Field 'Energy' of the Helmholtz Association. The institutional funding for the Helmholtz Centres (except for the German Aerospace Center (DLR)) is provided by the Federal Ministry of Education and Research. The Federal Ministry for Economic Affairs and Energy has taken over responsibility for institutional support for the German Aerospace Center.

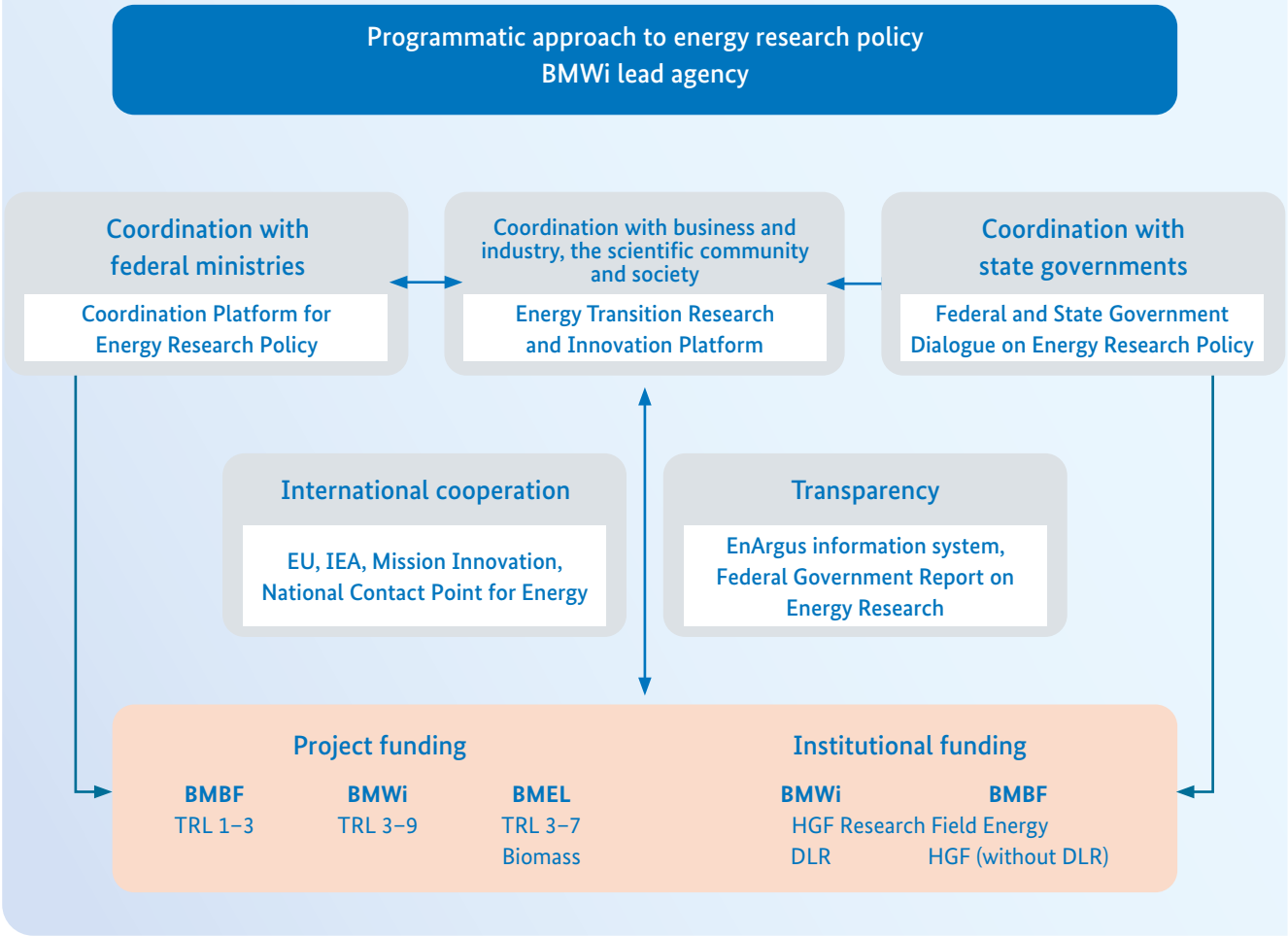
1.2.2 Coordination of energy research funding

The Federal Government's support for energy research not only takes place via the institutional and project-related funding within the framework of the energy research programme: various other programmes and measures also exist to strengthen this strategically important area. An intensive dialogue and coordination between the federal ministries, with the *Länder*, the municipalities, and also with the business community as well as other stakeholders is needed to ensure that all the instruments work smoothly and successfully together. Thematic cooperation and comprehensive coordination can create valuable synergies, which have a lasting and positive impact on the energy transition and the restructuring of Germany's energy supply system. In particular, close coordination is required with the Federal Ministry of Transport and Digital Infrastructure (BMVI) and the Federal Ministry of the Interior, Building and Community (BMI), as the Transport Ministry is responsible for mobility and transport, both of which depend on energy, and the Interior Ministry is responsible for policy on buildings. In view of its responsibility for climate change mitigation, the strategic orientation of energy research is also coordinated closely with the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

1.2.3 Networking at national level

The dialogue between policymakers, researchers, the business community and civil society is crucial to the success of the energy transition. Therefore, the Federal Ministry for Economic Affairs and Energy has set up a dialogue forum for these target groups: the Energy Transition "Research and Innovation Platform" (R&I Platform). The platform hosts a discussion of current trends, developments and strategic approaches to energy research by representatives of federal and *Länder* governments and selected stakeholders from research establishments, universities, businesses, municipalities and associations. The platform also provides an overarching structure for the energy research networks of the Federal Ministry for Economic Affairs and Energy, bringing them together and coordinating them.

Figure 4: Institutional setup for energy research



The energy research networks are open networks of experts, and are tasked with accelerating the transfer of research findings into practice and with facilitating a dialogue between policymakers, research and practitioners in the various priority areas. Also, the dialogue with the experts ensures that the funding strategies of the Federal Ministry for Economic Affairs and Energy are highly practical, and it also produces ideas for new topics and priorities. The research networks were set up in 2015 and bring approximately 4,000 members together. Not least, they were closely involved in the consultation process for the 7th Energy Research Programme, in order to gather valuable input for the substantive details. At present, there are eight research networks, on bioenergy, construction for the energy transition (buildings and neighbourhoods), energy systems analysis, renewable energy, flexible energy conversion, industry and commerce, electricity grids, and start-ups.

The start-ups research network is the youngest network, highlighting the important role that start-ups can play for the energy transition by providing ideas and innovations. Thanks to their dynamic structure, they can significantly expedite the transfer of research into practice. Young entrepreneurs support the reorientation of the energy system with innovative products, services and business models, thus tapping fresh potential. Many of them are working in interdisciplinary fields of research, such as sector coupling or digitisation, or are focused on socio-economic questions. These cross-cutting issues are crucial for the interplay of the various technologies and a smart, connected energy supply system. The Federal Government therefore also flags up the significance of start-ups in its 7th Energy Research Programme.

Coordination of research policy with the *Länder* takes place via the annual "Federal-*Länder* Dialogue on Energy Research". This ensures that the substantial funding provided by the *Länder* for energy research promotion is harmonised with the federal funding. At the same time, the feedback from the *Länder* is crucial for the strategic development of research funding within the Federal Government's Energy Research Programme.

1.2.4 Regulatory Sandboxes for the Energy Transition

The Federal Ministry for Economic Affairs and Energy has established the "Regulatory Sandboxes for the Energy Transition" as a new funding pillar in the 7th Energy Research Programme. The sandboxes stand at the threshold between application-related energy research and practical applications in the energy industry, and thus support the important goal of transferring technology and innovation from the research to the business community and people's day-to-day lives. They focus on examples of systemic challenges in clearly-defined, large-scale projects and process research issues, which play a key role in the implementation of the energy transition.

The Regulatory Sandboxes for the Energy Transition can test out innovative technologies in both action and interaction with one another, doing this on an industrial scale in real-life conditions, e.g. in a neighbourhood, one or several towns and cities, or across several *Länder*. They are therefore larger in scale and cover broader topics than demonstration projects, and can also embrace aspects of "regulatory learning". The experience gathered thereby can benefit the far-reaching overall restructuring of Germany's energy system. These include technologies for sector coupling, large thermal storage facilities for the zero-carbon and sustainable use of existing energy infrastructure, technologies for making use of CO_2 and the smart networking of energy infrastructure in climate-neutral urban neighbourhoods. They are designed to be large-scale innovation projects with key industrial policy goals. Regulatory Sandboxes prepare new technologies and solutions for the market, and thus serve as pioneers.

The Federal Ministry for Economic Affairs and Energy plans to provide up to €100 million euros of funding per year towards the Regulatory Sandboxes for the Energy Transition between 2019 and 2022. Unlike the ministry's traditional project funding, in which research projects are generally designed to last three years, the ministry funds the Regulatory Sandboxes for periods of up to five years. This includes a one-year to three-year test phase, and a monitoring phase. Further to this, a new funding guideline, which expands the scope under State aid rules for energy research to include the Regulatory Sandboxes for the Energy Transition, has been sent to the European

Commission in the course of prenotification. This will make it possible to give more funding towards operational expenditure and to extend the length of the projects to up to ten years (two phases of up to five years each).

In February 2019, the Federal Ministry for Economic Affairs and Energy launched the first competition for ideas for Regulatory Sandboxes for the Energy Transition. The focus of this first round was on concepts for "sector coupling and hydrogen technologies", "large-scale energy storage in the electricity sector" and "energy-optimised neighbourhoods". Economic Affairs Minister Peter Altmaier announced the 20 winners of the competition in July 2019. In December 2019, the ministry approved the first regulatory sandbox, "SmartQuart". The project was launched in January 2020 and will foster structural change in three urban areas. "SmartQuart" brings together key stakeholders in a neighbourhood, from residents to energy suppliers and local technology providers. The aim is to establish a climate-neutral energy supply in the model regions, and to network the energy infrastructure smartly and efficiently.

1.2.5 Transparency and communications

Major processes of structural change like the energy transition need backing from society if they are to succeed. Transparency is an important principle if advances in technology are to meet with public acceptance and to be integrated into people's day-to-day lives, in private life, in business and in public infrastructure. Further to this, if research findings are to be transferred into practice, the business community needs to be involved in publicly funded innovations. The Federal Government therefore attaches great importance to using appropriate information services to communicate its funding activities to the public and the expert community.

Communicating research creates transparency in the use of public funding and explains the goals and priorities of the funding policy. It illustrates forward-looking trends and reports on publicly funded research work. It maps out the paths taken by innovations to the market, which have been made possible thanks to the project funding. It builds up knowledge about the interrelationships in the energy system and the impact of innovations. The transparent provision of information creates a basis on which the best possible use can be made of the findings from the research and development funded with the tax-payers' money in the interest of a modernisation of the infrastructure. This means that communication of research is a central task within the Federal Government's energy research policy.

On the www.energieforschung.de website, the Federal Ministry for Economic Affairs and Energy offers a central portal with a broad range of information and facts about energy research for the interested public and for experts. The website is complemented by specialist websites going into greater depth about specific thematic priorities. These inform the expert community, from scientists to users, about the specific goals, challenges and research findings in the various funding priorities, and show specialists precisely how relevant the findings are for the energy transition. EnArgus, the central information system (www.enargus.de) of the Federal Ministry for Economic Affairs and Energy, also offers a wide-ranging insight into all the projects funded by the Federal Government under the energy research programmes. All of the communication measures aim to provide a wide range of information in order to establish a link between the scientific research and practical uses. In this way, a valuable boost is given to the deployment of newly developed technologies, services, systems and approaches in companies, municipal utilities and municipalities, and in the lives of the general public.

1.3 European and international networking

Germany's energy supply infrastructure is not a closed system which terminates at the national borders. Rather, it interacts with our neighbouring and partner countries. This exchange creates interactions and a large potential for innovation in the form of cooperation and joint strategies for action. Such joint approaches to solutions are particularly needed in view of the massive challenges caused by climate change. This makes cooperation on science and research all the more necessary in Europe and worldwide. On the one hand, this involves cooperation between states, but partnerships at international level between research establishments, universities and companies also offer great potential for an efficient and environmentally friendly energy supply.

1.3.1 European cooperation

The European Union is not just one of the most successful peace projects of our time: it is also a driving force for growth and progress in all its Member States and its neighbouring and partner countries. This is particularly true in the field of energy, since the supply of electricity and heat forms the basis for economic and social prosperity and stability.

When it comes to the funding of research and development in Europe, the European Union has established an effective package of measures under the Horizon 2020 framework programme (see Chapter 4.2). Its total budget amounts to some €80 billion. Of this, €6 billion is allocated to project funding for non-nuclear energy research. German applicants have so far received around €393.6 million in funding from the Horizon 2020 programme. This corresponds to a share of around 13.7 percent. The European Union's Horizon 2020 programme boosts Europe's international competitiveness, e.g. via innovations for the modernisation of local infrastructure, or via the resulting potential for exports.

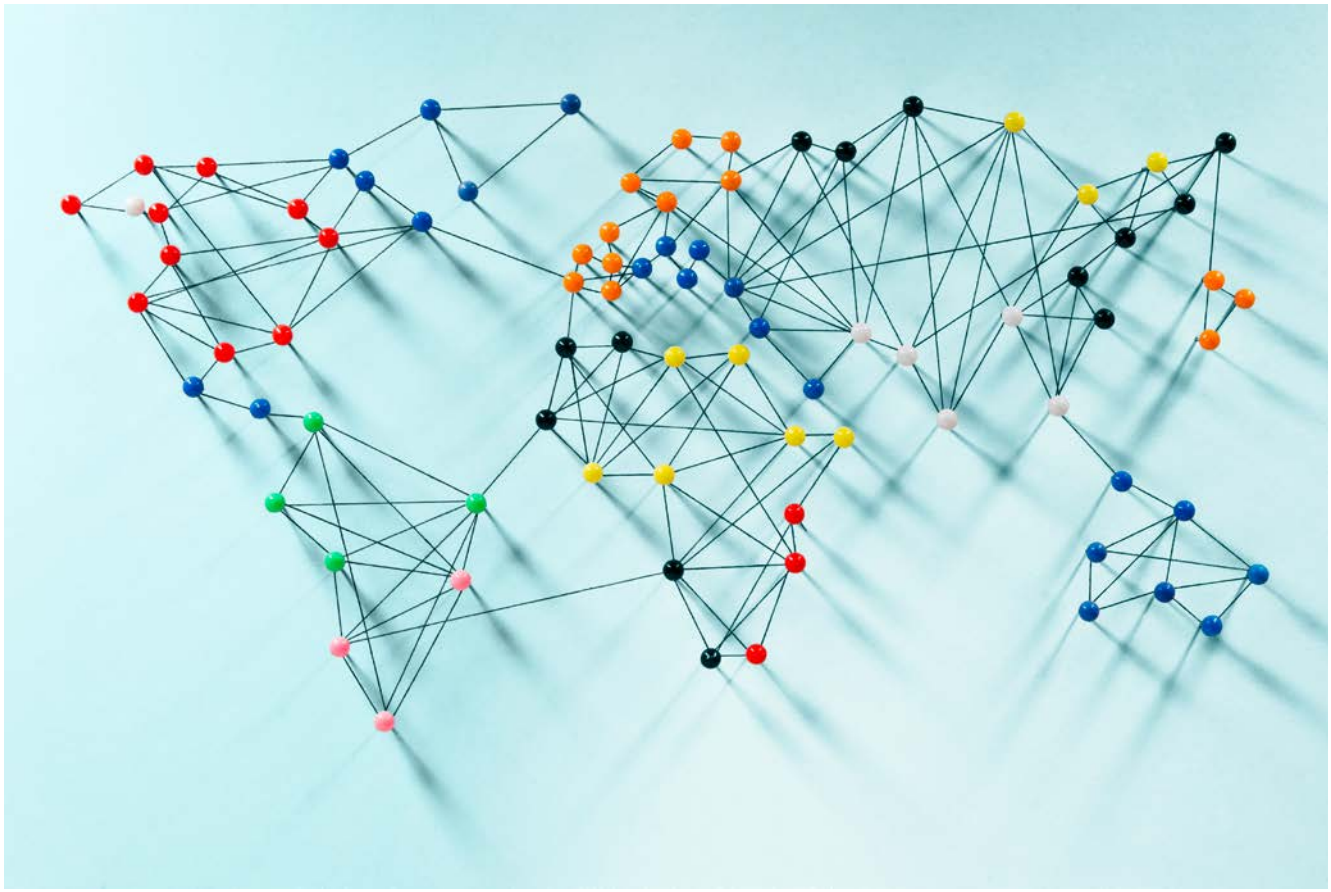
By supporting Horizon 2020, the Federal Government is playing a major part in helping to progress the European dimension of the energy transition. One aspect of this is the National Contact Point for Energy. On behalf of the Federal Ministry for Economic Affairs and Energy, it provides research establishments, universities, companies and SMEs with information about the content and priorities of the programme with regard to energy research, and provides advice on the identification of suitable funding opportunities and on the application process.

The EU's funding measures are backed by the European Strategic Energy Technology Plan (SET Plan). It sets out the guidelines for a rapid and competitive development of low-carbon technologies. The SET Plan supports the cooperation between the various Member States, industry and research institutions. The coordination of research activities is intended to generate synergies and cut costs. The ten key actions agreed in the SET Plan take up the goals of the Energy Union and form the basis for the 'energy' thematic priority in the EU research framework programme. The energy policy goals from the EU's Green Deal feed into the future development of the SET Plan.

The dialogue process for the follow-up programme to Horizon 2020 commenced in 2019. From 1 January 2021, Horizon Europe is to continue the intensive funding of research and development at European level. Energy research will again be an important pillar in this programme.

1.3.2 International cooperation

The development of innovations is increasingly a cross-border affair, and more and more frequently is the outcome of international cooperation and joint efforts by interdisciplinary, supranational and international research teams. This offers great opportunities for Germany in particular, with its multilayered and highly enmeshed scientific infrastructure. For this reason, the Federal Government has committed in the 7th Energy Research Programme to an even more intensive networking of research and development at European and international level. In this way, it takes account of the global dimension of the energy transition, because national approaches alone will not be able to achieve a climate-friendly energy supply. The focus is on a holistic, application-oriented approach so that viable innovations can be rapidly transferred into practical use.



International Energy Agency (IEA)

The International Energy Agency, with its 30 Member States, supports research, development and the use of climate-friendly energy technologies around the world. The IEA is an independent organisation within the OECD (Organisation for Economic Co-operation and Development) and aims to support its members on issues of energy security and the establishment of sustainable energy systems. In this context, the IEA also promotes international cooperation on research, development and the market entry of new energy technologies. Looking beyond the group of its members, the IEA has also been building up cooperation with non-OECD member countries, and particularly with major emerging economies, for some years now. In this way, the IEA aims to foster the deployment of climate-friendly energy technologies worldwide.

The Governing Board is the IEA's main decision-making body. Supported by another programming body, the CERT (Committee on Energy Research and Technology), it develops and implements research, development and innovation strategies and coordinates the various measures of the participating countries.

An Experts Group on Energy Technology R&D Priority Setting and Evaluation (EGRD) advises the CERT. The various topics are covered by four working parties, the End Use Working Party (EUWP), the Renewable Energy Working Party (REWP), the Fossil Fuels Working Party (FFWP) and the Fusion Power Coordinating Committee (FPCC). They support the work done in the Technology Collaboration Programmes.

The Technology Collaboration Programmes (TCPs) are multilateral initiatives and support research-based and market-related activities to implement the IEA's Energy Technology Programme. Germany is actively involved in 22 of 38 current TCPs of the IEA. The Federal Ministry for Economic Affairs and Energy has the lead responsibility for the German contribution.

Mission Innovation

Mission Innovation was set up in 2015 during the COP21 climate framework agreement conference in Paris. 24 countries belong to it, including the Federal Republic of Germany, as well as the European Union. The countries involved in Mission Innovation have

committed to doubling public investment in research and development for clean energy by 2021. Together, they wish to promote innovations for a climate-friendly, efficient and affordable energy supply around the world. Mission Innovation provides information about its goals, progress and initiatives at http://mission-innovation.net.

In structural terms, the initiative consists of eight Innovation Challenges.

- Innovation Challenge 1 (IC1): Smart grids
- Innovation Challenge 2 (IC2): Off-Grid Access to Electricity
- Innovation Challenge 3 (IC3): Carbon Capture
- Innovation Challenge 4 (IC4): Sustainable Biofuels
- Innovation Challenge 5 (IC5): Converting Sunlight
- Innovation Challenge 6 (IC6): Clean Energy Materials
- Innovation Challenge 7 (IC7): Affordable Heating and Cooling of Buildings
- Innovation Challenge 8 (IC8): Renewable and Clean Hydrogen

In the context of Mission Innovation, Germany is focusing on the inherently global issue of hydrogen. In this spirit, Germany is also participating in discussions about an extension of Mission Innovation beyond the five-year term agreed in 2015 into a potential second phase.

In September 2019, the European Joint Programming Platform ERA-Net Smart Energy Systems and Mission Innovation launched a first joint call for proposals on integrated energy storage systems (MICall19). Also, Germany is involved in the MI Champions Programme, which rewards people whose ideas contribute to the success of the global energy transition.

Bilateral initiatives/European cooperation

Bilateral cooperation with various European countries takes place in the funding area of the Federal Ministry of Education and Research. In 2019, for example, the projects of the Franco-German funding initiative for a sustainable European energy supply were launched. 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 to this, the ministry 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". The initial conference in Paris in October 2019 attracted international attention.

Working together with the Greek General Secretariat for Research and Technology (GSRT) of the Ministry of Education, Research and Religious Affairs, the Federal Ministry of Education and Research is strengthening German-Greek cooperation on energy research. The funding measure builds on the successful first German-Greek research programme from 2013, and highlights the continuity of the cooperation. Eight bilateral project associations have also been addressing various common challenges in the energy field since 2018, searching for innovative solutions for an efficient, affordable and environmentally friendly energy supply for Greece, Germany and Europe. In addition to technical aspects, a systemic approach is also being taken to economic and social challenges of the energy transition in Europe.

Further to the work within the European Union, the International Energy Agency and Mission Innovation, the Federal Government is also engaged in bilateral and multilateral cooperation with selected partner countries in the field of international promotion of research and innovation.

The Federal Ministry of Education and Research is working successfully in more than 15 African countries in the context of the centres entitled "WASCAL" (West African Science Service Centre for Climate Change and Adaptive Land Management) and "SASSCAL" (Southern African Science Service Centre for Climate Change and Adaptive Land Management). The countries of ECOWAS (Economic Community of West African States) and SADC (Southern African Development Community) are also being brought on board in the course of the work on the atlas showing the potential of green hydrogen. This means that the initiative is reaching 31 countries, or more than half of the population of Africa. The atlas showing the potential of green hydrogen will pinpoint where in Africa green hydrogen can play a key role in the local energy supply and in exports to Germany. The production of an interactive regional map forms the basis for forward-looking demonstration projects with the industrial and scientific communities in Africa. The Federal Ministry for Economic Cooperation and Development

is supplementing the atlas with analyses in additional countries and by preparing development policy measures. In the Waste2Energy project funded by the Federal Ministry of Education and Research, German research establishments and companies are working with Ghanaian universities and companies to develop a novel hybrid photovoltaic biogas pyrolysis facility. This facility uses solar energy and various decomposition processes to transform waste into green energy.

In the "START" focus project, German research establishments are working closely together with Australian partners on the transformation to zero-emission energy systems in Germany and Australia, looking particularly at the common challenges and the respective technology and policy options. Scenarios from the German-Australian Energy Transition Hub are now highlighting how Australia could increase its share of renewable electricity from 20 percent today to 200 percent. Some of this would then be available to generate exportable hydrogen from renewable energy.

2. Project funding

2.1 Energy transition in the consumption sectors

2.1.1 Energy in buildings and neighbourhoods

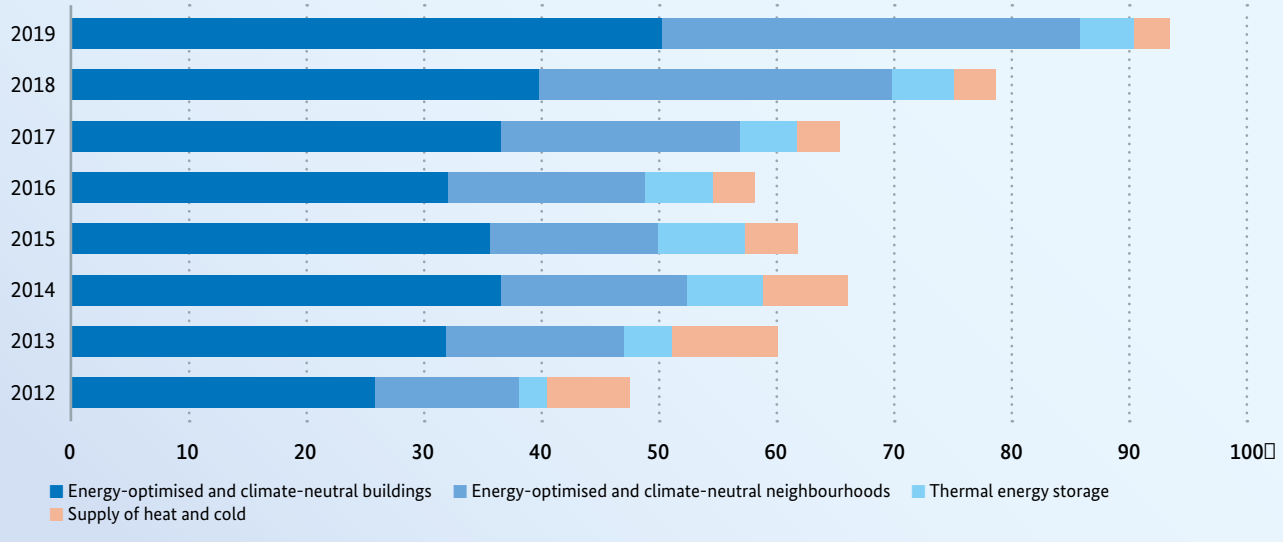
The measures implemented so far have already achieved clear progress in the building sector in terms of climate change mitigation and overall energy efficiency. Overall energy efficiency in the building sector improved by more than 25 percent between 2008 and 2018. Greenhouse gas emissions in the building sector were cut by around 44 percent between 1990 and 2018. In 2018, renewable energy accounted for more than 14 percent of final energy consumption for heating and cooling. This means that Germany's target of 14 percent for 2020, as set by the Renewable Energies Heat Act, which preempted the Renewable Energies Directive (2009/28/EC), was achieved as early as 2018. The implementation of the measures in the 2030 Climate Action Programme aims to attain the 2030 targets in the building sector. Research, development and demonstration of innovative technologies and concepts helps to achieve these goals and paves the way towards climate neutrality.

Funding priorities and scientific advances

The research being done into energy-optimised building considers details of individual buildings and ensembles, as well as interfaces to neighbouring buildings and the surrounding area. Key aspects are innovations in building and other materials and the continued development of technical components and systems for buildings. In the neighbourhood context, buildings can be used as energy sinks, energy sources or energy storage units for the local energy supply system. System solutions for better energy efficiency and improved integration of renewable energy are important research topics with a view to progressing the energy transition in neighbourhoods. In order to ensure that innovations can swiftly be transferred into practice, and to identify and overcome obstacles, funding is going into model realisations of ambitious projects. In future, buildings and neighbourhoods are increasingly to be able to interact with the grids flexibly and in line with their needs, and to deliver generation, energy storage and distribution functions in the energy system. Appropriate grids and energy management infrastructure are needed so that local and district heating can be delivered in an energy-efficient manner. Heat grids need to be expanded, modernised and digitally networked.

The Federal Government is pooling the funding available for research, development and demonstration in the field of energy-efficient buildings and neighbourhoods in the "energy transition construction" research initiative. Along with funding announcements and specialised websites, this also includes the "energy transition construction" research network. This brings experts from research and business together, giving them more opportunities to share experience.

Figure 5: Funding for energy efficiency in buildings, neighbourhoods and urban areas in € million
(Data cf. Table 2, p. 74)



The intensive dialogue makes it possible to transfer research findings into practice and to develop research promotion.

The strengthening of the transfer of technology and innovation is also a central aim of the Regulatory Sandboxes for the Energy Transition competition for ideas, which was launched in spring 2019 (see Chapter 1.2.4). Innovations are to be tested in a real-life environment, enabling blueprints to be developed for the restructuring of the energy system. The first regulatory sandbox, "SmartQuart", started operations in December 2019. Based in Essen and Bedburg in North Rhine-Westphalia and Kaisersesch in Rhineland-Palatinate, the "SmartQuart" regulatory sandbox represents typical neighbourhoods in rural and urban areas where people live close together. A distributed, sustainable and economic energy supply is to be implemented within and between neighbourhoods at these sites. To this end, the key local stakeholders are brought together, from residents to energy suppliers and local technology providers.

Other examples of major neighbourhood projects are the flagship projects in Esslingen, Heide, Kaiserslautern, Oldenburg, Überlingen, Stuttgart and Zwickau. Since 2017, they have been jointly funded for five-year periods by the Research and Economic Affairs Ministries under the "Solar Construction/Energy-efficient Cities" funding initiative. The systemically designed projects for energy-optimised buildings and energy infrastructure bring all the key stakeholders in research and implementation on board. The correspondingly broad-based consortia involve municipalities, research establishments, representatives of residents, and companies such as energy suppliers or house-building companies. The aim is to cut energy consumption, to press ahead with linking up the sectors of electricity, heat and mobility, and to gradually decarbonise the entire system by integrating renewable energy.

Project funding

In the field of energy in buildings and neighbourhoods, the Economic Affairs and Research Ministries provided approximately €93.51 million in funding for 911 ongoing projects in 2019. In 2019, the ministries also approved approximately €117.23 million to fund 207 new research projects (see Figure 5).

PROJECT ABSTRACT

Rendering Block B of Neue Weststadt Esslingen

EnStadt: Es_West_P2G2P – Neue Weststadt Esslingen climate-neutral neighbourhood
Green hydrogen for the urban energy transition

An urban neighbourhood is being built on a former freight railway station site in Esslingen with office and commercial zones, a new building for the higher education institution, and around 500 dwellings. Some parts have already been completed, so that the first tenants have already moved in. The project aims to realise a virtually climate-neutral neighbourhood. The integral energy supply concept developed for this is based on the coupling of the building (electricity, heat, cooling), mobility and industrial sectors. At the heart of the system is an electrolyser which converts surplus electricity from wind and solar installations into green hydrogen. This is fed into the local gas grid, used by industry or supplied to H_2 filling stations. If electricity is needed again, the hydrogen can be converted back. The waste heat produced during electrolysis is used via a local heating grid to meet the need for heating in the buildings. Electric buses using overhead lines are already integrated into Esslingen's local public transport system. More hybrid electric buses will be purchased at the end of the year. The networking, control and operational optimisation of the overall energy system is handled by a smart energy management system.

Beneficiary: The town of Esslingen a. N. and eight other partners
Funding ID: 03SBE115A-I
Estimated funding: approx. €10.6 million (Economic Affairs Ministry), approx. €2.5 million (Research Ministry)
Project duration: 2017 – 2022

PROJECT ABSTRACT

EG2050: Urban SolarDecathlon – planning and implementation of the Solar Decathlon Europe international building energy competition in an urban context coupled with scientific backing

The student competition is being held in Germany for the first time: the challenge is to implement the energy transition and climate action in an existing urban neighbourhood.

The solar house Rooftop by students of the Technische Universität Berlin and the Berlin University of the Arts at Solar Decathlon Europe 2014 in Versailles, France.

The Solar Decathlon Europe 21 is being realised in the Mirke district of Wuppertal. It is typical of an urban neighbourhood in Germany and Europe: the main architectural challenges here are rebuilding, adding to buildings, increasing the number of storeys, and closing gaps between buildings. For the first time, the competition is focusing on the energy transition and climate action in an existing urban neighbourhood. Real-life solutions on the path towards a resource-efficient, climate-neutral city are needed and are to be produced by the students in the competition. 18 international teams will compete in ten disciplines: architecture, building services engineering and design, energy performance, communications and education, innovation, feasibility and appropriateness, sustainability, comfort, functionality and urban mobility. Each of the 18 teams receives €100,000 to work with and then has nearly two years in which to design, plan and realise their building. Due to the COVID-19 pandemic, the finale of the competition originally planned for September 2021 will probably take place in June 2022.

Beneficiary: Bergische Universität Wuppertal
Funding ID: 03EGB0019
Estimated funding: €12.27 million
Project duration: 2019–2022

2.1.2 Energy efficiency in industry, commerce, trade and services

Energy is a cost factor for industry, and thus impacts on a company's competitiveness. After oil, coal and gas, electricity is the main source of energy for industry. Its importance is growing as industrial processes are electrified, renewable energy is integrated, and new infrastructure is built. Digitalised and automated processes can enable companies to make their processes more efficient, flexible and transparent, and can save resources, costs and energy.

Two-thirds of final energy consumption in the industrial sector takes the form of process heat. In order to improve energy efficiency in the field of industry, commerce, trade and services, energy researchers are working on the continued development of specific technologies in this sector and are also optimising entire value chains.

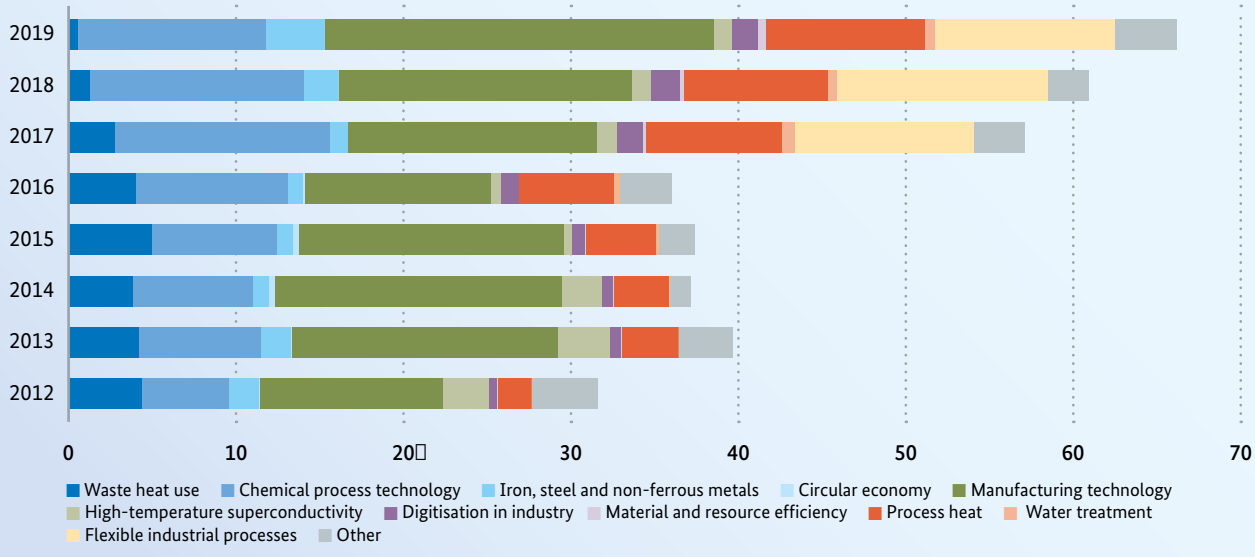
Funding priorities and scientific advances

There are many different ways to boost energy efficiency in industry: they range from improved motors, drives and pumps to redesigned manufacturing stages and entirely new production processes. Simulations are used to design energy-optimised and cheaper processes which, ideally, can be introduced across the sector. Examples of energy-optimised technologies, components and processes deriving from research, with improved efficiency ratios, reduced material input, and lower costs, can be found in various fields of research: waste heat and industrial heat storage units, chemical process technology, the carbon circular economy, iron and steel, manufacturing technology, high-temperature supraconductivity, artificial intelligence and sensor technology, material and resource efficiency, tribology (friction, lubrication, wear-and-tear), heating and cooling technologies, and water technologies.

Project funding

In the field of industry, commerce, trade and services, the Economic Affairs Ministry and the Research Ministry provided approximately €66.20 million in funding for 715 ongoing projects in 2019. In 2019, the ministries also approved approximately €96.21 million to fund 230 new research projects (see Figure 6).

Figure 6: Funding for energy efficiency in industry, commerce, trade and services in € million
(Data cf. Table 2, p. 74)



PROJECT ABSTRACT

Core sand specimen geometry with various aerogel additives

Aerogel alliance

Nano-structured, open-pore solid-state bodies as featherweight materials for energy-efficient industry

Aerogels can be made from various materials, such as silicates, metals and their oxides, polymers, biopolymers and carbonates. They are so porous that more than 90 percent of them consists of air or free space. This makes them extremely light. They are of low density, have a large internal surface, high sound absorption and extremely low heat conductivity, and can help to make sparing use of natural resources like energy from natural gas and oil. The extreme characteristics of the aerogels mean that they can be used where conventional materials fail: e.g. as super-insulating materials in the car industry, high-temperature applications, heat pumps. Before these materials can be launched onto the market, there is a need to demonstrate and make them on an industrial scale. With a view to a long-term strategy, the projects focusing on aerogels are connected in an alliance.

Project coordinators: ZAE Bayern, VDEh Betriebsforschungsinstitut, Technische Universität Dresden, German Aerospace Center, Hamburg University of Technology
Funding ID: 03ET1503A-C, 03ET1504A-B, 03ET1515A-D, 03ET1523A-B, 03ET1527A-B, 03EN2017
Estimated funding: €5.09 million

PROJECT ABSTRACT

Liquid molten glass in the area encompassing the batch insert of a glass melting tank

SynErgie Kopernikus project

Synchronised and energy-adaptive production technology for the flexible orientation of industrial processes to a fluctuating energy supply

By 2050, all of the electricity generated in Germany is to derive from renewable sources. The problem is that wind and solar power deliver fluctuating, not steady, amounts of electricity. The SynErgie Kopernikus project is studying how industry can offset these fluctuations by adapting the amount of electricity consumed by production processes. SynErgie has found that Germany's industry could increase its consumption by up to 1.1 gigawatts for a quarter of an hour, and could cut it by up 2.5 gigawatts when there is a lack of electricity. That is roughly equivalent to the capacity of one more or two fewer nuclear power stations. Taking the SynErgie approach, Germany's largest private-sector consumer of electricity, TRIMET Aluminium, can already boost or cut its electricity consumption by 22.5 megawatts for up to two days. To put this figure into perspective, that equates to the needs of around 25,000 3-person households.

This means that the flexibilisation of industry offers massive potential to stabilise the German electricity grid. However, current legislation prevents use being made of this potential. For this reason, SynErgie has drawn up a position paper outlining the need for change and proposing specific solutions.

Beneficiary: Technical University of Darmstadt and 57 other partners
Funding ID: 03SFK3A-03SFK3Z1
Estimated funding: €34.1 million
Project duration: 2016–2019

PROJECT ABSTRACT

EnPro 2.0
Energy efficiency and process acceleration for the chemical industry

Cars, clothing and breakfast muesli aren't the only things that are customised nowadays: the clients of the chemical industry also increasingly expect tailored products. However, the necessary short development and product life-cycles are virtually impossible to handle using conventional equipment. As a result, modularised units for a flexible, rapid and efficient chemical process industry have become a decisive factor for success in global competition: smartly networked modules will in future be able to implement various steps of the process, such as distilling, cooling or blending. Depending on the product, the various process stages will be put together in different ways within the unit. The researchers created the preconditions for this type of module system, including an automation function, control, interfaces and data integration, in the EnPro 1.0 project. In EnPro 2.0, gaps in modularisation, e.g. in the case of more complex processes like crystallisation or polymerisation, are to be closed, and the units expanded to become modular and smartly networked overall systems. EnPro 2.0 consists of individual collaborative projects and a coordinating project run by DECHEMA to network the projects with one another.

Modularized units for a flexible, rapid and efficient chemical process industry

Project coordinators: DECHEMA, TU Dortmund University, Technische Universität Dresden, Ruhr-Universität Bochum, Karlsruhe Institute of Technology, AixCAPE, Technical University of Darmstadt, BASF
Funding ID: 03ET1608A, 03ET2004A-N, 03ET2006A-F, 03ET2009A-F, 03ET1528A-F, 03ET1517A-I, 03ET1525A-E, 03ET1652A-F, 03ET1594A
Estimated funding: €17.49 million

2.1.3 Interfaces between energy research and mobility and transport

Nearly 30 percent of final energy consumption in Germany takes place in the transport sector. The volume of traffic is rising further, as are greenhouse gas emissions. The transport sector therefore definitely needs to be included in the restructuring of the energy system. Technological developments are focusing not least on battery-electric drives and fuel cells. The internal combustion engine can also contribute to defossilisation by using alternative fuels. Such fuels offer good prospects particularly where electrification reaches its limits. This applies to air traffic, shipping and some heavy goods transport. Also, the new advances in technology are fostering sector coupling: more renewable energy can be fed into the system and used more comprehensively.

Funding priorities and scientific advances

The current need for funding is concentrated not least on projects to manufacture and use gaseous and liquid fuels on the basis of renewable electricity. Funded by the Economic Affairs Ministry under the Energy Transition in Transport Initiative, a total of 16 research associations were launched between 2017 and 2019 in the field of "power-to-fuel" and the testing of alternative fuels in engines. The potential fuels include methanol, ethanol, OME, kerosene, synthetic natural gas and biogas containing hydrogen. Some of these synthetic fuels can be added to the fuels used in today's cars, trucks, aircraft and ships; others require changes to the engine technology. The large-scale project of the Federal Ministry of Education and Research entitled Sustainable Mobility through Synthetic Fuels (NAMOSYN, see project abstract) is linked

to this initiative. In the field of biofuels, potential for the transport sector can be found for example in lignocellulose fuel from woody biomass.

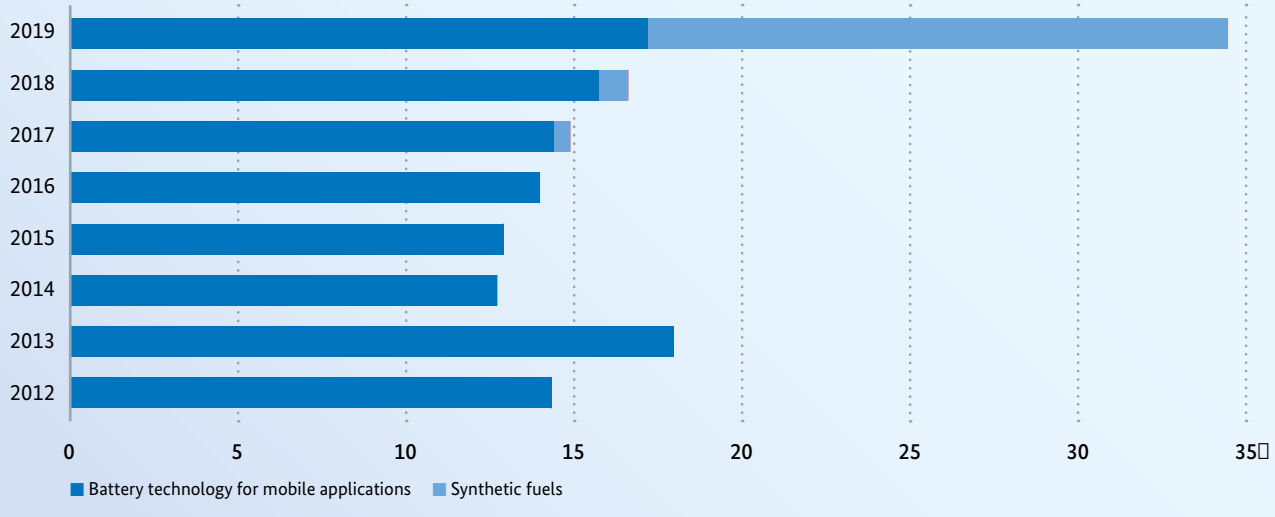
Electric mobility offers the potential to transfer the successful decarbonisation of the electricity sector to the transport sector. Whilst hydrogen technology is still in its infancy, many manufacturers are already marketing battery-electric vehicles. Research into the materials of batteries and fuel cells will deliver further efficiency gains in future and a more environmentally friendly use of raw materials, through to recycling. The "Mobility2Grid" research campus is also operating at the interface between the energy transition and the transport transition (see Chapter 4.3).

Another key boost is deriving from the National Innovation Programme on Hydrogen and Fuel Cell Technology (NIP) (see Chapter 4.3) and from application-oriented basic research, e.g. efficient and low-cost materials for fuel cells (see Chapters 2.3.3. and 2.4.6).

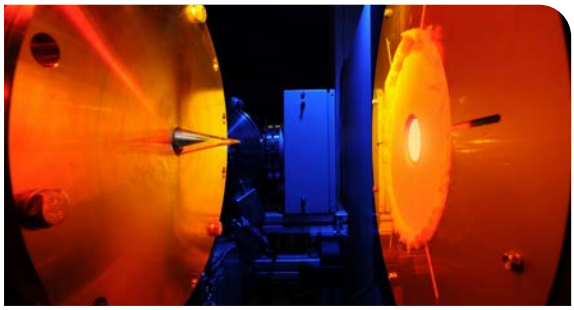
Project funding

In the field of the interface between energy research and mobility and transport, the Research and Economic Affairs Ministries provided approximately €34.21 million in funding for 273 ongoing projects in 2019. In 2019, the ministries also approved approximately €38.51 million to fund 72 new research projects (see Figure 7).

Figure 7: Funding for energy research on mobility and transport in € million
(Data cf. Table 2, p. 74)



PROJECT ABSTRACT



Molecular beam sample collection: Nozzle skimmer system to examine the chemistry

SolareKraftstoffe – Solar fuels for the energy mix of the future

Synthetic fuels produced using solar energy can speed up the defossilisation of transport – what is technically possible and competitive?

Fossil fuels increasingly have to be replaced in the transport sector in order to cut carbon emissions as quickly as possible. Carbon-neutral, sustainably made drop-in fuels can help here, as admixtures or substitutes for conventional fuels. One option for this is synthetic liquid fuels made using concentrated solar energy. The solar radiation concentrated in a solar thermal power station is used to produce these in thermochemical processes.

In the SolareKraftstoffe (SolarFuels) project, researchers from the German Aerospace Center are identifying potential drop-in fuels and studying what solar-thermal manufacturing methods are technically feasible and economically viable. The focus is on the entire chain, from solar fuel production from water and CO_2 through to the combustion in engines on the consumer side. The main thrust of the project is on drop-in fuels which could be used in vehicles via the existing filling and combustion infrastructure. In this way, a market roll-out could come much more quickly than in the case of concepts which require the replacement of vehicle fleets, the establishment of parallel infrastructure, or the upgrading of existing infrastructure.

Beneficiary: German Aerospace Center (DLR), Institute for Solar Research
Funding ID: 03EIV221
Estimated funding: approx. €1.3 million
Project duration: 2019–2021

PROJECT ABSTRACT

Flirt.AKKU prototype

FLIRT-AKKU – System integration and charging of a battery-driven railway vehicle in a way that serves the grid, for the covering of extended non-electrified or partially electrified sections of regional railway transport

A battery for trains is to replace diesel engines. Even without an overhead line, the Flirt-Akku battery offers a 150 kilometre range for trains.

Track-side residents in Northern Germany will be happy: Schleswig-Holstein has ordered 55 electric trains fitted with Flirt-Akku batteries from Stadler, the Swiss railway equipment manufacturer. Since 2018, its German subsidiary Stadler Pankow has been doing research into a battery-driven engine, with funding from the Federal Ministry for Economic Affairs and Energy. The zero-emission, energy-saving and quiet trains are to come into operation in 2022. In Northern Germany – which has plenty of wind power – a lot of diesel engines are in use on the railways because not many overhead lines are in place. The Flirt-Akku battery is powerful enough to move more than 100 tonnes unladen weight – and to do so for a large part of the journey. 150 kilometres should be possible, with much more on partly electrified routes, and should remain possible over years of operation. Further to this, Stadler Pankow is working with the system operator EWE Netz and the Institute of Energy and Automation Technology at Technische Universität Berlin on ways to ensure that the charging and discharging can serve the needs of the grid, i.e. that the batteries can provide balancing energy to the grid when needed.

Beneficiary: Stadler Pankow GmbH and two other partners
Funding ID: 03ETE008A-C
Estimated funding: €2.7 million
Project duration: 2018–2020

PROJECT ABSTRACT

Thanks to synthetic fuels for diesel and gasoline engines, transportation is to become more climate friendly

NAMOSYN - Sustainable mobility from synthetic fuels

Research is being done into highly promising synthetic fuels for use in gasoline and diesel engines in order to offer people and freight climate-neutral mobility in future.

The aim of the Federal Ministry of Education and Research's project is to create the basis for Germany to start producing synthetic fuels on a multi-tonne scale. To this end, four specialised working groups are studying all the steps from the manufacture to the combustion of highly promising synthetic fuels. Two groups are dedicated to the combustion of synthetic fuels in diesel and internal combustion engines. Another working group is developing energy-efficient and cost-efficient synthesis processes. The fourth group is evaluating the fuels in terms of their sustainability and the preconditions for a market launch. The fuels in question are the chemical substances of oxymethylene ether, dimethyl carbonate (DMC) and methyl formate (MeFo), which consist of hydrogen, carbon and oxygen. The project was launched in April 2019 and has so far developed, built and started operating the various test rigs and equipment, demonstrating in principle that the fuels can be used in the internal combustion engine.

Beneficiary: DECHEMA Gesellschaft für Chemische Technik und Biotechnologie and 30 other partners
Funding ID: 03SF0566A-U1
Estimated funding: €20.6 million
Project duration: 2019–2022

2.2 Energy generation

2.2.1 Photovoltaics

Photovoltaics has become an important pillar of electricity generation, both in the national and in the international context. In 2019, photovoltaics accounted for 9 percent of net electricity generation, i.e. of the electricity that reaches the consumer. In November 2019, Barth 5, Germany's first non-subsidised solar farm, came on stream with a capacity of 8.8 megawatts. Power purchase agreements (PPAs) ensure that these facilities can operate. PPAs are long-term contracts between power plant operators and electricity buyers. The fact that large solar farms are now economically viable is due to the constant efforts made by scientists to advance the technology. The leading technology continues to be solar cells based on crystalline silicon.

Funding priorities and scientific advances

In the projects funded by the Federal Ministry for Economic Affairs and Energy, institutes and companies are working continuously together to achieve further cost reductions of photovoltaic production and to improve the quality and efficiency of the cells and modules. The low electricity costs made possible by this form the basis for the expansion of this climate-friendly technology. Going forward, a key area (in addition to crystalline silicon photovoltaics) of the ministry's research funding will be on stacking cells. In stacking cells, different semiconductors are combined in order to utilise a larger spectrum of the sunlight. In 2019, scientists at the Fraunhofer Institute for Solar Energy Systems ISE succeeded in attaining a new world record efficiency rate of 34.1 percent from a triple solar cell. Also, stacking cells using perovskites are close to market maturity.

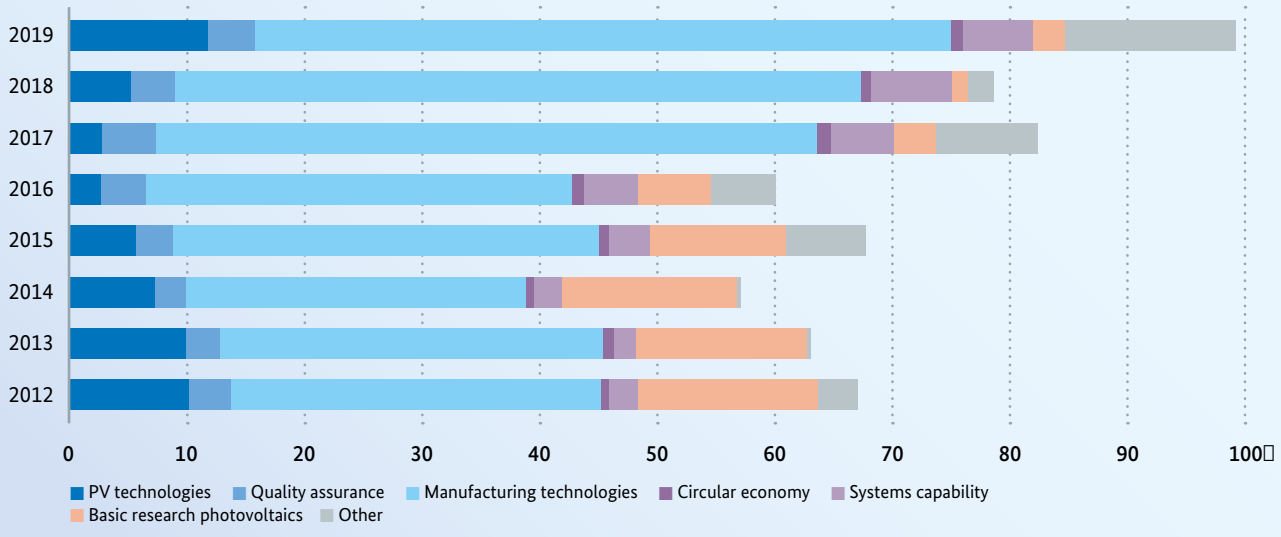
Funding from the Research Ministry towards work being done by research and industrial stakeholders in Germany and Greece is aiming to develop low-cost processes for the industrial production of perovskite solar cells. At 18.5 percent, the best solar cells from the Karlsruhe Institute of Technology reached the highest efficiency ratio so far achieved in solar cells using an inkjet printed perovskite layer. Several groups of researchers in the Make Our Planet Great Again initiative (see Chapter 1.3) are also researching

novel materials for solar cells. The digitisation of manufacturing offers the potential to achieve high efficiency levels at low costs – it therefore is another key area. New fields of use for photovoltaics are also of relevance, such as facades of buildings, or the fitting of electric vehicles with solar cells. The main aspects of the research being done here are costs, efficiency and handling.

Project funding

In the field of photovoltaics, the Economic Affairs and Research Ministries provided approximately €98.69 million in funding for 499 ongoing projects in 2019. In 2019, the ministries also approved approximately €106.79 million to fund 140 new research projects (see Figure 8).

Figure 8: Funding for photovoltaics in € million
(Data cf. Table 3, p. 75)

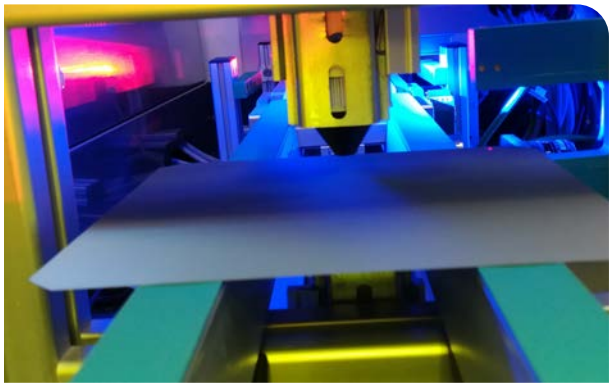


PROJECT ABSTRACT

HJT4.0 – Next-generation manufacturing and process technologies for heterojunction solar cells and modules for Industrie 4.0

Production facilities for photovoltaic modules are to be able to adapt processes flexibly in order to achieve a maximum of quality at low costs.

The partners in the project are looking to Industrie 4.0 to help them effectively cut the costs of PV-based electricity production. This means that they want to make installations which can adjust production processes flexibly in response to digital metering. For example, an Industrie 4.0 production facility could analyse the quality of the feedstock material and optimise the following stages in the process accordingly. To do this, it must have the prospect of being able to respond flexibly enough. The focus of the work is currently on an extended metering technology as a basis for Manufacturing 4.0. Detailed, reliable data are needed for each individual step. The project partners would also like to make the data from the metering useful for planning the details of maintenance work. The idea is that manufacturers should be able to order spare parts for their equipment before a component is at risk of failure. The target technology of the new facility is heterojunction technology (HJT).



By means of inline measuring systems all process relevant data of the wafers can be transmitted to a central data base in real-time.

In it, the traditional crystalline silicon solar cell is combined with amorphous silicon from thin-film technology. This combination provides perfect passivated contacts, i.e. less of the charge generated is lost. This cell concept is therefore regarded as a high-performance cell.

Beneficiary: Meyer Burger (Germany) GmbH and five other partners
Funding ID: 0324172A-D, F, G
Estimated funding: €9.2 million
Project duration: 2017–2020

PROJECT ABSTRACT

CIGS facade – Photovoltaic systems integrated into the facade using CIGS technology
Photovoltaic modules on building facades supply energy reliably even in shifting light conditions and shade.

The simple integration of solar modules into the building envelope is a compelling idea – but not easy to achieve. The scientists have developed a CIGS thin-film module which can make better use of the specific light conditions on building facades. CIGS stands for the elements contained in this technology: copper, indium, gallium and selenium. With an efficiency ratio of up to 17.5 percent, the CIGS modules are leaders in commercially available thin-film photovoltaics. Due to their homogeneous appearance, they are popular with architects. The entire installation system, from the module to the inverter, has now been further optimised within the CIGS facade for use on facades. This addresses not only light conditions, but also issues like the building structure, electrical system technology and operational safety. The engineers in the project have been able to improve the yield of the modules and the assembly. Flexible module sizes give architects greater scope for design. Further to this, the project partners have looked into the waste heat from facades as a source for heat pumps. The greatest benefits are reaped using a – rather complex – seasonal heat storage system.


The ZSW has mounted a test facade to their new institute building in Stuttgart to gather operating data of the modules.

Beneficiary: The Centre for Solar Energy and Hydrogen Research Baden-Wuerttemberg (ZSW), and two other partners
Funding ID: 0324156A-C
Estimated funding: €1 million
Project duration: 2017–2020

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 2019, was used to produce even more power than in the preceding year, creating another annual record. The volume of electricity generated from wind energy reached a new record of 126 terawatt hours (TWh), outstripping the 110 TWh recorded in 2018 – an increase of almost 15 percent year-on-year. In the month of March, a particularly noteworthy record for wind power generation was set when almost 16 TWh of power was produced. This was considerably higher than the previous monthly record set in December 2017 (15.1 TWh). An electricity volume of this magnitude could supply around five million households with power for one year. To counter the slump in the expansion of onshore wind energy since 2018, a series of measures to promote public acceptance for wind turbines and accelerate their expansion has been developed and set out in the 2030 Climate Action Programme.

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 for production, construction, operation, dismantling and recycling will be and how the wind tur-

bines/wind farms can be integrated into the electricity grid. Wind turbines and wind farms need to be operated flexibly using of 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, which helps to ensure security of supply. As for the continued expansion of wind energy, the number of windy sites that are easily accessible 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 efficiently and at low cost. When it comes to the operation of offshore wind farms, logistics and maintenance represent major challenges. The availability of the turbines is key to their economic efficiency, since offshore wind turbines are very complex and expensive to reach in the event that they malfunction. This is why it is important to have innovative grid connection and logistics concepts in place that take into account the availability of the turbines, 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 and the Federal Ministry of Research and Education provided approximately €72.95 million in funding for 461 ongoing projects in 2019. In addition, the ministries approved approximately €78.99 million in funding for 112 new research projects in 2019 (see Figure 9).

PROJECT ABSTRACT

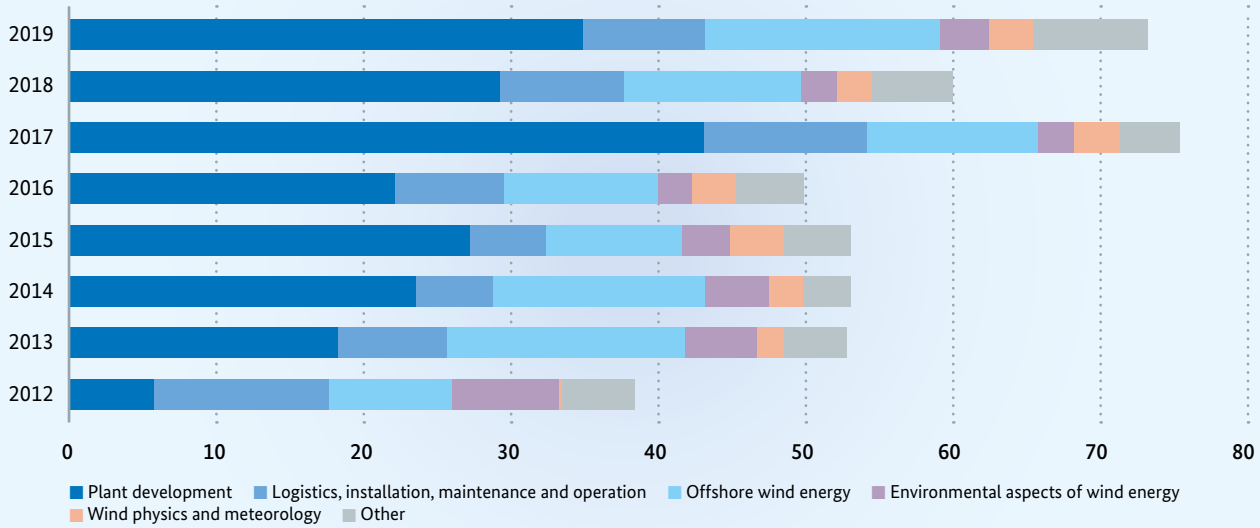
IsyMOO – Intelligent integrative systems for monitoring surface protection systems on offshore wind energy structures

Offshore wind farms are exposed to sea air, salt water, currents and vibrations. Towers and supporting structures of offshore wind turbines are thus exposed to intense stresses. For example, rust reduces the load-bearing capacity of the turbines' supporting structures. Various coatings are applied to the construction elements to ensure the intended service life is fulfilled. However, they cannot fully prevent the turbines from ageing. Wind farm operators must therefore regularly check the condition of the wind turbines. To date, this assessment has been conducted by climbers and divers, but their work is complex, dangerous and expensive. Experts from companies and universities are now joining together in the ISyMOO project to research how autonomous inspection devices, such as drones, can use cameras and other innovative technology to record the condition of wind turbines in order to save time and money. This also includes sensors that provide additional data on the current condition of the coatings and structures. In order to process and evaluate the complex image, video and sensor data collected, the IsyMOO project is developing a dedicated big data platform. Once evaluated, this data will enable appropriate inspection and repair concepts to be created. The maintenance specialists on the mainland can evaluate the data in real time and maintain or repair the systems in a timely and targeted manner.

Autonomous inspection equipment such as drones are intended to help minimize dangerous maintenance servicing on offshore wind energy plants in the future.

Beneficiary: Muehlhan AG and four other partners
Funding ID: 0324254A-F
Estimated funding: €1.3 million
Project duration: 2018–2021

Figure 9: Funding for wind energy in € million (Data cf. Table 3, p. 75)



PROJECT ABSTRACT

HiPE-WiND – Multidimensional strain on power electronics in wind turbines

Construction of a test facility in which performance electronics for wind turbines can be tested under real load and environmental conditions.

The power electronics of wind turbines are placed under particular strain. Set at the interface between the generator and the feed point into the grid, the relevant components are exposed to great stresses due to fluctuations in the wind and the grid. On top of this, environmental influences such as large jumps in temperature, high humidity and condensate compound the situation further. However, it is especially important for wind turbines to have a high level of reliability as conducting repairs or maintenance is laborious and expensive and often leads to high losses in yield. In the HiPE-WiND project, the project partners are investigating how the environmental conditions at the wind farm site influence the interior of the individual wind turbine and how they impact upon the construction elements and components of the power converters located there. To conduct this work, a test facility is currently being set up in Bremen, where independent tests can be carried out under realistic conditions. In a climatic chamber, complete converter systems used in 10 MW wind turbines can be exposed to predefined environmental stresses such as extreme cold, heat or high humidity. Both the electrical loads and the simulated disturbances/system interactions are also able to be reproduced in this testing environment. By artificially accelerating the aging of the converter components at the test facility, any weak points in the system hardware are able to be identified. The objectives are to understand the causes of ageing, extend the operating time of the components by making optimisations, and to prevent failures.

Inspection of water-cooled throttles of one out of four 3 MVA frequency converters of the test station

Beneficiary: Bremen University and Fraunhofer Institute for Wind Energy Systems (IWES)
Funding ID: 0324219A-B
Estimated funding: €11.57 million
Project duration: 2017–2020

2.2.3 Bioenergy

Bioenergy plays a special role in the field of renewable energy because it can be used flexibly and is available irrespective of weather conditions and the time of day or year. It currently accounts for about 54 percent 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 a 90 percent and 80 percent share respectively. Nevertheless, biomass accounts for only 7 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

A key player is the German Biomass Research Centre (DBFZ). Since 2008, the Centre has been conducting applied research and development 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.

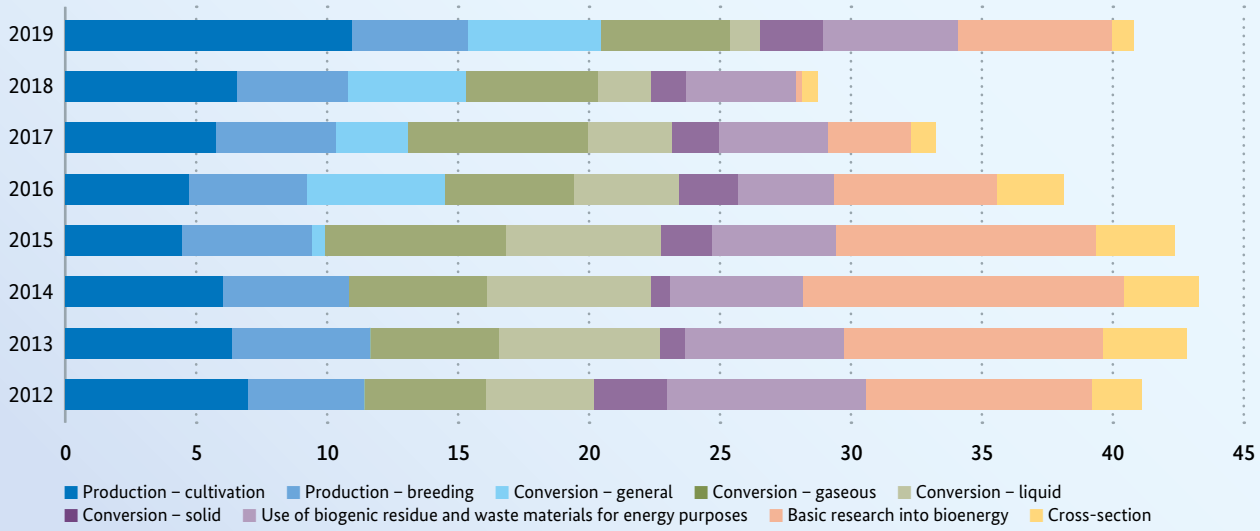
One of the objectives in this work is to increase the contribution that biomass makes to the energy system by developing sustainable bioenergy strategies, evaluating biomass utilisation concepts and investigating the efficiency and sustainability of biomass use etc. In addition, the Centre is developing 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 catalytic reduction 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 2018. This is a key area in which the Federal Ministry for Economic Affairs and Energy is supporting projects that aim to develop efficient and cost-effective technologies and concepts for generating electricity, heat and fuels based on the use of biogenic residual and waste materials. There is currently a particular need for funding in the area of system integration and sector coupling. Since 2008, the Federal Ministry for Economic Affairs and Energy has funded over 176 collaborative projects and more than 450 individual projects under its Energy-related Biomass Use programme. Among the 250 participating institutions, 125 were SMEs. The funding thereby enables promising research findings to be put into practice even faster.

Project funding

As part of its key focus on bioenergy, in 2019, the Federal Government provided around €40.52 million to fund a total of 597 ongoing projects. In 2019, the ministries also approved approximately €72.78 million to fund 241 new research projects (see Figure 10). Within the scope of funding for institutions, in 2019 the German Biomass Research Centre in Leipzig was provided with budget funds of around €9.5 million. It was also allocated a further €13.4 million in funding for construction work and furniture, fixtures and fittings for a new building.

Figure 10: Funding for bioenergy in € million
(Data cf. Table 3, p. 75)



PROJECT ABSTRACT

DAnkEE – Demonstration of a system for combined dust removal and denitrification - a project key to the environmentally friendly use of biomass residues and waste materials

Reduction of nitrogen oxides and particulate emissions: a new type of filter system is to enable exhaust gases to be cleaned and made environmentally friendly.

Biomass residues and waste materials are cost-effective fuels for heat and power generation. The systems technology developed in this project uses a novel flue gas cleaning system to reduce the level of nitrogen oxides and particulate emissions produced during combustion. This not only makes the energy use more environmentally friendly, but also means biomass can be used even more efficiently. A specific goal of the project is to demonstrate the new system at a practice-based test facility. In the future, this development can be transferred to biomass furnaces that generate 0.1 to 5 megawatts of thermal output. The two project partners Fraunhofer UMSICHT and Herding Filtertechnik are jointly developing a new type of combined filter, which can simultaneously reduce nitrogen oxides and cut out particulate matter. The first brings to the table expertise in technical and scientific development with proficiency in production engineering, the latter knowledge of the industry. It is anticipated that the combination of these skills will enable a novel, marketable product to be developed. At the same time, the project offers a solution for the stricter emission requirements introduced.


Test set-up at the technology centre of Fraunhofer UMSICHT

Beneficiary: Fraunhofer Institute for Environmental, Safety, and Energy Technology (UMSICHT) and Herding GmbH Filtertechnik
Funding ID: 03KB143A-B
Estimated funding: approx. €375,000
Project duration: 2018–2021

PROJECT ABSTRACT

BE20plus | Bioenergy – Potential, long-term prospects and strategies for electricity generation systems after 2020

In 2015, over 26.8 percent of renewable electricity and 87.8 percent of renewable heat came from bioenergy plants. In recent years, incentives and support for the operation and expansion of bioenergy plants generating electricity have primarily been regulated in the Renewable Energy Sources Act (EEG). Under the EEG, plants have thus far received fixed remuneration rates for a period of 20 years plus the year of commissioning. Since a large proportion of the bioenergy plants generating electricity were built between 2004 and 2014, the remuneration provided under the EEG for this part of the plant stock will expire between 2025 and 2035.

On behalf of the Federal Ministry of Food and Agriculture (BMEL), a scientific team coordinated by the German Biomass Research Centre (DBFZ) is evaluating which current business models for existing bioenergy plants could continue to be used beyond the period for which funding is provided under the EEG, in order to enable the plants generating electricity from biomass to continue to operate – potentially with a changed operational setup. The options to be examined include participation in auctions pursuant to the EEG of 2017 and the continued operation of these plants even without funding under the EEG. The researchers are carrying out energy-sector, technical and economic analyses and are evaluating different business areas based on this work. Using model calculations, they are showing the effects that the various options would have on the plant stock, on the electricity and heat supply and on agriculture and forestry, and are also setting out the environmental impact they each would have. The results of this work are intended to show plant operators and the industrial and service partners involved what the prospects are for continued operation of the systems concerned. The project results will go on to be made publicly available online in the form of an interactive final report.

Beneficiary: German Biomass Research Centre (DBFZ) and five other partners
Funding ID: 22404016, 22407817, 22406917, 22407117, 22407517, 22407417
Estimated funding (entire project): approx. €1.2 million
Project duration: 2017–2020

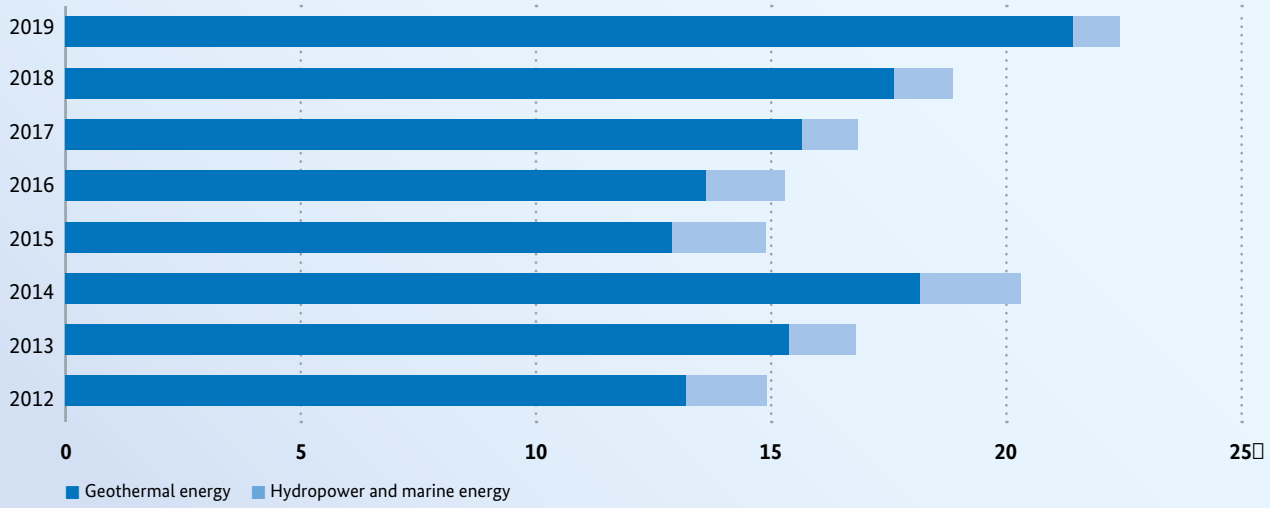
2.2.4 Geothermal energy

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), there are currently just under 40 heat and power plants and combined heat and power plants in operation in Germany. In the field of near-surface geothermal energy, around 390,000 systems are installed. In the future, the use of geothermal energy for heating and cooling as well as for seasonal heat storage is to be expanded. Research projects will primarily focus on reducing risks and costs, creating storage facilities and increasing awareness and acceptance of this form of renewable energy.

Project funding

In the field of geothermal energy, the Economic Affairs Ministry provided approximately €13.19 million in funding for 94 ongoing projects in 2019. In addition to this, the ministry approved approximately €24.10 million in funding for 25 new research projects in 2019 (see Figure 11).

Figure 11: Funding for geothermal energy, hydropower and marine energy in € million
(Data cf. Table 3, p. 75)



PROJECT ABSTRACT

QEWS II – Quality assurance for geothermal probes II incl. contribution to IEA ECES Annex 27

Using new technologies and methods in quality assurance to make the planning, construction and operation of geothermal probes for near-surface geothermal energy safer and more efficient.

Geothermal probes are pipe systems that are laid in a vertical or inclined borehole in order to harness near-surface geothermal energy and extract or convey heat into the ground. They are increasingly being used as a heat source pumped for heating, as a heat sink for cooling buildings or as a heat storage device, thus making an important contribution to the energy transition.

During the planning, construction and operation of geothermal probes, there are many sources of error, which can have negative consequences for the soil and for groundwater. Scientists at the Bavarian Center for Applied Energy Research have therefore set themselves the goal of improving the quality of geothermal probes across all three of these phases. Together with their project partners, they are working on central aspects of quality assurance in six sub-projects. This has led to the development of a procedure for checking the measuring equipment used to explore potential locations for the probes, and of consistent design models for geothermal plants. The investigation of materials and methods for filling and sealing boreholes has also been improved. Quality control and monitoring procedures for the operation of the probe systems have been developed and tested. The results and findings elaborated in IEA ECES Annex 27 are being directly incorporated into the current development of the European standard CEN TC 451.

The image shows a geothermal probe drilling with integrated measuring technology on the company premise of Burkhardt GmbH.

Beneficiary: Bavarian Center for Applied Energy Research (ZAE Bayern) and six other partners
Funding ID: 03ET1386A-G
Estimated funding: €4 million
Project duration: 2016–2020

2.2.5 Hydroelectric and marine power

Used as an energy source, hydropower has a decisive advantage over other forms of renewable energy: it does not depend on weather, so can be planned. Hydropower generates roughly 3 percent of Germany's electricity. Based on use of the technologies available today, suitable locations for hydropower generation have virtually all been exhausted. Research projects are being pursued to help experts to develop new technologies, such as innovative run-of-river wheels, which could open up new locations, and to modernise existing plants. 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 €1.71 million in funding for 16 ongoing projects in 2019. In addition to this, the ministry approved approximately €3.54 million in funding for seven new research projects in the same year (see Figure 11, page 37).

2.2.6 Thermal power plants

As Germany pursues its energy transition, conventional power plants ensure that industrial companies and households receive a reliable supply of electricity even in times when photovoltaic and wind energy plants generate lower volumes of electricity due to poor weather conditions. This allows the energy system to be transformed while preventing supply bottlenecks.

Existing large-scale power plants will continue to play an important role in the green energy system of the future. The 7th Energy Research Programme places a greater funding priority on research projects to develop the use of alternative fuels and fuel mixtures, such as biomass or waste, in power plants, in order to replace coal. In order for plants to be able to use these alternative energy carriers, they have to be adapted. This involves retrofitting both construction elements and the entire plant using new materials and modified operating processes. Research is also being conducted on solar-thermal power plant processes and components. Solar technology "made in Germany" is in demand worldwide.

In addition, greater consideration is being given to the use of thermal power plants within the overall energy system. The key focus is on adapting the existing infrastructure to a new energy landscape involving many different many players. Financial support is being provided, for example, for research projects that integrate large energy storage facilities into a complex of power plants. 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 (Power-to-X-to-Power). In addition to large thermal energy storage systems, key research topics also include high-temperature heat pumps, hybrid plant concepts and innovative process technology.

Today, digital technology enables innovations in construction elements and processes to be simulated on the computer before they are integrated into real power-plant operation. Known as 'digital twins', these simulations save both time and money. A lot of the information about power-plant operation that they are based on is provided by sensors. These data are continuously evaluated and serve as a basis for developing learning processes that constantly power-plant operation.

Project funding

In the field of thermal power plants, the Federal Ministry for Economic Affairs and Energy provided approximately €28.30 million in funding for 359 ongoing projects in 2019. In addition to this, the ministry approved approximately €31.29 million in funding for 74 new research projects in the same year (see Figure 12).

PROJECT ABSTRACT

Jülich Multi-focus Tower

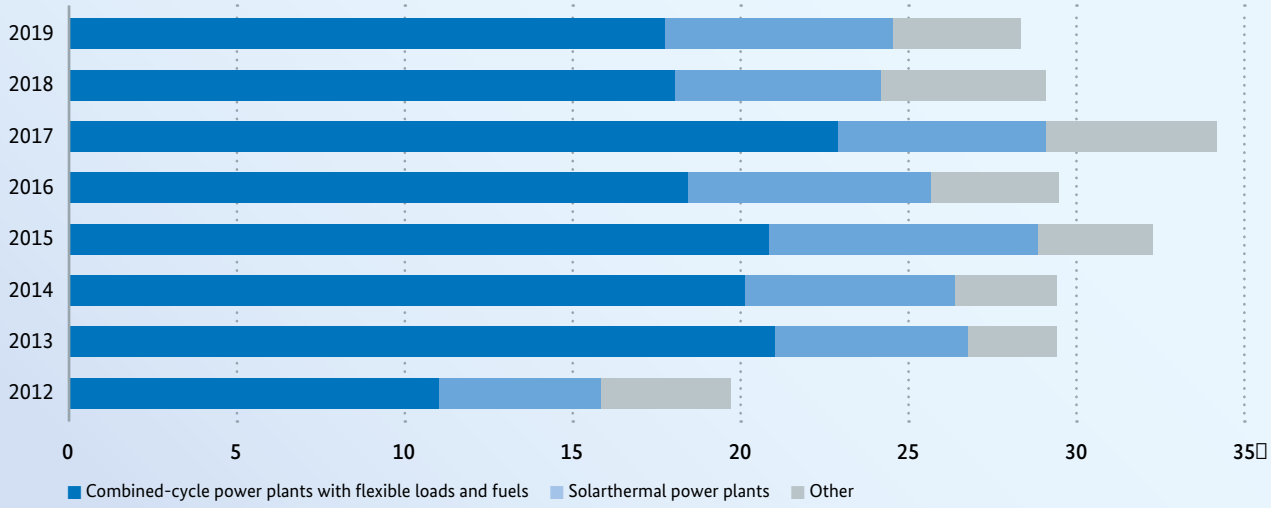
The solar tower plant will be developed into a world-leading centre for high-temperature experiments involving solar.

The German Aerospace Center (DLR) has built a solar tower plant on the outskirts of the German town of Jülich in order to conduct research into heliostat technology. This technology centres on the use of a heliostat field which captures sunrays and concentrates them onto a small area onto a solar tower. Scientists have been testing construction elements in the open field there for nine years now. The focus of the research is primarily on the receiver, but there is a great need for even broader testing to be conducted. This is why the facility is currently being expanded as part of the Jülich Multi-focus Tower project to turn it into one of the world's largest test centres for high-temperature solar technology. Construction work is progressing on a second solar tower which will provide three different test levels. The new tower will enable several experiments to be carried out at once based on the use of an extended heliostat field. These include, for example, salt receiver tests and solar-chemical experiments on hydrogen production.

The second solar tower is currently under construction. It enables the team of scientists to carry out several tests parallel.

Beneficiary: German Aerospace Center (DLR), Institute for Solar Research
Funding ID: 0325454
Estimated funding: approx. €1 million
Project duration: 2012 – 2020

Figure 12: Funding for thermal power plants in € million
(Data cf. Table 3, p. 75)



2.3 System Integration

2.3.1 Electricity grids

The energy transition is changing the entire structure of the electricity generation and supply system. This has hitherto been based on a small number of large central power plants producing plannable electricity volumes, which are now being replaced by a much larger number of decentralised energy plants offering fluctuating feed-in quantities. At the same time, the number of renewable generation facilities integrated into the energy-supply system fluctuates, and the distances that electricity has to travel across the grid are increasing. In addition, the electricity, heat and transport sectors are being coupled with one another based on the increasing electrification of mobility and the heat supply from renewables. This requires operations to be coordinated precisely between regional and supraregional electricity network operators, generation plants and consumers in order to push forward with efforts to flexibilise the energy system. The aim is to create a robust and resilient power grid that will serve as the key basis for electricity distribution and thus for an energy system that guarantees a high level of supply security and quality. Both sector coupling and an energy system based on a larger number of producers are crucial to Germany's competitiveness as a location for industry and business.

Funding priorities and scientific advances

One of the Federal Ministry for Economic Affairs and Energy's funding priorities is the development of operating resources and components. The aim is to increase the efficiency and reduce the costs of such elements, including power semiconductors and capacitors. The ministry also supports research projects exploring how flexibilities can be integrated into the electricity grid. These include projects on technical and regulatory aspects through to market design issues, such as the provision of data or market access via platforms. In addition, there is a continuing need to further develop automated grid management, including power flow management and energy redispatch. Furthermore, a power grid that receives electricity feed-in from a large number of small decentralised energy systems needs to be efficiently monitored in order to ensure it remains stable and secure. Against this background, the Federal Ministry for Economic Affairs and Energy is supporting projects to develop methods for fault-detection in close to real time as well as strategies for optimising the amount of electricity transmitted. The energy transition in transport and the heat transition are creating research needs in the area of sector coupling. The Federal Ministry for Economic Affairs and Energy is therefore funding projects that deal, for example, with the integration of electric mobility into the grid or the convergence of electricity, gas and hydrogen infrastructure. Given the increasing share of renewable energy being fed into the grid, there is also a continuing need for research into the provision of system services and inertial reserve. Digitalisation is playing an increasingly important role in all issues relating to the electricity grid. Although it offers major potential to help with the conversion and establishment of sustainable structures, it also creates many challenges at the same time. This is why the Federal Ministry for Economic Affairs and Energy also places a clear focus on this area in its project funding. In the funding area covered by the Federal Ministry of Education and Research, the focus is on the development of new network structures, which is being worked on as part of the ENSURE Kopernikus project (see project abstract). In addition, in 2019, follow-up funding was granted for selected projects part of the interministerial funding initiative 'Electricity Grids for the Future' in order to continue work on the areas of digitisation, sector coupling and direct current technology. The latter is also the subject of the research campus 'Flexible Electrical Networks' (see Chapter 4.3).

In September 2019, the European Joint Programming Platform ERA-Net Smart Energy Systems and Mission Innovation (cf. Chapter 1.3.2) launched their first joint call for proposals on integrated energy storage systems (MICall19). Some 21 countries and regions from around the world have responded to this call, including Germany, which is being represented by the Federal Ministry for Economic Affairs and Energy.

Project funding

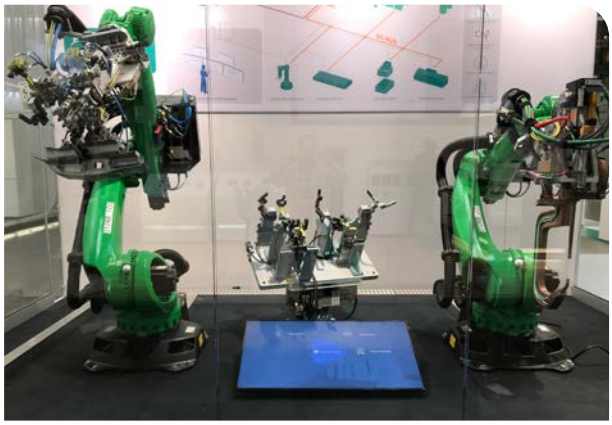
In the field of electricity grids, the Federal Ministry for Economic Affairs and Energy and the Federal Ministry of Education and Research provided approximately €64.85 million in funding for 589 ongoing projects in 2019. In 2019, the ministries also approved approximately €61.69 million to fund 143 new research projects (see Figure 13).

PROJECT ABSTRACT

DC-Industrie – Smart, open DC grid in industry enabling highly efficient system solutions based on electric drives and DC-Industrie 2 – Direct current for the factory of the future

Smart direct current grid to ensure a safe and robust energy supply to production plants based on the use of renewables

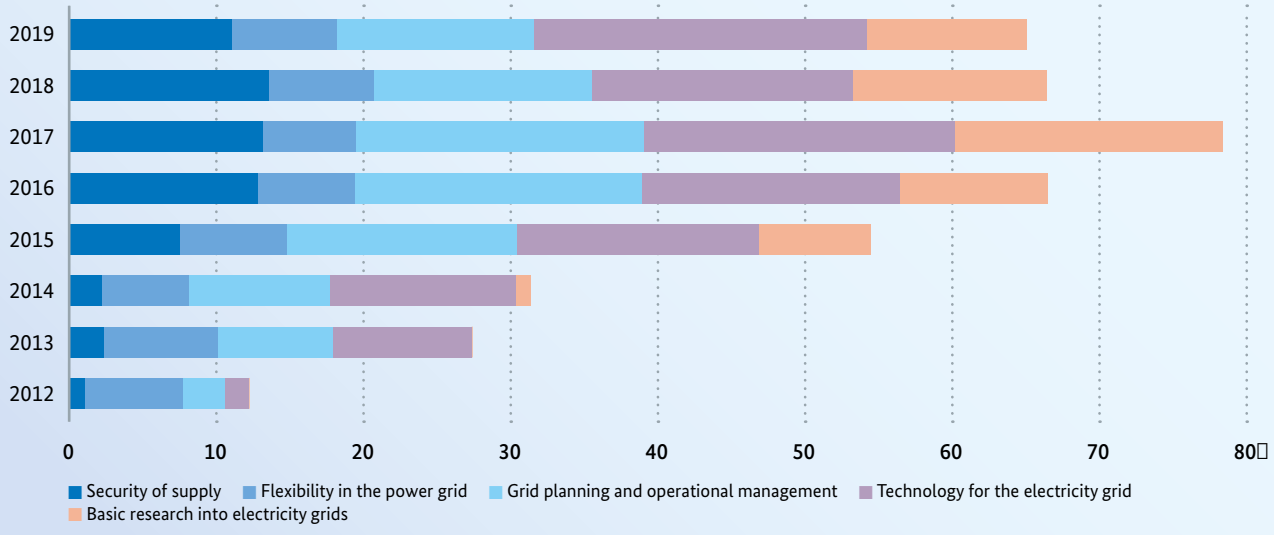
Direct current technology enables electricity from renewable-energy installations to be integrated into the grid using smart technology. Within the DC Industrie research project, 27 partners have designed a comprehensive system for a smart direct current grid (iDC grid) to supply power to industrial production plants. Their work focuses on the development, adaptation and testing of power electronic devices that supply and protect DC grids in production cells and on methods for ensuring robust operational management. As a follow-up to this first project, the DC-Industrie 2 project is seeking to expand the iDC grid and turn it into a smart direct current grid for a production shed or a large-scale processing plant. The system is to have four core properties: it is to be secure, robust, network-compatible and offer a high level of availability. A grid connection will enable it to connect to the superordinate supply network when power generation fluctuates. At the same time however, the system is designed to make maximum use of decentralised energy generation from renewables. In addition, the iDC network will use cognitive algorithms to ensure component availability.



Two industrial robots run on direct current at the booth of DC-INDUSTRIE at the Hannover Fair 2019

Beneficiary: DC-Industrie: Siemens and 13 other partners; DC-Industrie 2: Eaton Industries and 17 other partners
Funding ID: 03ET7558A-N and 03EI6002A-Q
Estimated funding: €6.3 million (DC-Industrie) and €7.5 million (DC-Industrie 2)
Project duration: 2016–2019 (DC-Industrie) and 2019–2022 (DC-Industrie 2)

Figure 13: Funding for grids in € million
(Data cf. Table 4, p. 76)



PROJECT ABSTRACT

Multi-megawatt laboratory - Research Centre for Power Electronics

Development of a low-voltage laboratory to research components for integrating renewable energy into the grid and decentralised storage technologies, and a medium-voltage laboratory to research feed-in components for AC and DC medium-voltage grids

Power electronics is a key technology for the energy system of the future in which a high share of electricity fed into the power grid is generated from renewables. In order to manage the grid in a way that ensures it remains secure and stable, novel components and functions are needed. A team of scientists from the Fraunhofer Institute for Solar Energy Systems ISE has therefore set up a centre for power electronics and sustainable grids in Freiburg where they have access to an innovative research infrastructure. The centre consists of three laboratories and is dedicated to the development of power electronics as well as issues relating to management and energy technology.

Within the 'Low-voltage laboratory' project funded by the Federal Ministry for Economic Affairs and Energy, scientists have developed a power electronics laboratory for researching components for integrating renewable energy into the grid and decentralised storage technologies. As part of another project supported by the ministry, Fraunhofer ISE has set up a medium-voltage laboratory in which components for feeding electricity into AC and DC medium-voltage grids are to be developed. The third laboratory, which was built with funding from the Federal Ministry of Education and Research, enables experiments to be carried out on the performance of large, decentralised systems, such as PV/wind-power plants, large battery storage facilities, and combined-heat-and-power plants in the low, medium and high-voltage grid.

Multi-megawatt laboratory at the centre for power electronics and sustainable grids

Beneficiary: Fraunhofer Institute for Solar Energy Systems ISE
Funding ID: 0325598 (low-voltage laboratory) and 03ET7515 (MV laboratory – multi-megawatt laboratory), 03SF0448 (high-voltage supply)
Estimated funding: €3.4 million (low voltage laboratory), €3.1 million (MV laboratory – multi-megawatt laboratory) and €3.6 million (high voltage supply)
Project duration: 2013 – 2019 (low voltage laboratory) and 2013–2019 (MV laboratory – multi-megawatt laboratory) and 2012–2013 (high voltage supply)

PROJECT ABSTRACT

ENSURE Kopernikus project
A holistic, systemic approach to designing a reliable, sustainable and affordable energy supply that integrates all relevant energy sources

Funded by the Federal Ministry of Education and Research, the ENSURE Kopernikus project is researching ways in which a renewables-based energy system of the future can be comprehensively optimised, looking at all of the energy sources to be integrated. The aim of the project is to clarify how centralised and decentralised energy-supply elements need to be designed as part of the overall system in order to ensure a reliable energy supply. It will also take into account technical, environmental, economic and social aspects.
In the first funding phase, ENSURE researchers looked at the socio-economic conditions required for restructuring the energy system, and at how this transformation might be designed in a way that ensures public acceptance. The findings from this phase formed the basis for developing a range of potential system structures that might be used for a future energy network. The various system scenarios were then compared as part of a system study. The consortium also designed a holistic system-management concept for implementing the system at technical level, which also included the development of smart network equipment.

ENSURE develops reliable power grids for the sustainable energy supply of tomorrow.

In the coming project phases, the design features that make the system-management concept viable for use will be presented to a broader public. An 'ENSURE energy cosmos' demonstrator is currently being developed to support the project in this work.

Beneficiary: Karlsruhe Institute of Technology (KIT) and 22 other partners
Funding ID: 03SFK1A-03SFK1X0
Estimated funding: €29.7 million
Project duration: 2016–2019

2.3.2 Electricity storage

One of the most important characteristics of an energy supply system integrating a high share of renewable energy is flexibility. Electricity storage systems play a crucial role in this, as they can absorb fluctuations in the feed-in of solar or wind power plants into the grid related to the weather/time of day by temporarily storing surpluses and releasing the electricity at times of low feed-in or increased demand. They also have a stabilising effect on the grid frequency. In addition, in the future they will be able to provide system services that extend into all areas of supply, from electric mobility to private and commercial buildings, neighbourhoods and industrial applications. Research and development is still needed along the entire value chain to make storage systems more powerful and more cost-efficient.

Funding priorities and scientific advances

The Federal Ministry for Economic Affairs and Energy's project funding for applied energy storage systems covers a range of different technologies. These include electrochemical 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). A key aspect in continued development of energy storage is digitisation, especially digital technology for networking and linking storage facilities with infrastructures. Despite major advances, extensive research is still needed into materials and components, production, standardisation, operation, and life cycle and circular management of electricity storage systems. Through its funding, the Federal Ministry for Economic Affairs and Energy is supporting not only the scientific work on

the various elements of the storage facilities themselves, but also the development of peripherals as well. The support provided covers the entire development chain, from in-depth matters of cell chemistry to large-scale demonstration projects, pilot plants, field tests and Regulatory Sandboxes of the Energy Transition (see Chapter 1.2.4).

Digitisation is also a key aspect of research on storage as it can help optimise the way in which the electricity grid is structured and operated. The Federal Ministry for Economic Affairs and Energy has made this a special focus, making a call for proposals on innovation in the energy system based on digital technology in January 2019. The Ministry is also addressing the socio-economic impact of energy storage systems. In April 2019, it published a call for proposals on societal change brought about by and during the energy transition (see Chapter 2.4.5).

The Federal Ministry of Education and Research's project funding for applied basic research focuses on cell chemistry, innovative battery concepts and novel flux batteries. The aim is to develop ideas and concepts that go beyond the lithium-ion technology we use today and look, for example, at solid-state batteries and other active materials that are potentially cheaper and also environmentally friendly. The Federal Ministry of Education and Research is also using synergies from bilateral cooperation, such as the Franco-German funding initiative for a sustainable European energy supply (see Chapter 1.3). In addition, a pilot competition for breakthrough innovations on 'world storage' was announced in 2019. This competition seeks to promote projects to develop particularly cost-effective storage technology that can be used worldwide in decentralised renewable electricity systems (home energy storage).

Project funding

In the field of energy storage, the Federal Ministry for Economic Affairs and Energy and the Federal Ministry of Education and Research provided approximately €21.43 million in funding for 201 ongoing projects in 2019. In 2019, the ministries also approved approximately €28.17 million to fund 57 new research projects (see Figure 14).

PROJECT ABSTRACT

Future Energy Solutions (FES) – Development of a cost-effective mass energy storage system for renewable energy

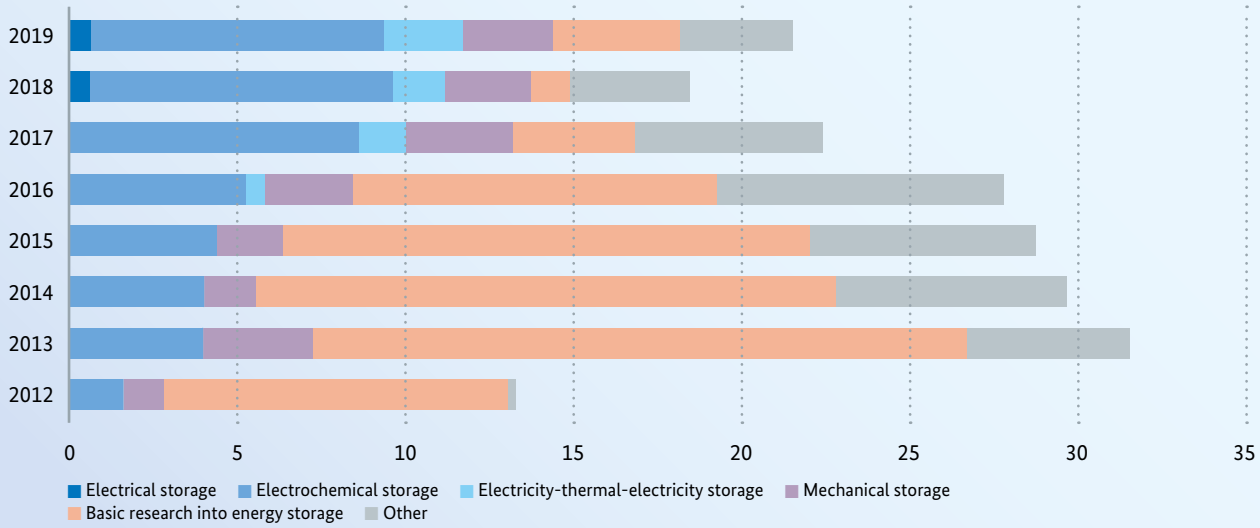
Power-to-heat-to-power for the storage of electricity from renewable energy using volcanic rock

The project team from Future Energy Solutions is seeking to optimise and increase the share of renewable energy used in electricity by developing effective heat storage technology. The test system developed by the researchers in Hamburg went into operation in 2019 and can store around 130 megawatt hours of thermal energy for up to a week. The next step is now to improve the technical process and bring down its commercial cost so that the test system can eventually offer capacities in the gigawatt hour range. The electrothermal storage unit stores surplus energy by converting electricity from wind turbines to heat and then back into electricity when needed (power-to-heat-to-power). The test energy storage system in Hamburg holds around 1,000 tonnes of volcanic rock. A resistance heating system is used to heat air up to 750 degrees Celsius. The hot

air transfers the heat to the volcanic rock in the solid heat storage unit, which is inexpensive and environmentally friendly. The heat is then converted back into electricity via a dynamic water-steam cycle.
In addition to this technological development, the scientists in the consortium are also looking at how the storage system can be integrated into the electricity market and working on various possible market designs and marketing scenarios.

Beneficiary: Siemens Gamesa Renewable Energy and two other partners
Funding ID: 03ET6072A-C
Estimated funding: €10.7 million
Project duration: 2016–2021

Figure 14: Funding for storage in € million
(Data cf. Table 4, p. 76)



PROJECT ABSTRACT

Extrusion plate – Novel large-scale bipolar plates in extrusion process for redox flow batteries
Development of a cost-effective manufacturing process for 1-m²-sized bipolar plates for vanadium redox flow batteries (VRFBs)

The core component of redox flow batteries is a bipolar plate. Several of these plates are joined together to form a stack. Until now, these batteries have been expensive and complex to produce and, on average, have only had an active area the size of an A4 sheet of paper. The aim of the project was therefore to develop a new, cost-effective manufacturing process and to produce batteries with a storage capacity in the two to three-digit megawatt range that can be used in industrial applications. To do this, the project team set itself the task of expanding the previous active area of the plates to over one square metre (1.2 m²). The particular challenge here was to ensure that the component remained mechanically stable and gas-tight and thus continued to offer the required level of electrical conductivity despite the change in size. The project partners set about this by using a substantially modernised production technology based on an extrusion process with a sheet width of up to 1,200 mm.

By using the extrusion process, the manufacturing of bipolar plates with a width of 1,200 millimetres will become more cost-effective.

Through this project, significant progress has been made on industrialising this energy storage technology, from the development and characterisation of the compound material, to the process for sheet extrusion, through to the assembly and testing of the new bipolar plates in redox flow batteries.

Beneficiary: Eisenhuth GmbH & Co. KG and three other partners
Funding ID: 03ET6050A-E
Estimated funding: €3.6 million
Project duration: 2015–2019

2.3.3 Sector coupling and hydrogen

Sector coupling comprises technologies that enable renewables-based electricity to be used in the heating and transport sectors, and for industry. Alongside energy efficiency, it holds great potential for replacing fossil fuels in all sectors and permanently reducing carbon emissions in the long term. By networking the energy infrastructure for electricity, gas, heat and fuels in an efficient way, total energy consumption can be reduced as well. In addition, sector coupling technologies are to increase the share of renewable electricity in the energy system as a whole and provide additional flexibility options for the electricity market.

Funding priorities and scientific advances

Across all sectors, the most efficient way of utilising renewable electricity is to use it directly. In addition, power-to-X technologies, in which electricity from renewable energy sources is converted into gases, liquids or heat, are also becoming increasingly important. There is a particular need for funding to promote technologies that use hydrogen as an energy carrier. Hydrogen is released through the process of electrolysis, where water is split into oxygen and hydrogen using electric current. It is then collected and processed to produce electricity-based fuels for aircraft, ships and large transport vehicles, for example. As a highly reactive energy carrier, hydrogen in its pure form is used as a key raw material in the chemical industry. It is therefore important for further research to be conducted on electrolysis plants and alternative approaches such as biochemical or solar processes, and for all of these processes to be optimised. There is also a need to develop innovative and safe concepts for storing, transporting and using hydrogen and its products given its property of being highly reactive. Further R&D is also needed on concepts for converting hydrogen back into electricity and on new smart production technologies for plant components.

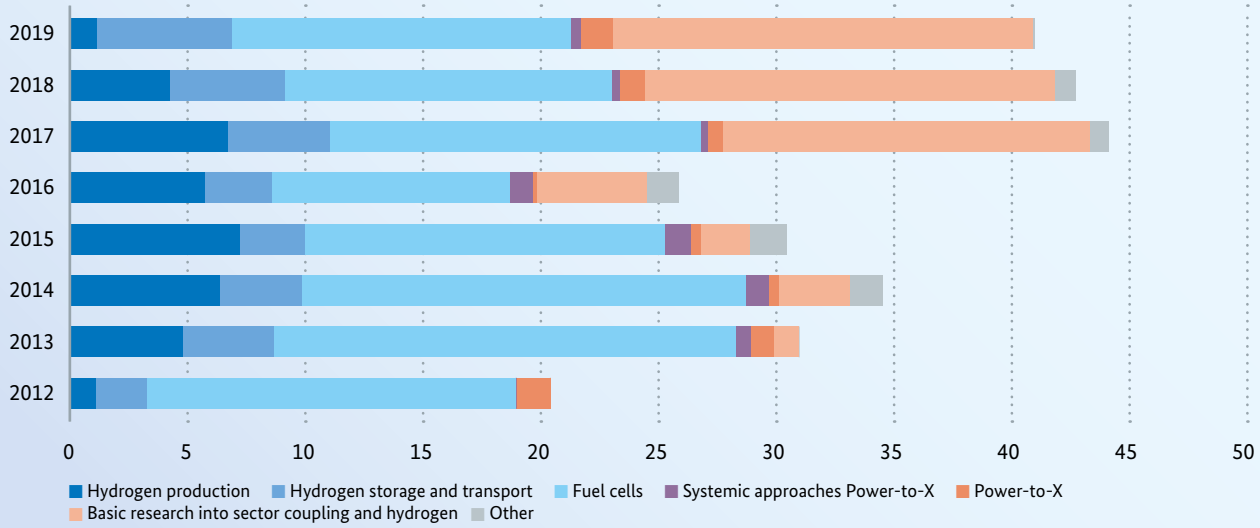
In all of the above-mentioned areas, application-oriented basic research is needed to enable the systems being developed to be cost-effective, flexible and durable. Research technologies include highly efficient, high-temperature electrolysers that simultaneously convert carbon dioxide, liquid hydrogen carriers, low-precious metal catalysts and the transfer of gases from industrial processes into cross-industrial networks.

Almost all initiatives operated by the Federal Ministry of Education and Research touch upon areas that relate to sector coupling. These particularly include the Kopernikus projects (see Chapter 1.2.4), research on carbon technologies (see Chapter 2.4.4), materials research for the energy transition (see Chapter 2.4.6) and international cooperation (see Chapter 1.3).

Project funding

In the field of sector coupling, the Federal Ministry for Economic Affairs and Energy and the Federal Ministry of Education and Research provided approximately €40.82 million in funding for 272 ongoing projects in 2019. In 2019, the ministries also approved approximately €96.95 million to fund 81 new research projects (see Figure 15).

Figure 15: Funding for fuel cells and hydrogen in € million
(Data cf. Table 4, p. 76)



PROJECT ABSTRACT

P2X Kopernikus project

This project is developing technologies to generate material energy and chemicals from electricity, water and carbon dioxide.

In the first, thee-year phase of the P2X project, which is funded by the Federal Ministry of Education and Research, researchers were able to make significant advances. Over this time, they have been able to make polymer electrolyte membrane (PEM) electrolysis for hydrogen production much more cost-effective. The required quantity of the rare and expensive element iridium which acts as a catalyst for this process has been reduced to a tenth of its original amount, without compromising on performance. A further line of research in the project has been to develop the simultaneous production of hydrogen and carbon monoxide via the high-temperature co-electrolysis of water and carbon dioxide. The researchers are now able to adjust the ratio of the electrolysis products in a way that ensures the subsequent processes for the production of chemicals are as efficient and effective as possible. This work has led to the development of a modular power-to-X plant, which was commissioned in November 2019. The operations at this plant represent the first time that green fuel has been produced from electricity, air carbon dioxide and water anywhere in the world. As part of the project, research is being conducted into the transport of hydrogen using

The researcher team has investigated the conversion of CO_2, water and renewable power into gases, fuels, chemicals and synthetic materials.

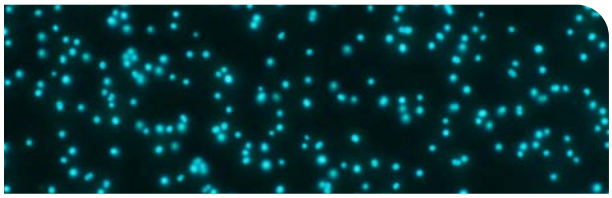
liquid organic hydrogen carriers (LOHCs). Such LOHCs are able to chemically bind hydrogen and release it again afterwards. This research has led to the important development of a new, cost-efficient catalyst for separating hydrogen. In addition, new production routes for the diesel substitute oxymethylene ether (OME) have also been developed. The P2X Roadmap 2.0, which sets out the various strands of the project, was published to provide information on the work being undertaken. The second phase of the project commenced in September 2019, following on directly from the end of the first.

Beneficiary: RWTH Aachen University and 41 other partners
Funding ID: 03SFK2A-X0
Estimated funding: €32.4 million
Project duration: 2016–2019

PROJECT ABSTRACT

ORBIT – Optimisation of a trickle-bed bioreactor for the dynamic microbial biosynthesis of methane using archaeae in power-to-gas plants

Microorganisms use renewables-based hydrogen to convert carbon dioxide into green methane



Fluorescence microscopic imaging of methane producing archaea.

Within the ORBIT project, scientists are looking at the production of methane from green hydrogen and carbon dioxide. The concept underlying this work is the conversion of power-to-gas, whereby wind power for example is used to split water into hydrogen and oxygen. If this hydrogen is then processed into methane using carbon dioxide from the atmosphere, it can be used as a climate-neutral energy carrier and raw material. The focus of the ORBIT project is to develop and test a trickle-bed reactor used for biological methanation. Here, the catalysts used in biosynthesis are archaeae – unicellular microorganisms that have a special metabolism and thrive under the most extreme conditions. The archaeae used in ORBIT absorb carbon dioxide and hydrogen as food and excrete methane as a 'waste product'. The ORBIT test system was constructed in Nuremberg and transported to Regensburg for 12 months of testing. It is now to be used in the town of Ibbenbüren in North Rhine-Westphalia to feed green methane into the natural gas network. It should be emphasised that the plant has passed through all of the different development stages to achieve technological maturity, starting with basic research in biology and progressing through to real-life use by a grid operator. The project has also ushered in the new VDI 4635 'power-to-X' standard.

Beneficiary: OTH Regensburg and five other partners
Funding ID: 03ET6125A-F
Estimated funding: approx. €996,000
Project duration: 2017–2020

innoKA – Material innovations for polymer aelectrolyte fuel cells

As part of the innoKA fuel cell research project, researchers are seeking to develop better catalysts and reduce the use of platinum.

The research team discusses a measurement at the fuel cells test rig

Platinum works well as a catalyst in fuel cells, but it is rare, expensive and methods for extracting it are not entirely environmentally friendly. In the innoKA project, the cathode of the polymer electrolyte membrane (PEM) fuel cell has therefore been designed to use a significantly lower amount of precious metal. Under the leadership of the Chair of Technical Electrochemistry at the Technical University of Munich, the researchers are also working to extend the service life of the catalysts used in the PEM and lower their material costs. Research into suitable materials is being conducted by the Electron Microscopy Center at Technische Universität Berlin. The microscopes available here enable researchers to examine the structure of individual nanoparticles and thus to monitor the behaviour of the various materials being tested. The membrane manufacturer Greenerity, which is also involved in the project, wants to get the most suitable materials ready enough to be used even as the manufacturing process is scaled up. These materials are therefore being tested as to their suitability for use in a fuel cell vehicle, for example.

Beneficiary: Technical University of Munich and two other partners
Funding ID: 03ET6096A-E
Estimated funding: €1.8 million
Project duration: 2017–2020

2.4 Cross-system research topics

2.4.1 Energy systems analysis

Energy systems analysis delivers models that paint a full, quantitative picture of processes, sectors and the energy system as a whole, and highlights development paths and factors that hinder or are conducive to these developments. Thereby, the insights gained from energy systems analysis provide important guidance and science-based support for policy-makers, the business community, and society at large in their decision-making and assessment of the potential ways forward. Energy systems analysis allows decision-makers to study the full impact of energy and efficiency technologies, and of market intervention. This is why the continuous development and improvement of tools, methods, and databases for systems analytics are a cornerstone of energy research policy.

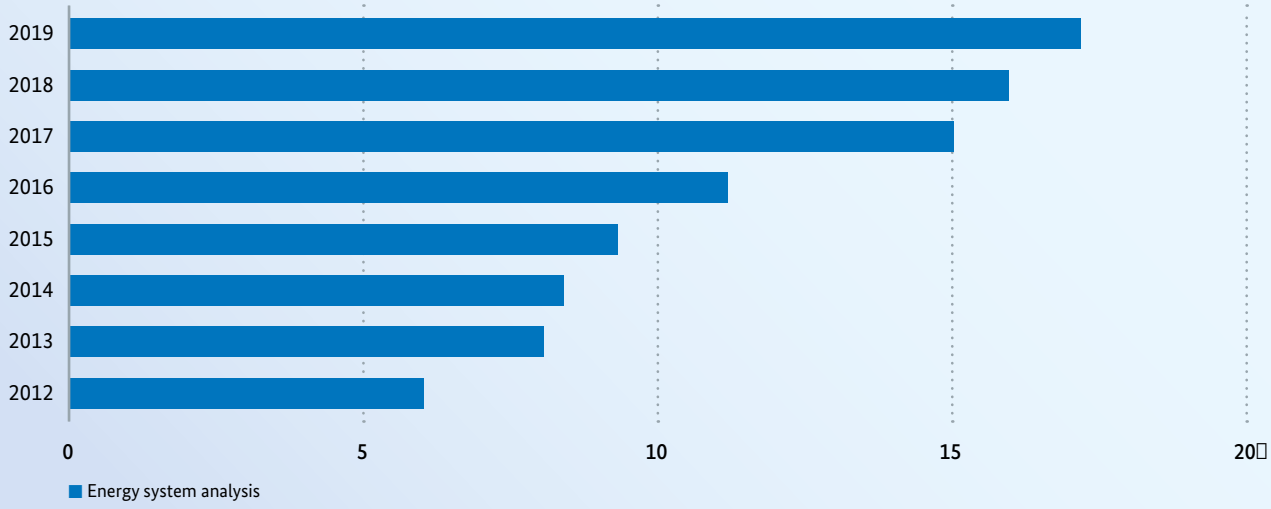
Funding priorities and scientific advances

The multitude of models and scientific angles that can be applied to what is an ever more complex energy system require continuous methodological development and, notably, standardised interfaces that allow for several different models to be coupled and compared to one another. Also in demand are cross-sectoral approaches that better integrate the heat and transport sectors into systems modelling. Another important focus is on research into validation methods for assessing the reliability of models. Strategies for open source, open data, and open access are to help foster transparency and allow for better comparability. This again is to help transfer scientific findings into the practical work of the energy sector. The Federal Ministry for Economic Affairs and Energy has also made it a focus of its work to include European and international factors in its models.

Project funding

In the focal field of energy systems analysis, the Federal Ministry for Economic Affairs and Energy provided approximately €17.16 million in funding for 233 ongoing projects in 2019. Also, the ministry approved approximately €24.75 million in funding for 60 new research projects in 2019 (see Figure 16).

Figure 16: Funding for systems analysis in € million
(Data cf. Table 5, p. 77)



PROJECT ABSTRACT

FlexEuro - Economic optimisation for flexible and power-intensive industrial processes
Development of methods and prototypes that foster the marketing of flexibility in power consumption

Flexibility will be a key feature of the future energy system, which will be characterised by fluctuations in the volume of power fed into the grid. This means that the demand side has a highly important role to play in maintaining grid stability. Power-intensive industrial processes, in particular, are a field where there is major potential for greater demand-side flexibility. For this reason, the FlexEuro project team is developing a basis for decisions that will make it possible to market this flexibility in power consumption. The work of the scientific team centres on a use case involving an aluminium electrolyser with a flexible capacity of 22 megawatts (in both the positive and negative directions). On this basis, the team seek to minimise the energy costs for the overall process.

The project partners are developing quantitative financial and mathematical models and algorithms that will allow flexible electricity users to optimise their utility bills. The focus of the work is on short-term options for marketing flexibility. The results gained from the research are to be tangible and lend themselves to practical application. Examples include market modelling for bids made on the balancing energy market, price forecasts for day-ahead auctions, and recommendations for the intraday market. At the stage of prototype software, the models and methods developed in the course of the research are then to be tested by the aluminium producer involved in the project.

Especially power-intensive industrial processes like aluminum production, offer opportunities for flexibilisation of energy consumption

Beneficiary: Fraunhofer Institute for Industrial Mathematics (ITWM) and three collaborative partners
Funding ID: 03EI1003A-D
Estimated funding: €1.7 million
Project duration: 2019–2022

2.4.2 Digitisation of the energy transition

Rapid technical progress in the field of digital technology is triggering change affecting almost all aspects of our lives. It is for good reason that this development is called the 'digital revolution'. This revolution is also having an impact on the energy system. Smart grids, smart neighbourhoods, smart factories, smart information and communications technology (ICT) are just some of the key components for a modern, future-proof energy infrastructure. Digitisation is therefore a horizontal aspect that must be factored into all fields of energy research. Beyond this, there are also effects that cannot be reduced to individual fields of technology, but are having an impact on the entire system. Digitisation can help make the energy transition more efficient, but the ways in which energy and resources are used must also be considered as part of the research, and further and continuous optimisation is needed. The Federal Ministry for Economic Affairs and Energy seeks to find answers to research questions resulting from this, which is why, in December 2018, it launched a call for applications for funding for 'digitisation of the energy transition'. From the entries received, the ministry selected eight research alliances (36 projects) and granted them funding. Five joint projects (22 projects) took up their work before the end of 2019.

Project funding

As part of its focal work on digitisation of the energy transition, the Federal Ministry for Economic Affairs and Energy provided funding for 13 projects in 2019. In addition to this, the ministry approved approximately €9.62 million in funding for 22 new research projects in 2019.

2.4.3 Resource-efficiency for the energy transition

The notion of a circular economy is that the value inherent in products, materials, and resources used in the economy is to be upheld and retained for as long as possible, which helps reduce the volume of waste and emissions to a minimum. In the energy sector, energy research has long fostered progress towards this goal, for instance by paving the way for PV modules and batteries that better lend themselves to recycling. Under the 7th Energy Research Programme, resource efficiency and the circular economy have been declared focal areas for research by the Federal Government. This means that the federal ministries involved in the programme have made resource efficiency on the part of applicants an important criterion during their project selection process.

2.4.4 CO_2 technologies

In some industrial processes, it is hard to avoid generating CO_2, but this waste product can be sequestrated. A key approach being pursued in the field of CO_2 technologies is to take the carbon dioxide and re-use it for different processes or to make new products that are as durable as possible. This is a way to render industrial processes largely climate-neutral.

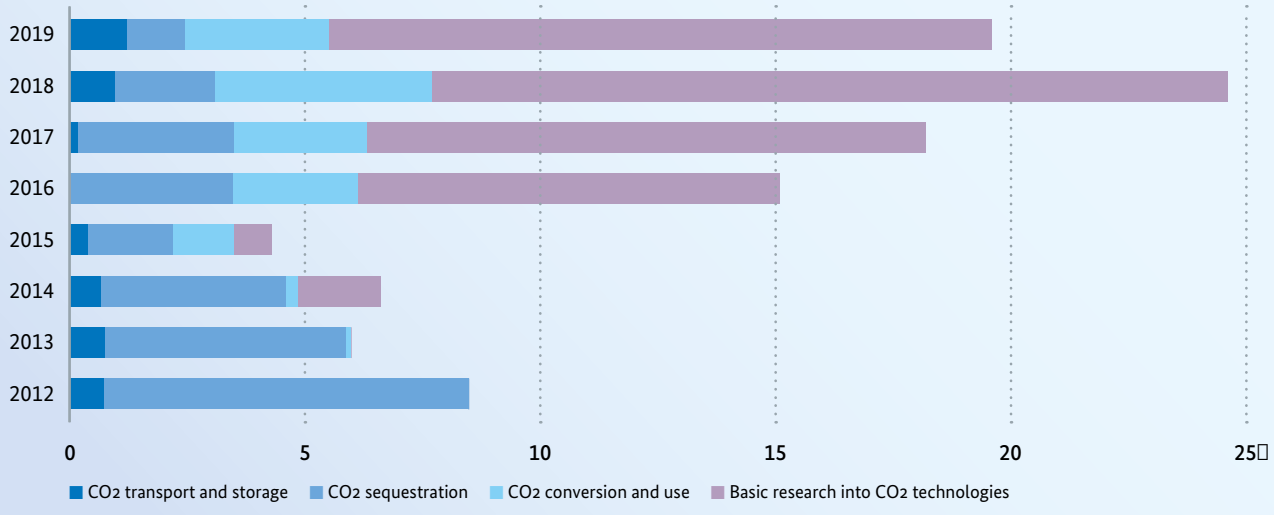
Funding priorities and scientific advances

The work receiving funding from the Economic Affairs and Research Ministries in this field of research falls into the category of Carbon Capture, Utilisation and Storage (CCUS), a blanket term subsuming all the different approaches for sequestrating carbon dioxide for later use or storage. Several different processes for sequestrating or scrubbing carbon dioxide from exhaust fumes are already available. The Federal Ministry for Economic Affairs and Energy provides funding for projects seeking to make these more efficient and economically viable. Another potential approach pursed by researchers is to use technology or biomass to extract the harmful gas from the atmosphere. By no means the least important objective for researchers and developers is to establish a well-functioning circular economy, in which carbon dioxide is reused rather than released into the atmosphere. One example for this type of project is Carbon2Chem, which is funded by the Federal Ministry of Education and Research. Under this project, the blast-furnace gases generated during steel production processes are then used as feed materials for chemical production.

Project funding

In the field of CO_2 technologies, the Economic Affairs and Research Ministries provided approximately €19.57 million in funding for 73 ongoing projects in 2019. In 2019, the ministries also approved approximately €9.83 million to fund 22 new research projects (see Figure 17).

Figure 17: Funding for CO_2 technologies in € million
(Data cf. Table 5, p. 77)



PROJECT ABSTRACT

Carbon2Chem

CO_2 reduction by means of cross-sectoral cooperation between the steel, chemical, and energy industries

The Carbon2Chem project, which receives funding from the Federal Ministry of Education and Research, is dedicated to exploring how blast-furnace gases can be used to manufacture basic chemicals, plastic, or fertilizer. The idea is to use up to 20 million tonnes of the CO_2 emitted by steel producers to create new materials and lay the basis for an optimised, cross-sectoral cooperation between steelworks, chemical plants, and energy installations.

Following the entry into operations of the Carbon2Chem technicum at the Duisburg steelworks in 2018, the Carbon2Chem lab in Oberhausen was completed in 2019. The technicum runs on blast-furnace gases from the steelworks. Various process routes can be studied an optimised in a real-life setting. The Carbon2Chem lab analyses the same processes, but in a controlled lab environment.

Some decisive results have been achieved in phase 1 of the project, which ends in mid-2020: a flexible and moveable electrolyser with a capacity of two megawatts has been established to ensure the necessary hydrogen supply. The purification of the blast-furnace gases in preparation of the chemical processes planned is also going well. The catalytic procedures used in the product routes have been optimised. At present, a second funding phase dedicated to the validation of the processes in demonstration plants is being prepared.

Federal Research Minister Karliczek and representatives of thyssenkrupp in front of the gas purification system at the Carbon2Chem technicum in Duisburg.

Beneficiaries: thyssenkrupp, Max Planck Society, Fraunhofer Society for the Promotion of Applied Research, and 14 collaborative partners organised in seven project alliances L0-L6
Funding ID: 03EK3037A-D, 03EK3038A-B, 03EK3039A-F, 03EK3040A-F, 03EK3041A-E, 03EK3042A-C, 03EK3043A-F
Estimated funding: €62.7 million
Project duration: 2016–2020

PROJECT ABSTRACT

ACT ALIGN-CCUS – Accelerating the growth of low-carbon technologies based on CCUS

Six European industrial regions want to lower their CO_2 emissions by sequestrating and storing CO_2, or by using it for new products.

The German partners involved in the project are focusing on ways of sequestrating and recycling CO_2. Other key questions to be answered relate to ways in which industrial associations can work together on this and to what can be done to raise the level of public acceptance for these technologies. As far as the technology itself is concerned, RWE is already operating one of the leading European CO_2 scrubbing plants – thanks to a number of funding projects. The facility has already clocked more than 80,000 operational hours during which it has been extracting CO_2 from the flue gas emitted by the Niedraußem coal-fired power plant in North Rhine-Westphalia. However, there are several mechanisms behind that, which have yet to be better understood. For instance, it is unclear why this plant uses only approximately a quarter of the average amount of detergent used by similar installations. A milestone set by ALIGN-CCUS is their demonstration plant that uses sequestered carbon-dioxide for the production of synthetic fuel and has been operating since the beginning of 2020. This marks the first time that the entire conversion process has been demonstrated in an actual power station. The technology underlying this installation can also be applied to energy-intensive industrial processes such as steel or cement production, which generate large amounts of carbon-dioxide.

Carbon-dioxide that is stored as a fluid, evaporates to gas in this plant.

Beneficiary: RWE Power and five collaborative partners in Germany
Funding ID: 0324186A, B, D-G
Estimated funding: €5.3 million
Project duration: 2017–2020

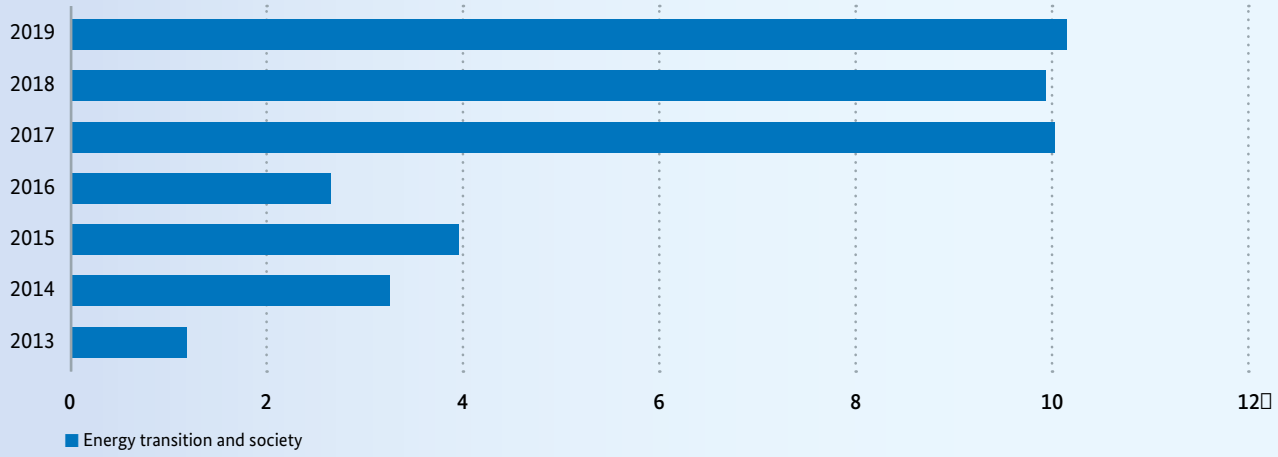
2.4.5 Energy transition and society

Over the coming decades, it will be necessary to restructure the energy system in a profound way. Innovative energy technologies and new processes are making important contributions to this and are having an impact on society at large and every individual. Not only that: the transformation of the energy system and the energy transition as a whole can only succeed if these changes are supported by citizens, municipalities and public-sector institutions, civil-society organisations and multipliers, energy suppliers, those in charge of planning and the hands-on work – in short: all of society. For this reason, the Federal Ministry for Economic Affairs and Energy launched a call for applications for funding entitled “energy transition and society”. This first call for applications, which was launched in April 2019, met with great interest and almost 60 ideas for research projects were submitted. Most of the abstracts focused on “acceptance of and participation in the transformation process” and “social and economic effects of financial investment opportunities”. As for more systemic questions, these are also addressed by the ENavi Kopernikus project that was launched in 2016 and receives funding from the Federal Ministry of Education and Research (see project abstract).

Project funding

In the field of ‘energy transition and society’, the Economic Affairs and Research Ministries provided approximately €10.15 million in funding for 49 ongoing projects in 2019. Also, the ministries approved approximately €1.26 million in funding for eight new research projects (see Figure 18, page 54).

Figure 18: Funding for the energy transition and society in € million
(Data cf. Table 5, p. 77)



PROJECT ABSTRACT

ENavi Kopernikus project

Energy transition navigation system to collate, analyse and simulate systemic interconnections

Under this project, which received funding from the Federal Ministry of Education and Research and was led by the Potsdam Institute for Advanced Sustainability Studies (IASS), more than 60 partners explored possibilities for identifying optimal pathways for the implementation of the energy transition in a way that brings all of society on board. The project, which ended at the end of 2019, sought to foster sectoral decarbonisation and was three-pronged, focusing on: the heating transition, transport transition, and the coal phase-out. The objective was to develop new strategies for citizens, business, associations, municipalities and public-sector organisations to help them better understand the complex systemic interplay at work. ENavi was about mapping scope for action and using a navigation tool to highlight opportunities and risks. The project was broad-based, transcended traditional scientific disciplines, and built on continuous, structured dialogue with stakeholders on the ground. Important indications of practicability and public recognition of the solutions were obtained in regulatory sandboxes and selected model regions. Commercial companies, utilities, NGOs, regional and local authorities were also among the stakeholders involved in the project.

ENavi has developed a navigation model that estimates the effects of technological development, forms of organisation, regulation and behaviour on the energy transition.

Beneficiary: Institute for Advanced Sustainability Studies (IASS) and 46 collaborative partners
Funding ID: 03SFK4A-Z1
Estimated funding: €30.5 million
Project duration: 2016–2019

2.4.6 Materials research for the energy transition

Basic research projects for the development of innovative materials designed to allow for an energy supply based on renewables are of strategic importance.

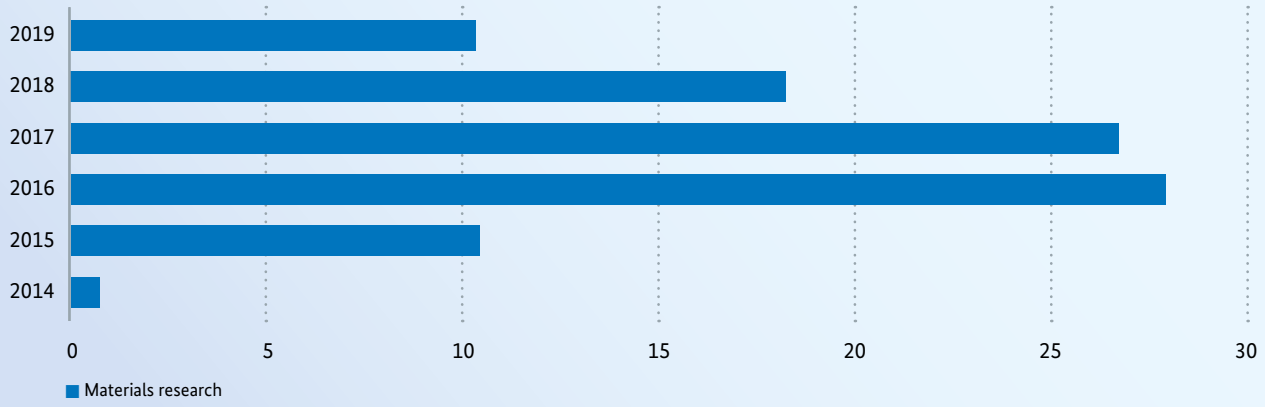
Funding priorities and scientific advances

This is why the support instruments offered by the Federal Ministry of Education and Research are designed to be neutral and cover fields spanning from materials research to power generation and storage to energy performance improvements. Photovoltaics projects have made it possible to achieve record levels of energy conversion efficiency, and to produce innovative materials. Important steps were also made towards the development of cells for direct solar hydrogen generation that can compete on the market. A new class of catalysts is opening up new opportunities in fuel cell technology. Furthermore, some successful research was conducted into a new material to be used in gas turbines. Several of the young scientists heading up junior research groups have since been appointed to university chairs or junior professorships.

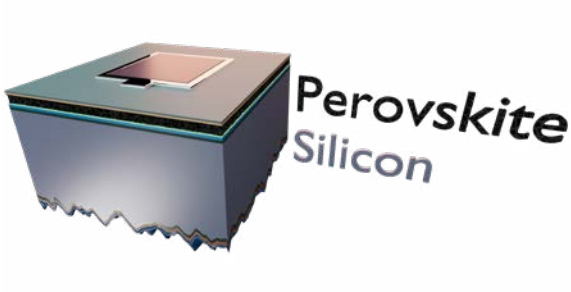
Project funding

In the field of materials research for the energy transition, the Federal Ministry of Education and Research provided approximately €10.30 million in funding for 89 ongoing projects in 2019 (see Figure 19).

Figure 19: Funding for materials research in € million
(Data cf. Table 5, p. 77)



PROJECT ABSTRACT



3D animation of a monolithic perovskite silicon tandem solar cells

MeSa-Zuma Junior Research Group – Development of spectrally optimised, highly efficient and long-term stable perovskite/silicon tandem solar cells

A combination of highly efficient solar cells based on perovskites and silicon delivers an energy conversion rate that far exceeds that of silicon-based solar cells available today.

There have been some very successful developments in the field of photovoltaics in recent years. If we are to increase the use of solar power, it is important to lower the cost of its generation. This can be achieved by making solar cells more energy efficient. Combining a silicon-based solar cell with metal-halide perovskites into a tandem solar cell can deliver a significant higher energy conversion rate. In summer 2019, the project, which is funded by the Federal Ministry of Education and Research, achieved the highest energy conversion efficiency rate on record so far (26 percent). In January 2020, it posted the certified world record of 29.15 percent for perovskite silicon tandem solar cells. The head of the junior research group that put this project into practice has been awarded a number of accolades, including the 2019 Karl-Scheel Award and the 2019 Berlin Science Award.

Beneficiary: Helmholtz-Zentrum Berlin für Materialien und Energie
Funding ID: 03SF0540
Estimated funding: €1.4 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. Against the backdrop of the phase-out of commercial nuclear power generation in Germany, one of the key objectives for this funding measure is to safeguard and further develop the expertise and infrastructure required to ensure this.

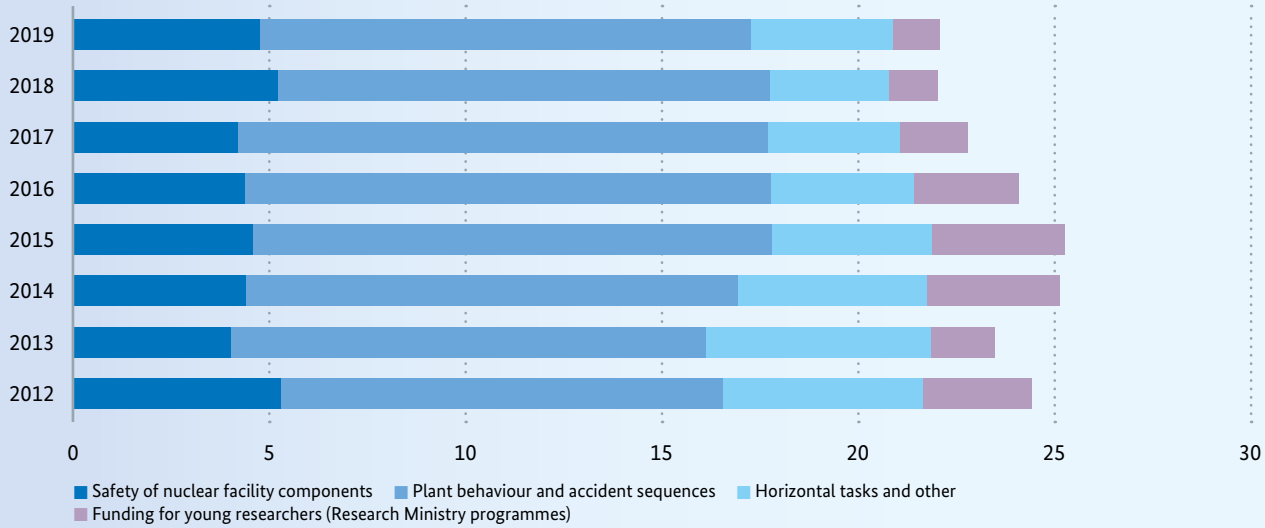
Funding priorities and scientific advances

The research on the safety of nuclear energy for which public funding is made available focuses on safety in nuclear power plants. At international level, there are discussions about potential life-time extensions for existing nuclear power plants and also about new technical developments. Even though Germany will have completed its phase-out of commercial nuclear power by the end of 2022 at the latest, it is critical for the country to conduct its own research into safety-related aspects of nuclear power, and to remain engaged in international initiatives for the safety of nuclear power. This will ensure that Germany continues to be able to wield political influence in this field. In funding terms, the focus is on the development and experimental verification of tools for the simulation and assessment of existing installations in and outside Germany and of new concepts for installations. The same applies to the assessment of the condition of NPP buildings and components, with a particular focus on age-related factors.

Project funding

The lead responsibility for the project funding in the field of nuclear safety research rests with the Federal Ministry for Economic Affairs and Energy, and 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 €20.86 million in funding for 131 ongoing projects in 2019. The Federal Ministry of Education and Research provided €1.19 million for eight projects. In addition to this, the Federal Ministry for Economic Affairs and Energy approved approximately €25.73 million in funding for 33 new research projects in 2019. (see Figure 20).

Figure 20: Funding for reactor safety research research in € million
(Data cf. Table 6, p. 78)



PROJECT ABSTRACT

PKL III i – Transients investigations in the PKL test facility

Systemic study of thermal-hydraulic behaviour in pressurised-water reactors in postulated accident scenarios

The PKL (primary coolant loop) test facility in Erlangen is one of the world's leading installations for experiments to investigate thermal-hydraulic processes in pressurised-water reactors (PWRs) in postulated accident scenarios. For this purpose, the installation has been designed as a copy of the primary circuit and the most essential parts of the secondary circuit of a PWR on a scale of 1:145, using the original height scales. Scientists from 14 countries are involved in the PKL IIIi project, where they conduct tests designed to answer safety questions that are being discussed internationally, for instance studying the behaviour of a PWR during a long blackout. The results from PKL IIIi are being used internationally to improve the phenomenological understanding of the complex thermal-hydraulic processes at work in a PWR and, in a next step, to develop advanced computing software for realistic simulations of incidents and accidents and for assessing the effectiveness of potential counteractions.

Reactor pressure vessel of the primary coolant loop (PKL) test facility with main coolant pipes of Framatome GmbH

Beneficiary: Framatome GmbH
Funding ID: 1501527
Estimated funding: €980,000
(rate of funding: 21.6 percent)
Project duration: 2016–2020

2.5.2 Disposal and repository research

The Federal Government continuously provides funding for nuclear waste disposal and repository research, thereby making significant contributions to the establishment and development of a scientific and technical basis for concepts for final nuclear repositories that use salt, clay, or crystalline as a host rock.

Funding priorities and scientific advances

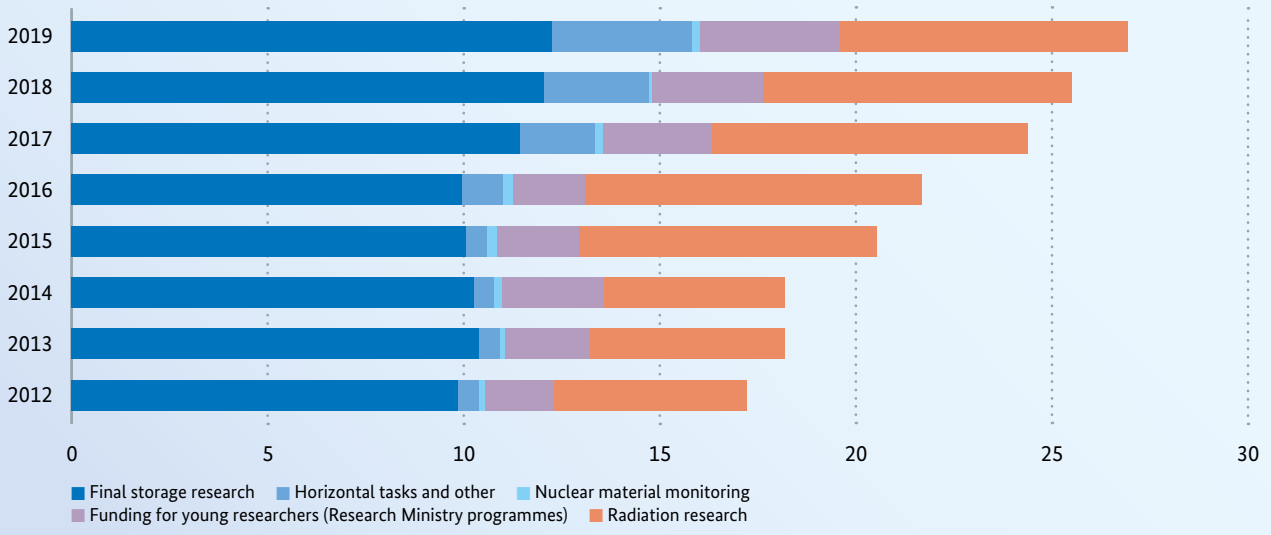
The funding priorities are projects designed to create the scientific and technical basis for the creation of a final repository. The studies conducted under the projects analyse the effectiveness of the barrier system and the monitoring system; others set out plans for the development of technologies for transporting nuclear waste and putting it into the final repository. There are also additional scientific projects that study the extent to which radionuclides spread in a final repository and on how this process is affected by various factors. All this work is rounded off with studies looking at social and technical impacts, which will form the basis for dialogue between the various stakeholders. Finally, there are also projects studying the impact that longer interim storage periods compared with original plans will have on the waste and the containers.

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.

In the field of nuclear waste disposal and repository research, the Economic Affairs Ministry provided approximately €16.0 million in funding for 91 ongoing projects in 2019. The Federal Ministry of Education and Research provided €3.5 million in support for young scientists across 20 projects. In addition to this, the Federal Ministry for Economic Affairs and Energy approved approximately €20.92 million in funding for 26 new research projects in 2019 (see Figure 21).

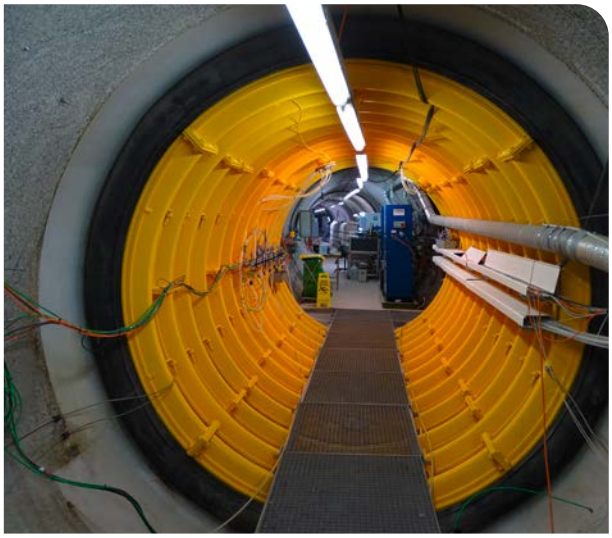
Figure 21: Funding for disposal and final storage research and radiation research in € million
(Data cf. Table 6, p. 78)



PROJECT ABSTRACT

Kollorado-e3 – In-situ experiments to study the long-term integrity of the bentonite barrier for the retention of radionuclides in crystalline host rock
Studying the processes happening in a near-natural environment in a final repository (granite) and how these affect the stability of the geotechnical barrier.

Researchers of the University of Jena, of the Karlsruhe Institute for Technology, and the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) are conducting research in the Grimsel rock lab (Switzerland), where they study materials and systems that could be used as a geotechnical barrier in a potential final repository. For these experiments, a small barrier system with a diameter of approximately 10 cm was created within a natural rift. The aim of the project is to conduct in-situ experiments to gain a better understanding of the erosion mechanism in the technical barrier (compacted betonite) and the interaction between radionuclides and colloids in a near-natural environment, and to assess the relevance of the colloid-driven transport of radionuclides in terms of the long-term safety of a final repository built in a solid rock formation. Also, generic findings on the relevance of colloids and on the mobility of radionuclides are being sought.
Initial results from the research suggest that the radionuclides put into the rift are mobile in principle, but not to an extent that would permit them to cross the barrier, which would mean that the barrier would, in principle, fulfil its purpose.



Set-up of a barrier system (megapacker system) at URL Grimsel

Beneficiary: University of Jena und two partners
Funding ID: 02E11759
Estimated funding: €1 million
Project duration: 2019–2022

2.5.3 Radiation research

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

In the 2019 reporting period, 12 research alliances with a total of 43 individual projects relating to radiation biology, radiation medicine, epidemiology, and radio-ecology received funding. With these projects, the Federal Ministry of Education and Research supported approximately 150 junior researchers during their training, which means that this funding priority was able to make a substantial contribution to the formation and retention of 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. The collaborative research was dedicated to highly relevant social and highly topical scientific issues. This also included a number of projects that produced results used in the National Decade Against Cancer.

Project funding

In 2019, 43 research projects in the field of radiation research were supported with funding totalling around €7.36 million. In addition to this, the ministry approved approximately €3.52 million in funding for six new research projects in 2019 (see Figure 21, page 58).

PROJECT ABSTRACT

Collaborative project ISIBELa: Intrinsic radiation sensitivity: identification of biological and epidemiological long-term effects

This research alliance has dedicated itself to the overarching goal of researching the genetic predispositions which may result in a higher risk of neoplasms following a therapeutic exposure to radiation during childhood. The group uses epidemiological methods in a cohort study of the secondary tumour incidents recorded in the German Childhood Cancer Register. In a molecular epidemiological case/control study, cell samples of persons without a tumour are being compared to those of patients with primary and secondary tumours. The focus here is on the genome and on gene expressions prior to and after the radiation therapy. The necessary statistical methods are being developed and radiation-related epigenical changes in gene regulation studied. Furthermore, tests are being conducted at the genome level to explore spontaneous and radiation-induced changes to the telomers. There are also dosimetric studies of radiation-induced genome lesions to determine the dosimetric effect of radiation therapy on the entire body.

ISIBELa investigates, if therapy for childhood cancer influences whether someone falls ill with tumour in future and researches the role of genetic predispositions

Beneficiary: University medicine at Johannes Gutenberg University, Mainz, and three associated partners
Funding ID: 02NUK042A-D
Estimated funding: approx. €5.4 million
Project duration: 2015–2021

3. Institutional energy research


Nr. 6

3.1 Energy research by the Helmholtz Association

The Research Field 'Energy' of the Helmholtz Association supports the implementation of the 7th Programme for Energy Research. The programme-based funding for the Helmholtz Association makes it possible to attribute funding to specific fields of research, such as energy research. This is different to other recipients of institutional funding, such as Fraunhofer, where this is not as straightforward. But irrespective of this, these other recipients of institutional funding are also highly important for energy research in Germany.

As for the Helmholtz Association and its Research Field 'Energy', 2019 was an important year in terms of setting the course for the future: it was the year when the relevant centres prepared their programme applications for the fourth period of programme-based funding, which is due to begin in 2021. The centres involved are the Research Centre Jülich (FZJ), the Karlsruhe Institute of Technology (KIT), the Helmholtz-Zentrum Berlin (HZB), the Helmholtz-Zentrum Dresden-Rossendorf (HZDR), the Max Planck Institute for Plasma Physics (IPP), and the German Aerospace Center (DLR). The institutional funding for the Helmholtz Centres is provided by the Federal Ministry of Education and Research; the only exception being the German Aerospace Center (DLR), which receives institutional funding from the Federal Ministry for Economic Affairs and Energy.

The programme applications are drawn up in line with the research-policy objectives agreed between the grant providers and the centres involved. In line with these objectives, the mission for the energy researchers working with the Helmholtz Association is to address the major challenges posed by climate change and the transformation of the energy system, and to develop viable solutions for Germany's energy transition and for a transition of the global energy supply to make it sustainable. The Research Field 'Energy' of the Helmholtz Association conducts both basic and applied research. Even the basic research, however, has a considerable link to energy applications. The results from the scientific assessment of 2018 were also taken into full consideration in the programme applications.

In October 2019, the programme applications were strategically reviewed by a high-ranking international expert panel. The review confirmed the strategic orientation of the Research Field 'Energy' of the Helmholtz Association. Numerous valuable pieces of advice on individual research topics are being taken into account as the research programmes for the fourth period of programme-based funding are prepared in detail. The panel of experts will continue to provide scientific advice to the Research Field 'Energy' of the Helmholtz Association.

One important task for Research Field 'Energy' of the Helmholtz Association is to provide high-performance research infrastructure which can also be used by other stakeholders working in the field of energy research. Among the key research infrastructure elements on which considerable progress was made in 2019 are some to ensure that researchers in Germany will continue to be able to conduct independent research into nuclear safety risks. This type of risk assessment remains necessary, for instance in the context of Germany's nuclear phase-out and also in connection with neighbouring countries' continued operation of nuclear power plants.

2019 was a year of important strategic decisions, but also of numerous scientific highlights: researchers at Helmholtz-Zentrum Berlin (HZB), for instance, set a world record for energy-conversion efficiency delivered by a tandem semiconductor solar made up of silicon and perovskite. The HZB is now working with Oxford PV, a private company, to transfer the research results into marketable products (see Chapter 2.4.6 materials research for the energy transition, project abstract Junior Research Group MeSa-Zuma, page 56). At KIT, some significant progress was made, including on production processes for supraconducting cables and battery electrodes. A modular production plant for synthetic fuels from renewable power, water, and carbon dioxide extracted from the air was successfully set up in cooperation with the INERATEC spin-off of KIT (see Chapter 2.3.3 Sector coupling and hydrogen, project abstract P2X Kopernikus project, page 47). The FZJ's own energy supply was also a subject of the Centre's work conducted within the Living Lab Energy Campus. This means that highly integrated energy supply systems for heat, power, chemical energy storage, and mobility can be researched in a highly realistic environment. Another

milestone reached in 2019 was the opening of the Emulation Centre for Networked Energy Systems under the auspices of the German Aerospace Center (DLR). This has made it possible to test hardware components such as charging infrastructure or inverters in a network copied from the real world, and have them interact with parts of the power system, e.g. urban neighbourhoods or transmission networks.

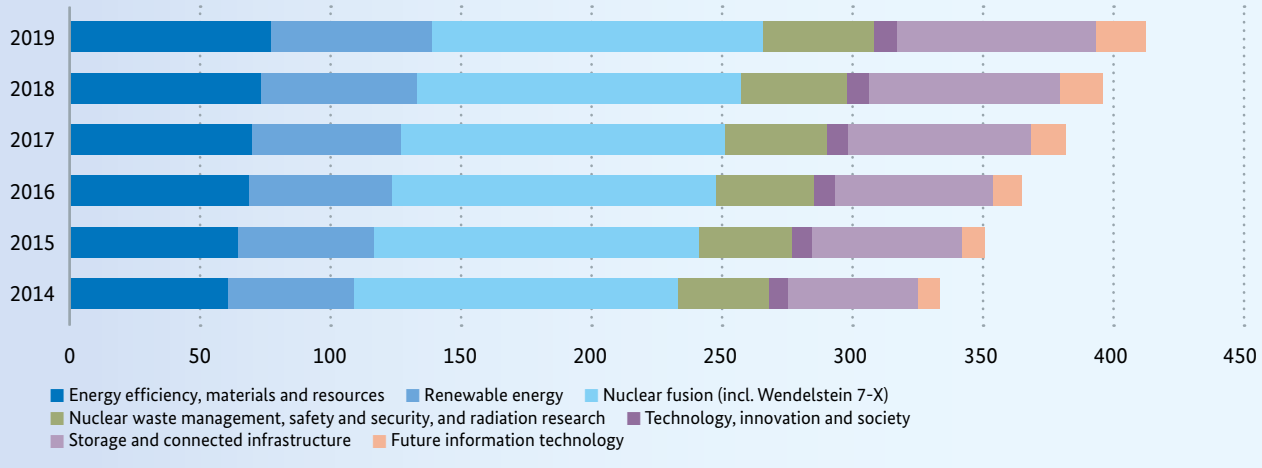
Figure 22 shows the funding deployed in the Research Field 'Energy'.

3.2 Fusion Research

In the context of programme-based Helmholtz Association funding, funding for application-oriented basic research also goes towards fusion research. The research into how energy can be generated from fusion is aimed at developing a non-fossil, reliable and affordable source of energy. 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. 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.

Figure 22: Funding for institutional energy research in € million
(Data cf. Table 7, p. 78)



4. Other energy-related research activities

4.1 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.

The latest survey, for 2018, says that spending by the *Länder* on project funding and institutional funding totalled approximately €220 million, with project funding accounting for €129.7 million and institutional funding accounting for €90.3 million.

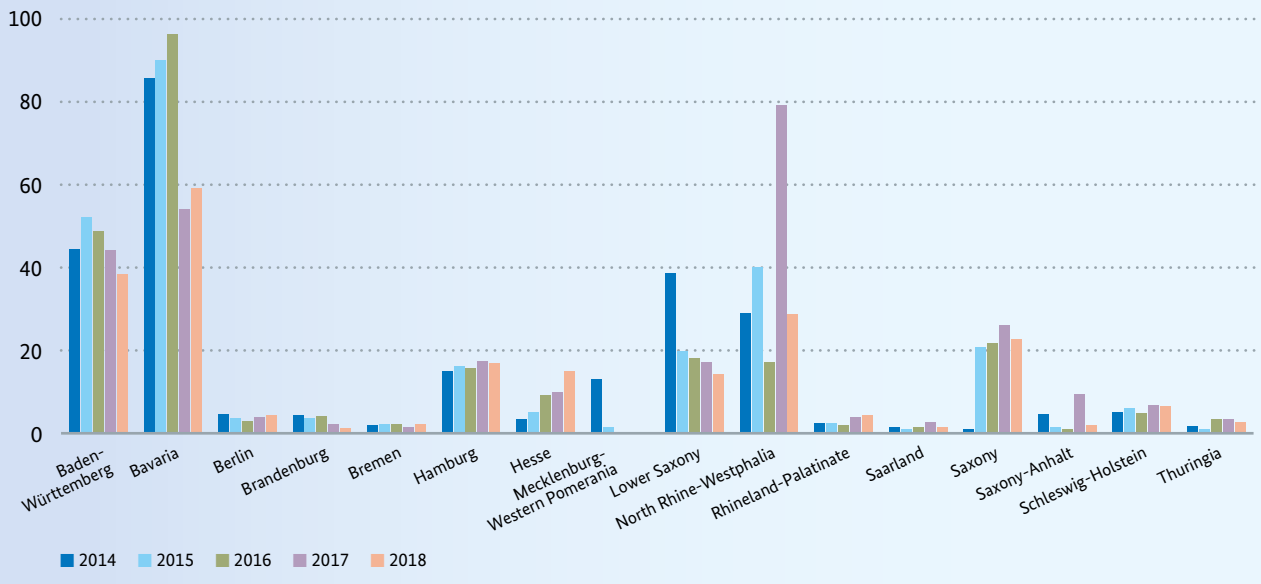
As in the preceding years, the horizontal focus of the funding in 2018 was on measures to improve energy efficiency. As for technology-specific research funding provided by the *Länder*, the focus was on energy efficiency in transport (€29.4 million), with electric mobility accounting for the bulk of the funding. Research into energy efficiency in the industrial sector, trade and commerce was also funded by the *Länder* (€24 million in total), especially Bavaria, where the main focus of the funding was on this type of research (€10.7 million). Financial support by the *Länder* for research into energy efficient buildings and neighbourhoods totalled almost €17 million, of which Hesse alone provided €4.4 million.

The figures for key-enabling technologies for system integration show that the amounts of funding for energy storage technologies (€26.4 million) and for the power grids (€6.4 million) were raised considerably year-on-year. Key building blocks for achieving efficient sector coupling are hydrogen technologies (€12.9 million) fuel cells (€6.5 million). In recognition of these technologies' growing importance for the energy system as a whole, they were recorded separately for the first time for this report.

Research funding for renewable energy was lower than the volume seen in previous years, but remains at a high level. The field of solarthermal energy and PV accounts for the largest sums of funding in this area (€18.4 million), with the most funding coming from Bavaria (€3.8 million), Lower Saxony (€3.6 million), and Baden-Württemberg (€3 million). Funding for bioenergy research (€10.9 million) was at a similar level to that of the preceding year, and came from Bavaria to a large extent (€6.6 million). Technology funding for wind energy increased considerably compared to 2017 levels (to €6.8 million), with Hamburg acting as a key driver (€1.5 million).

Geothermal energy also saw an increase in funding (€6.6 million), most of which was provided by Bavaria (€4.5 million) and Baden-Württemberg (€1.3 million).

Figure 23: Spending on non-nuclear energy research by *Land* in 2014–2018 in € million
(Data cf. Table 9, p. 79)



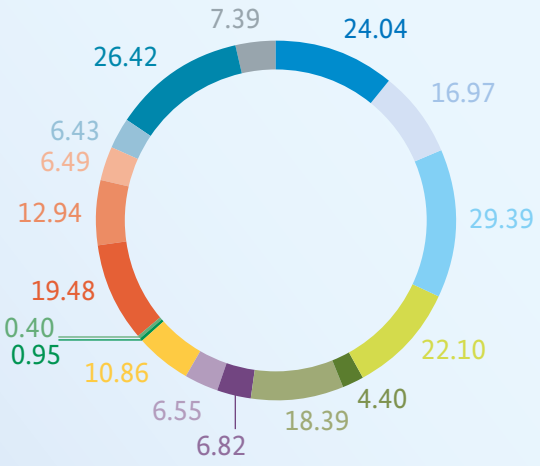
Funding for research activities in the field of hydropower (€1 million) was mostly provided for the modernisation of existing plants, with most of the funding being provided by Bavaria (€0.8 million).

Marine energy research is a niche and funding for it is provided only by Hamburg (€0.4 million).

The research activities supported by the *Länder* in the field of thermal power plants/CO_2 technologies total €4.4 million, of which the majority (€2.4 million) was provided by North Rhine-Westphalia.

The horizontal research topic of energy systems analysis and modelling covers aspects including the simulation of interactions between the different energy sectors and the development of valid energy scenarios. The growing importance of this field is reflected in the amount of funding provided by the *Länder* (€7.4 million).

Figure 24: Spending on non-nuclear energy research by *Land* in 2018 in € million
(Data cf. Table 11, p. 81)



Total spending on energy research funding in Bavaria (€59.3 million) exceeds that of the other *Länder*; the next highest amounts are in Baden-Württemberg (€38.3 million), North Rhine-Westphalia (€28.8 million) and Saxony (€22.7 million).

With their funding of more than €220 million in total for non-nuclear energy research, the *Länder* are making a major contribution to the achievement of the energy policy goals postulated by the Federal Government, and thereby act as a cornerstone of the national energy transition.

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 2018' [in German] can be accessed on the website of Project Management Jülich (PtJ).

4.2 EU Research Framework Programme (Horizon 2020)

The European research and innovation programme Horizon 2020 was designed to provide funding for transnational and interdisciplinary cooperation projects that make a significant contribution to the establishment of the European research area, and to improving Europe's competitiveness. As from 2021, it will be replaced by its successor, the Horizon Europe Research Framework Programme, which will provide for continuity of the work that has been so far undertaken under Horizon 2020, with support being given across the entire research and innovation cycle. At the centre of the funding will be developments and innovations that contribute to the European Commission's objective of a climate-neutral Europe, which is to be achieved by 2050.The so-called European Green Deal is to ensure that Europe is a frontrunner on climate-friendliness in the industrial sector, and on clean technologies. At least 35 percent of the research funding made available under Horizon Europe will go towards climate-friendly technologies.

Energy, climate and transport-related research under Horizon Europe has been packaged into a Climate, Energy & Mobility cluster to foster cross-sector cooperation and harness the full potential of innovation. Contentwise, the fundamental elements of the calls for projects in the field of energy will remain the same. New aspects such as climate change, the decar-

bonisation of infrastructure, and transport-related issues such as industrial competitiveness in transport, and clean and smart transport have been added under the new programme.

German applicants successful in the field of energy

In the first five years of Horizon 2020 (2014-2018 period) approximately. €2.88 billion of funding was approved under the Secure, Clean and Efficient Energy work programme and went to a total of 609 collaborative projects. Germany is represented here in 387 projects with a total of 806 project participants which won funding totalling around €393.6 million. That equates to roughly 13.7 percent of the funding approved (see Figure 25). The project coordinators of 93 of the 609 projects approved are based in Germany. Approximately 45 percent of the German beneficiaries are based at research institutes and institutes of higher education, another 41percent are from the private sector, and the remaining 14 percent are from public sector and other institutions. The share of applicants from Germany is especially high in the technology field of renewables (c. 39 percent), followed by project participation in the fields of energy systems (c. 12 percent) and consumers and public sector (c. 8 percent).

Priorities for energy research

Figure 26 shows the distribution of funding to beneficiaries from Germany for the 2014–2018 period, broken down by individual focal areas in the field of energy. The figures show that there was a strong focus (47 percent) on research and demonstration projects in the technology field of renewables. This field is followed by energy systems – grids and storage (18.3 percent) and Smart City projects (8.1 percent). "Hydrogen" and "fuel cells" do not feature in Figure 26, as they receive funding from the Fuel Cells and Hydrogen Joint Undertaking – a public-private partnership. Beyond the fields covered, there are others receiving funding under Horizon 2020, but in other sections. These include materials research and production technologies.

4.3 Federal Government activities beyond the Energy Research Programme

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. The Federal Ministry of Transport and Digital Infrastructure provided €450 million for the first phase of the programme from 2007–2016. In the programme's second phase (NIP 2), which ends in 2026, competitive hydrogen and fuel cell technologies for the transport sector and the energy market are to be established on the market.

SINTEG Smart Energy Showcases – Digital Agenda for the Energy Transition

The Smart Energy Showcases - Digital Agenda for the Energy Transition (SINTEG) funding programme, are designed for the development and demonstration of blueprint solutions for a smart, forward-looking energy supply. In five model regions, more than 300 partners from the energy sector, the industrial sector, research, the municipalities, rural districts, and the *Länder* are working on scalable blueprint solutions for a secure, affordable, and environmentally compatible energy supply involving high proportions of intermittent power generation from renewables. The programme places a clear focus on building smart networks linking up the electricity supply and demand sides, and on the use of innovative grid technology and operating strategies. The real-life experience gained in the showcase regions will help develop the future legal framework in accordance with the new situation. SINTEG is seen as the first regulatory sandbox for the smart energy supply of the future.

Figure 25: Beneficiaries and funding in the core field of energy research under Horizon 2020 (2014–2018) by country

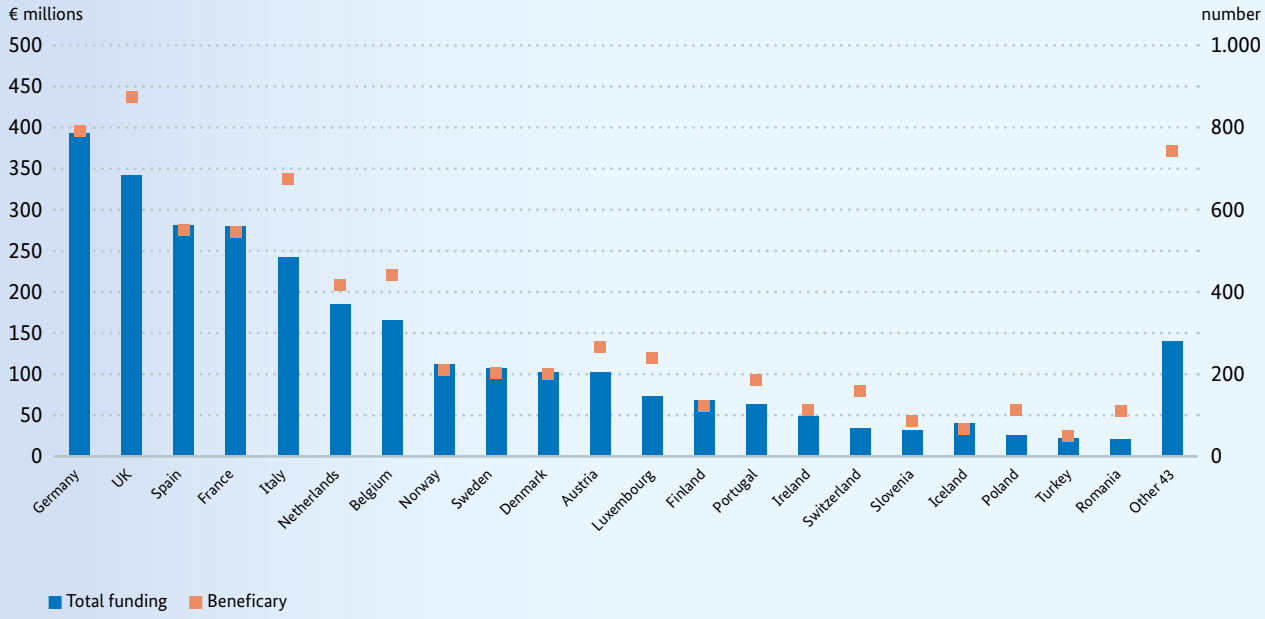
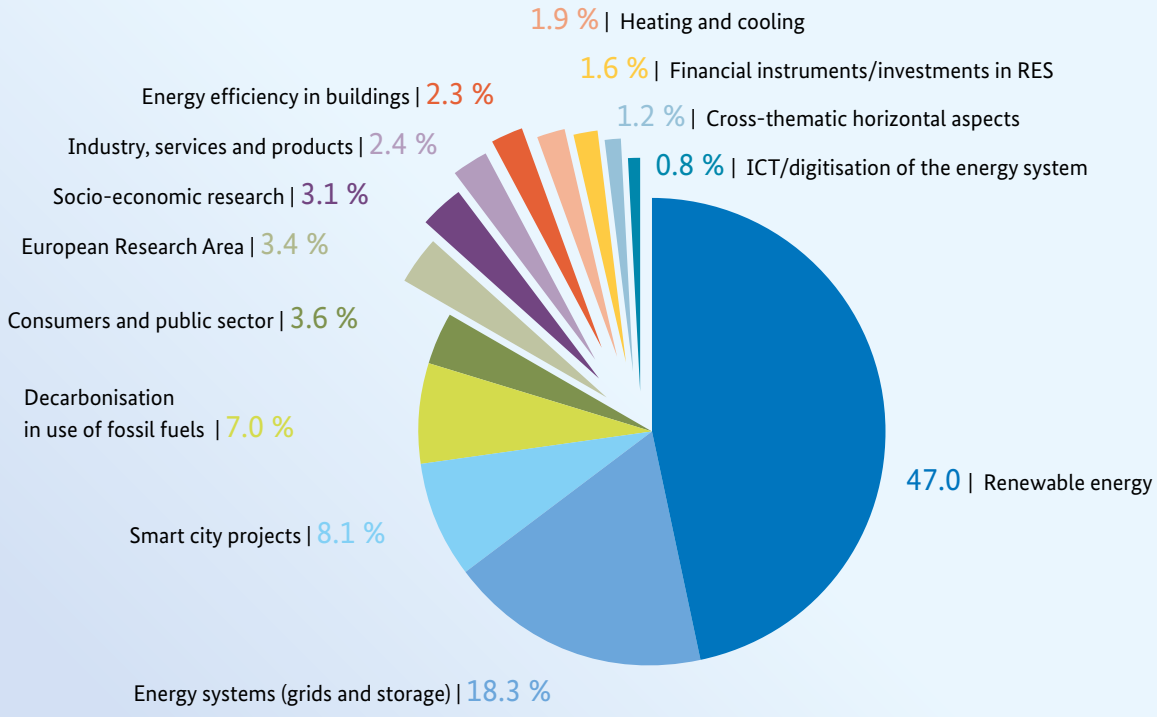


Figure 26: Distribution of funding under Horizon 2020 in the core area of energy research to beneficiaries from Germany by topic (2014–2018)



The showcases were selected in a competitive process and were launched at the end of 2016 or early 2017. The Federal Ministry for Economic Affairs and Energy is providing more than €200 million across four years for the projects. Together with more than €300 million from companies, more than half a billion euros is being invested in the digital transformation of the energy sector.

Research Campus

'The Research Campus – Public-private Partnership for Innovation' is an initiative by the Federal Ministry of Education and Research and seeks to promote cooperation between science and commerce in a long-term, binding partnership on a shared campus. The work tackles highly complex fields of research, which offer a lot of potential for breakthrough innovations.

The funding is provided in several successive phases (totalling up to 15 years) of up to €2 million a year. Under the energy arm of the initiative, the Federal Ministry of Education and Research provides funding for the research campus models Mobility2Grid and Flexible Electricity Networks. Mobility2Grid is based on the EUREF Campus in Berlin and uses a living-lab approach to study the innovative interplay between electric mobility and smart energy grids. Flexible Electrical Networks (FEN) is an Aachen-based research campus that has set up a medium-voltage direct current (DC) research network and developed key components for future smart DC networks.

Heating networks 4.0

Since July 2017, the Federal Government has been using its Pilot Project Heating Networks 4.0 funding programme to support heating network operators that either set up new, modern low-temperature heat networks carrying a high share of renewables and unavoidable waste heat (a minimum of 50 percent) or transform their existing heat networks into this type of modern, low-carbon networks. This marks the first time that the Federal Ministry for Economic Affairs and Energy has systemically introduced funding for overall systems in the heat infrastructure rather than just for individual technologies or components. Funding is provided towards the costs for the feasibility studies needed to verify the economic and technical viability of the envisaged heat network system 4.0, and towards the cost of investment into its actual implementation. As part of the revision of the funding programme in December 2019, the technical requirements were rephrased and access to the funding made more easily accessible to all heat network operators.

Efficiency House Plus initiative

As far as the construction sector is concerned, the Federal Government provides additional funding for research and development in the field of innovative, energy-specific technologies outside the Energy Research Programme. In its Efficiency House Plus initiative, for instance, the Federal Ministry of the Interior has been demonstrating since 2011 how the energy transition can work in buildings and neighbourhoods. The technology-neutral, future-proof building standard for Efficiency Houses Plus and the national network of Efficiency House Plus pilot projects helps promote the energy and climate targets and also encourages a swift transfer of expertise from research into practical application. The Efficiency House Plus standard brings renewables into the building sector, with an Efficiency House Plus generating more energy over the course of a year than it uses. This excess energy can be distributed in the neighbourhood via networks, or used for other purposes such as transport. The initiative creates a fresh impetus for the introduction of climate-compatible innovation in construction and housing to the market, activates the potential for reducing CO_2 emissions in the construction sector, and opens up new business fields, such as car-sharing models for electric vehicles in the housing sector. The first pilot projects that have been conducted in housing construction (new housing, retrofitting, neighbourhoods) have proven the viability of innovative solutions for climate-compatible construction. Since 2011, the Federal Ministry of the Interior has provided approximately €25 million under the Efficiency House Plus initiative to promote this innovative building standard; more than half of this funding was used to finance pilot projects. Between 2014 and 2019, approximately €12.5 million worth of funding was distributed.

5. Tables

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

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

	Disbursements in € million					
Funding topic	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Project funding[1]						
Energy transition in the consumption sectors	115.89	112.04	108.08	137.28	156.04	193.92
Energy generation	198.95	209.86	191.67	244.49	212.36	255.36
System integration: Grids, storage, sector coupling	95.22	113.30	119.79	144.44	127.15	127.11
Cross-system research topics of the energy transition	34.29	44.49	71.01	86.12	92.22	78.31
Nuclear safety research	43.29	45.74	45.73	47.13	47.48	48.98
Institutional funding (Helmholtz Association)[2]	**331.60**	**348.69**	**362.81**	**379.63**	**393.75**	**410.29**
Accompanying measures (e.g. project managers, international aspects, research networks, research communication)	**28.14**	**34.72**	**35.03**	**28.20**	**25.76**	**34.47**
total	**847.39**	**908.85**	**934.12**	**1,067.28**	**1,054.75**	**1,148.42**

1 Retroactive collection of data for project funding took place in 2020, in line with the new system introduced under the 7th Energy Research Programme

2 Since the 2018 Federal Report on Energy Research, the collection of data on institutional funding has been conducted in line with the system for programme-driven funding (POF) used by the Helmholtz Association of German Research Centres in the Research Field 'Energy' (allocation basis). This has meant that the total sum of research funding is adjusted for all years starting in 2014 (beginning of POF III) compared to earlier editions of the Federal Report.

Table 2 | Disbursements of project funding in the area of "energy transition in the consumption sectors"

Funding topic	Disbursements in € million								Number of projects		Total funding in € million
	2012	2013	2014	2015	2016	2017	2018	2019	Ongoing in 2019	Newly approved in 2019	Newly approved in 2019
Energy transition in buildings and neighbourhoods	**47.52**	**60.11**	**66.11**	**61.85**	**58.21**	**65.38**	**78.63**	**93.51**	**911**	**207**	**117.23**
Energy-optimised and climate-neutral buildings	25.83	31.82	36.55	35.64	32.00	36.57	39.78	50.24	507	122	60.58
Energy-optimised and climate-neutral neighbourhoods	12.23	15.16	15.78	14.30	16.82	20.30	30.02	35.57	301	69	49.01
Thermal energy storage	2.38	4.15	6.51	7.33	5.75	4.84	5.33	4.65	54	2	0.43
Supply of heat and cold	7.08	8.99	7.27	4.59	3.64	3.67	3.51	3.06	49	14	7.21
Other	–	–	–	–	–	–	–	–	–	–	–
Energy transition in industry, commerce, trade and services	**31.58**	**39.69**	**37.17**	**37.39**	**36.00**	**57.12**	**60.92**	**66.20**	**715**	**230**	**96.21**
Waste heat use	4.37	4.21	3.88	4.98	4.03	2.78	1.26	0.55	15	5	1.70
Chemical process technology	5.23	7.30	7.13	7.49	9.11	12.83	12.83	11.22	128	34	10.72
Iron, steel and non-ferrous metals	1.81	1.77	0.98	0.97	0.86	1.09	2.07	3.56	54	6	1.15
Circular economy	–	0.05	0.34	0.32	0.12	0.03	–	–	–	–	–
Manufacturing technology	10.93	15.93	17.13	15.82	11.09	14.82	17.49	23.19	228	70	28.35
High-temperature superconductivity	2.81	3.10	2.37	0.53	0.62	1.18	1.15	1.07	4	3	1.98
Industrial motors	–	–	–	–	–	–	–	–	–	–	–
Digitisation in industry	0.44	0.65	0.70	0.74	1.07	1.59	1.69	1.61	11	–	–
Material and resource efficiency	0.09	0.06	0.07	0.09	0.01	0.18	0.28	0.49	7	–	–
Process heat	2.02	3.41	3.29	4.14	5.65	8.15	8.58	9.45	96	27	12.73
Water treatment	–	–	0.04	0.18	0.35	0.72	0.58	0.57	10	–	–
Flexible industrial processes	–	–	–	–	–	10.70	12.54	10.80	106	50	26.08
Other	3.89	3.22	1.24	2.12	3.07	3.03	2.44	3.67	56	35	13.51
Energy transition in the transport sector	**14.22**	**17.83**	**12.61**	**12.80**	**13.87**	**14.78**	**16.49**	**34.21**	**273**	**72**	**38.51**
Battery technology for mobile applications	14.22	17.83	12.61	12.80	13.87	14.28	15.63	17.06	146	18	12.35
Synthetic fuels	–	–	–	–	–	0.50	0.86	17.15	122	49	24.51
Charging infrastructure and systems integration	–	–	–	–	–	–	–	–	5	5	1.66
Other	–	–	–	–	–	–	–	–	–	–	–
Total	**93.33**	**117.63**	**115.89**	**112.04**	**108.08**	**137.28**	**156.04**	**193.92**	**1,899**	**509**	**251.94**

Table 3 | Disbursements of project funding in the area of "energy generation"

Funding topic	Disbursements in € million								Number of projects		Total funding in € million
	2012	2013	2014	2015	2016	2017	2018	2019	Ongoing in 2019	Newly approved in 2019	Newly approved in 2019
Photovoltaics	**66.74**	**62.73**	**56.83**	**67.41**	**59.78**	**81.90**	**78.24**	**98.69**	**499**	**140**	**106.79**
PV technologies	10.11	9.88	7.22	5.64	2.65	2.75	5.24	11.75	49	18	14.70
Quality assurance	3.49	2.80	2.65	3.07	3.79	4.60	3.65	3.97	33	1	3.54
Manufacturing technologies	31.33	32.49	28.77	36.05	36.10	55.93	58.11	58.86	320	85	54.97
Circular economy	0.75	0.85	0.63	0.91	0.99	1.14	0.82	1.01	11	5	2.50
Systems capability	2.43	1.87	2.40	3.40	4.57	5.41	6.85	5.99	43	10	4.47
Basic research into photovoltaics	15.21	14.49	14.83	11.59	6.17	3.51	1.33	2.69	8	5	6.62
Other	3.41	0.34	0.34	6.75	5.51	8.56	2.24	14.41	35	16	19.99
Wind energy	**38.24**	**52.57**	**52.88**	**52.85**	**49.68**	**75.11**	**59.73**	**72.95**	**461**	**112**	**78.99**
Wind farm development	5.74	18.14	23.40	27.09	21.99	42.92	29.13	34.69	194	41	39.74
Logistics, installation, maintenance and operation	11.83	7.38	5.25	5.18	7.38	11.00	8.34	8.30	81	24	12.06
Offshore wind energy	8.30	16.09	14.34	9.19	10.45	11.56	12.03	15.88	86	22	16.97
Environmental aspects of wind energy	7.25	4.91	4.31	3.23	2.25	2.48	2.42	3.34	34	9	3.45
Wind physics and meteorology	0.21	1.78	2.34	3.63	3.03	3.06	2.33	2.96	41	11	4.89
Other	4.91	4.27	3.24	4.53	4.58	4.08	5.49	7.79	25	5	1.88
Bioenergy	**40.83**	**42.57**	**43.00**	**42.10**	**37.88**	**33.03**	**28.54**	**40.52**	**597**	**241**	**72.78**
Production – cultivation	6.91	6.31	5.98	4.43	4.69	5.70	6.52	10.86	156	58	16.72
Production – breeding	4.43	5.25	4.77	4.92	4.49	4.58	4.20	4.44	61	12	4.38
Conversion – general	–	–	–	0.53	5.22	2.73	4.46	5.03	78	15	1.92
Conversion – gaseous	4.61	4.87	5.27	6.84	4.92	6.79	5.04	4.88	84	38	8.90
Conversion – liquid	4.11	6.12	6.19	5.92	3.97	3.21	1.98	1.12	18	1	0.41
Conversion – solid	2.78	0.94	0.73	1.92	2.23	1.77	1.34	2.43	41	30	8.42
Use of biogenic residue and waste materials for energy purposes	7.52	6.05	5.06	4.69	3.66	4.17	4.20	5.12	137	69	16.96
Basic research into bioenergy	8.61	9.81	12.16	9.89	6.17	3.13	0.22	5.83	11	11	12.24
Cross-section	1.86	3.22	2.85	2.97	2.53	0.94	0.59	0.80	11	7	2.83
Thermal power plants	**19.68**	**29.38**	**29.39**	**32.22**	**29.44**	**34.14**	**29.05**	**28.30**	**359**	**74**	**31.29**
Combined-cycle power plants with flexible loads and fuels	11.00	21.01	20.12	20.82	18.42	22.87	18.01	17.74	233	34	17.13
Solar thermal power plants	4.82	5.72	6.23	8.01	7.21	6.20	6.13	6.75	92	28	11.68
Other	3.87	2.66	3.04	3.39	3.81	5.07	4.90	3.80	34	12	2.49
Geothermal energy	**21.42**	**17.61**	**15.64**	**13.61**	**12.89**	**18.15**	**15.38**	**13.19**	**94**	**25**	**24.10**
Hydroelectric and marine power	**0.98**	**1.25**	**1.21**	**1.68**	**2.01**	**2.15**	**1.40**	**1.71**	**16**	**7**	**3.54**
Total	**187.89**	**206.10**	**198.95**	**209.86**	**191.67**	**244.49**	**216.36**	**255.36**	**2,026**	**599**	**317.50**

Table 4 | Disbursements of project funding in the area of "systems integration and sector coupling"

Funding topic	Disbursements in € million								Number of projects		Total funding in € million
	2012	2013	2014	2015	2016	2017	2018	2019	Ongoing in 2019	Newly approved in 2019	Newly approved in 2019
Electricity grids	**12.20**	**27.31**	**31.24**	**54.32**	**66.32**	**78.14**	**66.24**	**64.85**	**589**	**143**	**61.69**
Security of supply	1.04	2.32	2.23	7.50	12.75	13.10	13.51	11.02	102	12	7.02
Flexibility in the power grid	6.67	7.75	5.88	7.21	6.60	6.30	7.13	7.14	101	44	20.16
Grid planning and operational management	2.80	7.82	9.53	15.65	19.45	19.56	14.74	13.35	136	23	7.85
Technology for the electricity grid	1.69	9.42	12.64	16.39	17.52	21.07	17.71	22.50	201	57	24.15
Basic research into electricity grids	–	–	0.96	7.57	10.01	18.11	13.15	10.85	49	7	2.51
Other	–	–	–	–	–	–	–	–	–	–	–
Energy storage	**13.23**	**31.43**	**29.57**	**28.63**	**27.69**	**22.35**	**18.37**	**21.43**	**201**	**57**	**28.17**
Electrical storage	–	–	–	–	–	0.02	0.61	0.63	9	–	–
Electrochemical storage	1.60	3.96	3.99	4.36	5.22	8.54	8.99	8.68	109	49	23.56
Electricity-thermal-electricity storage	–	–	–	–	0.58	1.39	1.54	2.36	7	–	–
Mechanical storage	1.19	3.26	1.53	1.97	2.60	3.19	2.53	2.65	26	4	3.40
Basic research into energy storage	10.20	19.37	17.21	15.61	10.79	3.60	1.17	3.77	21	–	–
Other	0.25	4.84	6.84	6.70	8.50	5.59	3.54	3.34	29	4	1.21
Sector coupling and hydrogen technologies	**20.33**	**30.85**	**34.41**	**30.35**	**25.77**	**43.95**	**42.53**	**40.82**	**272**	**81**	**96.95**
Hydrogen production	1.08	4.78	6.35	7.17	5.70	6.66	4.21	1.13	11	3	1.42
Hydrogen storage and transport	2.17	3.84	3.46	2.76	2.85	4.36	4.90	5.73	34	6	2.56
Fuel cells	15.64	19.58	18.82	15.23	10.04	15.67	13.81	14.31	88	17	21.42
Systemic approaches	–	0.62	0.96	1.12	0.99	0.32	0.33	0.46	4	–	–
Power-to-X	1.45	0.96	0.40	0.39	0.19	0.62	1.06	1.33	16	–	–
Basic research into sector coupling and hydrogen	–	1.08	3.04	2.10	4.63	15.53	17.36	17.78	114	48	67.96
Other	–	–	1.39	1.58	1.37	0.79	0.85	0.08	5	7	3.60
Total	**45.76**	**89.60**	**95.22**	**113.30**	**119.79**	**144.44**	**127.15**	**127.11**	**1,062**	**281**	**186.82**

Tabelle 5 | Disbursements of project funding in the area of "cross-system research topics of the energy transition"

Funding topic	Disbursements in € million								Number of projects		Total funding in € million
	2012	2013	2014	2015	2016	2017	2018	2019	Ongoing in 2019	Newly approved in 2019	Newly approved in 2019
Energy systems analysis	**6.02**	**8.06**	**8.39**	**9.32**	**11.18**	**15.01**	**15.94**	**17.16**	**233**	**60**	**24.75**
Digitisation in the energy transition	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**13**	**22**	**9.62**
Resource efficiency in the context of the energy transition	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
CO_2 technologies	**8.47**	**5.97**	**6.60**	**4.28**	**15.06**	**18.15**	**24.58**	**19.57**	**73**	**22**	**9.83**
CO_2 transport and storage	0.72	0.74	0.67	0.38	–	0.18	0.96	1.23	6	3	1.13
CO_2 sequestration	7.75	5.12	3.90	1.80	3.46	3.30	2.11	1.23	20	12	5.01
CO_2 conversion und use	–	0.11	0.27	1.30	2.64	2.83	4.61	3.04	18	7	3.69
Basic research into CO_2 technologies	–	–	1.76	0.79	8.95	11.84	16.90	14.08	29	–	–
Collective industrial research programme cooperation	**–**	**–**	**–**	**–**	**0.05**	**2.52**	**4.22**	**5.47**	**43**	**10**	**3.62**
Energy transition and society	**–**	**1.18**	**3.25**	**3.95**	**2.64**	**10.02**	**9.93**	**10.15**	**49**	**8**	**1.26**
Materials research	**–**	**–**	**0.72**	**10.41**	**27.87**	**26.68**	**18.21**	**10.30**	**89**	**–**	**–**
Basic research into the energy-related use of the subsurface	**4.51**	**4.65**	**4.22**	**3.69**	**3.59**	**1.81**	**2.02**	**1.36**	**18**	**1**	**0.64**
Technology-neutral funding with an international focus	**–**	**0.05**	**1.03**	**2.00**	**0.65**	**0.28**	**2.11**	**3.88**	**63**	**41**	**19.85**
Other basic research	**20.95**	**16.99**	**10.07**	**10.84**	**9.96**	**11.64**	**15.22**	**10.42**	**42**	**4**	**6.39**
Total	**39.95**	**36.90**	**34.29**	**44.49**	**71.01**	**86.12**	**92.22**	**78.31**	**623**	**168**	**75.95**

Table 6 | Disbursements of project funding in the area of "nuclear safety research"

Funding topic	Disbursements in € million								Number of projects		Total funding in € million
	2012	2013	2014	2015	2016	2017	2018	2019	Ongoing in 2019	Newly approved in 2019	Newly approved in 2019
Nuclear waste final storage and disposal research	**12.30**	**13.23**	**13.58**	**12.95**	**13.09**	**16.33**	**17.61**	**19.57**	**111**	**26**	**20.92**
Final storage research	9.84	10.39	10.25	10.06	9.94	11.43	12.02	12.23	64	14	7.14
Horizontal tasks and other	0.54	0.53	0.53	0.54	1.06	1.90	2.69	3.57	26	11	12.90
Nuclear material monitoring	0.18	0.15	0.19	0.24	0.26	0.21	0.09	0.22	1	1	0.89
Funding for young researchers (Research Ministry programmes)	1.74	2.17	2.61	2.11	1.83	2.78	2.81	3.54	20	–	–
Reactor safety research	**24.38**	**23.43**	**25.10**	**25.22**	**24.06**	**22.76**	**21.98**	**22.05**	**139**	**33**	**25.74**
Safety of nuclear facility components	5.28	4.01	4.38	4.55	4.38	4.20	5.19	4.75	41	6	2.16
Plant behaviour and accident sequences	11.25	12.09	12.51	13.22	13.37	13.46	12.52	12.47	68	15	15.18
Horizontal tasks and other	5.08	5.72	4.81	4.05	3.63	3.37	3.04	3.63	22	12	8.40
Funding for young researchers (Research Ministry programmes)	2.77	1.62	3.39	3.39	2.68	1.73	1.23	1.19	8	–	–
Radiation research (Research Ministry)	**4.91**	**4.95**	**4.61**	**7.58**	**8.58**	**8.05**	**7.89**	**7.36**	**43**	**6**	**3.52**
Total	**41.59**	**41.61**	**43.29**	**45.74**	**45.73**	**47.13**	**47.48**	**48.98**	**293**	**65**	**50.18**

Table 7 | Institutional funding

Funding topic	Disbursements in € million					
	2014	2015	2016	2017	2018	2019
Programme-oriented funding III						
Energy efficiency, materials and resources	60.49	64.12	68.43	69.45	73.00	76.67
Renewable energy	47.84	51.91	54.37	56.73	59.09	61.51
Nuclear fusion (incl. Wendelstein W 7-X)	123.51	123.51	123.51	123.51	123.51	126.00
Nuclear waste management, safety and security, and radiation research	34.62	35.76	37.27	38.84	40.47	42.16
Technology, innovation and society	7.11	7.65	7.95	8.25	8.54	8.84
Storage and connected infrastructure	49.93	57.12	60.47	69.61	72.86	76.21
Future Information Technology	8.11	8.62	10.81	13.24	16.28	18.90
Total	**331.60**	**348.69**	**362.81**	**379.63**	**393.75**	**410.29**

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

Broken down per ministry	Disbursements in € million					
	2014	2015	2016	2017	2018	2019
Federal Ministry for Economic Affairs and Energy	**400.53**	**426.59**	**426.07**	**529.15**	**510.62**	**576.81**
Project funding	376.82	401.74	399.83	501.37	481.26	545.81
Institutional funding (German Aerospace Centre)	23.72	24.85	26.25	27.78	29.36	31.00
Federal Ministry of Education and Research	**392.93**	**420.03**	**444.96**	**484.19**	**494.24**	**507.57**
Project funding	85.05	96.19	108.40	132.35	129.86	128.28
Institutional funding (Helmholtz Association excl. German Aerospace Center)	307.89	323.85	336.56	351.85	364.38	379.29
Federal Ministry of Food and Agriculture	**25.78**	**27.51**	**28.05**	**25.73**	**24.13**	**29.57**
Project funding	25.78	27.51	28.05	25.73	24.13	29.57
Total	**819.25**	**874.14**	**899.09**	**1,039.07**	**1,029.00**	**1,113.95**

5.2 Funding for energy research by the *Länder*

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

Länder	Disbursements in € million										
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Baden-Württemberg	11.54	26.83	15.10	23.12	24.77	35.55	44.37	52.22	48.77	44.10	38.30
Bavaria	16.67	14.14	22.64	32.28	88.13	114.82	85.61	89.98	96.34	54.15	59.26
Berlin	3.87	15.53	4.73	2.10	3.03	0.88	4.70	3.63	2.94	3.89	4.36
Brandenburg	11.34	4.65	4.37	5.81	4.03	7.86	4.40	3.54	4.05	2.20	1.22
Bremen	2.71	2.42	2.78	3.61	2.71	3.46	1.99	2.08	2.10	1.35	2.22
Hamburg	1.15	1.56	0.61	1.27	2.01	15.76	14.91	16.12	15.64	17.29	16.81
Hesse	7.02	5.77	9.10	8.12	12.57	9.63	3.48	5.17	9.11	9.95	14.93
Mecklenburg-Western Pomerania	–	1.64	5.68	3.99	8.76	3.22	13.02	1.50	–	–	–
Lower Saxony	15.74	24.60	26.36	30.53	32.82	33.00	38.57	19.78	18.21	17.15	14.22
North Rhine-Westphalia	31.52	22.68	31.80	26.55	37.27	28.52	28.99	40.14	17.24	79.08	28.84
Rhineland-Palatinate	2.43	2.76	2.40	2.79	2.10	2.43	2.37	2.51	1.95	4.00	4.39
Saarland	0.95	1.17	0.51	1.12	0.87	0.75	1.56	0.98	1.42	2.77	1.53
Saxony	14.18	29.26	17.42	23.60	24.88	44.06	1.01	20.89	21.78	26.04	22.66
Saxony Anhalt	2.51	3.83	7.81	6.04	3.43	4.11	4.62	1.53	0.89	9.45	1.94
Schleswig-Holstein	4.12	3.54	3.10	2.08	1.83	4.28	5.15	5.97	4.76	6.76	6.65
Thuringia	3.10	0.78	2.68	1.36	3.55	3.40	1.81	0.95	3.42	3.50	2.70
Total	**128.87**	**161.14**	**157.11**	**174.39**	**252.78**	**311.74**	**256.56**	**266.99**	**248.63**	**281.68**	**220.04**

Table 10 | Spending by the *Länder* on non-nuclear energy research by topic (2008–2017)

Topics	Disbursements in € million									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Biomass	21.48	7.79	15.90	18.73	18.71	22.44	20.56	21.53	11.78	13.05
Fuel cells/hydrogen	9.47	10.86	15.14	8.11	5.40	12.29	9.82	11.46	12.83	13.73
CO_2 storage	–	0.11	0.24	0.07	0.21	–	0.02	2.77	0.02	0.20
Energy savings	24.86	32.19	23.74	31.66	51.35	45.58	34.73	46.10	49.27	42.00
General energy research	22.21	40.20	12.97	14.96	21.01	72.81	61.73	73.03	69.02	118.87
Energy systems, modelling	4.48	12.02	7.87	2.46	5.37	4.53	4.33	3.13	3.33	3.35
Renewables (in general)	14.45	13.38	18.09	28.28	35.83	13.50	15.34	15.96	11.94	21.61
Geothermal energy	1.27	8.41	8.86	11.27	12.52	8.43	8.09	2.09	4.70	3.53
Power station technology/CCS	5.09	3.87	4.84	6.09	11.35	7.12	4.25	5.52	3.78	2.68
Photovoltaics	18.12	22.17	19.62	20.84	26.95	21.85	21.31	24.81	27.34	13.19
Wind energy	5.89	6.12	8.26	11.61	14.48	18.60	27.29	12.25	3.97	4.93
Electric mobility/ energy storage/grids	1.55	4.02	21.58	20.31	49.61	–	–	–	–	–
Electric mobility	–	–	–	–	–	54.19	22.54	15.88	20.73	21.43
Energy storage	–	–	–	–	–	25.84	24.16	28.12	26.34	18.32
Grids	–	–	–	–	–	4.58	2.40	4.33	3.60	4.81
Total	**128.87**	**161.14**	**157.11**	**174.39**	**252.78**	**311.74**	**256.56**	**266.99**	**248.63**	**281.68**

Table 11 | Spending by the *Länder* on non-nuclear energy research by topic in 2018 in line with new technology classification*

Topics	Disbursements in € million 2018
Energy efficiency in industry, trade and commerce	24.04
Energy efficiency in buildings and neighbourhoods	16.97
Energy efficiency in transport (including electric mobility)	29.39
Other energy efficiency measures	22.10
Thermal power plants/CO_2 technologies	4.40
Renewable energy – solar thermal and photovoltaics	18.39
Renewable energy – wind energy	6.82
Renewable energy – geothermal energy	6.55
Renewable energy – bioenergy	10.86
Renewable energy – hydropower	0.95
Renewable energy – marine energy	0.40
Other sources of renewable energy	19.48
Hydrogen technologies	12.94
Fuel cells	6.49
Grids (electricity transmission and distribution)	6.43
Energy storage technologies	26.42
Energy systems analysis/modelling	7.39
Total	**220.04**

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