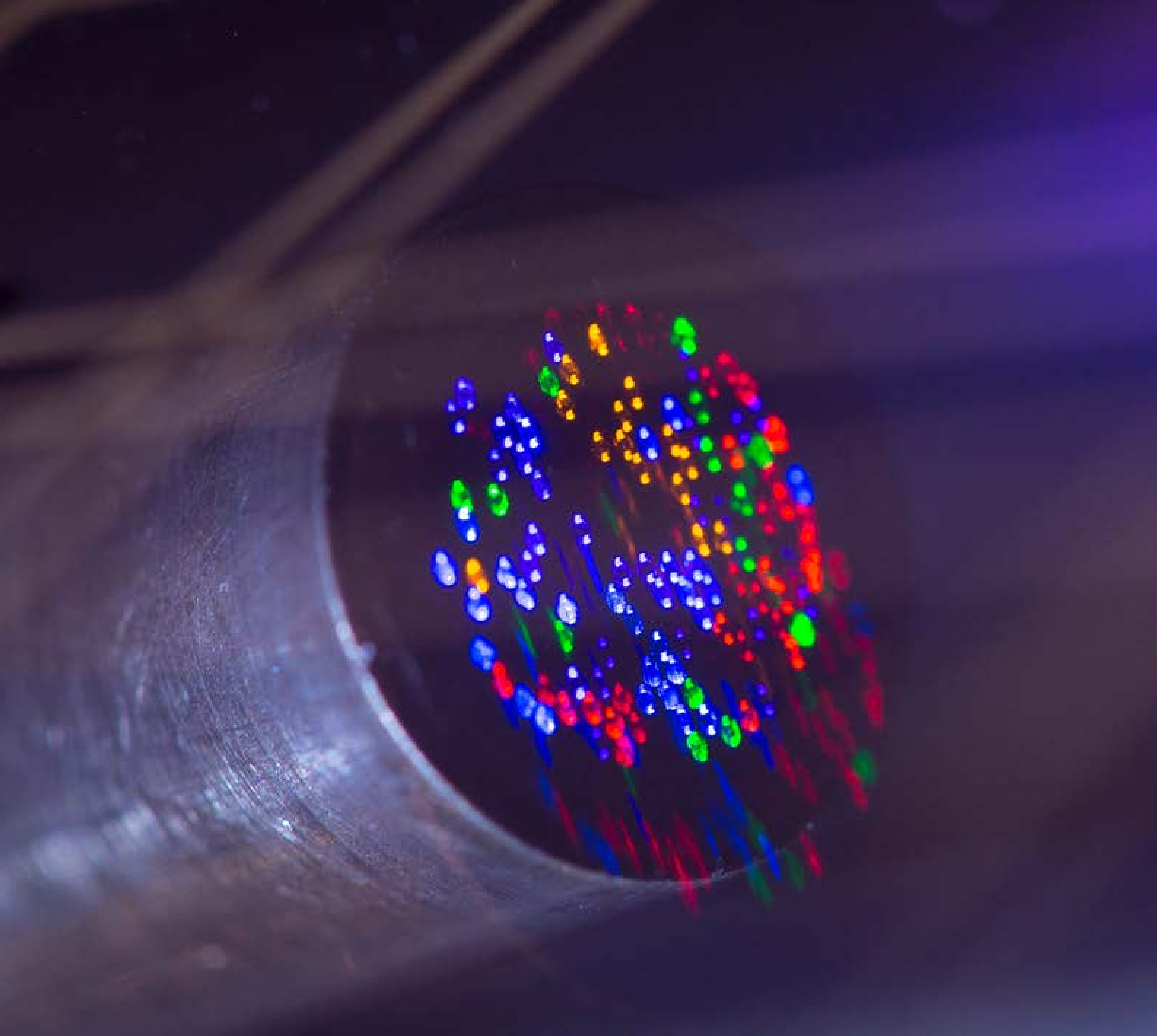
Federal Ministry
for Economic Affairs
and Energy

2019 Federal Government Report on Energy Research

Funding research for the energy transition



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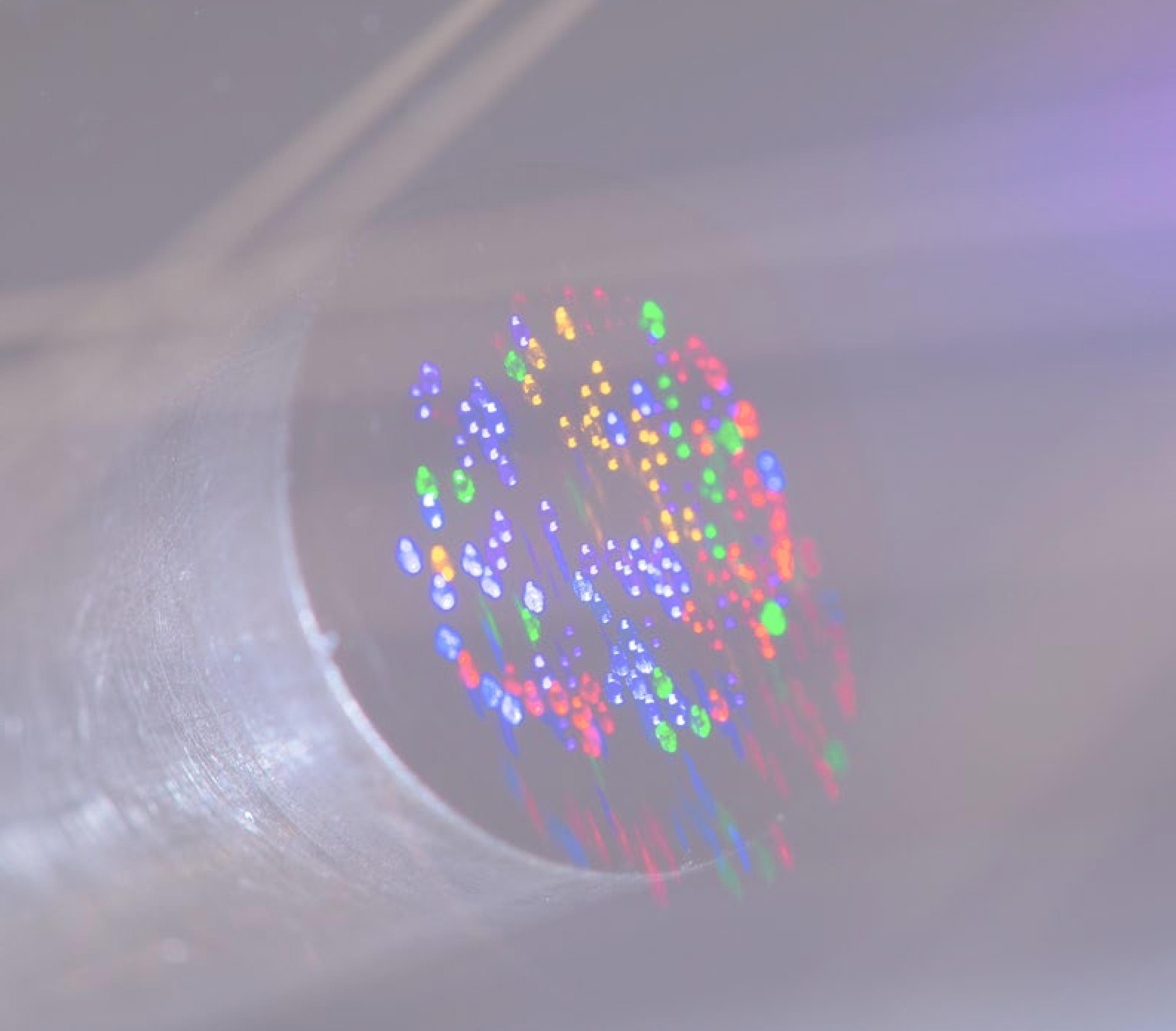

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1. Funding research for the energy transition

1.1 The Energy Research Programme of the Federal Government

1.1.1 The 7th Energy Research Programme of the Federal Government

Since 1977, the Federal Government has provided uninterrupted funding for research into non-nuclear energy technologies. The allocation of the funding is based on seven successive energy research programmes. In September 2018, the Federal Cabinet adopted the 7th Energy Research Programme entitled "Innovations for the Energy Transition". Funds amounting to €5 billion in total are earmarked to promote research in the energy field in the 2019-2022 period. The current programme was drawn up following a broad-based consultation process led by the Federal Ministry for Economic Affairs and Energy. Three ministries are involved: The Federal Ministry of Education and Research implements funding measures in all areas of application-oriented basic research, whilst the Federal Ministry for Economic Affairs and Energy funds research close to the market and living labs along the entire energy chain. The Federal Ministry of Food and Agriculture is responsible for research into biomass applications which are close to the market. Also, the Federal Ministry for Economic Affairs and Energy funds projects relating to the use of biogenic residue and waste materials for energy purposes.

The 7th Energy Research Programme goes beyond the technology-specific funding priorities for the first time to also address overarching horizontal issues which play a central role in the fundamental restructuring of the energy system for the energy transition: digitisation, sector coupling and the energy transition and society. Also, the new funding format for living labs permits holistically designed projects which accelerate the transfer of technology and innovation to be carried out under real-life conditions. Furthermore, the process of including start-ups in the research funding system is to be accelerated and improved, so that their high level of dynamism and innovation can help to drive the energy transition.

1.1.2 Look back to the 6th Energy Research Programme

The Federal Government's 6th Energy Research Programme was adopted by the federal cabinet on 3 August 2011. It was oriented to the Federal Government's Energy Concept of 28 September 2010 and its update on 11 March 2011. The 6th Energy Research Programme covered for the first time the entire energy chain, from energy provision and conversion to transport and distribution, including storage, and its use in various sectors. Close cooperation between the stakeholders from science and business was regarded as essential in order to ensure that the energy supply is secure, environmentally compatible and affordable.

The funding mainly went into projects of applied industrial research and precompetitive development, as well as projects taking an interdisciplinary approach. Here, the focus was to be on cross-technology coupling of largely developed individual components to form complete technical systems. Another priority was the further development and integration of new information and communication technologies, questions of system security and system reliability, and aspects of public acceptance. Another new feature in the 6th Energy Research Programme was the interministerial funding initiatives on energy storage, future electricity grids and solar construction. This enabled very broad-based research to be undertaken into these fields, as it was possible to address questions ranging from the fundamental issues to applied research and demonstration.

1.1.3 Funding amounts

In 2018, the Federal Government spent around €1.06 billion in the Energy Research Programme on the research, development and demonstration of modern energy and efficiency technologies and applications for the energy transition. This means that the volume of funding remained at the high level seen in the preceding year. The figures for project funding cited in this report are published on the website www.enargus.de where they are set out in a transparent and easy-to-understand manner. EnArgus is the Federal Ministry for Economic Affairs and Energy's central energy research information system offering information about ongoing and completed projects.

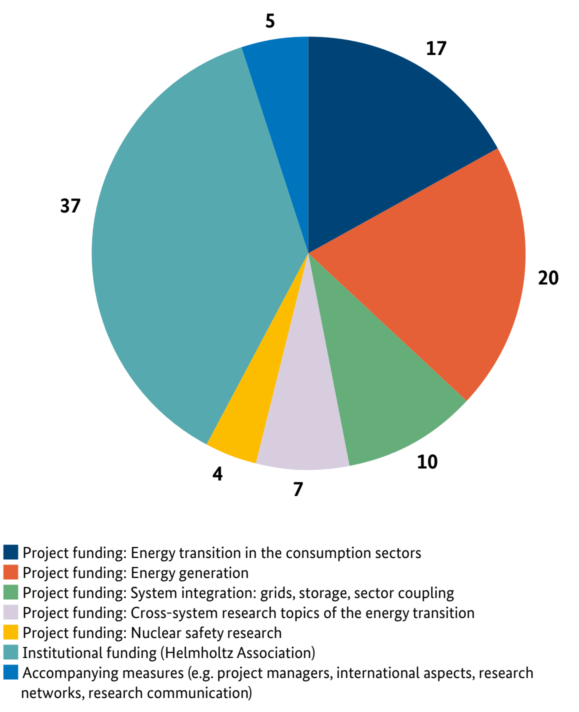
The switch to the new Energy Research Programme is also entailing a revision of the statistics on energy research. Figure 1 shows how the funding is distributed across the topics covered by the 7th Energy Research Programme. The tables on the specific fields of research (apart from Tables 1 and 7) remain based on the previous system, since the 2018 reference year covers research funding under the 6th Energy Research Programme.

1.1.4 Evaluations and performance review

How efficient and effective are the funded measures? Does the funding policy really address the necessary fields? In order to review this, the Federal Government uses scientific and technical evaluations as well as additional performance monitoring. In this way, the federal ministries involved in the energy research programme help to make energy research transparent. Further to this, the evaluations and success monitoring provide important pointers for the future design of the funding.

In 2018, Project Management Jülich (PtJ) presented its interim report commissioned by the Economic Affairs and Research Ministries on the ongoing performance review of the joint funding initiative entitled "Electricity Grids for the Future". In the context of the initiative, approximately €138 million was spent on the various funding projects, including 70 collaborative projects and 11 individual projects. Funding went towards technological measures to improve operational management and to develop innovative components and equipment, as well as methods to plan grids more efficiently. For example, the experts studied ways to respond appropriately to critical situations like power outages in a changing energy system and how forward-looking grid planning needs to be strategically designed.

Figure 1: Overview of funding in the Federal Government's Energy Research Programme in %
(see table 1 for data)



The project partners included 88 scientific institutions and 112 companies, e.g. grid operators, energy utilities, manufacturers of electrical equipment, components and equipment, and companies in the information and communications technology sector. The overall success of the funding initiative is shown by a glance at the level of technological development attained in the projects: on average, leaps forward of three technology readiness levels (TRLs) were achieved. This corresponds to, for example, the improvement of the maturity of a technology from general proof of functionality in the lab to a prototype with systematically important characteristics which has been tested in an operating environment. The scientific and technological goals were attained in 95% of the projects.

1.2 Structures of energy research policy

1.2.1 Tasks of the federal ministries

Since the Federal Ministry for Economic Affairs and Energy is responsible for the programmatic orientation of the Federal Government's energy research policy, it had the lead responsibility for the drafting of the 7th Energy Research Programme. Also, the Ministry is responsible for project funding for applied energy research apart from biomass. In terms of institutional funding, the Ministry is responsible for the strategic orientation of the energy research done by the Helmholtz Association (HGF), in coordination with the Federal Ministry of Education and Research and the representatives of the Länder and research centres. In addition, the Federal Ministry for Economic Affairs and Energy is responsible for awarding institutional support for the German Aerospace Center. Further to this, the Ministry represents Germany in international and European research policy bodies in the field of energy policy, and funds project-related multilateral research cooperation.

The Federal Ministry of Education and Research is responsible for project funding in the field of application-oriented basic research in all fields covered by the programme. It is responsible for the entire institutional funding of the Helmholtz Association, apart from the DLR, and plays a part in the strategic development of the energy research being done by the Helmholtz Association. Also, the Federal Ministry of Education and Research funds young scientists, academic exchanges and scientific cooperation at EU level and with international partners. The Federal Ministry of Food and Agriculture is responsible for project funding for the use of biomass for energy purposes.

1.2.2 Coordination of energy research funding

The new programme structure makes it possible to use synergies in thematic cooperation. An important role here is played by cooperation with federal ministries like the Federal Ministry of Transport and Digital Infrastructure, which has the lead responsibility for highly energy-dependent aspects of transport, and funds its own programmes to introduce forward-looking solutions in practice. Also, the Federal Government is continuing to strengthen the national dialogue with the other ministries involved in the Energy Research Programme – the Research and Agriculture Ministries – via the Energy Research Policy Coordination Platform. The Energy Research Policy Coordination Platform is headed by the Federal Ministry for Economic Affairs and Energy. In order to coordinate the research activities and ensure that the work being done is of relevance to practical needs, the Federal Government engages in a transparent dialogue with all the relevant stakeholders in energy research as it develops and implements funding strategies. The Research and Innovation Energy Transition Platform is an important forum for the dialogue between science, business and government. Its members – institutions from government, business, science and society – can discuss overarching questions of funding policy in the forum. Also, the Federal Government-Länder Energy Research Dialogue takes place once a year in order to intensify cooperation with the Länder on certain areas.

1.2.3 Networking at national level

The Research and Innovation Energy Transition Platform brings high-level stakeholders from government, science, business and civil society together. These are comprised of associations and selected companies, research institutes and the relevant federal and Länder ministries. The plenary session meets at regular intervals, and discusses and assesses current developments and energy research strategies.

The energy research networks provide the substantive basis for the work of the Energy Transition Research and Innovation Platform. Some 3,900 members take part in the open expert networks; their wide-ranging expertise stimulates activities and accelerates the transfer of research findings into practice. The work in the research networks takes place flexibly in self-organised working groups or research fields. This creates and cements important relations between the stakeholders, and these can feed into joint research projects in some cases. At present, there are eight research networks, on bioenergy, construction for the energy transition (buildings and neighbourhoods), renewable energy, flexible energy conversion, industry and commerce, electricity grids, start-ups, and systems analysis.

The Start-ups Research Network, which was set up in 2018, shows that the research networks bring important stakeholders together, serving as multipliers for the energy transition, and integrate them in strategic thinking. The 7th Energy Research Programme focuses more on horizontal issues like digitisation, energy storage and sector coupling, and will do more to address these in cross-network cooperation.

1.2.4 Transparency and communications

Research communication ensures transparency in the use of public funding and plays a key role in the transfer of research findings into practice. Specific information services are provided for discrete target groups, both for the general public and for the specialised community.

The www.energieforschung.de website provides information about projects of applied energy research funded by the Federal Ministry for Economic Affairs and Energy in the Federal Government's Energy Research Programme. Also, specialised websites offer in-depth access to key topics, findings and events. These include the websites about specific research priorities and research initiatives of the Federal Ministry for Economic Affairs and Energy and interministerial funding initiatives of the Federal Government:

- www.energiewendebauen.de
- www.eneff-industrie.info
- www.strom-forschung.de
- www.forschung-energiespeicher.info
- www.forschung-stromnetze.info
- www.forschungsnetzwerke-energie.de

The Federal Ministry for Economic Affairs and Energy's EnArgus information system (www.enargus.de) is a website providing information about ongoing and completed research projects, energy issues and technologies. The database contains more than 25,000 projects undertaken since 1977, and is updated daily.

1.3 European and international networking

The climate-relevant generation and distribution of renewable energy depends on transnational cooperation between research institutes and companies so that the energy transition can be successfully and efficiently progressed in global competition. For this reason, Germany's international research funding provides incentives for joint funding projects at European and international level. The pooling of strengths by international partners facilitates the widest possible expert dialogue and an efficient use of technical and material resources for the researching of climate-friendly energy technologies. The new Energy Research Programme also orients research funding to technologies for the global markets, particularly in developing and emerging economies.

1.3.1 European cooperation

The European Commission and Member States are continuing to progress the integration of and cooperation between the scientific and technological capacities of the Member States in the European Research Area (ERA). In order to achieve the goals of the ERA, the Commission has been running multi-annual programmes since 1984. Horizon 2020, the European research and innovation framework programme, has a total budget of around €80 billion. One focus is market-related funding, so that in addition to the traditional EU collaborative research, SMEs and public-private partnerships are also included. In total, around €5.9 billion is available for non-nuclear energy technologies under the Clean Secure and Efficient Energy Societal Challenge during the 2014-2020 programming period. Around a thousand research and innovation projects have been provided with more than €3.2 billion in funding. These particularly cover issues on the use of renewable energy (48%), energy efficiency (18%) and energy systems (22%). By 2020, another amount of approximately €2 billion will have been awarded in funding for excellent project proposals. In 2018, the horizontal issue of "next-generation batteries" was included in the programme of work, with funding of €2.2 billion. A particular role is played by hydrogen and fuel cells, which are being managed in a public-private partnership by the Fuel Cells and Hydrogen 2 Joint Undertaking – FCH 2 JU.

In June 2019, the calls for applications for the final year, 2020, of Horizon 2020 will be published. These also form the bridge to the new "Horizon Europe" EU framework programme. In addition to greater consideration of substantive interfaces with climate and transport aspects, energy issues continue to play a significant role in European funding. The EU's funding measures are backed by the European Strategic Energy Technology Plan (SET Plan). In coordination with Member States, stakeholder groups and

MetroHESS – Using braking energy in metro stations

The best of two storage systems – use of a hybrid storage system in metro stations

Many efficiency measures focus on the use of surplus energy from various processes. If this energy is to be used at a later time, it is necessary to use energy storage systems. The selection of storage technologies which are technologically and economically suitable represents a great challenge, since each technology has certain advantages and disadvantages. Some technologies can store a lot of energy, but provide little output. Others can respond very quickly to changing demand or have a very low self-discharge rate. For these reasons, it can make sense to use a hybrid storage system, i.e. a storage system consisting of two different storage technologies. This makes it possible to combine the advantages of the respective technologies and offset the disadvantages. In the German-Greek MetroHESS project, a hybrid system is to be designed to quickly receive the braking energy from a train and then to provide it slowly and steadily to the metro station.

Metro line 3, Keramikos station

Beneficiary: Leibniz University Hannover and three other partners
Grant number: 03SF0560A-B
Estimated funding: approx. €380,000
Project duration: 2018 – 2020

the European Commission, the energy sectors in Europe are being studied, and potential for greater needs for cooperation and research are being highlighted. The latest strategy papers are Implementation Plans (IPs), which describe intentions between different Member States to cooperate on issues like renewable energy technologies, energy efficiency in buildings, industry and neighbourhoods, alternative fuels, possibilities for storage, and flexible and smart energy systems.

Since 2018, Implementation Working Groups consisting of representatives of EU Member States have ensured that the energy strategies of the IPs are implemented. There, the Mission Innovation Initiative combines EU funding with global energy strategies and makes further international cooperation possible. The National Contact Point for Energy offers German applicants free and unbiased information and advice on compiling and submitting applications. The National Contact Point for Energy works on behalf of the Federal Ministry for Economic Affairs and Energy, which represents German interests in the field of energy at European level.

Together with MESRI, the French Research Ministry, the Federal Ministry of Education and Research launched a funding initiative for a sustainable European energy supply in October 2018. The aim is to strengthen Franco-German cooperation and to stimulate innovation processes in Germany and France. The bilateral projects are to deliver solutions in the fields of “converting and storing energy from renewable sources” and “smart grids at transmission and distribution system level”. In addition to taking a cross-sector approach, the projects must be practical and give consideration to economic and social aspects. The selection was made in the spring of 2019.

The German-Greek research and innovation programme, which is broad-based in thematic terms, was first set up in 2013 and continued in December 2016. Together, the Federal Ministry of Education and Research and Greece’s Ministry of Education, Research and Religious Affairs are providing a total of €18 million in funding for this programme. The selected projects began in March 2018 and make an important contribution to strengthening cooperation between science and business and to fostering the next generation of scientists in both countries. Amongst in the areas of health, bioeconomy, the humanities and social sciences, culture and tourism, materials, and key enabling technologies, energy research plays a key role, with 8 out of 24 ongoing collaborative groups. Thematically, the projects cover energy generation, e.g. the development of advanced small-scale wind turbines, system integration, e.g. research into sustainable fuel cell applications for stand-alone energy systems, and social issues.

1.3.2 International cooperation

If there is to be a sustainable and forward-looking energy supply, an ongoing dialogue between governments, research institutes, universities and industrial companies is required at both European and global level.

International Energy Agency (IEA)

The International Energy Agency is an advisory body, and helps its 30 Member States to progress the research, development and application of sustainable energy technologies worldwide. Whilst the focus used to be on safeguarding the supply of oil, it has since moved to a common climate policy, market reforms, cooperation on the development of new energy technologies, and advising and bringing on board aspiring emerging economies with regard to energy policy issues. Further to this, the IEA offers a platform for cooperation on research and development of energy technologies via its Energy Technology Network (ETN). The ETN's steering body is the Committee on Energy Research and Technology (CERT), which coordinates research and development activities at political level. The technology cooperation programmes (TCPs) governed by the CERT and the Working Parties cover the entire range of energy technologies and agree bindingly on topics, rules and goals of the multilateral cooperation. Germany is currently involved in 22 of the total of 38 ongoing TCPs.

Mission Innovation

Mission Innovation is a global initiative which now involves 23 countries and the European Commission. Mission Innovation was launched at the COP 21 climate conference with a view to supporting compliance with the Paris Agreement by expediting innovation in clean-energy technologies. The Member States and the European Commission have committed in Mission Innovation to doubling the budget for research and innovation promotion in the field of energy by 2021. Here, an important contribution is made by the European Commission's Horizon 2020 framework programme. Thematically, Mission Innovation was set up in "Innovation Challenges" at COP 22 in Morocco, and international projects are being funded around the world to tackle these challenges. In Mission Innovation, Germany places a strategic focus on the issue of hydrogen and synthetic fuels, and is co-lead of the Innovation Challenges on hydrogen and the conversion of solar energy into chemical energy sources. Topics covered in the 2018 – 2020 programme of work of the Energy Societal Challenge under Horizon 2020 refer explicitly to Mission Innovation.

Bilateral initiatives/European cooperation

The second German-Finnish funding initiative was launched in 2017 and oriented to the goals laid down in the SET Plan. 10 selected projects out of the large number of submitted proposals finally started in 2018, and Germany is providing more than €7 million in funding.

The Federal Ministry of Education and Research is continuing to work 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). On the basis of these structures, the commitment in the field of renewable energy is being expanded further, since simple access to energy is key to Africa's economic and social development. This will help to reduce the gap in development and prosperity, and is therefore of great interest in terms of economic, security and migration policy. In the context of several studies in West African countries, reliable data were collected, and the need for and potential of renewable energy evaluated. Following this, technical strategies and scenarios were identified and developed in line with local climatic, economic and social conditions.

The Federal Ministry of Education and Research has further expanded the existing energy partnership with Australia in the context of scientific and technological cooperation.

International cooperation (Australia)

Comparative analysis of energy policy transformation processes, identifying potential for transfer

If the energy transition is to be implemented efficiently in Germany and a coordinated approach taken to implementing the Paris climate targets, it is vital to coordinate internationally with key partners. The Federal Ministry of Education and Research therefore funds research projects which undertake comparative analyses of the energy policy transformation processes in various countries and maintain an intensive dialogue about challenges and solutions. The cooperative project entitled Fundamentals of Energy Research in the International Perspective, involving acatech and the Federation of German Industries (BDI), is devoted primarily to networking at practical level. It mainly consists of fact-finding missions in which ministries, leading academic institutions, companies and NGOs, etc. are brought together for an intensive dialogue, not least by means of mutual visits by delegations. An intensive specialised dialogue is organised in the Energy Transition Hub, a German-Australian innovation partnership between the Federal Ministry of Education and Research and the Australian Trade Ministry. In the START focus project, leading research establishments from both countries work together to address each country's energy policy challenges together.

Project 1: Fundamentals of energy research in the international perspective
Beneficiary: Acatech – National Academy of Science and Engineering, Berlin
Grant number: GDEI2016
Estimated funding: approx. €994,520
Project duration: 2016 – 2020

Project 2: Strategic Scenario Analysis (START) – A first German-Australian focus project
Beneficiary: Potsdam Institute for Climate Impact Research (PIK) e. V. and five other partners
Grant number: 03EK3046A-F
Estimated funding: approx. €2.1 million
Project duration: 2017 – 2019

2. Project funding

2.1 Energy transition in the consumption sectors

2.1.1 Energy in buildings and neighbourhoods

The Federal Government wants to make Germany's building stock virtually climate-neutral by 2050. This is primarily to be achieved by modernising the building envelope, i.e. the walls, roof, cellar and windows, and by renewing the building technology, converting it to renewable energy sources like solar units or heat pumps.

An analysis of the figures in the latest monitoring report on the energy transition, "The Energy of the Future", shows that considerable further efforts are needed to reduce final energy consumption as planned. For example, primary energy demand in the buildings sector did drop by 3.2% in year-on-year terms in 2016, and was 18.3% lower than the 2008 reference year. However, final energy consumption in the buildings sector rose by 4.3% against 2015. The drop from the 2008 figure was 6.3%. There are positive trends in heat consumption: in 2018, the proportion of heat consumption covered by renewable energy stood at 13.9%. This is very close to the 2020 target of 14%. In order to reduce final energy consumption and greenhouse gas emissions to the planned degree, energy-saving buildings, integrational energy concepts and innovative and economic supply structures for neighbourhoods are required. These can make a significant contribution to a successful energy and heat transition in Germany. The Federal Government's Energy Efficiency Strategy for Buildings sets out the future direction for the buildings sector. This includes the interaction between the buildings sector and the electricity sector (sector coupling). The aim is to provide a clear framework for action for the energy transition in the buildings sector.

ENaQ – Oldenburg Airfield Energy-related Neighbourhood

21 project partners headed by OFFIs e. V. are planning a new neighbourhood on the former airfield, the infrastructure of which links up electricity, heat, cold and electric mobility and permits energy trading between neighbours.

On roughly four hectares of the former airfield in Oldenburg, a connected, low-emission neighbourhood of approximately 110 residential units will be built by 2022, and most of its energy needs are to be met from locally generated energy. The Oldenburg Airfield Energy-related Neighbourhood is designed so that scientists can test the planned smart city concept and optimise it directly in the system. Various energy provision scenarios are to be simulated and compared in terms of different assessment criteria with a view to developing suitable systemic solutions for a distributed energy supply.

Beneficiary: OFFIS e.V. and 20 other partners
Grant number: 03SBE111A-L, N-V
Estimated funding: approx. €8.5 million (Economic Affairs Ministry), approx. €9.8 million (Research Ministry)
Project duration: 2018 – 2022

N5GEH – National 5G Energy Hub Introduction of forward-looking communication standards in energy technology

How the 5G mobile communications standard could be used for applications in buildings and neighbourhoods

The 5G standard moves massive quantities of data from A to B. The Internet of Things will also impact on building services engineering and the upstream electricity distribution systems. Many things in buildings – such as the figures registered by temperature sensors, pressure sensors or status recognition – can be recorded, structured in a uniform way, transmitted and used for data processing. The aim of the N5GEH research project headed by Dresden University is to enable energy technology applications to use the 5G standard. To this end, the researchers are starting by developing an open source platform for energy systems.

Beneficiary: Dresden Technical University and two other partners
Grant number: 03ET1561A-C
Estimated funding: approx. €3.1 million
Project duration: 2018 – 2020

It is less and less the case that buildings are stand-alone systems. As elements of a large network, they have energy-related interfaces with neighbouring buildings, the neighbourhood, and electricity, gas and heating systems. They play a central role in the energy system as consumers, generators, storage facilities and energy distributors. This necessitates a smart linkage of the electricity, heat and transport sectors. Digitisation is of great importance in this context. It fosters more efficient control of appliances and better planning of the deployment of renewable energy. This will require more and more links between communication technology and energy technology. Companies and private home-owners have an increasing array of digital options available when they plan and manage buildings. These include Building Information Modelling (BIM), which has been developed further and can be used in combination, for example in calculating the energy efficiency of buildings. The 5G mobile communications standard could also play a greater role in future in building services engineering and upstream electricity distribution systems. Scientists are analysing the possibilities in the N5GEH project.

In order to bring innovations to market more quickly, the transfer of scientific findings into practice is to be accelerated. An important role here is played by demonstration projects. For this reason, the Federal Government is using the new “living labs” funding format to create temporary regulatory test beds in specific areas. In these test beds, teams of researchers, manufacturers and users can trial innovative technologies and integrated energy concepts under real-life conditions, close to the market, and in a systemic context. Also, energy research into buildings and neighbourhoods is to give greater consideration to the needs of the users. For example, the researchers are not only to view the development of technologies and concepts from the technical perspective, but are also to include the wishes of the future users. Issues like the effect on the cost of incidentals in rented accommodation, affordable construction prices, comfort and the protection of users' data are coming increasingly to the fore. In future, buildings and neighbourhoods will have to interact more with the electricity and transport system in the context of sector coupling. This will require much greater flexibility in the grid-based energy supply, since there will be more and more distributed supply structures and increasing links between the electricity, transport and heat sectors.

The Federal Government is pooling the funding available for research, development and demonstration of energy-efficient buildings and neighbourhoods in the "energy transition construction" research initiative. Along with current funding announcements and specialised websites, this also includes the "energy transition construction" research network. It serves to network the stakeholders involved with energy efficiency and renewable energy in buildings and neighbourhoods.

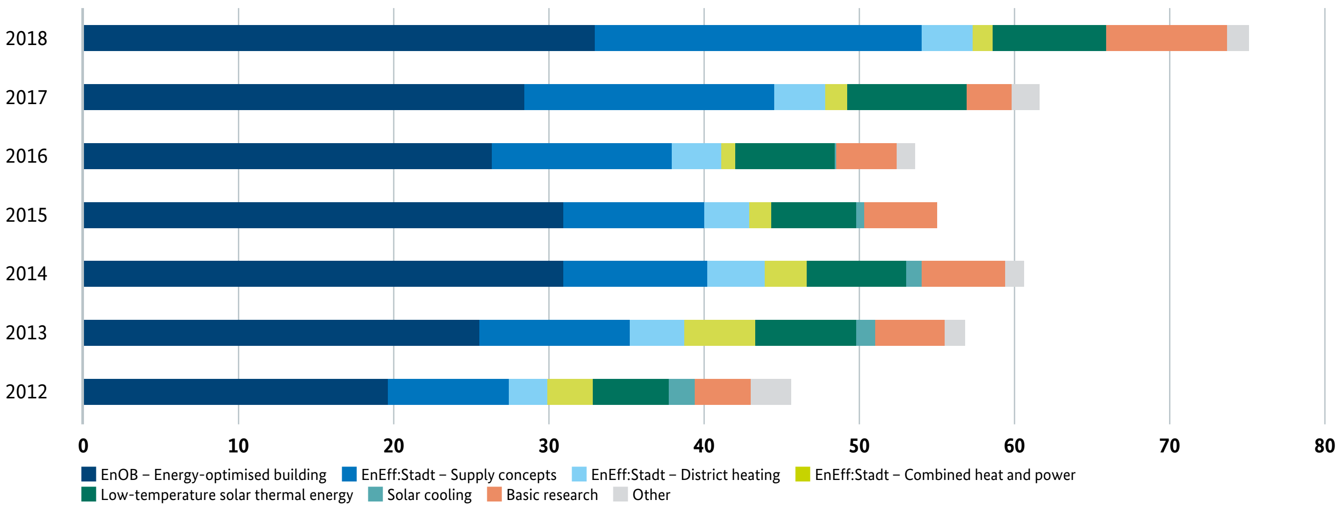
SolarAutomotive – Solar process heat for the automotive and component supplier industry

The German-Austrian research project entitled SolarAutomotive studied the use of solar process heat in the automotive and component supplier industry

The German team of researchers at Kassel University and the Foundation for Resource Efficiency and Climate Protection studied German companies at 19 sites to find out which production processes can best use solar heat and how solar heat can be efficiently and economically integrated into existing heat supply structures. The spectrum ranged from company heat networks to heated baths and hot water production, air-conditioning and drying processes. The researchers developed tools which solar companies, engineering offices and energy consultants can use to plan the use of solar process heat in facilities.

Beneficiary: Kassel University, Foundation for Resource Efficiency and Climate Protection
Grant number: 03ET1326A-B
Estimated funding: approx. €800,000
Project duration: 2016–2019

Figure 2: Project funding for energy efficiency in buildings, neighbourhoods and urban areas, and low-temperature solar thermal energy in million euros (see table 3 for data)



QUARREE100 – Resilient and integrated energy supply systems which help the system in an existing urban neighbourhood with full integration of renewable energy

How an innovative neighbourhood is emerging with 100% renewable energy in Heide, Schleswig-Holstein

QUARREE100 studies how renewable energy needs to be converted into other forms of energy, stored and distributed in order to permit a competitive, reliable and sustainable energy supply in neighbourhoods. The partners in QUARREE100 intend to research, model and implement this core element of the energy transition in Rüsdorfer Kamp in Heide. Their aim is to work together with and for the people to develop a holistic energy system which is supplied with electricity, heat and mobility from 100% renewable sources all year round. Also, battery storage, heat storage and flexible forms of energy, such as hydrogen-based technologies, are to be used.

Beneficiary: Heide regional development agency and 21 other partners
Grant number: 03SBE113A-V
Estimated funding: approx. €20.5 million (Research Ministry), approx. €3.1 million (Economic Affairs Ministry)
Project duration: 2017–2022

Wärmedrehscheibe II – Renewable District Heating 2020 – the multifunctional district heating network as a heat hub

In the Wärmedrehscheibe II research project, the proportion of renewable heat in the district heating network in Hennigsdorf near Berlin is to be expanded to more than 80% by 2022.

Led by Kraftwerks- und Projektentwicklungsgesellschaft Hennigsdorf, the researchers analysed the district heating network and the solar thermal and existing waste heat potential in a first phase. In a second phase, the waste heat from the local steelworks, solar heat from large solar collector fields and power-to-heat from surplus renewable electricity is to be integrated into the district heating network. At the same time, heat generated on a distributed basis, e.g. from solar thermal installations, is to be received by the heat network. A multifunctional large-scale heat storage facility creates the necessary flexibility.

Beneficiary: Steinbeis Forschungs- und Innovationszentren GmbH and Kraftwerks- und Projektentwicklungsgesellschaft Hennigsdorf mbH & Co. KG
Grant number: 03ETS002A-B
Estimated funding: approx. €3.8 million
Project duration: 2017 – 2022

2.1.2 Energy efficiency in industry, commerce, trade and services

Industry accounts for roughly 30% of final energy consumption in Germany. Two-thirds of this is needed in the form of heat. Here, companies need to work with researchers and developers to systematically use more of the potential for energy efficiency and to find ways to cut the amount of energy needed for heat whilst maintaining product quality. In many technical processes, more than half of the energy used is lost as waste heat. But waste heat is not trash: using it can help mitigate climate change and strengthen competition. There is a need to analyse and optimise products along the entire value chain with a view to leveraging more of the potential for energy efficiency in industry: from the extraction of raw materials to processing, manufacturing and energy consumption during the deployment phase, and disposal or reprocessing at the end of the product's life. Industrial processes need to become more flexible and lower-carbon so that they can be integrated into the energy system as it transforms itself.

There are many different ways to save energy, ranging from improved motors, drives and pumps to redesigned processing stages or entirely new production processes. Research and development is tasked with expanding the scope of action from independent individual processes to entire process chains and cross-technology efficiency strategies.

In the industry, commerce, trade, and services sectors, electricity is one of the leading sources of energy, after oil, coal and gas. As processes become more automated and digitised, its share is increasing. The use of artificial intelligence in production poses a challenge to research and development and must be further intensified so that Germany can remain internationally competitive. Digitised production creates transparency, but also needs to ensure reliable and secure processes. Cross-system solutions need to be developed further in research and development, and the transfer of research findings into commercial products and business models needs to be accelerated.

ERICAA project – Saving energy and resources via innovative and CFD-based design of liquid/liquid gravity separators

Energy-efficient separation of liquids in gravity separators

Gravity separators are used in the chemical, oil, foodstuff and pharmaceutical industry. They separate two-phase mixtures of organic and watery liquids: these include hydrocarbons and water, organic solvents and water, or methyl ester and glycerine. In order to ensure that the process of separating the liquids is reliable, gravity separators tend to be built on too large a scale, thus resulting in unnecessarily high energy consumption. In the ERICAA research project, scientists aim to develop a practical design standard for gravity separators based on flow simulations.

Beneficiary: Franken Filtertechnik Kommanditgesellschaft and five other partners
Grant number: 03ET1391A-F
Estimated funding: approx. €1.4 million
Project duration: 2016 – 2019

Like process heat and mechanical friction (tribology), digitisation is a cross-cutting industrial technology which is used in various sectors and processes; research and development must work hard to improve the take-up of its potential for energy efficiency. Research funding relies both on the ongoing further development of existing and on the creation of new, innovative technologies, components, processes and procedures to improve efficiency which have yet to become established on the market. Another goal on the road to a low-carbon industrial sector is the establishment of a sustainable circular economy. The funding therefore focuses on the reusability of materials, plant, components and equipment, and the processing of waste flows.

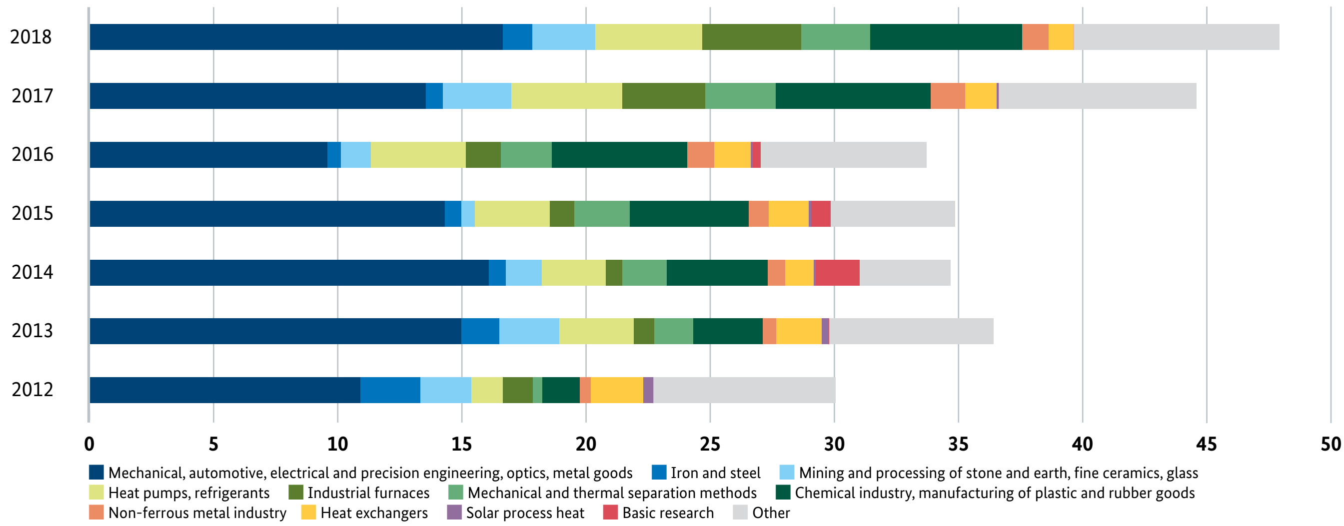
µPAS II project – Miniaturised photoacoustic gas sensor as an application to improve the efficiency of combustion processes and energy transport processes

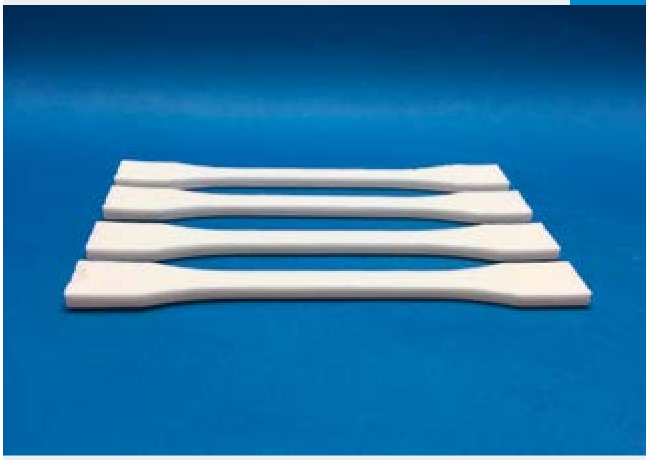
Using photoacoustics to measure gases and optimise industrial processes

In the µPAS I research project, researchers developed a photoacoustic measuring system for trace analysis of process gases. In µPAS II, the team of scientists is building a miniaturised photoacoustic sensor and testing it in transformers and combustion equipment in different real gas environments. It is expected to offer a lot of potential in industrial processes in terms of saving energy and boosting efficiency. The photoacoustic sensor can identify and quantify highly sensitive gases – such as nitrogen dioxide or short-chain hydrocarbons – via the creation of a sound signal following the light absorption of highly sensitive gases.

Beneficiary: Regensburg Eastern Bavarian Technical University and four other partners
Grant number: 03ET1317A-E
Estimated funding: approx. €1.3 million
Project duration: 2015 – 2019

Figure 3: Project funding for energy efficiency in industry, commerce, trade and services in million euros
(see table 3 for data)





A team of scientists in the PolySLS research project has used the SLS process to make tension testers from a novel plastic powder.

PolySLS project – Plastic blends for selective laser sintering

Innovative polymer powder permits recycling and saves energy in additive manufacturing

Selective laser sintering melts powder particles by laser and builds them up layer by layer. In this way, complex three-dimensional objects can be made of plastic in every possible form. At present, laser sintering uses a lot of energy. In the PolySLS research project, scientists are developing a polymer powder based on styrene which has a lower melting point than the polyamide-based polymer powder used in the process so far. The team of researchers aims to use the novel polymer powder to reduce the temperature and cycle time of the additive manufacturing construction process and to improve the recycling rate of the powder.

Beneficiary: INEOS Styrolution Group GmbH
Grant number: 03ET1505A
Estimated funding: approx. €650,000
Project duration: 2017 – 2020

Artificial intelligence controls the process of the baler press to optimise the baling.

vKBP project – Boosting energy efficiency of fully automated horizontal balers via smart collection of data on materials

How a fully automated horizontal baler equipped with artificial intelligence can make the waste management industry more energy-efficient

In the vKBP research project, a team of scientists is developing a fully automated horizontal baler equipped with artificial intelligence. The machine itself learns from analysing complex data how to cut the transported volume of recyclable material in the most energy-efficient way and how to make bales of optimal density in a waste management operation. So far, paper, cardboard and plastics have been made into bales using machine parameters based on experience. The fully automated horizontal baler and artificial intelligence integrated into the system might be able to ensure optimal operation of such equipment in terms of energy input and product quality.

Other energy efficiency aspects which have used artificial intelligence to produce innovative solutions have already been derived from the KIPro collaborative project with Bremen University, Agrarfrost and Schulz Systemtechnik (03ET1265A, 03ET1422A, 03ET1036A-B).

Beneficiary: Sutco Recycling Technik GmbH
Grant number: 03ET1326A
Estimated funding: approx. €1.5 million
Project duration: 2015 – 2019

2.1.3 Interfaces with mobility and transport

The transport sector is becoming more and more important with a view to an effective roll-out of the energy transition in Germany. It is true that the specific emissions per vehicle have improved in recent years. However, the increasing volume of traffic means that transport-related greenhouse gas emissions are continuing to rise. For this reason, the development of innovative mobility concepts and alternative and low-polluting drive technologies poses some of the greatest challenges in the mobility and transport sector. Battery and fuel cell systems need to become more efficient and cheaper with a longer lifespan if there is to be market penetration across the country. The task for research and development in the field of fuel cell technology is to improve the respective individual components and their interplay in the overall system. The fuel cell research field is tied into the National Hydrogen and Fuel Cell Technology Innovation Programme (NIP2). Alternative fuels for internal combustion engines are also a highly promising option: projects to manufacture and use gaseous and liquid fuels on the basis of renewable electricity can help to defossilise mobility and progress the coupling of the electricity and transport sectors (cf. also Chapter 2.3.3).

Sustainable battery-powered electric mobility requires a consideration of the entire value chain from the raw materials to production and use, and on to the follow-up use and recycling of batteries. Range and rapid charging are just as important as smart battery management systems and power electronics. Developments in the field of electric mobility must also be taken into account in technologies and concepts for the distribution systems and energy-related neighbourhood planning. Finally, public acceptance plays a key role in the evolution of the mobility and transport sector.

Different battery sizes can be put together from a standard battery module.

BaSyMo project – Battery system for modularity

One system for everything: How a standard battery module is universally deployable and cuts costs

The use of modern battery technology requires low-cost, reliable and easy-to-use battery systems. So far, the solutions available on the market have been too expensive for most potential applications because too few units are made. In the BaSyMo research project, scientists are testing and optimising a modular battery system: different battery sizes can be put together from a standard battery module, for example for a small vehicle, a cleaning machine or a stationary storage facility, and can thus be used anywhere. This results in high numbers of units for the standard module and offers the potential to cut costs.

Beneficiary: ElringKlinger and six other partners
Grant number: 03ET6087A, D, E, G, H, I, K
Estimated funding: approx. €3.9 million
Project duration: 2016 – 2019

2.2 Energy generation

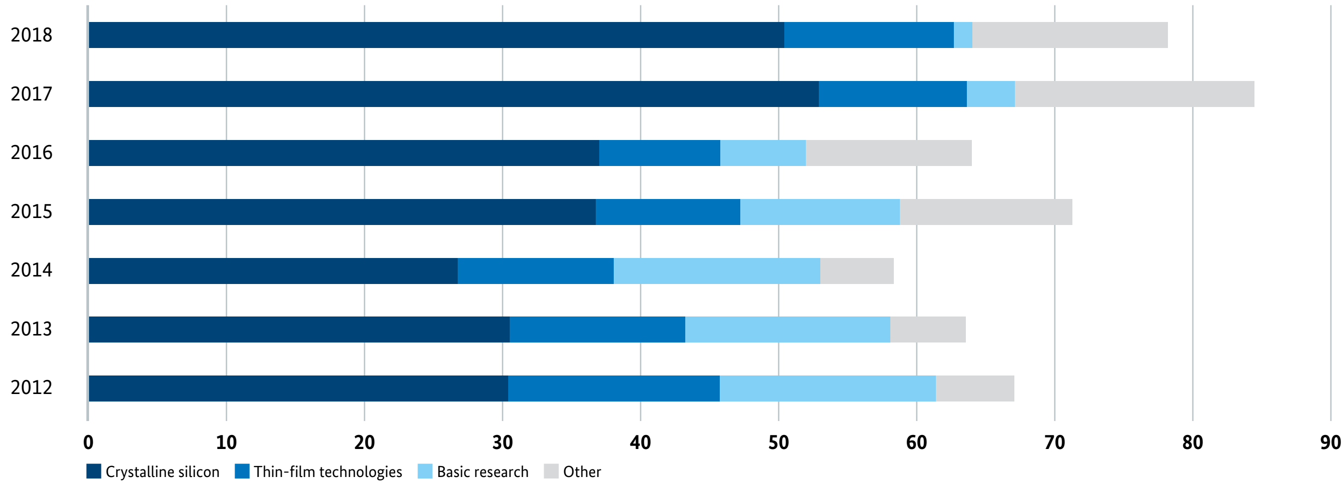
2.2.1 Photovoltaics

Along with wind energy, photovoltaics is one of the key pillars of the energy transition. Electricity from large-scale photovoltaic installations currently costs less than six cents per kilowatt-hour. A comparison with the figure of 50 cents per kilowatt-hour which had to be paid for the electricity in 2000 shows just how successful research and development has been in this field.

In principle, various semiconductor materials can be used to generate electricity from sunlight. The leading technology continues to be solar cells based on crystalline silicon. In future, innovations are expected to derive from the combination of the already highly developed silicon solar cell concepts and other semiconductors. As the different materials respond to different parts of the solar light spectrum, combinations can utilise higher proportions of the sunlight. In 2018, the Fraunhofer Institute for Solar Energy Systems ISE succeeded in attaining a record efficiency rate of 33.3% from a triple solar cell. This means that roughly one-third of the sunlight was converted into electricity. The Federal Ministry for Economic Affairs and Energy is funding the research work as part of the PoTaSi project.

Continuous improvements are also being attained with a new thin-film material, the perovskites. This material is readily available and easy to process. Research has been carried out into perovskites for use in photovoltaics for more than ten years now. The original efficiency rate of 3.8% has already been boosted to over 23% in the laboratory, placing it on the same level as other established thin-film technologies. The project partners in the ProTandem funding project now plan to demonstrate the suitability of perovskite-silicon tandem solar cells for industrial production. In addition to higher efficiency rates, another way to cut electricity costs is to improve the efficiency of production processes. Innovative manufacturing processes offer favourable alternatives to the established processes. The 7th Energy Research Programme is placing more of an emphasis on research and development of production processes. Alongside the customary approach to developing the technologies – cutting costs whilst improving quality – greater attention is being paid to overarching systemic approaches. Lifetime and quality assurance at system level, stable grid operation due to inverters and battery storage, pilot trials with pre-industrial demonstration facilities and broader deployment areas such as photovoltaics integrated into buildings or means of transport play a role here.

Figure 4: Project funding for photovoltaics in million euros
(see table 2 for data)



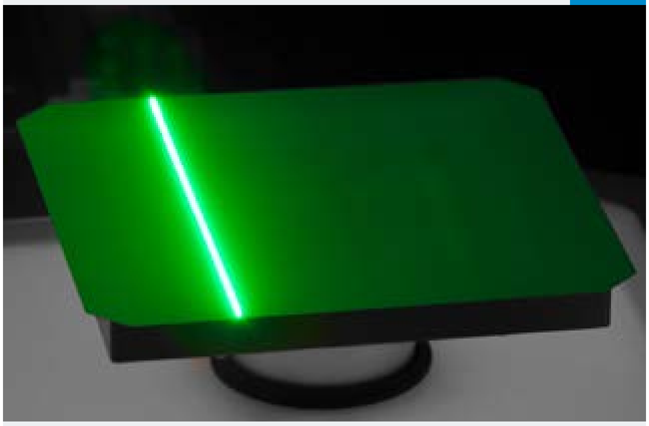
ProConCVD inline epitaxial system in NexWafe technology centre

Epi-POESIE – Epitaxial wafers for high-end cell concepts with the aid of in-process characterisation of statistically relevant quantities

The comparatively cheap epitaxial silicon wafers (EpiWafers) are to be made in mass production equipment – and in a high quality

The costs of the silicon wafer account for around 40% of the solar module costs. Epitaxia offers a possibility for a cheaper manufacturing process which uses less resources. Silicon atoms are precipitated onto a substrate, where they crystallise. In comparison to traditional monocrystalline silicon wafers, cost of producing the EpiWafers can be up to 50% lower. Potentially, they can even attain higher qualities and thus higher efficiency rates, and this has already been achieved in laboratories. The project now aims to transfer suitable processes to procedures and equipment which permit a high industrial throughput. If the project succeeds, a roll-out in industrial production is planned.

Beneficiary: NexWafe GmbH and two other partners
Grant number: 0324290A-C
Estimated funding: approx. €3.1 million
Project duration: 2018 – 2020



A laser is used locally to produce a selective emitter on the front of the solar cells in order to boost efficiency.

GENESIS – Novel and further developed production processes for the next generation of silicon solar cells

New and optimised individual processes are to enable the production of highly efficient crystalline silicon solar cells (c-Si) with efficiency rates of up to 23.5%.

This project is targeted at industrial processes which are to be implemented and subsequently marketed by the mechanical engineering companies participating in the project – InnoLas, RENA Technologies and centrotherm. The SolarTeC facilities of the Institute for Solar Energy Research ISFH and PV-TEC of the Fraunhofer Institute for Solar Energy Systems ISE are being used as a development and test platform. Processes are being developed for two new generations of solar cells, firstly for PERC solar cells contacted either on the front or on both sides: PERC stands for "passivated emitter and rear cell"; the front and rear side of the cell are better tempered than in the previous generation of cells. Secondly, charge carrier-selective contacts permit an even higher yield: the project partners are planning to transfer the relevant cell concepts of the ISFH ("POLO"") and the Fraunhofer ISE ("TOPCon") to manufacturing processes with a high throughput.

Beneficiary: InnoLas Solutions GmbH and six other partners
Grant number: 0324274A-G
Estimated funding: approx. €9.8 million
Project duration: 2018 – 2021

The project partners have demonstrated the conductive adhesion of solar cells on a teamtechnik stringer with an adhesion unit.

KleVer – Cost-saving adhesive-based connection technology for high-efficiency solar cells

The project partners have shown that adhesive technology can be used as a reliable alternative circuit technology.

So far, solar cells in solar modules have generally been connected by soldering thin strips. If, instead, they are glued together, much lower process temperatures of below 180°C are sufficient. This means that temperature-sensitive heterojunction solar cells in particular, i.e. highly efficient solar cell concepts made up of different cell layers, can be linked up adhesively in a way that places less stress on them and uses less material. The lower material and process costs cut the costs of manufacturing the modules. For example, the consumption of silver is substantially reduced, as cells can be linked up which do not require metallic busbars. Further to this, another major advantage is the fact that the adhesive technology is lead-free.

Beneficiary: teamtechnik Maschinen und Anlagen GmbH and Fraunhofer Institute for Solar Energy Systems ISE
Grant number: 0325833A-B
Estimated funding: approx. €2.6 million
Project duration: 2015 – 2018

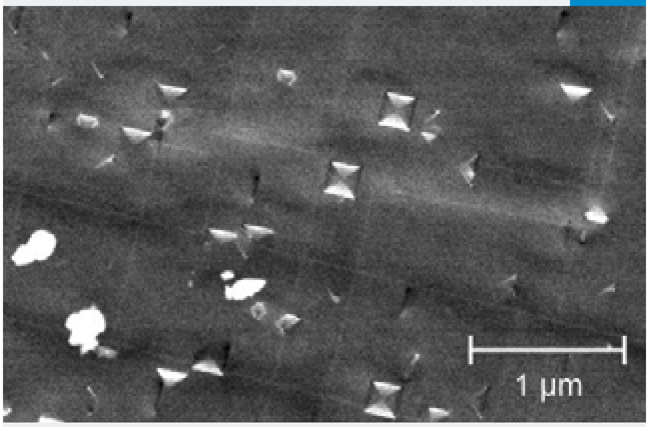
Inverters will have to provide system services for stable grid operation in future.

LUIZ – Power electronics – smart and reliable

Improving the quality and reliability of photovoltaic inverters

In future, inverters will have to deliver reliable permanent operation so that, given a further expansion of renewable energy, not only electricity can be fed in in line with demand, but also the necessary system services can be provided to ensure stable grid operation. The project partners are studying suitable solutions and developing improved switching technology with a view for example to providing intelligent information about the condition of an installation. The aim is to permit cost-efficient, preventative maintenance work to take place. The scientists are identifying the necessary improvements from studies into potential faults. A modified demonstrator is being used to evaluate the desired innovations.

Beneficiary: Fraunhofer Institute for Solar Energy Systems ISE and three other partners
Grant number: 0324363A-D
Estimated funding: approx. €2.4 million
Project duration: 2019 – 2021



Electron Channeling Contrast Image (ECCI) of a gallium phosphide nucleation layer on silicon

MehrSi – Highly efficient III-V multi-junction solar cells on silicon

Tandem solar cells made of III-V semiconductors and silicon

Silicon solar cells currently dominate the photovoltaics market, but the technology is approaching the maximum theoretical efficiency rate which can be attained using silicon as the sole absorber material. In contrast, III-V multi-junction solar cells attain efficiency rates of up to 37.9% for the conversion of solar light into electricity. These solar cells are precipitated onto gallium-arsenide substrates. Use in industrial scale solar modules has so far appeared unrealistic due to the high substrate and manufacturing costs. For this reason, the consortium is finding out how to combine the two technologies by placing thin III-V semiconductor layers directly on a silicon-pn junction. This avoids the high substrate costs of the III-V crystals. In view of the higher potential efficiency, they could form the basis of future generations of solar cells.

Beneficiary: Fraunhofer Institute for Solar Energy Systems ISE and three other partners
Grant number: 03SF0525A-D
Estimated funding: approx. €3.4 million
Project duration: 2015 – 2019

2.2.2 Wind power

Wind energy installations are the main pillar of the energy transition in Germany. Some 30,000 wind turbines are now to be found both onshore and offshore. According to the TSOs, a total of 89.5 terawatt-hours of electricity was generated onshore in 2018 – roughly 4% more than in 2017. This is mainly due to technical innovations. For example, the nominal capacity of the more recent newly built wind turbines rose by 9% compared with 2017, to an average level exceeding three megawatts. This has been achieved not least by larger rotor diameters and higher towers: the average rotor diameter of onshore wind turbines is now 118 metres, and the average hub height 132 metres. More and more efficient, higher and larger: this is also true of the offshore wind turbines. The new installations which came on stream in 2018 have an average nominal capacity of more than seven megawatts. These wind turbines also attain top figures in terms of rotor diameter and hub height. Compared with the average of previous years, the rotor diameter has increased from 129 to 158 metres, and the hub height from 93 to 106 metres. At the end of 2018, 22 offshore wind farms were in operation. According to provisional calculations by Fraunhofer ISE, they fed 18.8 terawatt-hours of electricity into the grid, 8% more than the previous year.

Higher output is generally achieved by means of increasingly large wind turbines. Traditional plant technology needs to respond to the higher requirements to be met by the individual components. Research establishments are developing new materials which help to reduce the weight of the components so that the stress on the towers, rotors and foundations is not too great. For example, scientists at the Fraunhofer Institute for Wind Energy Systems IWES are engaged in a research project called BladeFactory on how increasingly long rotor blades can be designed as effectively as possible and how their manufacture can be automated. As wind energy is rolled out further, it will be necessary to make the installations even more efficient, reliable and cheap. All the components – from the foundations to the rotor blade tips – will therefore have to be continuously developed.

But not only individual components are of relevance to research: it is also possible to achieve improved reliability and longer lifetimes by using new scientific knowledge of wind flows and other meteorological forces to minimise the stresses on the wind turbine. The 7th Energy Research Programme therefore places the focus more on the overall system of wind turbines by combining site analyses, meteorological findings and component development. This is made clear by another research priority: in the next few years, many wind turbines will be dismantled due to their age, and their materials will be recycled as far as possible. Ongoing research and development work is to help ensure that, even more than in the past, the design and planning stage for an installation or a wind farm gives greater consideration to the various aspects of future reusability of individual components, through to the design of entire wind turbines with a view to reusability.

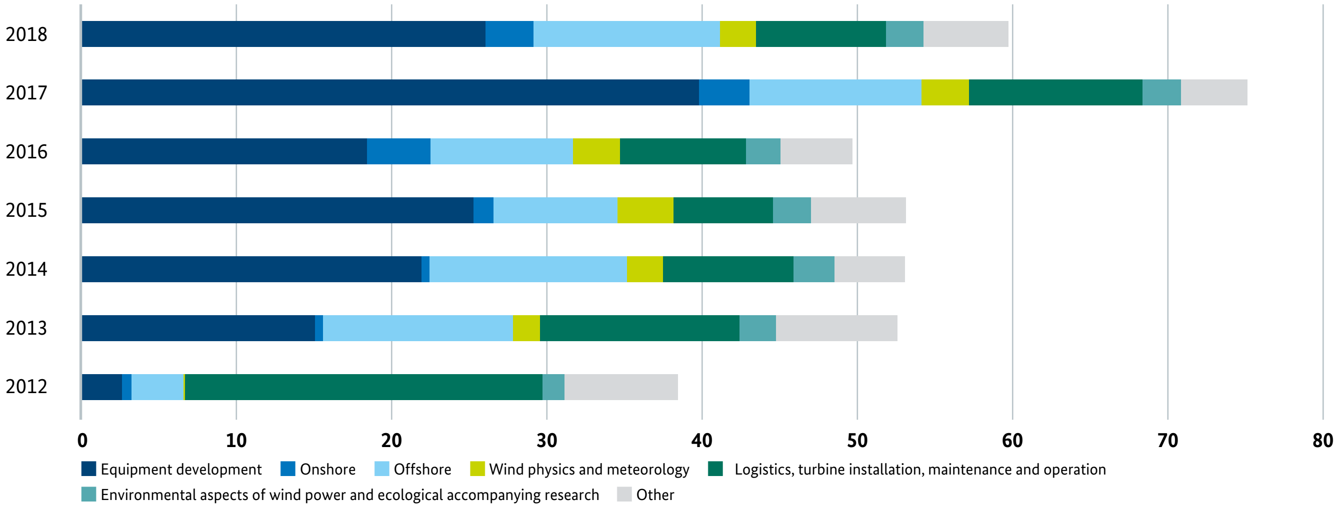
BladeFactory – Manufacturing technologies and process-oriented materials evaluation for rotor blade production with a high level of parallelisation

Rotor blades are to be manufactured more efficiently in order to cut manufacturing costs

Using today's technology, it takes roughly 24 hours to manufacturing a rotor blade blank. The process is protracted because almost all the manufacturing stages take place sequentially in the main mould. The two half-shells which are visible from outside are manufactured from the various materials, and are usually glued together with bars to form a rotor blade. Finally, everything is heated to fully harden the composite material. The main mould is occupied during the sequence of work stages. In order to cut production time, the scientists at the Fraunhofer Institute for Wind Energy Systems IWES and their research partners in the BladeFactory project plan to carry out various processes in parallel. For this, it is necessary to shift work stages from the main mould to other devices. Another focus of the research project is on improving the quality of the rotor blades, and this is to be achieved not least by the use of comprehensive measuring technology.

Beneficiary: Fraunhofer Institute for Wind Energy Systems IWES and three other partners
Grant number: 0324272A-D
Estimated funding: approx. €7 million
Project duration: 2018 – 2022

Figure 5: Project funding for wind power in million euros
(see table 2 for data)



ModernWindABS – Modern methods for new applications in the operation and service of wind turbines in the information flow of Industrie 4.0

Innovative data model optimises maintenance intervals

In the ModernWindABS research project headed by the Fraunhofer Institute for Energy Economics and Energy System Technology IEE, wind turbine operators and research institutes are working on a smart, self-optimising "installation memory". Via machine learning processes, it uses data from the operation of wind turbines to predict maintenance intervals and detect faults at an early stage. The aim is to avoid downtimes and costs. Selected applications, e.g. for predictive maintenance, are being developed and tested in the research project. The aim is to use the available data to attain a high detection rate with as few false alarms as possible and to classify the faults in the most detailed way possible. This should result in new business models.

Beneficiary: Fraunhofer Institute for Energy Economics and Energy System Technology IEE
Grant number: 0324128
Estimated funding: approx. €740,000
Project duration: 2016 – 2019

WEA-GLiTS – Thermally sprayed slide bearing coatings for main bearings of wind turbines

A materials concept for slide bearing coatings in wind turbines

At present, the main bearings of wind turbines all use roller bearings, but due to fatigue and wear and tear, these cause downtimes in the turbines. The research work is developing an innovative bearing concept using new thermally sprayed slide bearing coatings to replace the less reliable roller bearings in the long term. The slide bearings are known from other fields of large bearing technology, and in order to transfer them to the new deployment in wind turbines, work is particularly needed on bearing design and the selection of an appropriate coating: the high and very dynamic loads, combined with the large bearing diameters in wind turbines, necessitate measures to improve the load-bearing behaviour – resolved here for the first time by a new springy elastic support structure for the bearing pads. The many ramp-up procedures also impose demands to be met by the coating, as the low rotational speeds can result in wear and tear. New materials are being developed on the basis of thermal spraying. The testing is taking place under realistic operating conditions on a wind turbine system test rig.

Beneficiary: RWTH Aachen University and two other partners
Grant number: 03EK3036A-C
Estimated funding: approx. €1.5 million
Project duration: 2016–2019

KOKON II – Reliable corrosion protection for highly stressed flange connections in offshore wind energy installations

Offshore wind energy installations need protection against corrosion.

Salt water, gusts of wind and high waves: offshore wind energy installations have quite a lot to cope with. For this reason, the manufacturers of components stress the need for high-quality materials which can cope with the different weather situations. In the KOKON II collaborative project, teams of scientists at RWTH Aachen and the companies Linde and Krebs, led by Grillo-Werke, are investigating corrosion protection to see how flange connections installed in wind turbines can be reliably and lastingly protected against rust. To this end, they are optimising a zinc-aluminium coating which was the subject of a previous research project. The aim is to develop a duplex corrosion protection system which protects the steel construction for at least 25 years without maintenance. Flanges are installed in the tower, the rotor blades, the foundation structures and the nacelle.

Beneficiary: Grillo-Werke and three other partners
Grant number: 0325672D-G
Estimated funding: approx. €670,000
Project duration: 2017–2020

2.2.3 Bioenergy

The high-grade use of biomass for efficient conversion into bioenergy plays an important role in expanding the use of renewable energy: bioenergy can easily be stored, is very flexible and can be used to produce electricity, heat or fuel on a distributed basis. In the 7th Energy Research Programme of the Federal Government, the activities of the Federal Ministry for Economic Affairs and Energy which used to be funded in a separate programme (Energy-related Biomass Use) are now part of the field of the energy-related use of biogenic waste residues and waste materials. Further projects in this field are funded via the Renewable Resources programme of the Federal Ministry of Food and Agriculture.

The Agriculture Ministry's funding for R&D covers not just research, development and demonstration programmes on the use of regenerative raw materials for energy production, but also selective farming and cultivation, the use of materials, international cooperation and societal dialogue.

The amount of project funding which can be categorised as energy research is therefore only one element of the measures funded in the Renewable Resources programme. Since 2000, it has provided funding for research into the use of regenerative raw materials and of waste and by-products from agriculture and forestry for energy production. The current edition of the funding programme was published by the Federal Ministry of Food and Agriculture on 7 May 2015.

The Ministry's current Renewable Raw Materials funding programme covers the various uses in ten funding priorities. Two of the priorities are solely concerned with the use of biomass for energy production:

- development of technology and systems to generate and use bioenergy with a view to further reductions in greenhouse gas emissions
- flexible and efficient bioenergy installations to generate renewable fuels (electricity, heat and mobility) in conjunction with system integration and sector coupling.

Optiflex – Collaborative project to optimise the operation and design of biogas plants for needs-based, flexible and efficient biogas production taking account of process stability as a post-Renewable Energy Sources Act strategy

Making biogas plants fit for flexible electricity generation in the period after the Renewable Energy Sources Act

The future expansion of the renewables-based electricity system will necessitate optimised flexible operation of biogas plants. In the context of the project, an efficient and economic systemic solution using stable and sustainable, flexible biogas plant operation for the period after the Renewable Energy Sources Act is to be developed and demonstrated in practical conditions. Via coupling with a model-based predictive arrangement on feed management and an adapted approach to hydrodynamic processes, existing approaches towards optimisation are to be merged and developed further.

The following scientific and technical goals are being pursued in the collaborative project:

- Derivation of a comprehensive control algorithm for all central and peripheral plant components
- Adaptation of equipment
- Preparation of a wide-ranging retrofitting of the existing biogas plants in the market stability reserve as a precondition for stable, flexible plant operation.

Beneficiary: Hohenheim University and four other partners
Grant number: 22402716, 22401617, 22401717, 22402017, 22402117
Estimated funding: approx. €1.5 million
Project duration: 2017–2020

FlexFuture – Integration of biogas plants into grids with a high proportion of intermittent electricity generation

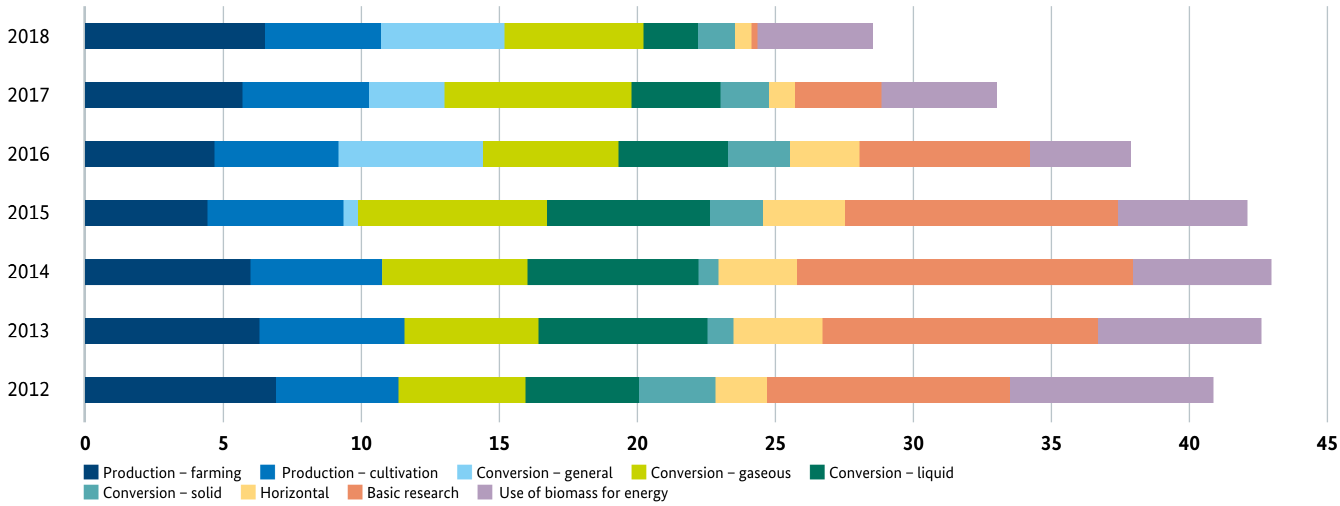
Operation of block-type thermal power stations: adapted to maximum feed-in from local photovoltaic installations

The predictive control of biogas plants can cut the costs of grid expansion. Also, optimised schedules for biogas plants can stabilise the grid more cheaply than electricity storage. The FlexFuture project should be able to help here, as it centred on the integration and automated control of such installations as a balancing element in distribution grids. The volumes of electricity exchanged via the distribution grid were significantly increased in the project. More electricity flowed through the grid without any need for grid expansion. At the same time, with a view to the overall efficiency of the biogas plants, the heat generated was used as far as possible via a local heat network. The partners were able to implement and demonstrate their findings at the Zellerfeld biogas plant.

Beneficiary: TH Ingolstadt and three other partners
Grant number: 03KB102A-B, D-E
Estimated funding: approx. €200,000
Project duration: 2014 – 2017

Since 2008, the Federal Ministry for Economic Affairs and Energy has been funding the Energy-related Biomass Use programme to promote the cost-effective and energy-efficient use of biomass in the electricity and heating markets. The focus is particularly on biogenic residues and wastes. More than 600 partners have been working on more than 150 projects in the context of this programme. In 2018, the Federal Ministry for Economic Affairs and Energy's previously separate Energy-related Biomass Use programme was integrated into the 7th Energy Research Programme and, with funding area 3.7, into the Ministry's central funding announcement. In addition to the related continuity in bioenergy research, there are also possibilities for networking with the other technologies and sectoral applications, e.g. in the field of heat for buildings (bioheat) or transport (biofuel). Also, the Bioenergy Research Network was reoriented in the Federal Ministry for Economic Affairs and Energy's research networks, and backed up by research from the German Biomass Research Centre in its working groups and transfer measures.

Figure 6: Project funding for bioenergy in million euros
(see table 2 for data)



2.2.4 Geothermal energy

Geothermal energy is a reliable source of energy. More strategic use is to be made of it in future for the supply of heating and cooling. According to the German Geothermal Association (BVG), Germany has 33 regional geothermal heating plants in operation. Furthermore, more than 30 installations are being planned or built. Munich's municipal utilities plan to supply the city's district heating network predominantly with geothermal heat by 2040. Research projects funded via the 7th Energy Research Programme are intended primarily to make geothermal energy easy to use. Risks are to be reduced, costs cut, storage created and the awareness and public acceptance of this form of renewable energy boosted. The work focuses particularly on demonstration and pilot projects which can be used as models for future site development.

EBIMA – Development, construction and commissioning of a mobile installation for the safe and efficient switching of underwater pumps for deep geothermal energy

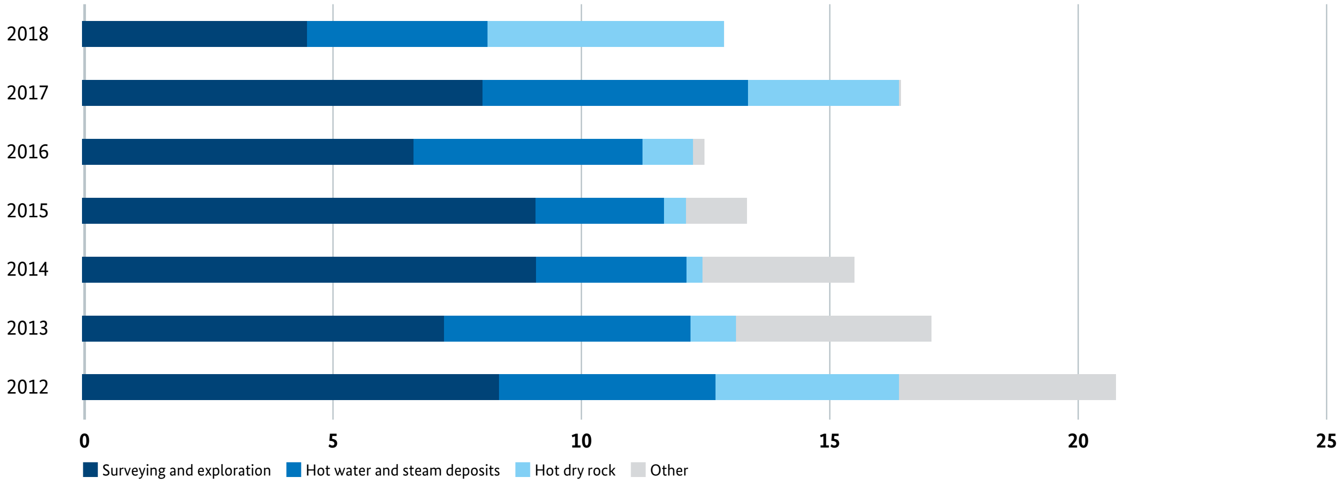
The workover installation developed here permits pumps to be replaced quickly and automatically.

When the extraction pump fails in a geothermal energy power plant, and the pump is located several hundred meters down a borehole, both the pump itself and the joined-up delivery pipes need to be brought to the surface. This operation has been very complex in the past. For this reason, engineers at Max Streicher have developed an appliance for this "workover" of deep pumps which carries out the entire process in automated sequences of steps. This is a worldwide first in the field of geothermal energy. The appliance is fitted on to a specially developed semi-trailer which is licensed for use in the city of Munich and can thus now be used flexibly by Munich municipal utilities for their various installations.

The lifting carriage is moved up and down by remote control.

Beneficiary: SWM Services GmbH and MAX STREICHER GmbH & Co. KG aA
Grant number: 0324072A-B
Estimated funding: approx. €1.5 million
Project duration: 2016 – 2018

Figure 7: Project funding for deep geothermal energy in million euros
(see table 2 for data)



2.2.5 Hydropower and marine energy

Hydropower has a key advantage over wind and solar energy: electricity production does not depend on the weather, so can be planned. Hydropower generates roughly 3% of Germany's electricity. Since almost all the geographically suitable sites are already in use, the emphasis is on modernising the existing installations. Teams of scientists are also researching innovative run-of-river wheels which could be used in new sites. Installations which generate electricity from marine energy are still at a demonstration stage around the world. The Federal Ministry for Economic Affairs and Energy is funding the development and demonstration of marine current turbines and wave energy converters.

2.2.6 Thermal power plants

Conventional power stations are reliable guarantors of a secure electricity supply, even during the energy transition. However, their task has changed: whilst they were previously always on stream in the past, they have now become flexible service providers for when there is little sun or wind. Specifically, this means that power stations have to be ramped up and down more quickly and more frequently, or operated at partial load, and this imposes new demands on operating processes and components. Also, the efficiency of the power stations needs to be increased, including in partial-load operation, so that the carbon emissions are cut in order to meet the climate targets. The Federal Ministry for Economic Affairs and Energy is supporting these efforts via its applied research funding.

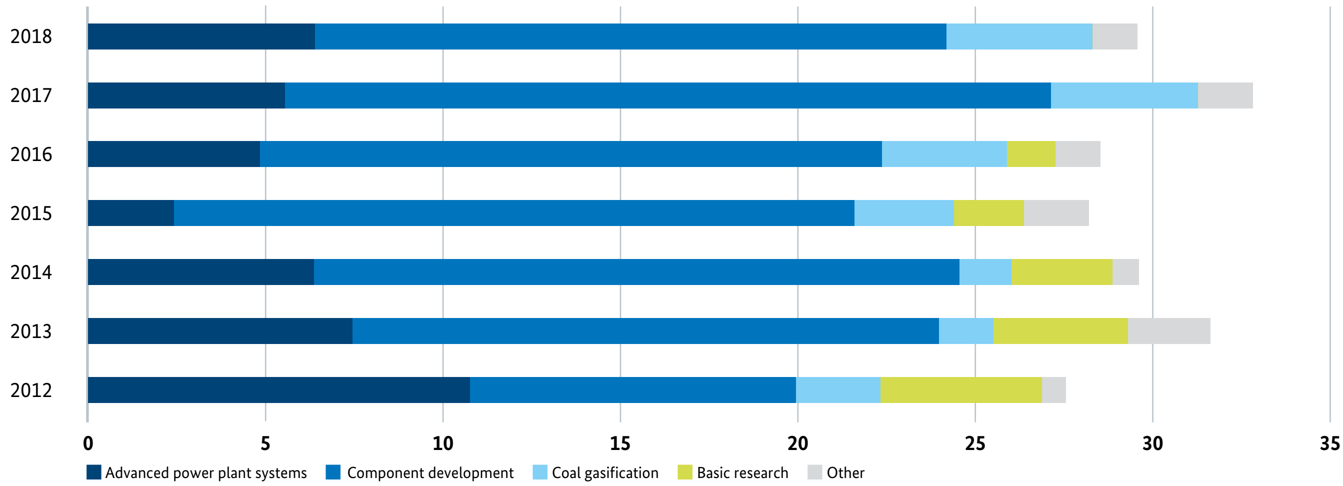
Developments in manufacturing technology for future and competitive gas turbines – Siemens Manufacturing Center of Excellence (MCoE)

High efficiency rates cut costs and carbon emissions.

New digitisation and manufacturing technologies are to improve the efficiency of combined-cycle gas turbine power stations. Scientists at Siemens are therefore working on developments in gas turbines as part of the MCoE project. The project aims to help improve the efficiency of a combined-cycle gas turbine power station from 61.5% today to 65%, and to cut the production costs via new and improved manufacturing technologies. Various aspects are being studied. For example, the project team has developed a method which can produce improved cooling air holes for the turbine blades, so that the turbine can be cooled more effectively during operations. Efforts are also focusing on processing layer systems of turbine blades more quickly and efficiently in order to permit new designs, and on digitisation of measurement technology and the integration of CAX (computer aided technologies) in turbine manufacturing.

Beneficiary: Siemens
Grant number: 03ET7085
Estimated funding: approx. €2.5 million
Project duration: 2016 – 2021

Figure 8: Project funding for power plant technology in million euros
(see table 2 for data)



Kryolens – Cryogenic air energy storage

Electricity storage plays a vital role in a flexible energy system.

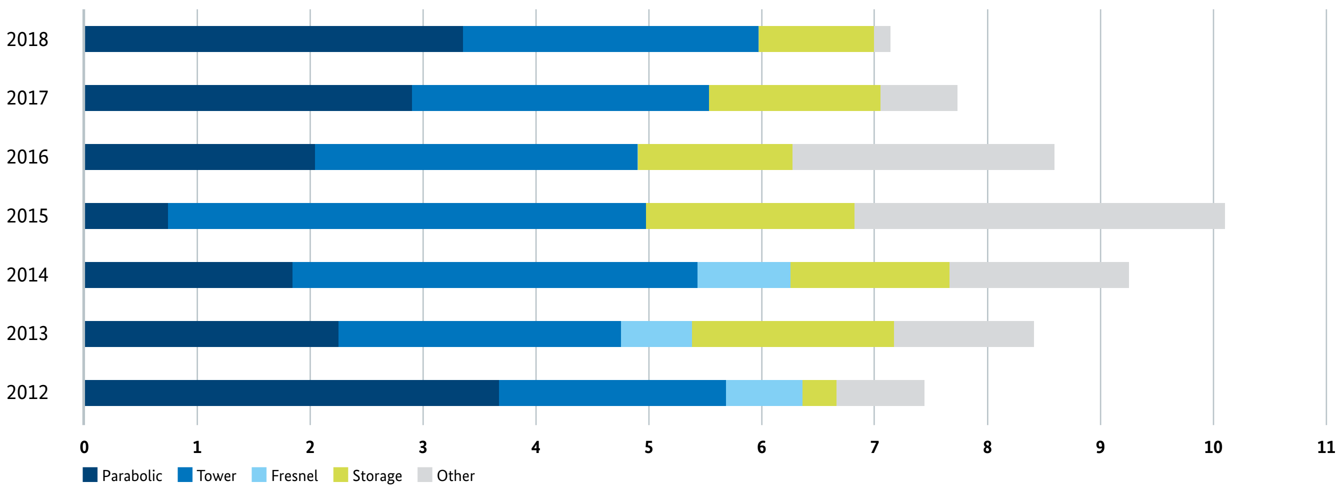
The energy transition is transforming the energy system: whereas in the past a few large-scale power plants generated electricity, there are now a large number of distributed electricity generators like wind farms and photovoltaic installations feeding electricity into the grid in parallel. Electricity storage facilities can offset peaks by storing electricity. In the Kryolens project, scientists are working on innovative liquid air energy storage. The project team is studying which solution – depending on the deployment scenario – is most efficient. Also, the project assesses the likelihood of commercial success and the environmental footprint of the technology. These analyses are intended to create a basis for decision-making as to whether and to what extent liquid air-based energy storage can meet the future need for large-scale electricity storage. Following the project, there is to be a large-scale demonstration.

Beneficiary: Mitsubishi Hitachi Power Systems Europe and Ruhr University Bochum
Grant number: 03ET7068B-F
Estimated funding: approx. €1.1 million
Project duration: 2016 – 2019

Under the 7th Energy Research Programme, the power stations are considered more as part of the overall energy system. Firstly, there is the question of how new technological solutions can make the existing large-scale power plants fit for the energy transition. This includes retrofitting, so that in future the power stations can be operated not only under different operating conditions, but can also make more use of alternative fuels and fuel blends like biomass or waste. Secondly, the research activities on energy storage are to be stepped up. For instance, surplus electricity could be converted into hydrogen or heat using Power-to-X technologies, and then subsequently converted back to generate electricity (Power-to-X-to-Power).

The fact is that power station processes are becoming more complex. For this reason, the simulation of installations and components using a "digital twin" is becoming more important with a view to using models, simulations and algorithms to virtually optimise power station processes and subsequently to implement the findings in real operations. Research is taking place not only into conventional power stations, but also into solar thermal power stations, with a focus on exports. A further field of research is the power station part of a geothermal energy facility. In the case of both technologies, expertise and products Made in Germany are in high demand around the world.

Figure 9: Project funding for solar thermal power plants in million euros
(see table 2 for data)



2.3 System integration

2.3.1 Electricity grids

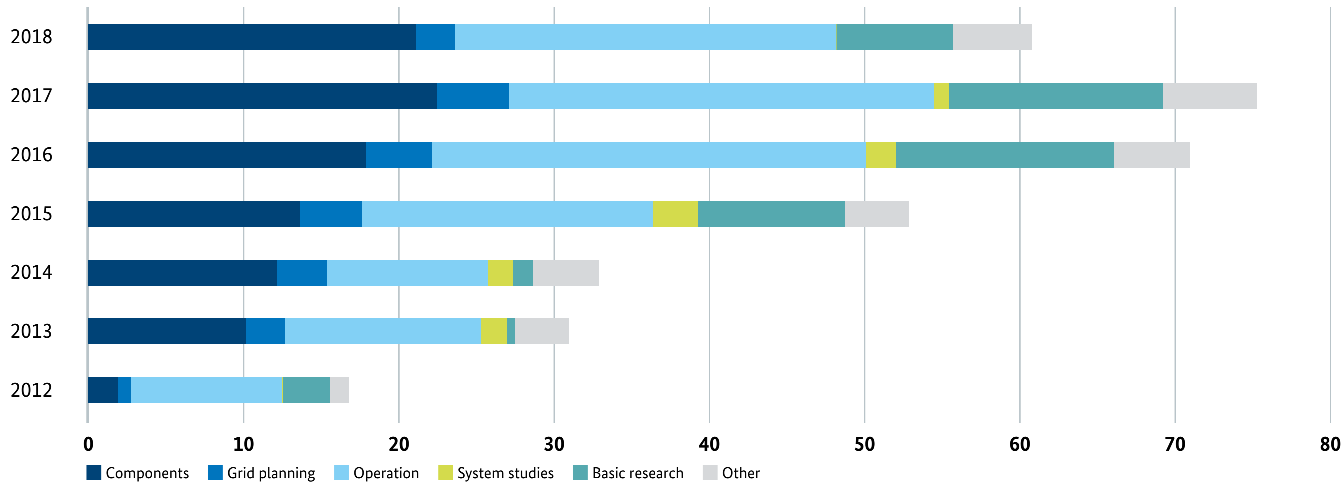
If the conversion of the energy supply to renewables is to succeed in the context of the energy transition, the energy system must be adapted to the changing generation and consumption patterns. This particularly includes the expansion and restructuring of the electricity grids as an essential element and backbone of the energy system. For this reason, a central policy goal is the expansion of the grid at transmission and distribution level so that, for example, the electricity generated in the windy parts of northern and eastern Germany can be transported across long distances to the consumers in the densely populated, industrial parts of the west and the south of the country. At the same time, energy research policy is also focusing on a better utilisation and a modernisation of the existing electricity grids. This takes account of the current development towards local, distributed supply structures. The linking up of the energy system with the heat supply and the transport and industrial sectors in the holistic context of sector coupling necessitates a coordinated operation of generating installations, electricity system operators, and consumers.

A basic prerequisite for the ongoing development is always the maintenance of the quality and security of the electricity provision, as the competitiveness of German industry and commerce depends on this. At the same time, the expansion and restructuring of the grid help to shape Germany's energy supply in a more efficient and environmentally friendly manner. These efforts include digitisation as an opportunity and a challenge which transforms grids into smart grids and provides an overarching link between research and development projects.

In view of the complexity of energy system integration, the research topics in the field of electricity grids cover a broad spectrum. The basis is formed by research to improve equipment and components and to develop innovative technologies which boost the capacity of the grid to take up and transport electricity. The focus is, for example, on converters, new materials, such as cables, power lines and switches, and AC/DC grids. In the field of grid operation and planning, the experts are focusing on control and protective technology, including optimised operational management concepts, automated monitoring of the energy system structure and the state of the grid at all voltage levels, measures for emergency operations and the restoration of the system, increasing resilience, cyber security including new information and communication technologies in data processing and analysis, the development of new business models and the establishment of service platforms.

In order to stabilise the effect on the system resulting from the naturally fluctuating renewable energies, experts are working on making greater use of flexibility options. In this field, research is addressing demand side management, new modelling and planning methods, and the development of uniform standards.

Figure 10: Project funding for power grids in million euros
(see table 4 for data)



In view of the decisive central function of the electricity grids within the energy system, research into grids and the integration into the grid of renewable energy has many interfaces with other research fields. The embedding in a larger, more holistic context also characterises the cooperation between science, government, commerce and society and the cooperation at regional and supra-regional level and across borders at European and international level. A coordinated approach means that the shared goals of European climate policy can be attained more quickly.

A project worker uses a laptop to monitor the heat pump system to test load shift strategies.

LAGE-EE – Potential to shift demand from buildings for renewables-based electricity

Experts are studying how best to arrange thermal storage of surplus energy.

Utilising the potential flexibility offered by heat pumps to shift demand: when there is a lot of electricity in the grid, the appliances absorb surplus local electricity and transform it into heat. This Power-to-Heat process helps to better coordinate electricity generation and consumption. To this end, experts are developing a holistic system for heating and cooling buildings and for hot water in the project. These include aspects like the control of technology in the home, so that heat pumps respond automatically to signals from the system operators. The team of researchers aims to maintain the residents' sense of comfort. In the final field trial, they are testing the practicability of the results.

Beneficiary: Fraunhofer Institute for Energy Economics and Energy System Technology IEE and five other partners
Grant number: 0325794A-F
Estimated funding: approx. €1.3 million
Project duration: 2015 – 2019

Shift engineers control the high voltage grid in the Tennet balancing zone.

InnoSys2030 – Innovations in system management

The team of researchers is developing solutions for a more equal and higher level of grid capacity utilisation.

The project aims to optimise system management. In order to achieve this, the experts are working on deploying additional grid components, on increasing the level of automation in operations, on improving information and communication technology, and on boosting computer power. To this end, the experts are analysing and assessing innovative approaches with regard to their feasibility in terms of electrical engineering, economic and safety/security aspects. They subsequently simulate selected measures and test them in laboratory environments. Computer systems installed in control stations and supplied with real-time data help the experts to undertake field tests and study possible effects on capacity utilisation and voltage levels.

Beneficiary: TenneT TSO, Bayreuth and 14 other partners
Grant number: 0350036A-O
Estimated funding: approx. €9.4 million
Project duration: 2018 – 2021

LADEINFRASTRUKTUR 2.0 – Optimising the coordinated expansion and operation of the charging infrastructure for electric vehicles and the distribution grids

New solutions ensure greater public acceptance of electric mobility. The environment benefits from this.

In the project, experts take a holistic approach to analysing the interactions surrounding the process of charging electric vehicles. This makes it possible for the stakeholders to develop and offer better coordinated solutions, e.g. in terms of planning, operation and regulation. Smart charging strategies and technology as well as innovative incentive systems should help to reduce the amount of grid expansion. Vehicle and charging infrastructure manufacturers benefit from the optimisation, as do system operators and energy suppliers, e.g. via new possibilities for system integration, a cross-sectoral exchange of information, and specific recommendations to the business community and policy-makers regarding the best way to progress electric mobility.

Beneficiary: Fraunhofer Institute for Energy Economics and Energy System Technology IEE and six other partners
Grant number: 0350048A-G
Estimated funding: approx. €8.8 million
Project duration: 2018 – 2022

iNET-FA² collaborative project – Smart distribution grids with fractal automation architecture

Smart distribution grids offer greater flexibility: a seamless platform for system services from the prosumer to the transmission system operator.

The iNET-FA² collaborative project elegantly maps the "self-similar" structure of the distribution grid in a fractal automation architecture. To this end, a solution for a smart distribution grid consisting of software and hardware was elaborated, validated and verified. Smart Grid Cluster Controllers (SGCCs) measure power flows, voltage quality and stress on equipment and share data at selected network nodes and connection points.

This enables the SGCCs to register the status of the observed grid section and to propose actions that will serve the grid to grid operators and customers. In a specially designed software environment, the SGCCs run functional apps via which the grid customers can offer their flexibilities and have them automatically controlled. This approach permits active control at all grid levels with a seamless mapping of the market, so that prosumers can contribute to primary and secondary control. This system is already functioning in the laboratory.

Beneficiary: Südwestfalen University of Applied Sciences and four other partners
Grant number: 03EK3541A-D, -F
Estimated funding: approx. €1.1 million
Project duration: 2014 – 2018

2.3.2 Electricity storage

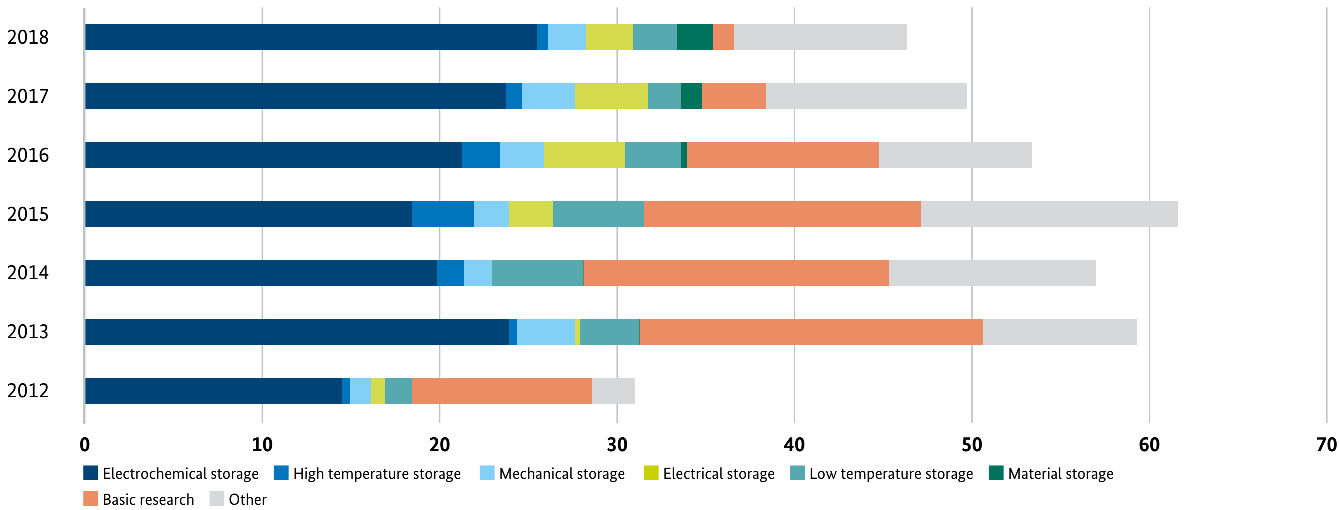
By 2050, at least 80% of electricity is to be generated from renewables. Unlike conventional power stations, however, wind and solar farms cannot generate the required electricity on an ongoing and steady basis. The generation of electricity from renewable energy sources depends very much on the weather, and fluctuates widely in the course of the day. Electricity storage can offset these fluctuations by taking up electricity which cannot be consumed directly during periods of strong wind or sunshine. Then, when the weather is unfavourable, for example at night or when there is no wind, the storage facility can return the electricity to the grid and supply the consumers.

Electricity storage is also essential for the stabilisation of the electricity grid. The tiniest fluctuations in the grid frequency can imperil the electricity supply to entire suburbs or industrial areas. When placed strategically at certain points in the grid, electricity storage can help to maintain the grid frequency, and smart demand side management can facilitate the building of more renewable energy installations. Small electricity storage units are already a key element of electric mobility. In 2016, the Federal Motor Transport Authority recorded 11,410 new registrations of electric vehicles, but this figure had more than doubled to over 25,000 by 2017. In 2018, there were more than 36,000 new registrations (a rise of roughly 44%), meaning that the number of electric vehicles in Germany rose to around 83,000 in 2018.

Demand for electricity storage also keeps rising in the residential and commercial sector. For example, the 100,000th solar electricity storage unit came on stream in Berlin in August 2018. This figure is set to double in the next two years. At the same time, the purchase price for lithium-ion batteries, which are mainly used as residential and commercial storage units, has more than halved since 2013, from €400 a kilowatt-hour to less than €200. The demand for powerful, efficient and cheap electricity storage in all sorts of fields of application is thus rising – as is the international race to produce the best technologies. To help Germany remain one of the leading players in the energy transition and to become firmly established on the international storage market, the Federal Government is continuing to fund basic (Research Ministry) and applied (Economic Affairs Ministry) research and development along the entire value chain in the 7th Energy Research Programme. In order to test the use of new storage technology under something approaching real-life conditions, the 7th Energy Research Programme also funds demonstration projects, pilot facilities, field tests and living labs.

The storage technologies and concepts to be researched are as diverse as the fields in which they are to be used. One particular priority for research into electricity storage is placed on the differing technology types of batteries as central technical components at important points of the energy system. The research aims at improvements in costs, overall efficiency, power density, energy density, storage capacity, response time, lifetime, cycle stability, and speed

Figure 11: Project funding energy storage in million euros
(see table 4 for data)

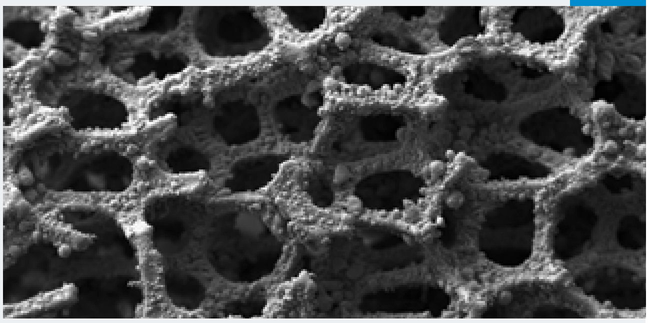


of charging and discharging. Also, the storage units must function stably and reliably at high and low temperatures. The research into alternative sources of raw materials and optimised electrode materials for battery cells is intended to improve the environmental footprint of high-performance storage units and to reduce dependency on imports. In view of the growing demand for battery storage units, redox-flow batteries are to be developed further and brought to market maturity. In the case of electrochemical storage, the development of fundamentally new cellular chemistries is also a very important field of research. And post-lithium batteries, especially metal-air and solid state batteries, play an important role. In addition to laboratory-based research, the further development of manufacturing processes, the standardisation of different storage technologies, and safety/security aspects are also key priorities.

Batt3D – High-performance and solid state batteries based on three-dimensional current collectors

Lithium-ion storage units with foam which contains air cells for higher power density

In view of their rapid charging and discharging times, lithium-ion batteries are ideal for use in electric vehicles and stationary energy storage units. In the course of the energy transition, demand for such high-performance storage units is growing, and so are the demands placed on power and energy density, environmental compatibility and cost. Researchers are therefore developing a novel battery concept in the Batt3D project: rather than clearly spatially separating anodes and cathodes, as is customary with lithium-ion batteries, the researchers are working on an open-pored metal foam. The pores in the foam are coated with electrochemically active electrode materials, resulting in a sort of three-dimensional electrode with a very large contact surface. This electrode structure makes it possible to boost the battery's power and energy density without increasing the volume. Also, these three-dimensional electrode structures permit novel geometrical structures which can be used in many different ways.



Illustrative depiction of the alloy foam used as a current collector for electrode manufacture

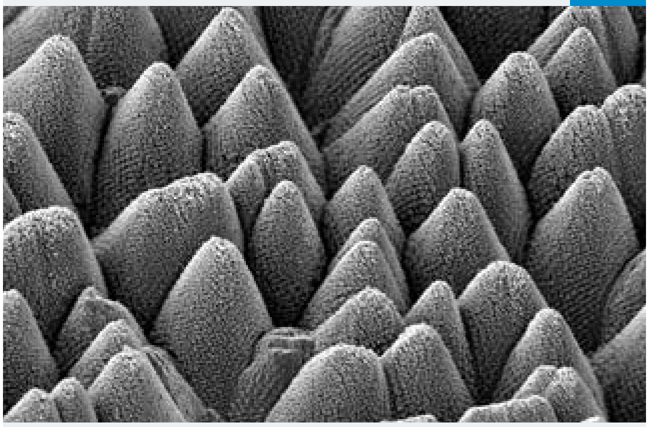
Beneficiary: Alantum Europe and seven other partners
Grant number: 03ET6111A-J
Estimated funding: approx. €2.3 million
Project duration: 2017 – 2020

UnABESA – Universal connection of battery storage units from electric vehicles for stationary applications

Coupling batteries smartly rather than dismantling them

The UnABESA collaborative project is developing stationary energy storage units on the basis of batteries for electric vehicles. The special feature of this project is that the high-voltage storage unit is not dismantled, so that it does not lose its certification. Instead, the interface between the automobile energy storage unit and the stationary inverter is optimally designed and realised via a smart bidirectional coupler. All of the battery's functions – efficiency, safety and security, and economic viability – remain in place. Together with the coupler element, the battery ultimately forms a stationary energy storage unit with a uniform electrical and logical interface. The DC-DC transformer of the coupler element transforms the voltage of the automotive battery to the level required for the grid inverter in a highly efficient manner. This means that the safety specifications to be met by the battery are fulfilled, and a high-cost grid transformer is not required.

Beneficiary: BMW AG and three other partners
Grant number: 03ET6126 A-D
Estimated funding: approx. €1.7 million
Project duration: 2017 – 2020



GreenH2 – Cheap and sustainable production of green hydrogen in the face of fluctuating loads

Optimised electrode structures for efficient and low-cost manufacture of electrolysers

The larger the surface of the electrode material in an electrolyser, the smaller the overvoltage required, and the more efficient the electrolysis. For this reason, the electrodes in customary alkaline electrolysers are made of porous Raney nickel structures, as they offer a large surface. However, they are not very suitable for use in conjunction with renewable energy installations, as they lose efficiency over time when there are sharp fluctuations in the load. In order to solve this problem, the team of researchers at GreenH2 has developed a manufacturing process based on ultra-short pulse laser technology. Here, the surface of the electrodes is structured to make them more resilient in the fact of fluctuating loads. This method is more efficient than other processes which functionalise surfaces, and also cheaper on a large scale. It can quickly and cheaply optimise electrolysers currently in use today, and this can advance the market for Power-to-Gas installations in conjunction with renewable energy installations in Germany.

Beneficiary: Fraunhofer Institute for Telecommunications HHI and five other partners
Grant number: 03ET6058A-F
Estimated funding: approx. €4.1 million
Project duration: 2015 – 2019

R2RBattery – Tailored material systems and technologies for the roll-to-roll manufacture of electrochemical energy storage units on flexible bearers

High-valency ions for the energy transition – novel post-lithium energy storage units cover the future need for energy storage and meet the ever increasing demands.

In the field of electrochemical electricity storage units for electric mobility and stationary applications, the energy transition cannot be realised using lithium-ion technology alone. For this reason, additional alternative material systems are needed for technology diversification. In cooperation between partners from industry and research, the R2RBattery project is developing a post-lithium energy storage system based on high-valency ions and designing tailored solutions for mass production. These aluminium ion solid state battery material systems make an important contribution to the energy transition by permitting volumetric energy densities which are two to four times as great as state-of-the-art lithium-ion batteries, a long lifetime with several thousand charging/discharging cycles, and safe and secure operation. With aluminium as an anode material, which is available in large quantities and benefits from large-scale production processes and a recycling infrastructure, there are promising prospects for a low-cost substitution of scarce lithium and for an energy-efficient cell production process. This makes manufacturing possible which is low-cost and sparing in its use of resources, particularly for stationary applications to support the expansion of renewable energy.

Beneficiary: TU Bergakademie Freiberg and three other partners
Grant number: 03SF0542A-B, D-E
Estimated funding: approx. €3.6 million
Project duration: 2016 – 2019

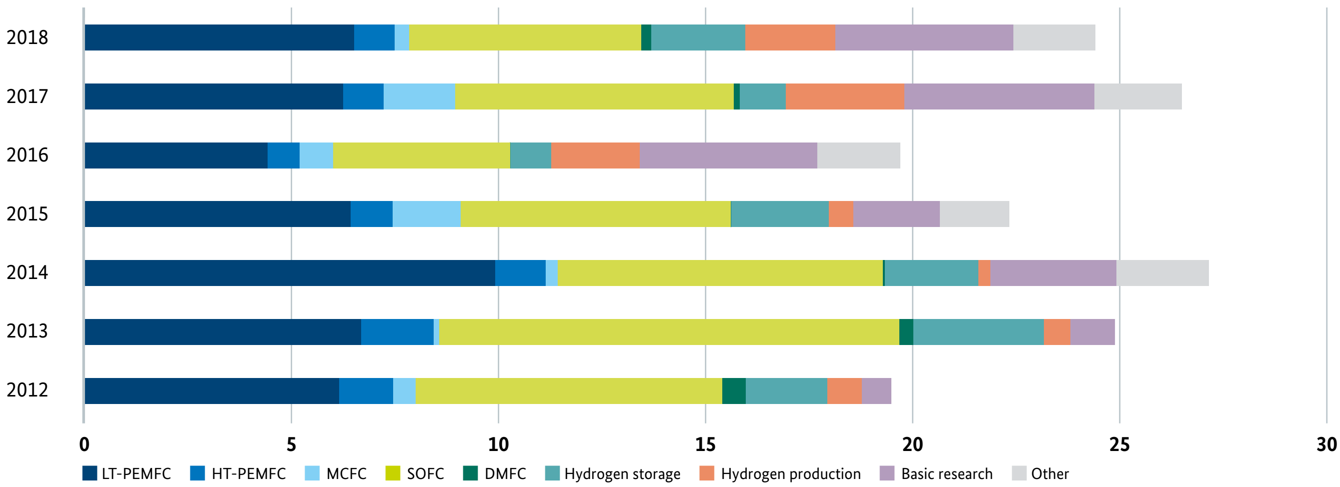
2.3.3 Sector coupling

Sector coupling is included in the 7th Energy Research Programme as a new cross-technology horizontal issue. Whilst the previous programmes have primarily concentrated on specific technologies and systemic issues, a priority is now being placed on research into the transformation of the energy system as a whole. Many individual technologies need to be successfully integrated, interact in the overall system, and share information quickly and reliably. Here, a key challenge is the efficient coupling of the electricity, heating/cooling and transport sectors. Renewable energy sources are currently better integrated into the electricity sector than the other sectors.

Via sector coupling, the fields of transport and heating/cooling are to benefit from this as well. Renewable electricity can either be used directly or via efficient connecting of the energy infrastructures for electricity, gas, heating and fuel. An important element of this is hydrogen, which can for example be generated by electrolysis using renewable electricity: hydrogen can take up local surpluses of electricity, e.g. from wind turbines, and store them long-term. The hydrogen itself could be fed into the existing gas grid. It can be used for chemical processes and serves as a basis for synthetic gases and for alternative fuels.

Specifically, for example, the Energy Transition in the Transport Sector initiative with approximately €87 million in funding from the Federal Ministry for Economic Affairs and Energy is to progress sector coupling in Germany. Since the summer of 2018, 16 large associations with partners from research and industry have been launching roughly 150 individual projects on the manufacture and use of alternative electricity-based fuel (Power-to-Fuel). Based on the research findings, the accompanying scientific research is to produce a roadmap by 2022 setting out recommendations for the development, production and market launch of sustainable fuels as a precondition for more climate-friendly mobility. In addition to the Federal Government's Energy Research Programme, the initiative is also funded from the Maritime Research Programme and the Federal Ministry for Economic Affairs and Energy's New Vehicles and System Technologies programme.

Figure 12: Project funding for fuel cells and hydrogen in million euros
(see table 2 for data)



DESS2020+ – District energy storage and supply system 2020+

Distributed energy supply using fuel cells to store electricity

In order to further increase the share of renewables in the energy supply system, ways to store the intermittent electricity generated from the wind and the sun are required. The engineers and researchers at Bosch and the Fraunhofer ISE have studied a largely closed system for residential areas in which electricity is generated from renewable sources, stored and consumed in the area, so that "green" electricity does not need to be transported across large distances. The focus here was on hydrogen as a low-cost and economic storage medium. Not only does the system function in connected households, but in future it is expected to work in hydrogen-powered vehicles. The core components: a PEM electrolyser, a solid oxide fuel cell and several hydrogen storage tanks.

Beneficiary: Robert Bosch GmbH and Fraunhofer Institute for Solar Energy Systems ISE
Grant number: 03ET6075A-B
Estimated funding: approx. €2.3 million
Project duration: 2015 – 2018

KEROSyN100 – Development and demonstration of a dynamic, efficient and scalable process chain for electricity-based kerosene – Phase 1

Using electricity-based kerosene to defossilise air traffic

Kerosene manufactured using electricity from renewable sources is a promising way to make air traffic more sustainable. It could cut the consumption of fossil fuels here. KEROSyN100 aims to produce the necessary "green" synthetic kerosene. Studies analysing the system and the development of an innovative technology to synthesise kerosene from methanol are feeding into a process layout for the first power-to-fuel installation focusing on kerosene. The emphasis is on integrating the installation in a way which helps the grid, and on a use exclusively of electricity from renewable energy. In a second phase, the findings are to be implemented in a commercially oriented demonstration environment.

Cutting air traffic carbon emissions is a challenge for the energy transition.

Beneficiary: Bremen University and six other partners
Grant number: 03EIV051A-G
Estimated funding: approx. €4.1 million
Project duration: 2018 – 2021

2.4 Cross-system research topics

2.4.1 Energy systems analysis

As the energy transition advances, the generation and distribution structures are becoming more and more complex. The interactions between different voltage levels and different sectors has a great influence on the interplay between stakeholders, markets and the technologies used. Models which analyse the systems can show up the interactions between and factors influencing these different levels, and make it possible to simulate the effects of changes to the system. For governments in particular, but also for commercial and social actors, energy system models are therefore a valuable tool for the timely and comprehensive assessment of the impact of new technologies or market structures in the energy sector.

However, if system models are to be used as a robust basis for decision-making processes, the findings of the analyses must be comprehensible, transparent and verifiable. In order to ensure this, the Federal Government is funding the development of validation methods like comparisons of models and comparisons of historic data series in the 7th Energy Research Programme. Another aim of the scientific analysis of the energy system is to reduce the complexity of established models, i.e. to simplify them without losing important details. Also, funding is going towards open source solutions, since they can firstly accelerate the further development and improvement of existing models, and secondly facilitate the development of interfaces with other models.

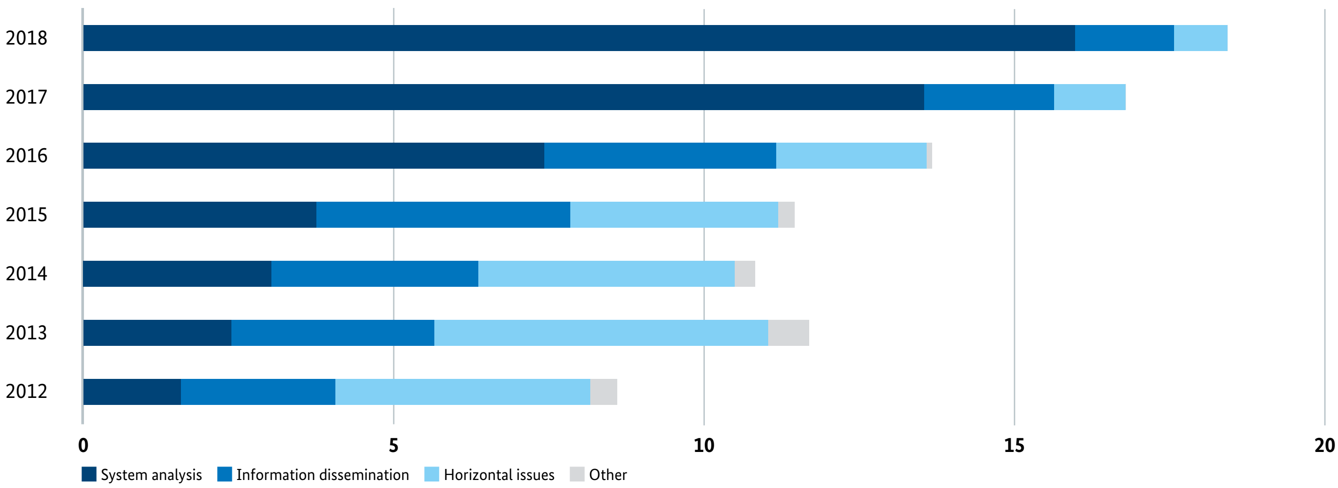
open_MODEX – Model experiment to compare and identify potential synergies of open-source frameworks in energy systems analysis

Investigating energy system models

In order to take forward-looking decisions about the future energy system, there is a need for analyses and an understanding of systemic interrelationships. Here, open science is an important prerequisite for ensuring that the messages intended to inform policy makers and society are transmitted in a quality that is easy to understand. Open source (OS) frameworks are available to shape the energy system analyses in a transparent way. These enable all sorts of scenarios to be modelled on computers. The OS publication of the source codes makes it possible to draw conclusions about the quality of the models and to include equations, logic and organisational forms in the analysis. In open_MODEX, known open frameworks are subjected to a theoretical comparison and compared in terms of the outcomes of their calculations. The project is part of the MODEX thematic association, with €5.25 million in funding from the Federal Ministry for Economic Affairs and Energy and a total of six model experiments from different fields which should contribute to quality assurance and transparency of system-analytical modelling.

Beneficiary: Reiner Lemoine Institut gGmbH and four other partners
Grant number: 03ET4076A-E
Estimated funding: approx. €970,000
Project duration: 2019–2021

Figure 13: Project funding for system analysis and horizontal issues in million euros
(see table 4 for data)



2.4.2 Digitisation

Information and communications technology (ICT) is advancing rapidly. For this reason, ICT plays a central role in mastering the challenges of the energy transition, such as increasing decentralisation and flexibilisation. Research and development is focusing on the internet of things, big data analytics, artificial intelligence, ICT security and resilience, data processing and protection, simulation methods, human-machine interaction, robotics, open science and digital business models. Also, energy technologies are being adapted to new ICTs, such as 5G, cloud computing, quantum computers and blockchain. The digitisation is a horizontal issue which affects all subsectors of energy research.

DECENT – Distributed, cross-sectoral energy management

Dynamic and stable energy distribution systems for smart neighbourhoods

In many cases, electricity and heat from renewable energy installations are generated and stored on a distributed basis, e.g. in residential and industrial areas. This means that the buildings sector in particular offers great potential to make the energy supply and energy management more efficient and less resource-intensive. However, in many cases, there is a lack of infrastructure to jointly use and manage heat, electricity and storage. The DECENT project therefore aims to produce an ICT solution which makes possible local but distributed energy trading via blockchain technology, taking account of the interests of all the stakeholders. New business models which build on this should then be developed and assessed. This includes an evaluation of the existing legal framework. Subsequently, the research team will provide the political decision-makers with recommendations for improvements. The project is being carried out as part of a German-Finnish funding initiative in cooperation with Finnish industrial and research partners.

Beneficiary: Technical University of Munich and three other partners
Grant number: 0350024A–C, E
Estimated funding: approx. €740,000
Project duration: 2018 – 2020

2.4.3 Resource efficiency in the context of the energy transition

The issue of resource efficiency in the context of the energy transition has been taken up in the 7th Energy Research Programme. Research projects in this field aim to help protect raw materials which are of strategic importance and limited availability and to make more sustainable use of them. Also, consideration is to be given in future to the principles of the circular economy in all the funded projects. Further to this, funding is also to go to projects which shed light on resource efficiency from an overarching perspective. Certain projects already have addressed this issue in the context of the 6th Energy Research Programme. For example, the KoReMo project studies how to reduce the amount of rare earths (like indium) in the manufacture of solar cells.

2.4.4 Carbon2Chem und other CO_2 technologies

CO_2 technologies are another new overarching systemic field of research in the 7th Energy Research Programme. An important focus is placed on the question of how industrial processes which are very difficult to decarbonise can nevertheless become climate-friendly. This is for example possible via the use of CO_2 which arises in such processes (carbon capture and utilisation – CCU) in the manufacture of long-life products. But other issues like the direct capture of CO_2 from the air and overarching issues of the development of a CO_2 circular economy are also being addressed. The question of CCU in particular has already been addressed in the context of the 6th Energy Research Programme. Mention should particularly be made here of the Carbon2Chem research initiative.

Carbon2Chem – CO_2 reduction via cross-industrial cooperation between the steel, chemical and energy sectors

CO_2 reduction by using blast furnace gases from steel works to produce basic chemicals

Headed by thyssenkrupp, the UMSICHT Fraunhofer Institute and the Max Planck Institute for Chemical Energy Conversion (MPI-CEC), 17 partners from science and industry participating in the Federal Ministry of Education and Research's Carbon2Chem project are studying how to cut CO_2 emissions from steel works in a way that benefits the climate. Rather than emitting waste gases from steelmaking into the atmosphere, the valuable raw materials contained in the blast furnace gases are to be processed and used to make basic chemicals like ammonia, methanol and polymers. To this end, steel works, chemical production facilities and energy generation facilities will be brought together in an optimised cross-industrial association.
The intention is to save up to 20 million tonnes of carbon emissions a year. In addition to the processes to create the envisaged chemical products, the project is also studying the production of large quantities of hydrogen from renewable sources, the necessary scrubbing of the blast furnace gases, and technical implementation in the steel mill.

In the course of the project so far, the complex process and plant simulation of the cross-industrial association has already been largely realised in the form of a distributed co-simulation. Also, the project at the Technikum on the site of the Duisburg steelworks now has a Carbon2Chem pilot facility which contains a 2MW electrolyser to produce hydrogen, a gas scrubber for the blast furnace gases, and laboratories and test facilities for various chemical product routes. The world's first production plant for methanol from blast-furnace gases came on stream just in time for the opening of the Technikum in September 2018. In November 2018, the second conference on sustainable chemical conversion in industry took place in Berlin, at which the results of the project were presented to the public and discussed with the conference participants.

In the context of the Federal Ministry of Education and Research's MACOR project in the same field, which as an alternative to Carbon2Chem is conducting a feasibility study into the technical and economic aspects of the large-scale integration of direct reduction facilities into an existing blast-furnace process, following conclusion of the modelling work for the existing blast furnace, initial studies were carried out into the effects of the direct reduction process on CO_2 emissions and the specific energy input. These comprised both material analyses of directly reduced iron (DRI) and the development of a model for calculating economic viability.

Cluster coordinators: thyssenkrupp AG, Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT, Max Planck Institute for Chemical Energy Conversion MPI-CEC

Cluster of 7 collaborative projects (L0-L6)

L0 – System integration: thyssenkrupp AG, Max Planck Institute for Chemical Energy Conversion (MPI-CEC), Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT, Siemens AG
L1 – Water electrolysis in non-stationary operations: thyssenkrupp AG, Hydrogen and Fuel Cell Center ZBT
L2 – Sustainable methanol production: Nouryon Akzo Nobel Chemicals GmbH, Ruhr University Bochum (RUB), FhG-UMSICHT, MPI-CEC, Fraunhofer Institute for Solar Energy Systems ISE, Clariant Produkte (Deutschland) GmbH, thyssenkrupp AG
L3 – Gas scrubbing: Linde AG, RUB, Clariant Produkte (Deutschland) GmbH, FhG-UMSICHT, MPI-CEC, thyssenkrupp AG
L4 – Higher alcohols: EVONIK Resource Efficiency GmbH, RUB, FhG-UMSICHT, RWTH Aachen – Institute of Technical and Macromolecular Chemistry, thyssenkrupp AG
L5 – Polymers: Covestro Deutschland AG, MPI-CEC, RWTH Aachen Catalytic Center, Max-Planck-Institut für Kohlenforschung, RWTH Aachen – chairs of fluid separations, technical thermodynamics and technical and macromolecular chemistry
L6 – Oxymethyl ether: BASF SE, Volkswagen AG, Linde AG, FhG-UMSICHT, Karlsruhe Institute of Technology (KIT) – Institute of Catalysis Research and Technology, thyssenkrupp AG

Grant number: 03EK3037-03EK3043
Estimated funding: approx. €63.3 million
Project duration: 2016 – 2020

MONIKA – Methanol from electricity and CO_2 from a waste incinerator

Waste incinerators could be used to store electricity.

Waste incinerators release CO_2 in the combustion process. The MONIKA research project looks into the extent to which it is technically and economically feasible to retrofit existing incinerators to produce methanol from electricity and CO_2. Specifically, the electricity produced in the incinerator is (partly) used to make hydrogen via electrolysis. This then reacts with the CO_2 previously separated from the exhaust gas to become methanol. The process would offer incinerator operators the possibility to store electricity when the grids are overloaded. Another benefit: methanol can be used as a fuel both in industry and in the transport sector.

Beneficiary: TU Darmstadt
Grant number: 03ET7089
Estimated funding: approx. €370,000
Project duration: 2017 – 2019

2.4.5 Energy transition and society

The development of forward-looking energy technologies and innovative concepts is changing not only the energy system, but also day-to-day life. How can energy research help to ensure that the effects of these changes are as positive as possible and that consideration is given to the desires and ideas of the public? This question is addressed in the 7th Energy Research Programme by the Energy Transition and Society horizontal issue. A focus of this research priority is on research projects which take a cross-system and cross-technology approach. These can for example be cross-sector analyses of societal factors, or the socio-economic study of measures to cope with structural change in traditional energy industry regions. Certain projects already have addressed such questions in the context of the 6th Energy Research Programme: for example, the research accompanying the Energy Transition in the Transport Sector funding initiative is studying the circumstances in which electricity-based fuels meet with acceptance or rejection.

2.4.6 Materials research for the energy transition

In this funding measure, the Federal Ministry of Education and Research is pursuing the goal of using basic research into materials to address current challenges facing the energy transition. Here, a broad approach is being taken to addressing the demands placed on materials by an energy supply which is largely based on renewable sources. In three funding phases, approximately €96 million in funding supported a total of 149 projects in 38 associations, one individual project and seven groups of young scientists. The various challenges include energy-efficient building materials, thermally stressed components in power stations, storage of electricity and heat, and high-performance materials for wind and solar energy installations.

These projects produced many different instances of important scientific progress. World record efficiency rates were achieved for perovskite-based solar cells (“MeSa-Zuma”) and solar water splitting using metal oxides (“MeOx4H2”). In particular in the case of perovskite solar cells, cooperation between researchers and industry was able to take major steps towards market-readiness; a joint patent has already been registered (“MeSa-Zuma”). In the case of stationary and mobile hydrogen storage, HySCORE achieved a breakthrough in material stability. NEMEZU developed a catalytic converter system without noble metals, which could be useful not only for use in fuel cells but also for battery systems and electrolysers.

The continuing high level of need for research into materials and their use in technologies of relevance to the energy transition is being thoroughly addressed in the 7th Energy Research Programme (cf. Chapter 4.4.6 in the 7th Energy Research Programme).

Mechanocarb young scientists group – Mechanochemistry as a sustainable principle for synthesis and functionalisation of nanostructured carbon materials in electrochemical energy storage

The Mechanocarb young scientists group aims to establish a resource-efficient, energy-efficient and time-efficient principle for the manufacture of porous carbon-based energy storage material.

Porous, nanostructured carbons are of particular importance as electrode material in supercondensors, lithium-sulphur batteries and fuel cells. However, their synthesis processes often tend to be multistaged and produce large quantities of waste. For this reason, they are not yet ready for commercial take-up (top materials cost up to €10,000 a kilogram). The synthesis creates 5 to 50 times more (toxic) waste than desired end product. The new process aims to meet the economic and environmental demands of the energy transition. There is therefore a need not only for the development of better high-performance materials, but also for research into sustainable cost-efficient, resource-efficient and energy-efficient synthesis methods. The Mechanocarb young scientists group aims to establish mechanochemistry as such a synthesis method to functionalise porous carbon-based electrode materials. The researchers expect this synthesis method for future energy storage materials to cut the cost of high-performance materials to below €100/kg, which would foster market take-up.

Beneficiary: TU Dresden
Grant number: 03SF0498
Estimated funding: approx. €2.2 million
Project duration: 2015 – 2020

2.4.7 Kopernikus projects for the energy transition

The Kopernikus projects, which are mission-oriented and scheduled to last ten years, cover the key issues of grid structures, storage, industrial processes and system integration. They develop medium-term to long-term prospects for the energy transition in these fields. In this way, the work is to move from basic research into applications. At present, more than 250 research establishments, companies and associations are working in the four Kopernikus projects. In 2018, the Kopernikus projects entered the second half of the first funding phase, and reported initial successes.

In the ENSURE Kopernikus project, storylines for potential energy scenarios have been developed into which the aspects of climate change mitigation, decentrality, electrification and pan-European cooperation are built to differing degrees. Further to this, there are technical innovations, such as Digital System Protection Design (DSPD), which automatically produces different variations of protection concepts and thus makes the electricity grids more secure.

The work on P2X offers the great potential of oxymethylene ethers for use as a clean synthetic fuel for diesel engines. For this reason, the P2X-derived activities are being developed further in the new NAMOSYN research initiative (project launch in spring 2019). The P2X Kopernikus project also generated the Rheticus satellite project in which carbon dioxide is converted into special chemicals via the use of bacteria and electricity from renewable sources. The highly promising results produced by the partners made it possible to rapidly achieve market readiness of the P2X technology.

In order to be able to gather initial experience with the implementation of flexibility measures at an early stage of the project, two “fast tracks” were integrated into the SynErgie Kopernikus project. Taking aluminium production and air separation as examples, various companies built demonstrators. The partners have already been able to show that the output of an electrolysis furnace to produce aluminium can be rapidly cut or boosted by around 18 megawatts whilst in operation. Further to this, SynErgie estimated the future potential for the flexibilisation of industrial processes. It found that, in a 15-minute period, the electrical load could be cut by up to 2.5 gigawatts and raised by 1.1 gigawatts. This would stabilise the electricity grid to the same extent as Germany’s largest pumped storage hydro electric station or two gas-fired power stations.

Almost 90% of the German population continue to back the energy transition. This was shown by the study into social sustainability of the energy transition, involving the ENavi Kopernikus project. However, more than half of those surveyed believe that its implementation is expensive and unfair. Proposals and strategies to implement the energy transition are continuously examined in a dialogue with representatives of society. This is an important element of the ENavi concept.

ENSURE – New EnergieNetzStruktURen (energy grid structures) for the energy transition

New grid structures for a holistic energy supply system with optimal distribution of centralised and distributed supply elements

In the ENSURE Kopernikus project, scientists, industrial firms and civil society organisations are trying to adapt the future electrical energy supply to the changes entailed by the energy transition. The aim is to identify a useful structure of centralised and distributed supply. The technical focus of the project is on the study of new grid structures and management concepts, and on the integration of new technologies into the supply system. In a later funding period, the findings of the project are to be realised on a large scale and the possibilities for a future holistic energy supply system to be demonstrated and tested. All of the work is being backed by a comprehensive analysis of the socio-economic factors.

Beneficiary: Karlsruhe Institute of Technology and 22 other partners
Grant number: 03SFK1A-X0
Estimated funding: approx. €29.7 million
Project duration: 2016 – 2019

P2X – Research, validation and implementation of Power-to-X concepts

Hydrogen and carbon monoxide for the PtX process chain

In the Power-to-X Kopernikus project, six research clusters are investigating solutions which use renewable energy to manufacture material energy sources and chemical products for the energy, mobility and chemical sectors. Three of the clusters are using various electrolysis technologies to research the manufacture of hydrogen and carbon monoxide, feedstock materials for the PtX process chain. One research cluster is studying storage and the transport of hydrogen via liquid organic carriers of hydrogen. The other two clusters are looking into the realisation of the feedstock materials into the corresponding target products. A roadmapping process is accompanying and validating the clusters' work. The PtX Kopernikus project is thus making an important contribution to the energy transition in Germany.

Beneficiary: RWTH Aachen University and 41 other partners
Grant number: 03SF2KA-X0
Estimated funding: approx. €32.4 million
Project duration: 2016 – 2019

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

Flexible production processes for industry

The aim of the SynErgie Kopernikus project is to synchronise the energy-intensive industrial production processes, e.g. in aluminium, paper and cement making, and their energy requirements with the intermittent supply of renewable energy. If this succeeds, the energy supply costs for industry can be cut, and the proportion of renewable energy clearly increased. In order to make the energy demand more flexible in various sectors, demand-side management offers a chance to shape the restructuring of the energy system in a cost-effective and socially acceptable manner. Modern approaches to information and communications technology (ICT) have a key role to play in helping demand to respond flexibly to supply. ICT is used to regulate the distribution of energy between the industrial processes, taking account of the fluctuating supply. In addition to technical and economic aspects, SynErgie is also integrating legal and social perspectives in its solutions.

Beneficiary: TU Darmstadt and 57 other partners
Grant number: 03SFK3A-Z1
Estimated funding: approx. €34.1 million
Project duration: 2016 – 2019

ENavi – Energy transition navigation system

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

More than 60 partners are working in the ENavi project, headed by the Potsdam Institute for Advanced Sustainability Studies (IASS), on a research programme to identify the optimal paths for the implementation of the energy transition. The programme develops new strategies for individuals, companies, associations, municipalities and state agencies. These are to be merged in a map which depicts the scope for action and highlights the opportunities and risks. The broad-based study crosses the boundaries between all relevant scientific disciplines and engages in a close dialogue with stakeholders working on the ground. The project work includes NGOs, businesses, municipal utilities and territorial authorities. Important indications of practicability and public recognition of the solutions are also being obtained in living labs and selected model regions. In the funding period up to 2019, the focus is on strategies to transform the electricity system, for smart control of the heat supply, and to decarbonise the transport sector.

Beneficiary: Potsdam Institute for Advanced Sustainability Studies IASS and 46 other partners
Grant number: 03SFK4A-Z1
Estimated funding: approx. €30.5 million
Project duration: 2016–2019

2.5 Nuclear safety research

2.5.1 Reactor safety research

Publicly funded nuclear safety research focuses on the safety of nuclear power plants. Secure methods and tools are to be developed which permit an independent state-of-the-art assessment of the safety of nuclear facilities in Germany and abroad and foster a further development of safety standards. In view of the potential cross-border nature of operating risks, consideration is also being given to reactor designs which differ from the installations still in operation in Germany until 2022, or which are being developed around the world. A key motive behind the funding measure is the preservation and development of the necessary scientific and technical expertise, particularly against the background of the phase-out of nuclear-based electricity generation in Germany. 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 to promote young scientists.

In 2018, the Federal Ministry for Economic Affairs and Energy supported 136 ongoing projects with funding totalling around €20.75 million, and approved 26 new research projects with estimated funding of approximately €16.93 million (cf. Figure 14). The focus of the funding was on the development and experimental back-up of computer programmes to describe the processes in the reactor core, the cooling circuits and the safety container, on materials science studies and on the development of methods to assess the integrity of buildings and components, on probabilistic methods, security issues of digital control technology, and the study of the impact of human action and of organisation on the safety and security of nuclear power plants.

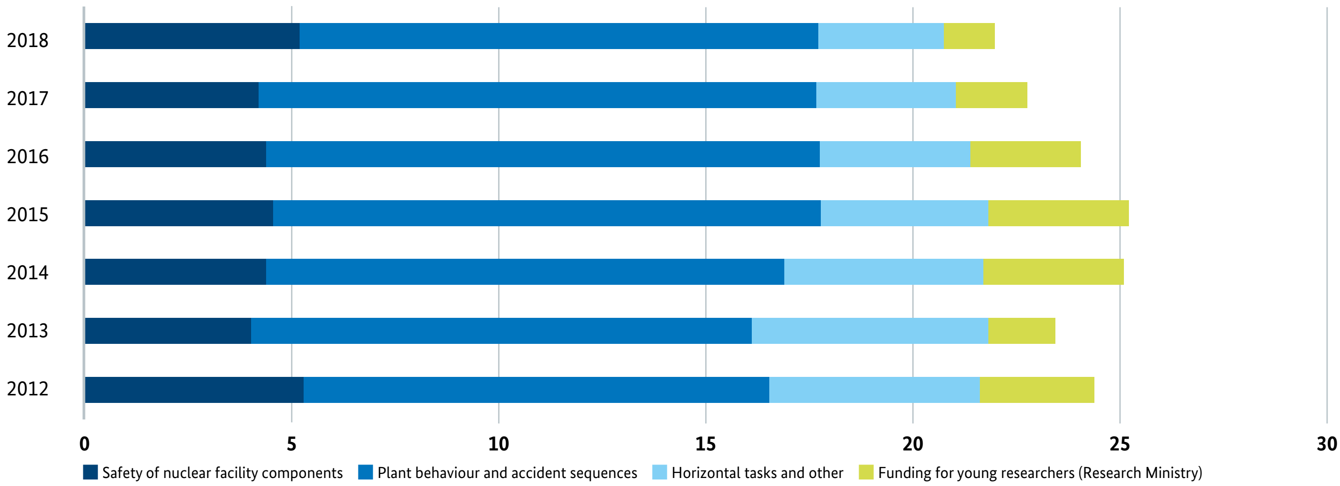
MeKom – Experimental and numerical studies into multiple cracks in pressure boundary components

Development and validation of a method to quantify the safety distance to prevent failure of components with crack zones

In large forged components, crack zones can emerge due to the influence of hydrogen in the manufacturing process. Studies conducted in recent years have shown that such crack zones can also exist in components in nuclear facilities, as seen in the reactor pressure vessels of Belgium's Doel 3 and Tihange 2 nuclear power plants. In the MeKom collaborative project, a method is to be developed to quantify the safety distance to prevent the loss of integrity of safety-related components with crack zones. The project's trial programme produced robust information about the interaction of individual cracks in a crack zone. The mechanical damage models developed in the project are capable of describing the interaction of the cracks in crack zones. In a follow-up project, in-depth studies are to be undertaken to assess components affected by crack zones.

Beneficiary: Stuttgart University and RWTH Aachen University
Grant number: 1501513A-B
Estimated funding: approx. €1.2 million
Project duration: 2015 – 2019

Figure 14: Project funding for reactor safety research in million euros
(see table 6 for data)



2.5.2 Disposal and repository research

The funding measures carried out in recent decades have helped to establish the scientific and technical basis for future final storage concepts and safety verification. In recent decades, research has been carried out into the final storage of highly radioactive, thermogenic waste in all host rock formations. Overarching aspects of final repository, irrespective of the host rock, have also been covered. The Federal Ministry for Economic Affairs and Energy's project funding in the field of waste disposal research is backed by the Federal Ministry of Education and Research's research funding, which is targeted at retaining the expertise in the field of basic research and promoting young talent.

In 2018, approval was given to the funding of ten new projects which are focused on the strategic goal of designing a scientific and technical basis for the realisation of a final repository and the study of the effects of extended periods of intermediate storage. The scientific progress can be summarised as follows:

- Establishing the foundations for and providing modelling tools for geomechanical site models
- Verification and validation of the predictive analyses of structural stability and integrity of final repositories
- Calculation of realistic distribution coefficients as a function of important geochemical parameters (smart Kd concept) and examination of the transferability to other geological formations and transport codes
- Further development of the analysis of thermo-hydro-mechanical-chemical (THMC) processes with regard to the testing of the integrity of the technical barriers
- Further development of the safety verification of a rock salt final repository
- Compilation of the requirements to be met by supports in a final repository in clay host rock
- Improvement of expertise in the impact of longer interim storage on waste and containers

In ongoing projects, studies continued into the issues of the safety case, systemic behaviour, monitoring, social-technical issues, governance and safeguards.

BASEL

Assessment of the interdependency between the secure construction and operation of a final repository for thermogenic waste and long-term safety

The undertaking of a safety verification for a final repository for thermogenic radioactive waste and spent fuel elements distinguishes between the operational and post-operational phase. The safety concept must show what technical and organisational measures are to ensure safety during operations. In the past, the discussion of the approach to developing a safety case has focused to a very large extent on long-term safety. This has overlooked the fact that the course of the operational phase determines the initial status for the long-term safety analysis. At the same time, many requirements for the verification of long-term safety impact on the design of the final repository. The BASEL project is developing an approach which aims to permit a comprehensible weighing up between safety requirements during the operational phase and long-term safety.

Beneficiary: Gesellschaft für Anlagen- und Reaktorsicherheit (GRS)/Braunschweig and BGE TECHNOLOGY GmbH/Peine
Grant number: 02E11486A-B
Estimated funding: approx. €645,000
Project duration: 2016 – 2019

2.5.3 Radiation research

The focus of the Federal Ministry of Education and Research funding for nuclear safety and radiation research is on radiation research. In the field of radiation research, funding in 2018 went to 16 associations working on 53 individual projects in the field of radiation biology, radiation medicine, and radioecology. The structure of the collaborative projects has fostered interdisciplinary cooperation and enabled work to be done even on highly complex issues. In total, the Federal Ministry of Education and Research funded the training of some 150 young scientists in the field in 2018, and thus made a substantial contribution towards maintaining expertise.

New and attractive teaching programmes were also established at various universities and research institutes. The project-funded research projects generate numerous publications in high-quality specialist magazines and journals. The research associations worked on highly relevant social and highly topical scientific issues. A large number of outstanding results were achieved. By generating these findings, the research associations help to ensure that Germany's population continues to benefit from efficient radiation protection and the optimal and successful use of radiation in medicine. In 2018, research projects in the field of radiation research were supported with funding totalling around €7.9 million (cf. Figure 15).

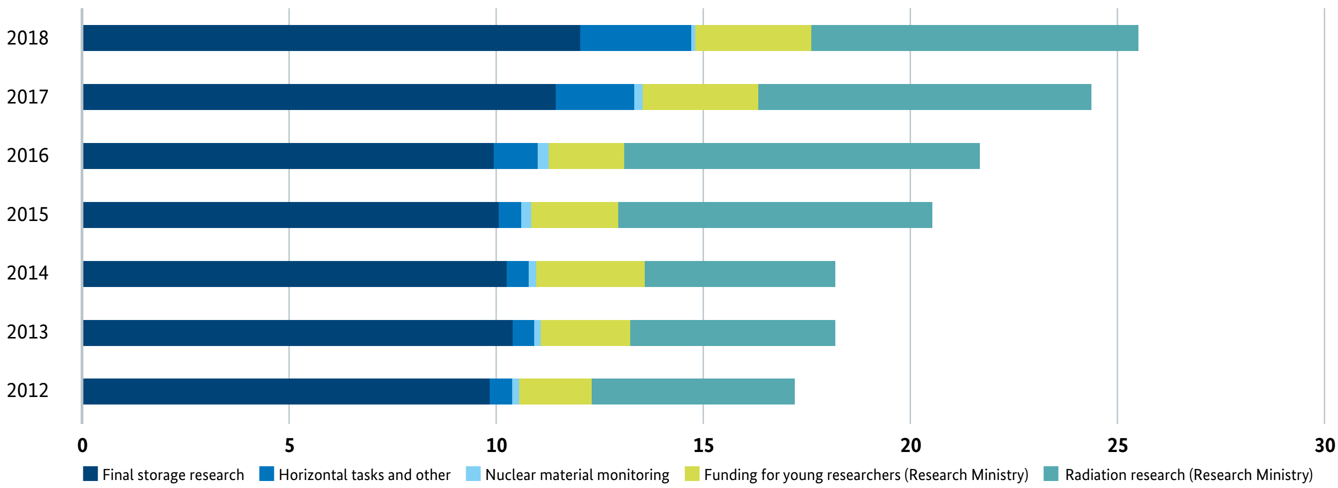
DNA repair foci collaborative project – DNA repair foci as markers of individual radiation sensitivity

Establishing DNA repair foci as markers of individual radiation sensitivity

The biological effect of exposure to even the same physical dose of radiation can vary widely, as there are large differences in individual radiation sensitivity. This collaborative research project aims to establish and validate specific DNA repair foci, as formed in the repair of DNA double strand breaks, a biological markers of individual radiation sensitivity. To this end, more than 100 samples were taken from 50 tumour patients via a biopsy, irradiated in a laboratory and analysed. Special colouration can now for the first time determine which prostate carcinomas are particularly responsive to radiation therapy. In particular, the researchers now know what the radiation therapy has to be combined with so that its effect is enhanced solely in the tumour, and not in the adjacent normal tissue.

Beneficiary: Saarland University and four other partners
Grant number: 02NUK035A-E
Estimated funding: approx. €4.1 million
Project duration: 2014 – 2020

Figure 15: Project funding for nuclear waste final storage and disposal research in million euros
(see table 6 for data)



3. Institutional energy research

3.1 Energy research by the Helmholtz Association

Many of the research establishments receiving institutional funding in Germany are working on the energy transition and new energy technologies. In view of the close coordination between research centres and grant providers in the context of programme-oriented funding, the energy research being done by the Helmholtz Association forms part of the Energy Research Programme. Experts working in this part of the Association's Research Field Energy are to help us tackle the major challenges of mitigating climate change and transforming the energy system. In the context of its research programmes, the Association's energy researchers are developing viable solutions for the energy transition in Germany and for the sustainable restructuring of the energy supply. Institutional funding is going to both basic and applied research here, and the basic research being done should also have a clear relationship to specific energy applications.

The Research Field Energy is characterised by two unique features:

1. Firstly, the Helmholtz Centres undertaking energy research deploy research infrastructure which is funded on a long-term basis and some of which are uniquely large in scale; this infrastructure is used sustainably for their own activities and is also made available to external parties, including from the commercial sector. This attractive infrastructure makes the Helmholtz Centres desirable partners for research establishments from all around the world, universities in the regional, national and international context, and companies.

2. Secondly, the structures of the Helmholtz Association give the experts in the Research Field Energy the possibility to take a holistic approach to the complex issues of energy supply, i.e. in the context of the system and along process and value chains. The research program-

mes bring together their broad-based expertise. From January to April 2018, the Research Field Energy was subjected to a comprehensive and detailed scientific evaluation. Internationally reputed scientists started by evaluating the centres on the basis of written documents, and then spent several days visiting the centres. In total, 107 people evaluated the scientific quality of the research work. Also, the progress made on attaining the goals of the third period of programme-oriented funding was assessed. Overall, the experts were most impressed by the quality of the scientific work and particularly by the research infrastructures in the centres undertaking research into energy. The wide-ranging findings of the evaluation were summarised in six centre reports and seven programme reports. The differentiated evaluation and detailed suggestions in the studies are proving highly valuable for the future development of energy research in the Helmholtz Centres.

Similar studies took place in all of the Helmholtz Association's research fields. The findings were discussed in detail in the bodies managing the Helmholtz Association and with the grant providers. In the case of the Research Field Energy, they and the 7th Energy Research Programme formed the basis for the research policy goals agreed at the end of 2018 for the coming fourth period of programme-oriented funding. The agreed goals for research policy included cooperation between the Research Field Energy and other research fields on materials research and digitisation. Also, the transfer of innovations and research findings into business and society is to be boosted. Further to this, the thematic structure will in future only consist of four programmes.

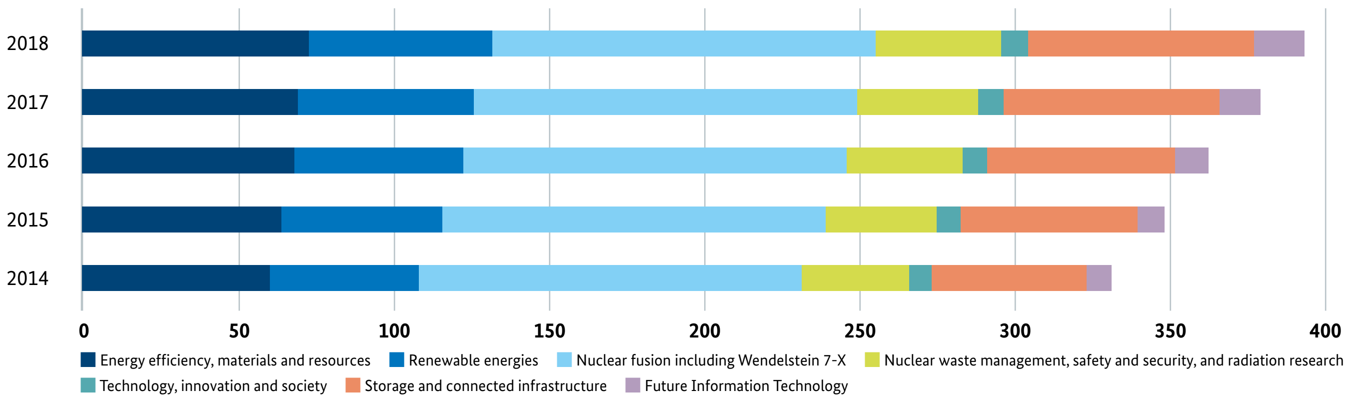
The centres will develop their own programme applications by autumn 2019 on the basis of the agreed goals. In October 2019, these applications will be subject to a strategic evaluation by a high-level body of international experts. The outcome of the strategic evaluation and the question of how the applications fit in with the research policy goals of the fourth programme period will then form the basis for the funding recommendations to the grant providers for the fourth period of programme-oriented funding, which is to commence in 2021. Table 7 shows the funding deployed in the Research Field Energy of the Helmholtz Centres.

3.2 Fusion research

In the context of programme-oriented Helmholtz Association funding, funding for application-oriented basic research also goes towards fusion research. The research into the generation of energy from fusion aims to develop a reliable and economic energy source which is not reliant on fossil fuels in the long term. In view of the global rise in energy demand, the Federal Government believes it is necessary to research a broad range of options for future energy supply. With its outstanding scientific expertise in the field of fusion research, Germany also has a global responsibility to progress the understanding of high-temperature plasmas and fusion processes and to provide this expertise to the world. 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 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 16: Disbursements for topics of energy research within the Helmholtz Association in million euros
(see table 7 for data)



4. Further energy-related funding

4.1. Funding activities of 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 Federal Ministry for Economic Affairs and Energy (cf. Figure 17). The latest survey, for 2017, says that spending by the Länder on energy research totalled close to €282 million.

Measures to promote energy efficiency formed the main funding priority of the Länder in 2017, with spending totalling €152.7 million.

The detailed breakdown of the key enabling technologies shows (cf. Figure 18) that funding for electric mobility rose slightly compared to 2016, to €21.4 million. Financial support for research into electricity grids stood at €4.8 million, well above the preceding year's level, whilst funding for energy storage declined slightly to €18.3 million.

Research funding for regenerative energy amounted to a total of €129 million, and was slightly higher than the volume seen in the previous year. The largest amount of funding is going into photovoltaic technology, at €13.2 million, with the highest amounts of funding coming from Lower Saxony (€3.8 million) and Bavaria (€3.4 million). Research into biomass (€13 million) is mainly funded in Bavaria (€7.5 million). Funding for research into wind energy was expanded slightly, to €4.9 million in 2017. The Länder provided €3.5 million in funding for research into geothermal energy, almost all of this coming from Bavaria (€1.6 million) and Baden-Württemberg (€1.1 million).

Research into conventional power plant technology is only taking place in a few of the Länder, with total funding of €2.7 million; significant amounts of technology funding come from North Rhine-Westphalia (€1.2 million) and Bavaria (€1 million).

Figure 17: Spending by the *Länder* on non-nuclear energy research 2008 – 2017 in million euros
(see table 8 for data)

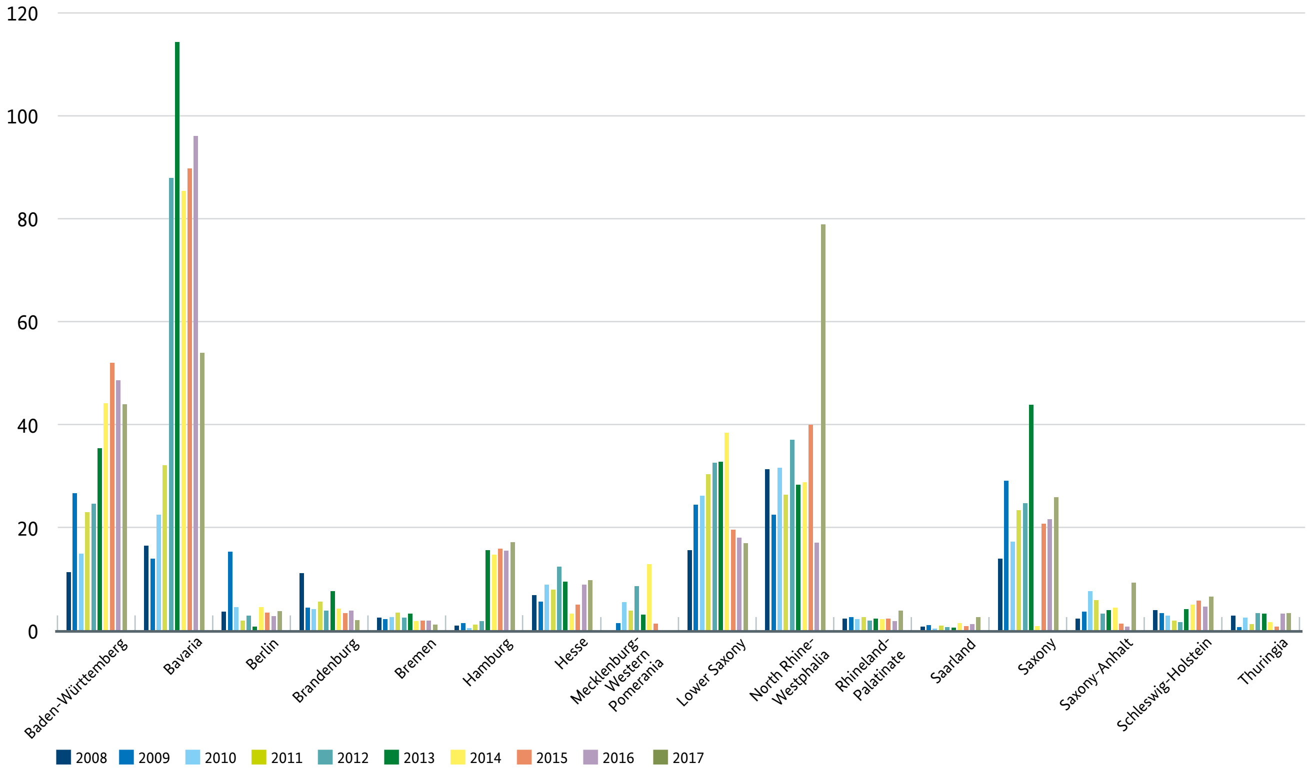
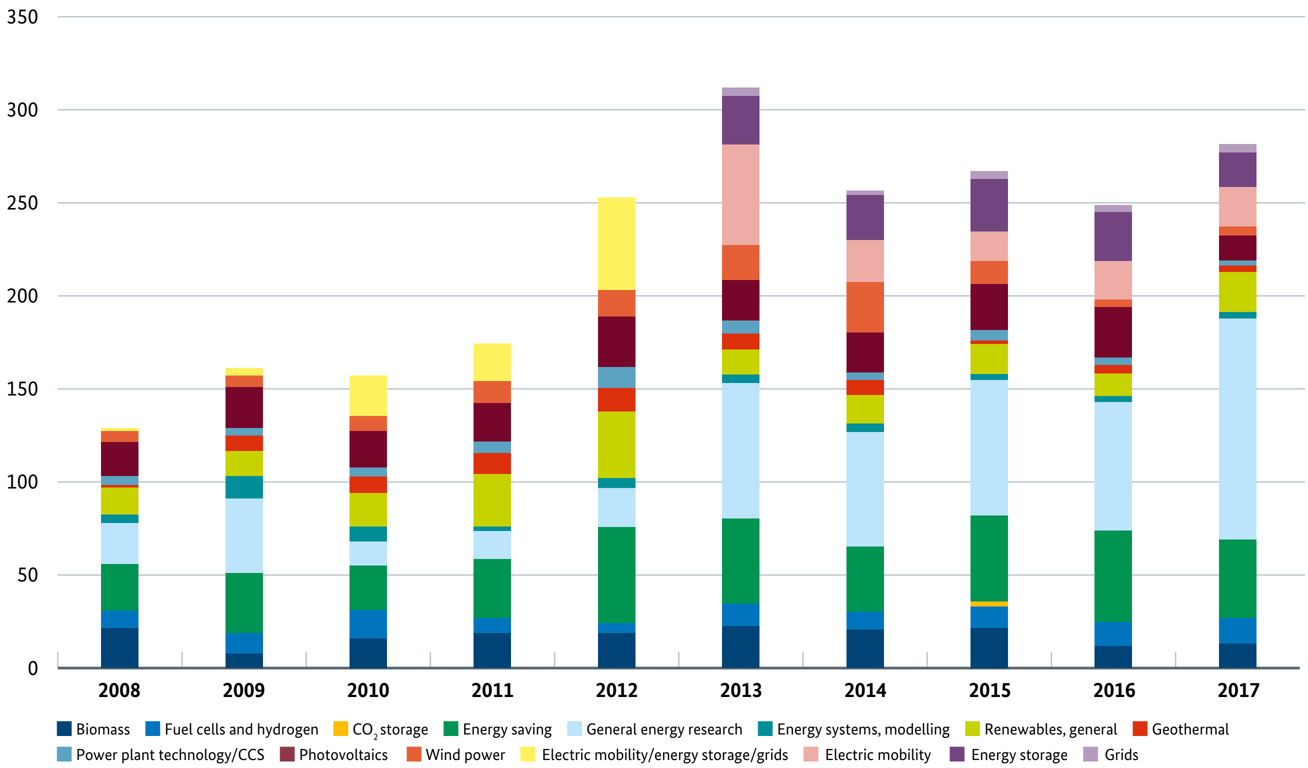


Figure 18: Spending by the Länder on non-nuclear energy research by topic 2008 – 2017 in million euros
(see table 9 for data)



Research into energy systems analysis and modelling is mainly focused on the potential shape of the future energy system based on valid energy scenarios, and Länder funding for this amounts to €3.3 million.

Funding for research into fuel cell and hydrogen technology rose further from the levels of the preceding years, to €13.7 million, and is a major aspect of research funding in Bavaria (€5.3 million) and Baden-Württemberg (€3.8 million).

Total spending on energy research funding in North Rhine-Westphalia is far higher than in the other Länder; the next highest amounts are in Bavaria (€54.1 million), Baden-Württemberg (€44.1 million) and Saxony (€26 million).

With their funding of more than €281 million in total, the Länder are making a major contribution to the national energy transition process in the field of non-nuclear energy research and towards the achievement of the energy policy goals postulated by the Federal Government.

The detailed report into funding of non-nuclear energy research by the Länder in 2017 can be obtained (in German) online with the other published Länder reports at https://www.ptj.de/ueber-uns/unsere-geschaeftsfelder/energie/arbeitsgruppeenergiestrategie/laenderbericht-energieforschung.

4.2 EU Research Framework Programme

4.2.1 Aim and scope of EU research funding

Research and development and the ensuing innovations generate constant economic, technological and social development and thus safeguard progress in society. In Europe, the Horizon 2020 research framework programme for research and innovation lays the foundation stone for realising the European research space and improving European competitiveness. An important element of the programme is the Clean Secure and Efficient Energy Societal Challenge.

With a view to establishing a climate-friendly, modern and harmonised European energy system, Europe also needs a sustainable, competitive, affordable and secure energy supply. In addition to improving energy efficiency, making increased use of renewable energy sources, and integrating energy systems intelligently at regional and international level, the focus of the calls for bids is also on the needs of the citizens and optimised energy systems in conurbations. In addition, the optimisation of energy characteristics in the building sector and research into battery technologies are of special importance.

Figure 19: Horizon 2020 grant recipients and funding broken down by country in the field of Challenge Energy in 2017

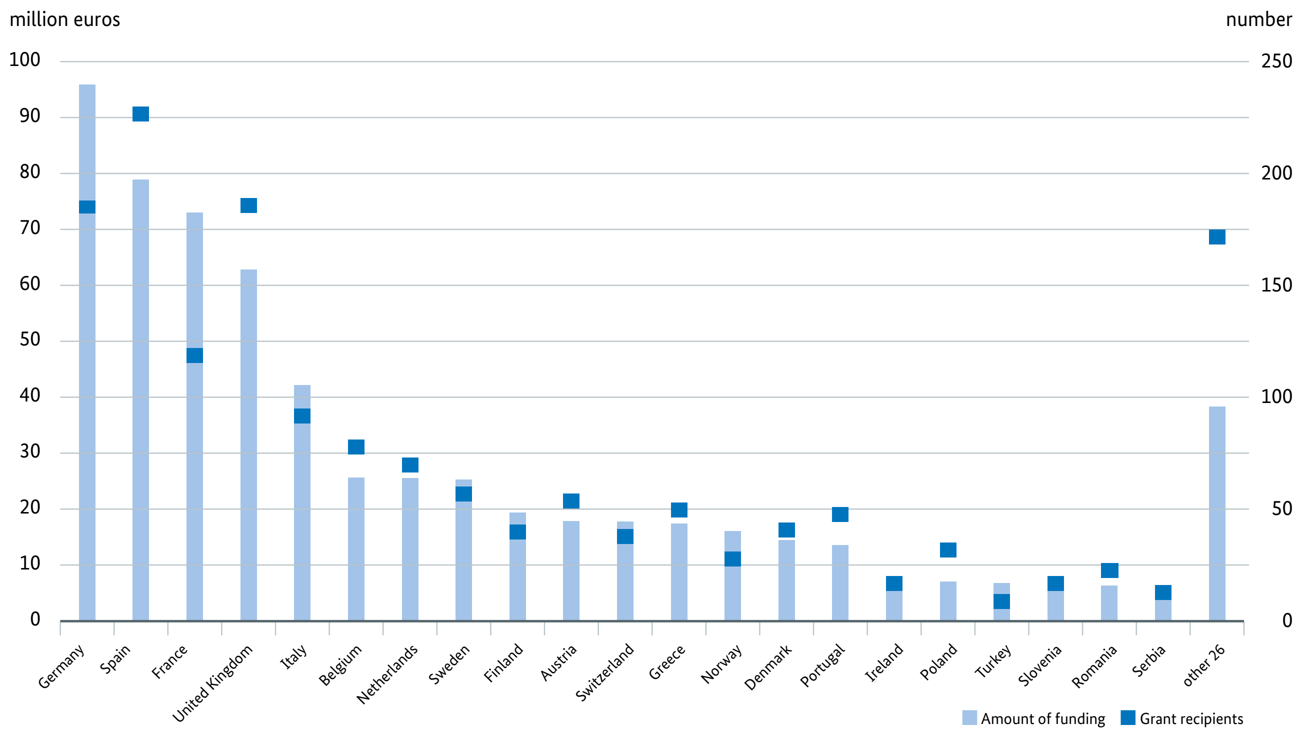
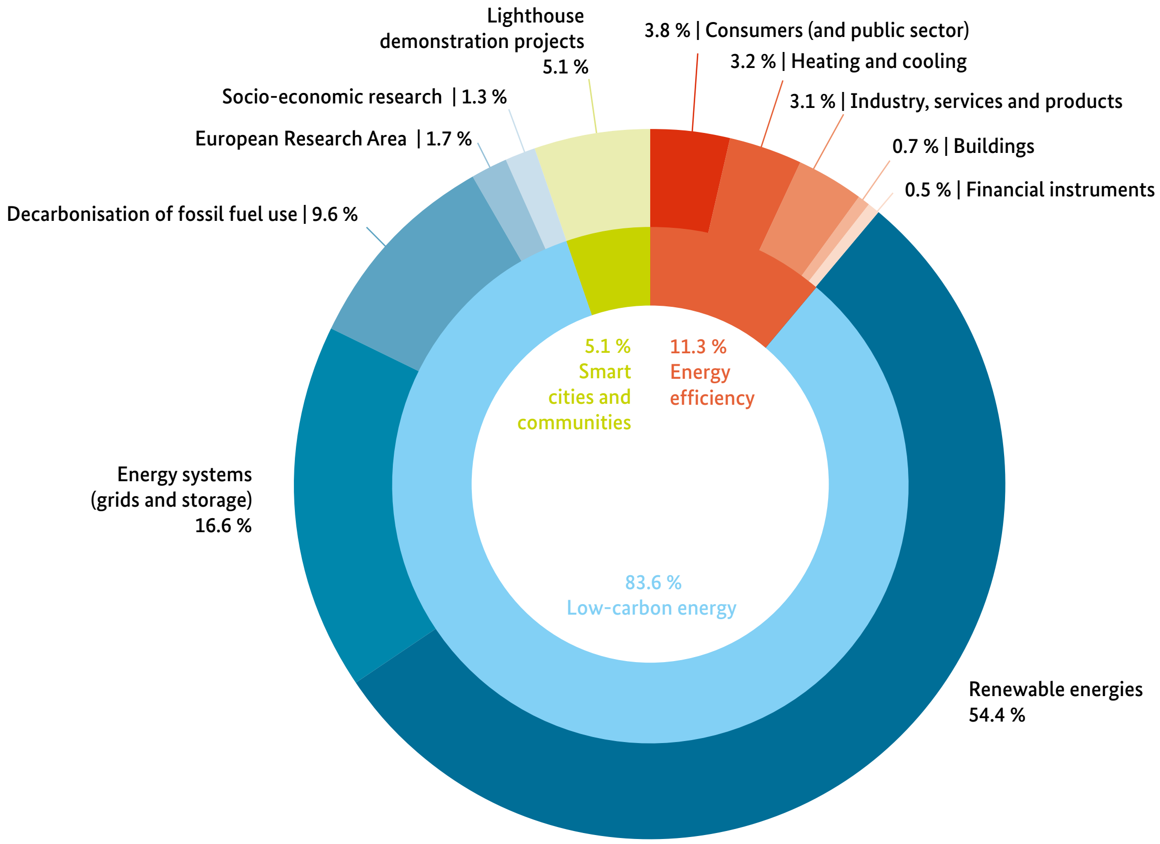


Figure 20: Budget allocation to German project partners in the Challenge Energy under Horizon 2020 (in 2017)



4.2.2 German applicants successful in the field of energy

In 2017, nearly €623 million was approved for a total of 125 collaborative projects in the main fields of energy promotion alone – 'Energy efficiency', 'Low-carbon energy' and 'Smart cities and communities'. Germany is represented here in 77 projects with a total of 188 project participants which won funding totalling around €96 million. That equates to roughly 15.4% of the funding approved (cf. Figure 19). The project coordinator is based in Germany in the case of 17 of the 125 approved projects. Around 40% of the German beneficiaries are based in research institutes and higher education institutions. 47% are based in private-sector companies, and the remaining 13% come from public and other institutions. The proportion of applicants from Germany is particularly high (69%) in the case of projects funded in the field of 'Low-carbon energy'. The other beneficiaries can be found in the fields of 'Energy efficiency' (25%) and 'Smart cities and communities' (6%).

4.2.3 Priorities of energy research

Figure 20 shows the distribution of funding to recipients from Germany in 2017 broken down by research field. The figures reflect a clear focus (83.6%) on issues relating to low-carbon energy, and particularly on research and demonstration projects in the field of renewable energy – approximately 54.4% of funding is destined for this field. The topics of hydrogen and fuel cells are not listed in the figure, since they are funded under the Fuel Cells and Hydrogen Joint Undertaking – a public-private partnership. Further to this, there are other energy-related issues funded in other parts of Horizon 2020. These include materials research and production technologies.

4.3 Federal Government activities outside the Energy Research Programme

4.3.1 EnEff.Gebäude.2050

The Federal Government aims to make the building stock in Germany virtually climate-neutral by 2050. The EnEff. Gebäude.2050 funding initiative – innovative projects for a virtually climate-neutral building stock in 2050 – is intended to link research more closely with widespread use, and to support the market launch of existing technologies and processes. The focus of the research is on demonstration projects to boost efficiency and to integrate renewable energy into buildings. The initiative was originally part of the 6th Energy Research Programme and has now also been integrated into the 7th Energy Research Programme.

In 2017 and 2018, the Federal Ministry for Economic Affairs and Energy provided approx. €21 million in funding to 59 projects under this practice-oriented funding initiative. A similar amount of funding is available for the next few years.

In a competition run as part of the EnEff.Gebäude.2050 funding initiative, the Federal Ministry for Economic Affairs and Energy called for innovative ideas for a buildings energy competition in Germany. The Solar Decathlon goes Urban concept, submitted by Wuppertal University, the city of Wuppertal, Wuppertal Institute for Climate, Environment, Energy, the municipal utility, Neue Effizienz and Initiative Utopiastadt, was designated the winner. This formed the basis for the German bid to hold the Solar Decathlon Europe in 2021, which the Energy Endeavour Foundation awarded to Wuppertal in January 2019.

4.3.2 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 internationally competitive sector in Germany. The Federal Ministry of Transport and Digital Infrastructure provided €500 million for the first phase of the programme from 2007-2016. In the programme's second phase (NIP 2), the hydrogen and fuel cell technology is to be made competitive in the transport sector and the energy market, and research is to be undertaken into future generations of technology.

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

As part of the Smart Energy Showcases - Digital Agenda for the Energy Transition (SINTEG) funding programme, experts develop and demonstrate model solutions for the smart energy supply of the future. In five model regions, more than 300 partners from the energy sector, industry, research, municipalities, rural districts and Länder throughout Germany are drafting a blueprint for a secure, economic and environmentally acceptable energy supply involving high proportions of intermittent power generation from renewable sources. The experts are developing innovative digital technologies and new business models to make the power grids and markets flexible and smart. Also, the practical experience gained in the showcases is to help with the development the legal framework. This means that SINTEG is a living lab for the smart energy system for the future.

The model regions were selected in a competition. The Federal Ministry for Economic Affairs and Energy has been funding SINTEG since early 2017 for a period of four years and is providing more than €200 million. Together with the investment from the other project partners, more than half a billion euros is being invested in the digitalisation of the energy sector.

4.3.4 Research Campus

The Federal Ministry of Education and Research's funding initiative Research Campus – Public-private Partnership for Innovation promotes 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. In the energy sector, the Federal Ministry of Education and Research is funding two research campuses: Flexible Electrical Grids (FEN) in Aachen and Mobility2Grid (M2G) in Berlin. FEN is building a medium voltage DC research network on the campus of RWTH Aachen University, an unprecedented project of its type. M2G is using a living lab on the EUREF Campus in Berlin-Schöneberg to study the innovative interplay of electric mobility and smart energy grids.

5. Tables

5.1 Funding in the 6th Energy Research Programme of the Federal Government

The following tables show federal funding, citing the outflows for the respective budget years. Table 1 provides an overview of the fields covered. Tables 2 to 6 show the funding going to the various fields. The data were collected in January 2019 and still follow the 6th Energy Research Programme structure, since research funding was based on this in the 2018 reference year, and this therefore ensures that the figures make sense. The research statistics are currently being revised and are to be oriented to the structure of the 7th Energy Research Programme in all funding areas next year.

In addition to this, the number of ongoing projects (including those not yet completed) and the newly approved projects are presented for 2018, as well as the stipulated amounts of funding distributed across the years in the typical case of multi-annual projects.

The funding disbursed as institutional funding is presented in Table 7. The funding disbursed by the Länder is broken down by Land in Table 8 and by topic in Table 9.

Table 1 | Overview of topics in the Federal Government's Energy Research Programme[1]

Funding topic	Actual outlays in million euros 2018
Project Funding	**615.77**
Energy transition in the consumption sectors	176.24
Energy generation	212.36
System integration: grids, storage, sector coupling	110.90
Cross-system research topics of the energy transition	68.78
Nuclear safety research	47.48
Institutional funding (Helmholtz Association)	**393.75**
Accompanying measures (e.g. project managers, international aspects, research networks, research communication)	**48.18**
Total	**1,057.69**

1 In contrast to previous editions of the Federal Report on Energy Research, the categories in this overview are based on the structure of the 7th Energy Research Programme, since this corresponds better to the diversity of fields already being funded under the 6th Energy Research Programme. In view of the ongoing revision of the research statistics, the figures in Table 1 are provisional.

Table 2 | Disbursements of project funding in the area of energy conversion

Funding topic	Actual outlays (in million euros)							Number of projects		New funding (in million euros)
	2012	2013	2014	2015	2016	2017	2018	ongoing in 2018	new in 2018	appropriated in 2018
Photovoltaics (incl. other programmes)	**67.08** (85.69)	**63.59** (81.16)	**58.34** (64.92)	**71.26** (73.60)	**63.99** (65.66)	**84.46** (84.56)	**78.25** (78.25)	**460**	**96**	**83.21**
Crystalline silicon	30.40	30.51	26.72	36.74	36.99	52.92	50.39	246	52	45.29
Thin-film technologies	15.33	12.69	11.31	10.45	8.78	10.69	12.36	103	24	10.61
Basic research (incl. other programmes)	15.62 (34.23)	14.87 (32.44)	15.00 (21.59)	11.59 (13.93)	6.17 (7.84)	3.51 (3.61)	1.33 (1.33)	13	–	–
Other	5.73	5.53	5.31	12.47	12.05	17.33	14.17	98	20	27.31
Wind Power	**38.42**	**52.57**	**53.06**	**53.04**	**49.69**	**75.11**	**59.73**	**420**	**121**	**90.59**
Wind farm development	2.62	15.07	21.93	25.26	18.40	39.80	26.03	165	50	56.05
Onshore	0.62	0.51	0.50	1.29	4.10	3.23	3.10	12	–	–
Offshore	3.34	12.23	12.72	7.98	9.18	11.09	12.00	78	18	13.48
Wind physics and meteorology	0.12	1.73	2.33	3.62	3.03	3.06	2.33	31	11	4.15
Logistics, turbine installation, maintenance and operation	23.00	12.88	8.39	6.39	8.10	11.18	8.37	81	22	10.07
Environmental aspects of wind power and ecological accompanying research	1.43	2.33	2.64	2.46	2.23	2.48	2.42	26	16	5.51
Other	7.29	7.82	4.54	6.04	4.65	4.27	5.49	27	4	1.34
Bioenergy (incl. other programmes)	**40.86** (48.59)	**42.61** (48.68)	**42.97** (44.11)	**42.10** (43.92)	**37.88** (37.88)	**33.04** (33.04)	**28.54** (28.54)	**528**	**128**	**33.58**
Production – farming	6.91	6.31	5.98	4.43	4.69	5.70	6.52	107	41	13.78
Production – cultivation	4.43	5.25	4.77	4.92	4.49	4.58	4.20	63	9	2.20
Conversion – general	–	–	–	0.53	5.22	2.73	4.46	67	21	5.10
Conversion – gaseous	4.61	4.87	5.27	6.84	4.92	6.79	5.04	93	4	1.60
Conversion – liquid	4.11	6.12	6.19	5.92	3.97	3.21	1.98	33	3	0.78
Conversion – solid	2.78	0.94	0.73	1.92	2.23	1.77	1.34	25	3	1.01
Horizontal	1.86	3.22	2.85	2.97	2.53	0.94	0.59	9	–	–
Basic research (incl. other programmes)	8.81 (16.53)	9.99 (16.06)	12.16 (13.30)	9.89 (11.72)	6.17 (6.17)	3.13 (3.13)	0.22 (0.22)	3	–	–
Use of biomass for energy	7.36	5.91	5.03	4.69	3.66	4.18	4.20	128	47	9.10
Deep geothermal energy	**20.82**	**17.10**	**15.55**	**13.38**	**12.54**	**16.49**	**12.92**	**81**	**21**	**10.48**
Surveying and exploration	8.39	7.28	9.13	9.12	6.67	8.06	4.52	25	–	–
Hot water and steam deposits	4.36	4.97	3.03	2.59	4.61	5.34	3.64	22	4	3.49
Hot dry rock	3.69	0.91	0.33	0.45	1.02	3.04	4.76	34	17	6.99
Other	4.37	3.94	3.05	1.22	0.23	0.05	–	–	–	–

Funding topic	Actual outlays (in million euros)							Number of projects		New funding (in million euros)
	2012	2013	2014	2015	2016	2017	2018	ongoing in 2018	new in 2018	appropriated in 2018
Power plant technology and CCS technologies	**27.54**	**31.62**	**29.60**	**28.20**	**28.52**	**32.82**	**29.57**	**297**	**66**	**23.61**
(incl. other programmes)	(28.58)	(35.09)	(30.96)	(28.20)	(28.52)	(32.90)	(29.85)			
Advanced power plant systems	10.76	7.45	6.36	2.41	4.84	5.54	6.39	46	1	0.29
Component development	9.18	16.52	18.19	19.19	17.53	21.59	17.79	228	60	20.78
Coal gasification	2.39	1.54	1.46	2.80	3.52	4.14	4.12	8	–	–
Basic research	4.54	3.79	2.86	1.97	1.36	–	–	–	–	–
(incl. other programmes)	(5.58)	(7.27)	(4.22)	(1.97)	(1.36)	(0.08)	(0.29)			
Other	0.68	2.32	0.74	1.82	1.27	1.55	1.26	15	5	2.53
Fuel cells and hydrogen	**19.47**	**24.88**	**27.16**	**22.32**	**19.69**	**26.50**	**24.41**	**151**	**25**	**15.96**
LT-PEMFC	6.15	6.68	9.92	6.43	4.42	6.24	6.51	53	18	10.07
HT-PEMFC	1.30	1.75	1.21	1.01	0.77	0.99	0.98	9	–	–
MCFC	0.55	0.14	0.30	1.64	0.82	1.72	0.35	–	–	–
SOFC	7.40	11.10	7.84	6.53	4.27	6.73	5.60	30	5	5.50
DMFC	0.56	0.34	0.06	–	–	0.14	0.25	4	–	–
Hydrogen storage	1.98	3.16	2.25	2.36	0.99	1.12	2.27	14	–	–
Hydrogen production	0.83	0.63	0.30	0.59	2.14	2.86	2.17	14	–	–
Basic research	0.71	1.08	3.04	2.10	4.28	4.58	4.30	20	–	–
Other	–	–	2.23	1.67	2.01	2.12	1.98	7	2	0.40
Solar thermal power plants	**7.45**	**8.41**	**9.25**	**10.09**	**8.58**	**7.73**	**7.15**	**81**	**29**	**13.21**
Parabol	3.67	2.25	1.84	0.74	2.04	2.90	3.35	26	–	–
Tower	2.01	2.50	3.59	4.23	2.86	2.63	2.62	46	25	12.04
Fresnel	0.68	0.63	0.82	–	–	0.00	–	–	–	–
Storage	0.30	1.79	1.41	1.85	1.37	1.52	1.02	1	–	–
Other	0.78	1.24	1.59	3.28	2.32	0.68	0.15	8	4	1.16
Hydroelectric and marine power	**0.98**	**1.25**	**1.21**	**1.68**	**2.01**	**2.15**	**1.40**	**16**	**–**	**–**
Total	**222.62**	**242.02**	**237.14**	**242.06**	**222.90**	**278.30**	**241.97**	**2,034**	**486**	**270.63**
(incl. other programmes)	(249.99)	(269.15)	(246.23)	(246.22)	(224.57)	(278.47)	(242.26)			

Table 3 | Disbursements of project funding in the area of energy use

Funding topic	Actual outlays (in million euros)							Number of projects		New funding (in million euros)
	2012	2013	2014	2015	2016	2017	2018	ongoing in 2018	new in 2018	appropriated in 2018
Energy efficiency in buildings and cities	**45.81**	**56.76**	**60.55**	**54.86**	**53.60**	**61.76**	**75.01**	**800**	**257**	**131.94**
(incl. other programmes)	(47.74)	(58.94)	(63.53)	(54.86)	(53.80)	(62.46)	(76.13)			
EnOB – Energy-optimised building	19.65	25.50	30.95	30.86	26.33	28.44	32.95	396	134	54.41
EnEff:Stadt – Supply concepts	7.85	9.69	9.28	9.06	11.62	16.10	21.04	218	76	48.45
EnEff:Stadt – District heating	2.50	3.53	3.75	2.87	3.16	3.35	3.29	40	7	1.61
EnEff:Stadt – Combined heat and power	2.93	4.61	2.65	1.39	0.89	1.39	1.27	14	4	2.89
Low-temperature solar thermal energy	4.90	6.47	6.36	5.54	6.43	7.71	7.30	67	13	5.57
Solar cooling	1.73	1.21	1.02	0.48	0.13	–	–	–	–	–
Basic research	3.63	4.49	5.36	4.65	3.88	2.92	7.77	59	23	19.01
(incl. other programmes)	(3.63)	(4.49)	(5.36)	(4.65)	(4.00)	(2.96)	(7.77)			
Research Initiative: The Building of the Future (Environment Ministry) (other programme)	(1.93)	(2.18)	(2.98)	(–)	(0.08)	(0.66)	(1.12)			
Other	2.62	1.25	1.19	–	1.17	1.85	1.39	6	–	–
Energy efficiency in industry, commerce, trade and services	**30.01**	**36.38**	**34.70**	**34.85**	**33.70**	**44.59**	**47.92**	**504**	**123**	**62.71**
Mechanical, automotive, electrical and precision engineering, optics, metal goods	10.90	14.97	16.07	14.30	9.57	13.54	16.63	154	55	30.61
Iron and steel industry	2.42	1.54	0.69	0.67	0.55	0.69	1.19	24	6	3.11
Mining and processing of stone and earth, fine ceramics, glass	2.05	2.41	1.45	0.54	1.20	2.76	2.55	15	–	–
Heat pumps, refrigerants	1.28	2.99	2.58	3.02	3.83	4.45	4.30	31	7	4.41
Industrial furnaces	1.19	0.83	0.67	0.99	1.41	3.36	4.00	43	2	1.25
Mechanical and thermal separation methods	0.39	1.57	1.79	2.23	2.05	2.82	2.77	35	–	–
Chemical industry, manufacturing of plastic and rubber goods	1.52	2.79	4.05	4.81	5.46	6.25	6.12	58	6	2.12
Non-ferrous metal industry	0.44	0.56	0.72	0.79	1.09	1.40	1.05	24	14	4.36
Heat exchangers	2.11	1.82	1.13	1.61	1.46	1.26	1.01	6	–	–
Solar process heat	0.35	0.25	0.10	0.10	0.09	0.08	0.01	2	1	0.13
Basic research	–	–	1.76	0.79	0.32	0.00	–	–	–	–
Other	7.35	6.64	3.68	5.01	6.68	7.98	8.29	112	32	16.71
Total	**75.81**	**93.14**	**95.25**	**89.70**	**87.30**	**106.35**	**122.93**	**1,304**	**380**	**194.66**
(incl. other programmes)	(77.74)	(95.32)	(98.23)	(89.70)	(87.51)	(107.04)	(124.05)			

Table 4 | Disbursements in energy distribution and system-oriented project funding incl. horizontal issues

Funding topic	Actual outlays (in million euros)							Number of projects		New funding in million euros
	2012	2013	2014	2015	2016	2017	2018	ongoing in 2018	new in 2018	appropriated in 2018
Horizontal issues and system analysis	**8.60**	**11.70**	**10.82**	**11.46**	**13.67**	**16.79**	**18.43**	**179**	**79**	**28.05**
System analysis	1.57	2.38	3.03	3.75	7.42	13.54	15.97	171	79	28.05
Information dissemination	2.49	3.27	3.33	4.09	3.74	2.10	1.60	1	–	–
Horizontal issues	4.10	5.38	4.13	3.35	2.42	1.15	0.86	7	–	–
Other	0.44	0.66	0.33	0.27	0.09	–	–	–	–	–
Energy storage	**31.02**	**59.30**	**56.99**	**61.59**	**53.34**	**49.70**	**46.34**	**453**	**165**	**83.46**
(incl. other programmes)	(38.90)	(61.46)	(57.26)	(61.76)	(53.34)	(49.70)	(46.34)			
Electrochemical storage	14.48	23.87	19.86	18.41	21.24	23.71	25.45	197	52	23.16
High temperature storage	0.47	0.47	1.52	3.51	2.16	0.92	0.62	22	12	3.54
Mechanical storage	1.19	3.26	1.53	1.97	2.48	3.01	2.16	23	6	1.88
Electrical storage	0.74	0.28	0.05	2.48	4.54	4.11	2.67	33	–	–
Low temperature storage	1.53	3.37	5.13	5.14	3.19	1.86	2.49	22	5	3.46
Material storage	–	–	–	–	0.34	1.15	2.02	66	60	39.44
Basic research	10.20	19.37	17.21	15.61	10.79	3.60	1.17	23	21	7.87
(incl. other programmes)	(18.08)	(21.53)	(17.48)	(15.77)	(10.79)	(3.60)	(1.17)			
Other	2.41	8.67	11.70	14.48	8.61	11.34	9.77	67	9	4.11
Power grids	**16.74**	**30.95**	**34.88**	**52.85**	**70.93**	**75.23**	**60.76**	**627**	**147**	**73.77**
Components	1.93	10.15	12.12	13.60	17.87	22.44	21.10	159	–	–
Grid planning	0.78	2.51	3.24	4.00	4.26	4.62	2.50	45	21	6.58
System management	9.74	12.62	10.40	18.72	27.98	27.38	24.57	225	5	2.41
System studies	0.06	1.68	3.60	2.94	1.90	0.99	–	–	–	–
Basic research	3.06	0.49	1.26	9.46	14.02	13.77	7.50	77	12	6.52
Other	1.17	3.50	4.26	4.12	4.90	6.03	5.09	121	109	58.26
Industrial Community Research	–	–	–	–	**0.05**	**2.52**	**4.22**	**31**	**11**	**5.12**
Total	**56.35**	**101.95**	**102.69**	**125.90**	**137.99**	**144.23**	**129.75**	**1,290**	**402**	**190.40**
(incl. other programmes)	(64.23)	(104.10)	(102.96)	(126.06)	(137.99)	(144.23)	(129.75)			

Table 5 | Disbursements of other Federal Ministry of Education and Research project funding

Funding topic	Actual outlays (in million euros)							Number of projects		New funding in million euros
	2012	2013	2014	2015	2016	2017	2018	ongoing in 2018	new in 2018	appropriated in 2018
Socio-ecological research	–	**1.18**	**3.25**	**3.95**	**2.64**	**0.36**	–	–	–	–
(incl. other programmes)	–	(3.08)	(8.58)	(11.11)	(4.42)	(2.07)	(0.85)			
Energy materials	–	–	**0.72**	**10.41**	**27.87**	**26.68**	**18.21**	**132**	**1**	**0.20**
Kopernikus projects	–	–	–	–	**0.40**	**40.16**	**44.83**	**172**	**2**	**2.75**
Carbon2Chem	–	–	–	–	**8.64**	**11.84**	**16.90**	**29**	–	–
Decarbonisation	–	–	–	–	–	–	**0.23**	**4**	**4**	**4.02**
Project-related fusion research	**2.58**	**6.29**	**5.55**	**7.70**	**3.12**	**2.23**	–	–	–	–
Other project funding of the Federal Ministry of Education and Research	**7.11**	**2.35**	**3.93**	**3.23**	**4.19**	**5.27**	**10.35**	**36**	**25**	**17.58**
(incl. other programmes)	(7.11)	(3.23)	(3.93)	(3.23)	(4.19)	(5.27)	(10.35)			
Total	**9.69**	**9.82**	**13.45**	**25.29**	**46.86**	**86.53**	**90.29**	**369**	**28**	**20.53**
(incl. other programmes)	(9.69)	(12.61)	(18.79)	(32.46)	(48.63)	(88.24)	(91.37)			

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

Funding topic	Actual outlays (in million euros)							Number of projects		New funding in million euros
	2012	2013	2014	2015	2016	2017	2018	ongoing in 2018	new in 2018	appropriated in 2018
Nuclear waste final storage and disposal research	**12.30**	**13.23**	**13.58**	**12.95**	**13.09**	**16.33**	**17.61**	**121**	**24**	**14.38**
Final storage research	9.84	10.39	10.25	10.06	9.94	11.43	12.02	87	17	9.36
Horizontal tasks and other	0.54	0.53	0.53	0.54	1.06	1.90	2.69	18	2	1.33
Nuclear material monitoring	0.18	0.15	0.19	0.24	0.26	0.21	0.09	1	–	–
Funding for young researchers (Federal Ministry of Education and Research)	1.74	2.17	2.61	2.11	1.83	2.78	2.81	15	5	3.69
Reactor safety research	**24.38**	**23.43**	**25.10**	**25.22**	**24.06**	**22.76**	**21.98**	**149**	**26**	**16.93**
Safety of nuclear facility components	5.28	4.01	4.38	4.55	4.38	4.20	5.19	48	10	6.02
Plant behaviour and accident sequences	11.25	12.09	12.51	13.22	13.37	13.46	12.52	72	14	10.17
Horizontal tasks and other	5.08	5.72	4.81	4.05	3.63	3.37	3.04	16	2	0.74
Funding for young researchers (Federal Ministry of Education and Research)	2.77	1.62	3.39	3.39	2.68	1.73	1.23	13	–	–
Radiation research (Federal Ministry of Education and Research)	**4.91**	**4.95**	**4.61**	**7.58**	**8.58**	**8.05**	**7.89**	**57**	–	–
Total	**41.59**	**41.61**	**43.29**	**45.74**	**45.73**	**47.13**	**47.48**	**327**	**50**	**31.31**

Table 7 | Disbursements in institutional energy research (Energy research by the Helmholtz Association)[2]

Funding topic	Actual outlays in million euros						
	2012	2013	2014	2015	2016	2017	2018
Programme-oriented funding II							
Renewable energies	34.42	36.95					
Rational energy conversion and use	40.73	46.09					
Nuclear fusion (incl. Wendelstein W 7-X)	105.04	101.57					
Nuclear safety research	21.76	22.13					
Technology, innovation and society	6.87	6.95					
Programme-independent research	47.96	49.04					
Programme-oriented funding III							
Energy efficiency, materials and resources			60.49	64.12	68.43	69.45	73.00
Renewable energies			47.84	51.91	54.37	56.73	59.09
Nuclear fusion (incl. Wendelstein W 7-X)			123.51	123.51	123.51	123.51	123.51
Nuclear waste management, safety and security, and radiation research			34.62	35.76	37.27	38.84	40.47
Technology, innovation and society			7.11	7.65	7.95	8.25	8.54
Storage and connected infrastructure			49.93	57.12	60.47	69.61	72.86
Future Information Technology			8.11	8.62	10.81	13.24	16.28
Total	**256.78**	**262.73**	**331.60**	**348.69**	**362.81**	**379.63**	**393.75**

2 With respect to previous editions of the Federal Government Report on Energy Research, the reporting of institutional funding is adjusted to match the framework of programme oriented funding within the Helmholtz Association.

5.2 Funding for energy research by the Länder

The figures are based on reports by the Länder from a regular survey conducted on behalf of the Federal Ministry for Economic Affairs and Energy. In the case of funding from the European Regional Development Fund, only the funding from the Länder is included.

In 2017, Mecklenburg-Western Pomerania spent ERDF grants but none of its own money on non-nuclear energy research.

No figures for 2018 are available yet.

Table 8 | Spending by the *Länder* on non-nuclear energy research

Land	**Actual outlays in million euros**									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Baden-Württemberg	11.54	26.83	15.10	23.12	24.77	35.55	44.37	52.22	48.77	44.10
Bavaria	16.67	14.14	22.64	32.28	88.13	114.82	85.61	89.98	96.34	54.15
Berlin	3.87	15.53	4.73	2.10	3.03	0.88	4.70	3.63	2.94	3.89
Brandenburg	11.34	4.65	4.37	5.81	4.03	7.86	4.40	3.54	4.05	2.20
Bremen	2.71	2.42	2.78	3.61	2.71	3.46	1.99	2.08	2.10	1.35
Hamburg	1.15	1.56	0.61	1.27	2.01	15.76	14.91	16.12	15.64	17.29
Hesse	7.02	5.77	9.10	8.12	12.57	9.63	3.48	5.17	9.11	9.95
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
North Rhine-Westphalia	31.52	22.68	31.80	26.55	37.27	28.52	28.99	40.14	17.24	79.08
Rhineland-Palatinate	2.43	2.76	2.40	2.79	2.10	2.43	2.37	2.51	1.95	4.00
Saarland	0.95	1.17	0.51	1.12	0.87	0.75	1.56	0.98	1.42	2.77
Saxony	14.18	29.26	17.42	23.60	24.88	44.06	1.01	20.89	21.78	26.04
Saxony-Anhalt	2.51	3.83	7.81	6.04	3.43	4.11	4.62	1.53	0.89	9.45
Schleswig-Holstein	4.12	3.54	3.10	2.08	1.83	4.28	5.15	5.97	4.76	6.76
Thuringia	3.10	0.78	2.68	1.36	3.55	3.40	1.81	0.95	3.42	3.50
Total	**128.87**	**161.14**	**157.11**	**174.39**	**252.78**	**311.74**	**256.56**	**266.99**	**248.63**	**281.68**

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

Topic	Actual outlays in million euros									
	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 and hydrogen	9.47	10.86	15.14	8.11	5.40	12.29	9.82	11.46	12.83	13.73
$C0_2$-storage	-	0.11	0.24	0.07	0.21	-	0.02	2.77	0.02	0.20
Energy saving	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, general	14.45	13.38	18.09	28.28	35.83	13.50	15.34	15.96	11.94	21.61
Geothermal	1.27	8.41	8.86	11.27	12.52	8.43	8.09	2.09	4.70	3.53
Power plant 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 power	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**

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