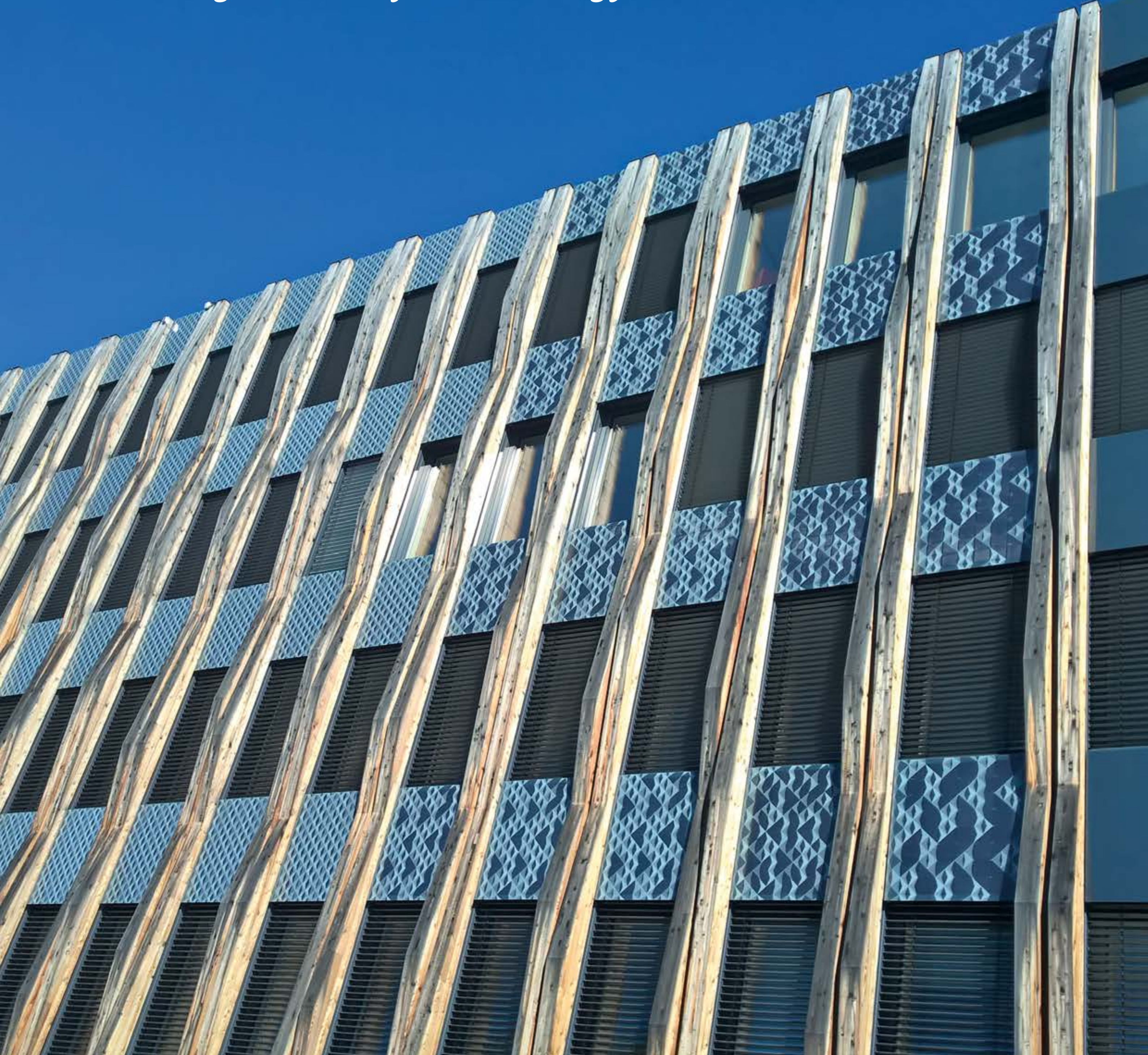
Federal Ministry
for Economic Affairs
and Energy

2018 Federal Government Report on Energy Research

Funding research for the energy transition



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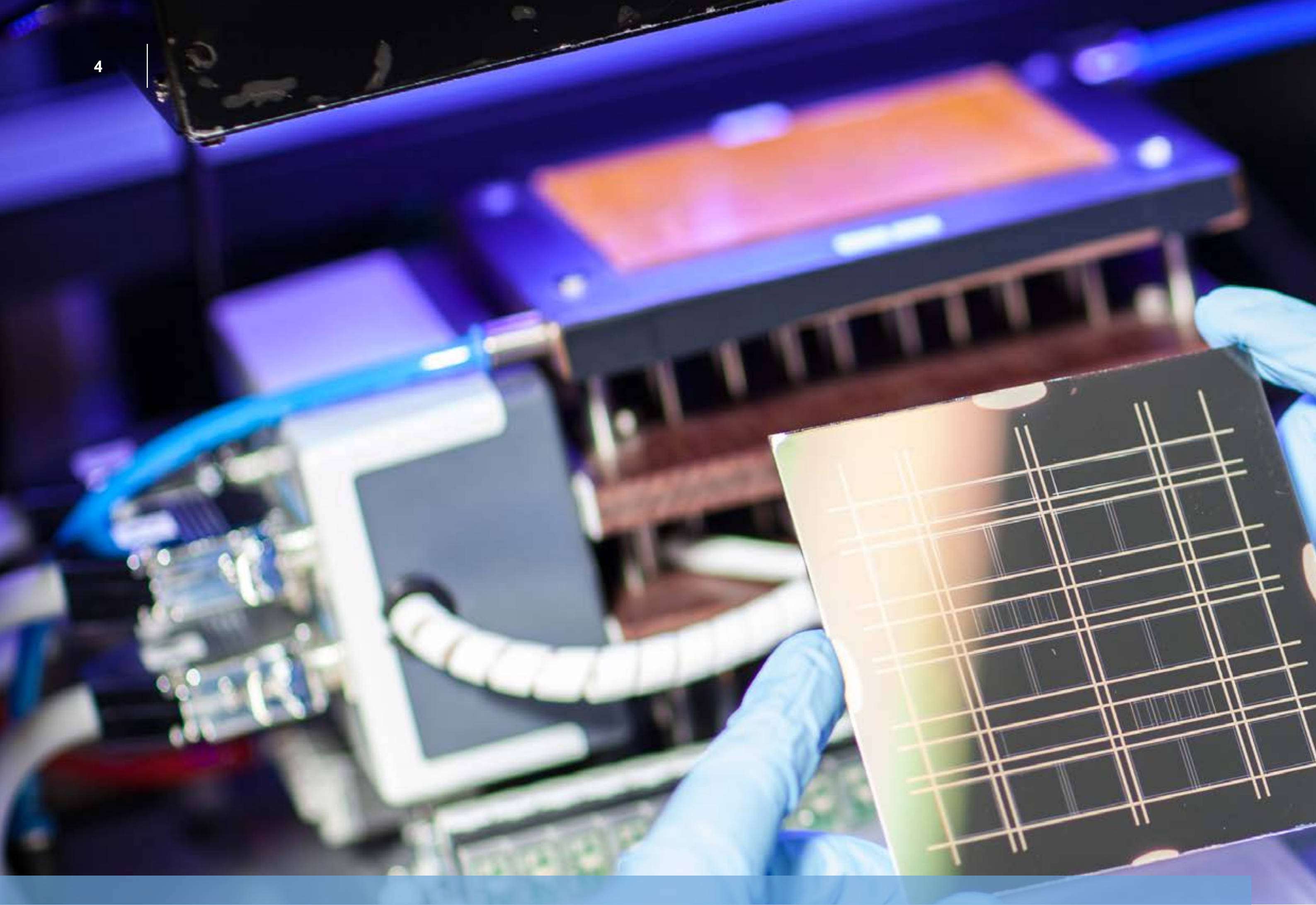


1. Funding research for the energy transition

1.1 The Federal Government's Energy Research Programme

The promotion of energy research is a strategic element in any energy policy that is also designed to safeguard the future. Such funding helps to implement the Federal Government's targets for the energy sector and climate linked to Germany's energy transition. Federal Government funding for energy research is based on the Energy Research Programme. Funding allocated under this programme is used to support both specific projects with a limited timeframe, as well as large research communities over long periods of time. In addition to enabling the development of competitive, innovative and sustainable energy and efficiency technologies for the energy transition, research funding also generates sustainable growth and high-skilled jobs in Germany, as well as creating large export potential. At the same time, Germany also makes an important contribution to meeting global climate targets.

The year 2017 was a special one for the public funding of research and development. Some forty years ago, in 1977, the Federal Government's first Energy Research Programme entered into force. This created a reversal in trend as it was the first time that a programme was established for research into non-nuclear energy technologies. From this point onwards, research policy was not only oriented towards ensuring supply security, as it had been to date, but environmental aspects also became increasingly important. Since 1977, the federal ministries involved have consistently supported, consolidated and expanded the research and development of innovative energy technologies. The Energy Research Programme has been continually adapted to meet new requirements resulting from changes to the policy environment and new developments. The new editions of the Programme have enabled it to remain just as relevant throughout. One of the most impressive feats achieved by the Programme has been its contribution towards breaking the link between GDP growth and energy consumption. Normally, the amount of energy consumed rises in parallel with economic growth. However, between 1990 and 2010, GDP grew by almost 30 per cent in Germany but thanks to a diverse range of efficiency measures, the country's energy use remained unchanged.

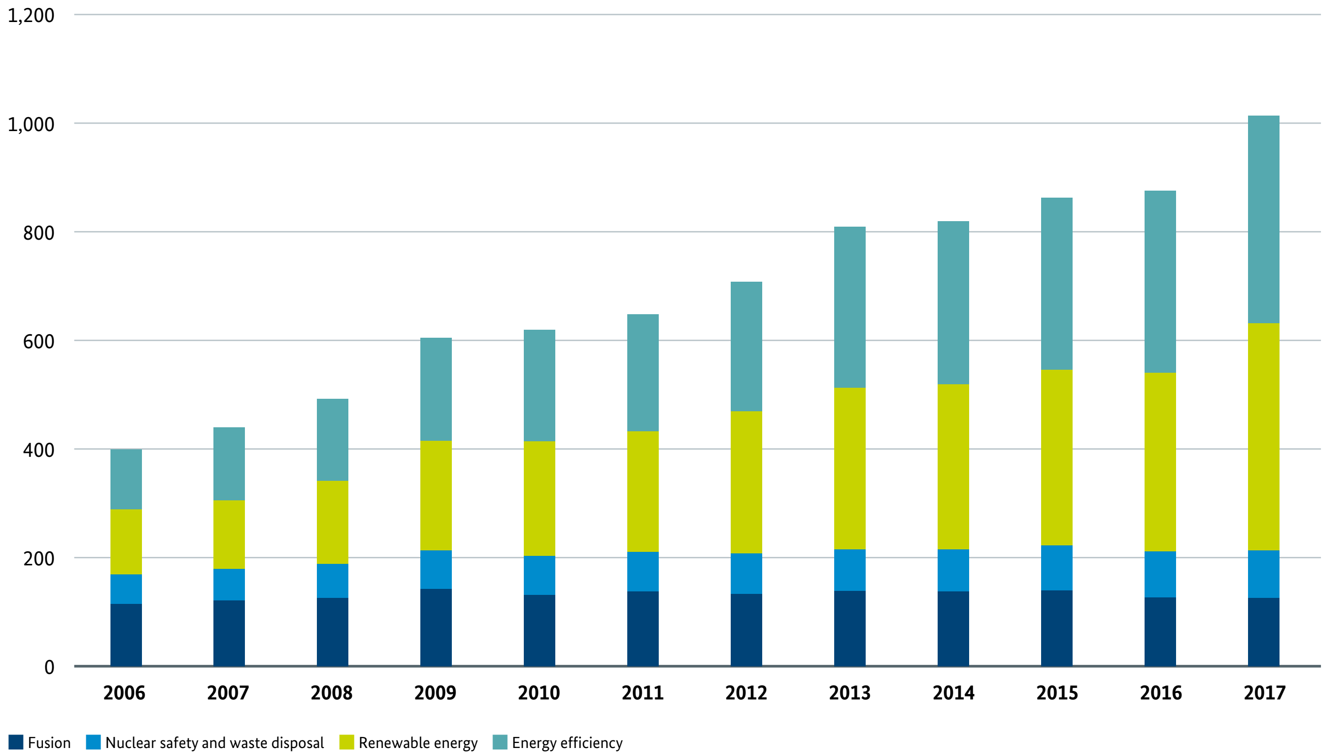
1.1.1 Goals and Successes of the 6th Energy Research Programme

The 6th Energy Research Programme came into force in 2011, with the Federal Government orienting its funding policy towards achieving the goals of the energy transition throughout. The Programme focuses on the research and development of innovative technologies and solutions with a view to making the energy supply of the future more environmentally friendly, more reliable and affordable. In this way, it has also been designed to ensure Germany remains a competitive centre for industry. In addition to improving energy efficiency, the Federal Government seeks to expand the share of renewable energy used in Germany's electricity, heating and cooling supply, as well as that of green energy in transport. The 6th Energy Research Programme is not just based on individually targeted measures, such as raising the operating efficiency of PV modules, but is also built upon overarching, system-oriented approaches to research in areas that are especially relevant to the energy transition. A notable example here is Module II of the inter-ministerial call for proposals 'Solar-powered Buildings/Energy-efficient Cities'. During the 6th Energy Research Programme, the ministries involved spent around 5 billion euros on institutional and project funding between 2012 and 2017 (see Fig. 1, p. 6).

1.1.2 Development of the 7th Energy Research Programme

The Federal Ministry for Economic Affairs and Energy launched the consultation process for the development of the 7th Energy Research Programme in December 2016. This open and transparent participatory process enabled all stakeholders with a specific interest to submit position papers setting out their recommendations on how the programme should continue. Recommendations were also provided by experts from the energy research networks established by the Federal Ministry for Economic Affairs and Energy, and an online survey open to all members of the research networks provided additional input. To mark the 40th anniversary of the Energy Research Programme, the Federal Ministry for Economic Affairs and Energy hosted a symposium at the ministry's conference centre on 2 May 2017. The experts attending took part in workshops to discuss how the programme should be developed. In addition, two research consortia funded by the Federal Ministry for Economic Affairs and Energy examined the status, outlook for, and innovation and market potential of various energy technologies as part of the key strategic project 'Trends and Perspectives in Energy Research', and also published technology reports. The consultation process was concluded at the end of 2017. All of the findings are published online by

Figure 1: Overview of topics in the 6th Energy Research Programme of the Federal Government in million euros (see table 1 for data)



Project Management Jülich on behalf of the Federal Ministry for Economic Affairs and Energy at www.energieforschung.de. The website provides information about the developments and progress taking place towards the establishment of the next programme. The 7th Energy Research Programme is scheduled to be adopted by the Federal Cabinet in 2018.

1.1.3 Tasks of the federal ministries

Within the Federal Government, lead responsibility for the coordination, future direction and continued development of the Energy Research Programme lies with the Federal Ministry for Economic Affairs and Energy. The Federal Ministry of Education and Research and the Federal Ministry of Food and Agriculture are also involved in implementing the programme. Together, these three ministries cover the entire innovation chain – from basic energy technology research right through to applied research, development and demonstration. In this way, the Federal Government supports promising approaches for the development of competitive, affordable, environmentally compatible and reliable solutions for the energy transition.

Whilst the Federal Ministry of Education and Research is responsible for project-based basic research in the fields of energy efficiency, renewable energy, energy infrastructure such as electricity grids and energy storage, socio-ecological research in the field of energy as well as nuclear safety, disposal, radiation research and fusion, the Federal Ministry for Economic Affairs and Energy disburses funding for applied research, development and demonstration. This covers the entire spectrum of energy efficiency and renewable energy, the electricity grids, energy storage and the integration of renewable energy into the energy system, and nuclear safety research. In addition, the Federal Ministry for Economic Affairs and Energy is responsible for awarding institutional support for the German Aerospace Center. Institutional support for the other centres belonging to Helmholtz Association of German Research Centres is disbursed by the Federal Ministry of Education and Research. Project funding for bioenergy is awarded by the Federal Ministry of Food and Agriculture.

1.1.4 Funding amounts

In 2017, the Federal Government spent around 1.01 billion euros on research, development and demonstration of modern energy and efficiency technologies and applications for the energy transition (see Fig. 1). This marks a further rise in the funding volume compared to the previous year (2016: 876 million euros). The largest proportion of the funds (around 80 per cent) was invested in research on renewable energy and energy efficiency. This reflects just how important innovations are for succeeding with the transformation of the energy system. The figures for project funding cited in this report are published on the website of the Federal Ministry for Economic Affairs and Energy's central energy research information system EnArgus (www.enargus.de), where they are set out in a transparent and easy-to-understand manner.

1.1.5 Evaluations and performance review

In order to ensure that funding policy is both need-based and forward-looking, the Federal Government regularly conducts scientific and technical evaluations as well as ongoing performance reviews to examine the efficiency and effectiveness of the funding that has been disbursed. In this way, the ministries involved in the Energy Research Programme support efforts to ensure transparency in energy research. Reviews like this also enable future funding activities to be awarded in line with research needs and help the transfer of innovations to market later on.

In 2017, Project Management Jülich presented its final report on the ongoing performance review of a joint call for proposals being undertaken by the Federal Ministry for Economic Affairs and Energy and the Federal Ministry of Education and Research in the field of energy storage. A total of 186 million euros of funding was available for this purpose. The review shows that all relevant research fields were covered – from basic materials research through to applied research in demonstrations – and that the goals set were essentially achieved. This included removing obstacles to market entry, working to enhance our understanding of the role that storage can play in the energy system, and accelerating progress on the development of storage technologies. At the same time, the funding initiative still needs to be developed and optimised further in order to get energy storage established in practice, for example by strengthening international research cooperation. The conclusions and recommendations set out in the report are also being fed into the consultation process for the 7th Energy Research Programme.

The joint evaluation of the National Innovation Programme on Hydrogen and Fuel Cell Technology conducted by the Federal Ministry for Economic Affairs and Energy and the Federal Ministry of Transport and Digital Infrastructure was also concluded in 2017.

1.2 Structures of energy research policy

In its promotion of energy research, the Federal Government relies on a transparent dialogue with all stakeholders in this field. Throughout its promotion of energy research, the Federal Government seeks to ensure it holds transparent dialogue with the actors involved this area. This ensures that research and development have a very strong focus on practical applications and supports the transfer of innovations to industry. The federal ministries have set up structures to foster this exchange between science, industry and government.

1.2.1 Energy Transition Research and Innovation Platform and energy research networks

The Federal Ministry for Economic Affairs and Energy set up the energy transition research and Innovation Platform in 2015, as one of five different energy transition platforms. It serves as a strategic advisory body for overarching issues within energy research funding policy and convenes bi-annually. The plenary meetings are attended by representatives from political institutions, the energy industry, research establishments and civil society, who discuss current developments in energy research and support the work of the energy research networks. The platform provided important input for preparations for the 7th Energy Research Programme as part of celebrations marking the 40th anniversary of the Energy Research Programme and the associated specialist conference which followed in May 2017. At the second meeting in December 2017, the energy research networks handed their expert recommendations on a range of key issues over to the Federal Ministry for Economic Affairs and Energy.

Together, the energy research networks form the key structure behind the energy transition Research and Innovation Platform. They are open to all experts wishing to be involved and are organised and run by the participants themselves. There are currently eight networks with a total of 3,500 members working in the following areas:

- Bioenergy
- Energy in Industry and Commerce
- *ENERGIEWENDEBAUEN* (until October 2017: energy in buildings and cities)
- Renewable Energies
- Flexible Energy Conversion (emerged from the COORETEC initiative in January 2017)
- Power Grids
- System Analysis
- Startups (launched in 2018)

Each network is organised into working groups in which members cooperate on joint activities. There are also regular conferences which enable all members of a particular network to come together to discuss trends and developments in their respective fields of research. In addition, network members have also been able to individually take part in an online survey as part of the consultation process on the strategic flagship project 'Trends and prospects in energy research' (see chapter 1.1.2).

1.2.2 Energy Transition Research Forum

An essential step in implementing the energy transition is to gather, evaluate and process key issues and research needs. This is the job of the Energy Transition Research Forum. The forum is led by the Federal Ministry of Education and Research in cooperation with all of the other ministries whose competencies are affected. It is made up of high-level actors from government, science, industry and civil society who meet to discuss and assess different options for action based on the cooperative work of a number of scientific establishments as part of the 'Energy Systems of the Future' project (see chapter 1.2.3).

The work of the forum has led to the development of four 'Kopernikus' projects dealing with key current topics of the energy transition.

1.2.3 'Energy Systems of the Future' project

'Energy Systems of the Future' (ESYS) is a joint project that is being conducted by a number of German science academies in order to pool scientific expertise on energy issues from across different disciplines. The project involves more than a hundred different experts who meet together in multi-disciplinary working groups to develop blueprints for how a sustainable, secure and affordable energy supply of the future might be designed.

The groups explore the feasibility of different technologies for the supply, transport, and storage of energy, whilst also considering economic, ecological, legal and social aspects. The work is done systematically, with Germany always looking beyond its own national borders.

To date, the members of ESYS have produced 18 comments, analyses and information aids setting out various options for action vis-à-vis restructuring the energy system. They have also published background material (supplementary analyses and information material) which goes into individual aspects in more detail. One of the project's most recent publications is a position paper entitled 'Input for the Federal Government's 7th Energy Research Programme', which was developed as part of the participatory process. This emphasises that there needs to be space in energy research for creativity and innovations, for flexible and practice-oriented funding projects, and for greater participation and international cooperation. In these ways, the academies-based project makes an important contribution to developing energy research in Germany and drives the energy transition further forward. Additional current publications deal with topics such as consumer policy, energy conservation, raw materials for the energy transition, and sector coupling as an option for the next phase of the energy transition.

In the trialogues on the energy transition, ESYS experts exchange views with representatives from government, business and organised civil society. The meetings are used to look at new topics from different perspectives and to better define how relevant issues can be successfully addressed by society in practice.

In 2017, the academies taking part in the project hosted a total of 12 events, serving to lead the debate about the opportunities and challenges linked to the energy transition in Germany. For example, this included developing strategies designed to enable the climate targets to be achieved.

1.2.4 Central Information System for Energy Research

The Federal Ministry for Economic Affairs and Energy operates a central information system on energy research, known as EnArgus (www.enargus.de). The system enables users to search an extensive catalogue of current and completed publicly funded research, development and demonstration projects, as well as search through research funding per topic and energy technology. The platform database comprises all projects undertaken since records started to be kept electronically (1976), enabling users to gain comprehensive insights into historical projects and the progress that has been made across more than 40 years. It contains more than 25,000 projects, with the system updating itself each day. The Federal Ministry for Economic Affairs and Energy thus provides the means to gain a transparent overview of current funding activities at a single location. The platform is managed by Project Management Jülich on behalf of the ministry.

The central energy research information platform has two different user levels. Members of the public can gain access to platform data via the publicly accessible website. Staff from the federal ministries and project management agencies involved can additionally gain access to the platform via a uniform and central access point which enables them to obtain further information and to research the funding projects in more detail.

1.3 European and international networking

The energy transition is a challenge internationally. Binational and multinational initiatives create new synergies and stimuli for the transformation of European and global energy systems. The Federal Government is therefore working to foster dialogue with other countries. Cooperation in the EU is taking on particular importance. When it comes to EU funding, it's therefore vital to have coordinated, joint strategies in place. Germany is also involved in the International Energy Agency's Energy Technology Network.

1.3.1 European Cooperation

The European Union's framework programme for Research and Development, 'Horizon 2020', helps European industry to further develop its scientific excellence and to extend its leading role in global competition, not least when it comes to expertise on providing a secure, clean and efficient energy supply. Funding areas are defined in accordance with the goals set out in the EU's Strategic Energy Technology Plan and also correlate with the global energy initiative 'Mission Innovation'. Since 2014, some 2.25 billion euros of funding has been made available for 828 projects conducted by actors from science, research and industry. Up to 2020, a total of almost 6 billion euros will be available for projects and support measures. The results of the projects help the EU to meet its energy and climate goals (Europe 2020).

The current political and strategic framework for energy is focused on improving energy efficiency, reducing carbon emissions, and raising the share of renewables in energy generation. Funding priorities are agreed between the Directorates-General for Research (RTD) and Energy (ENER) of the European Commission and the EU Member States. Current funding options are set out in work programmes, which are published at regular intervals. German companies can access free and unbiased information and advisory services from the National Contact Point for Energy to assist them in filing their applications. The National Contact Point for Energy falls under the responsibility of the Federal Ministry for Economic Affairs and Energy.

The Joint European energy research projects are conducted by partners from science, industry and application across all stages– from basic applied research, to the demonstration phase, through to support for the introduction of innovative new approaches on the market. Research, technological development and demonstration activities in fuel cell and hydrogen energy technologies are also conducted by the 'Fuel Cells and Hydrogen 2 Joint Undertaking' (FCH 2 JU). Joint European funding measures create important synergy effects at both European and national level, whether through the ERA-Net scheme or through cooperation based on the Berlin model. One example of successful funding is the CPVMatch project coordinated by Germany, which aims to further promote the use of solar energy.

Other projects being funded by the Federal Ministry for Economic Affairs Energy that follow the goals of European Strategic Energy Technology Plan include the second German-Finnish call for proposals, which was launched in 2017. Some 32 research project proposals were submitted in the areas of energy conservation, energy efficiency, and renewables. The projects selected to receive funding will commence in summer 2018.

The German-Greek Research and Innovation Programme, which was first launched in 2013, is a bilateral scheme that covers a huge range of different research areas, including research on energy. The successful work that has been carried out under the programme is now continuing following its relaunch in December 2016. The bilateral programme serves to strengthen cooperation between science and industry, to foster the next generation of scientists in both countries, and helps the joint research projects to fit in with European programmes. Together, the Federal Ministry of Education and Research and Greece's Ministry of Education, Research and Religious Affairs provide a total of 18 million euros of funding for this programme.

More than 200 research project proposals were submitted in the areas of health, bioeconomy, energy, the humanities and social sciences, culture and tourism, materials, and key technologies. The projects selected to receive funding commenced in March 2018.

1.3.2 International Cooperation (International Energy Agency – IEA, Mission Innovation, Bilateral Initiatives)

Governments, research institutes, universities and companies are also involved in close cooperation on energy research at an international level. The Technology Collaboration Programmes operated by the IEA provide an important platform for this. In addition, there is also a variety of bilateral and multilateral cooperation that takes place.

International Energy Agency (IEA)

The International Energy Agency is an autonomous establishment within the Organisation for Economic Co-operation and Development (OECD) and advises governments in its 30 member countries on energy issues. Research and development activities are coordinated and supported by the IEA's Committee on Energy Research and Technology (CERT). The Federal Government is represented in this committee by the Federal Ministry for Economic Affairs and Energy. The Working Parties and technology cooperation programmes (TCP) within the CERT cover the entire range of energy technologies that exist. Germany is represented in all four Working Parties and is involved in 22 of the 38 TCPs that are currently in operation. Within the Wind TCP, for example, participants are looking at what communicative and participatory instruments can be employed in order to raise acceptance levels for wind farms (Task 28). The *Institut für Zukunftsenergie- und Stoffstromsysteme* (Institute for forward-looking energy and material flow systems) and the Medical School Hamburg also feed their expertise into the consortium as partners representing Germany.

Mission Innovation

'Mission Innovation' is a global initiative designed to foster research and innovation in clean energy technologies through international cooperation. The initiative involves the European Union and 23 countries. The Mission has defined eight key 'Innovation challenges' to be undertaken by participating countries. Research areas not only comprise the more traditional fields of energy research, such as bioenergy, smart power grids, and heating and cooling, but also include automated Materials Research, as well as the direct conversion of solar energy into chemical energy sources.

In addition to strengthening cooperation between different countries, Mission Innovation also seeks to stimulate private investment. One of the ways in which it is doing this is by intensifying its cooperation with the 'Breakthrough Energy Coalition' set up by private investors parallel to the initiative. Cooperation is also being developed with the World Economic Forum.

The involvement of the Federal Government in Mission Innovation is testament to the high level of importance it places on research and development for the energy transition in Germany and worldwide. Taking part in international cooperation in energy research enables Germany to remain competitive in the key markets of tomorrow and strengthens the export of innovative energy technologies.

Bilateral Initiatives

One of the ways in which Germany assumes its responsibility for tackling global challenges is through its cooperation with emerging and developing countries on R&D. For this reason, the 'CLIENT II – International partnerships for sustainable innovations' funding scheme operated by the Federal Ministry of Education and Research focuses on providing funding for R&D cooperation which is led by demand. The central aim of the collective applied research projects with partners in selected emerging and developing countries is to develop and implement technologies, products, services and system solutions in areas including climate protection, energy efficiency and sustainable energy systems.

The joint 'German-Canadian cooperation on kinetics and mass transport optimisation in PEM fuel cells' (GECKO), which came to an end in 2016, is now being continued under the title 'German-Canadian fuel cell cooperation: diagnosis and development of components for automobile fuel cells' (DEKADE). The new project serves to continue the close scientific cooperation between research institutions in both countries, while also drawing upon a key source of further expertise by involving companies. The aim of the cooperation is to develop novel catalyst systems and membrane electrode units which use as little platinum as possible in order to make them cheaper. The Federal Ministry of Education and Research is providing around 3.8 million euros in funding for the project.

Australia's economy, like Germany's, is characterised by energy-intensive industries, and Australia also has great potential for developing the use of renewable energy. At the same time, Australia is already facing extreme climatic challenges, which would be further exacerbated by the consequences of further climate change. Nevertheless, 86 per cent of the electricity generation is based on fossil sources. Within the efforts to implement the Paris Climate Agreement, Australia is an important strategic partner in energy research. A joint German-Australian focus project is taking place that seeks to develop knowledge and solutions that will enable both countries to operate a low-emission energy system. The Federal Ministry of Education and Research is providing around 2 million euros for this work (as of 1 October 2017).

The Federal Government is also undertaking additional initiatives that aim to make innovations from Germany known around the world and to strengthen international cooperation between science and research conducted by industry. These notably include the 'German Houses of Research and Innovation' (DWIH), an initiative developed by the Federal Foreign Office and the Alliance of Science Organisations in Germany.

1.4 National networking

Energy research is a vast area, so it is crucial for government, science, industry and civil society to engage in close networking with one another. The Federal Government coordinates its own policies in the Coordination Platform for Energy Research Policy, which falls under the responsibility of the Federal Ministry for Economic Affairs and Energy. The platform enables information to be shared between different ministries, and makes it possible to coordinate with other support programmes that have close links to energy research.

The *Länder* governments make an important contribution to the promotion of research and development for the energy transition. In 2016, they provided a combined total of more than 248 million euros for this purpose (see chapter 4.1). In order to coordinate on key areas, issues and trends, the Federal Ministry for Economic Affairs and Energy hosts federal-*Länder* talks on energy research policy each year. In 2017, the focus of these consultations was on preparations for the new Energy Research Programme.

2. Project funding in the 6th Energy Research Programme

2.1 Energy conversion

2.1.1 Photovoltaics

In technological terms, the focus in photovoltaics is still on cells based on crystalline silicon as a semiconductor. The current standard is Passivated Emitter and Rear Contact (PERC). Here, the front and rear of the cells have a better coating than was the case in the previous standard cell concept, and the output from long wavelength light is higher. Further developments in this technology are already in sight, in the form of passivated selective contacts. These allow only one type of charge carrier to pass and thus prevent free positive and negative charge carriers from recombining with each other so that they can no longer be extracted as electricity. Making new cell concepts ready for industrial production is a key aspect of research and development. The equipment builders are also opting increasingly for innovative Industry 4.0-based manufacturing methods in order to reduce the investment costs for potential clients. There are also successes in the field of thin-film technologies. At the PVSEC 2017 conference, various manufacturers presented improvements in the efficiency of their CIGS modules. In CIGS cells, the semiconductor consists not of silicon, but of copper, indium, gallium and selenium. In addition to the low cost of manufacture, the main benefit of all thin-film technologies is the ease of integration into facades of buildings.

Funding priorities and scientific advances

In order to safeguard Germany's competitive advantages – high product quality and technically advanced and innovative production processes – the Federal Ministry for Economic Affairs and is supporting research projects in the field of photovoltaics. Cutting costs whilst boosting quality continues to be a key objective. Research projects should help to cut the consumption of materials and energy, to establish more efficient manufacturing processes, and to improve the efficiency of the cells in order to create high-performance modules and efficient systems technology.

For example, scientists at the Fraunhofer Institute for Solar Energy Systems (ISE) set a new world record in the spring of

2017 for multi-crystalline silicon solar cells, the most common form of silicon used in photovoltaics, with an operating efficiency of 21.9 per cent. The multiTOP project, which set the record, receives funding from the Federal Ministry for Economic Affairs and Energy. These successes in research are going hand in hand with progress in industry. For example, Heckert Solar GmbH, a leading PV module producer from Saxony, has boosted its modules' efficiency by altering their width and length by just a few millimetres. These optimal dimensions were the result of simulations developed by a team of researchers working on the CTM100 project funded by the Federal Ministry for Economic Affairs and Energy. This project, which involves Fraunhofer ISE, Fraunhofer Center for Silicon Photovoltaics (CSP) and twelve German industrial partners, focuses not on the cell, but instead optimises the whole module.

Furthermore, improvements in the quality of the modules are of particular interest in view of the rising amount of solar energy in the electricity grids. Here, it is vital to be able to rely on a robust assessment of the efficiency of the module and the system. With regard to the PV-system as a whole, a major role is played by the inverter as a component. In the ModulWR_4 project, the project partners are working on a new generation of inverters for solar modules. In future, they are to be integrated in the module itself, with a view to increasing the efficiency and reducing the system costs. The new inverters are to be so thin that they can be laminated into the rear side of the module. This entails rethinking the entire structure.

In order to reduce the burden on the electricity grids, research and development work is also focusing on local consumption of locally generated electricity. If this is optimised, work to expand the grid or build storage capacity can be reduced, thus cutting the overall costs.

Under the call for proposals issued by the Ministry of Education and Research for Materials Research for the Energy Transition, internationally competitive expertise has been built up in the field of perovskite solar cells. This funding has enabled Germany to catch up with the world leaders in perovskite research. In the CISOVSKIT project, the focus is on developing perovskite materials for thin-film-based solar cell types. Two solar cells on a CIGS and perovskite basis are linked up in a tandem configuration. The idea is that these hybrid solar cells will be much more efficient than the sum of the efficiency of the individual cells, and that this could revolutionise photovoltaics in the future. The funding is also going to three other projects in the field of photovoltaics. They are developing novel electrode materials for silicon solar cells, efficient multi-junction solar cells based on III/V semiconductors, and absorber layers for use in environmentally friendly thin-film solar cells.

Organic electronics is a forward looking technology which promises to make efficient use of resources and energy. With this in mind, the Ministry of Education and Research launched the call for proposals entitled Organic Electronics, most notably Organic Light-Emitting Diodes and Organic Photovoltaics in 2011. The aims include boosting the efficiency of organic solar cells and modules in order to make them more attractive for the photovoltaics market. Organic solar cells are adaptable in terms of shape, colour and transparency. They can thus be used in many different applications, such as glass facades, vehicle construction and textiles. As part of the POPUP project, which has been completed, the prototype of solar spectacles with glass made of semi-transparent, organic solar cells was presented at the 2017 Hannover Messe.

Project funding

In the field of photovoltaics, the Economic Affairs and Research Ministries provided approximately 84.46 million euros in funding for 449 ongoing projects in 2017. Also, the ministries appropriated approximately 90.71 million euros in funding for 104 new research projects in 2017 (see Fig. 2).

2.1.2 Wind power

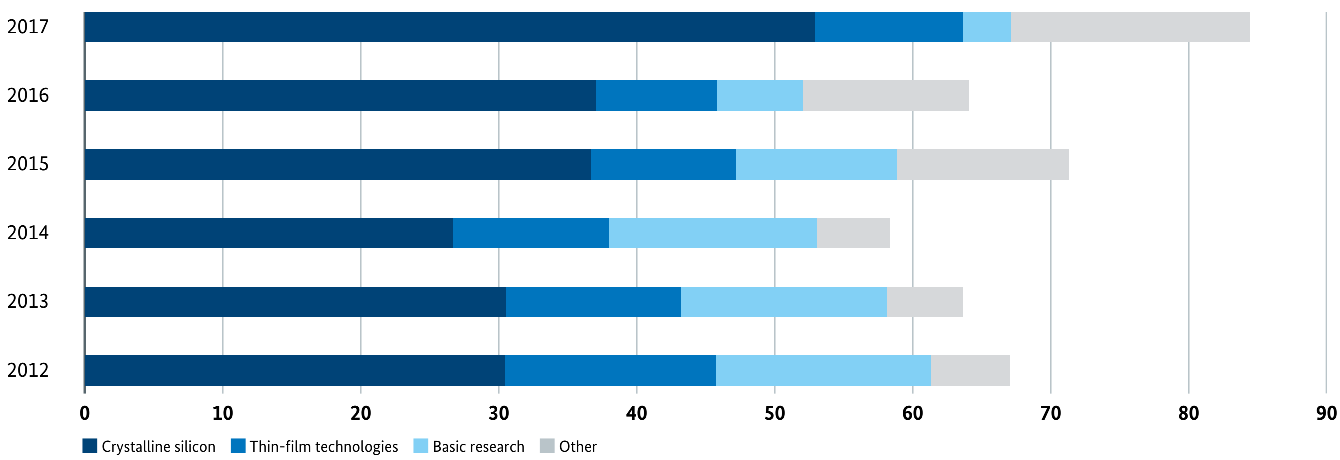
The bulk of renewable electricity is currently generated by modern wind energy installations. A number of new wind farms have come online both onshore and offshore in recent months. In addition to installing new wind turbines, 'repowering' sees existing installations being replaced by new, more efficient turbines in order to boost the yield at the site. Offshore wind energy is particularly attractive, because in many cases an installation can generate twice as much electricity as one with the same output on land, due to the strong and steady winds at sea. Despite this, electricity generation has so far been much more expensive offshore due to the challenging technical and logistical demands, for example in terms of construction and maintenance.

At present, three-bladed horizontal-axis wind turbines are the most prevalent type. The trend is towards larger wind energy installations with higher yields. However, blade lengths of 80 metres and more also represent a major logistical challenge.

Research priorities and scientific advances

In recent years, intensive research and development work has helped electricity generation from wind power to become steadily cheaper. The focus of the Federal Government's research funding continues to be on using innovative technologies and processes to boost the wind yields whilst cutting costs. The work starts with the planning and production of the wind energy installations. Researchers are working, for example, on using computer-based design processes to successively automate the manufacture of rotor blades.

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



In order to harvest as much energy as possible from the wind, the tower designs are becoming higher and higher, and the blades longer and longer. This results in a much greater load on the individual components. In response to this, teams of scientists are developing new materials and composites which help to cut the weight of the rotor blades and to enable the deployment of very long blades. Innovative control processes and robust power electronics also aim to permit the operation of the wind energy installations to be as smooth and low-maintenance as possible.

Before wind energy installations come on to the market, they need to be fully tested. The Bremerhaven test field, Germany's third such field, started operating in 2017. It is run by the Fraunhofer Institute for Wind Energy Systems (IWES) on the site of a disused airport. Both here and in the nearby DyNaLab, scientific research establishments and manufacturers of components for wind energy installations can conduct wide-ranging tests in real field operations and on indoor test rigs.

Wind energy installations built at sea face additional challenges relating to their foundations. For example, strong currents can cause scour through the movement of sediment that can erode the seabed around the foundations. In the marTech research project, scientists are using the Great Wave Flume of the Coastal Research Centre (FZK) to find out how such scouring effects can be prevented or at least reduced. The wave flume is one of the world's largest maritime test facilities.

Scope to cut costs further exists not just in the traditional components, but also in the operational processes. Digitalisation offers a lot of potential here. For example, it is possible to use sensors to document wear-and-tear of components and to monitor this on computers at control stations. This enables service staff to carry out the necessary maintenance work in good time, well before the equipment fails and expensive down times have to be coped with.

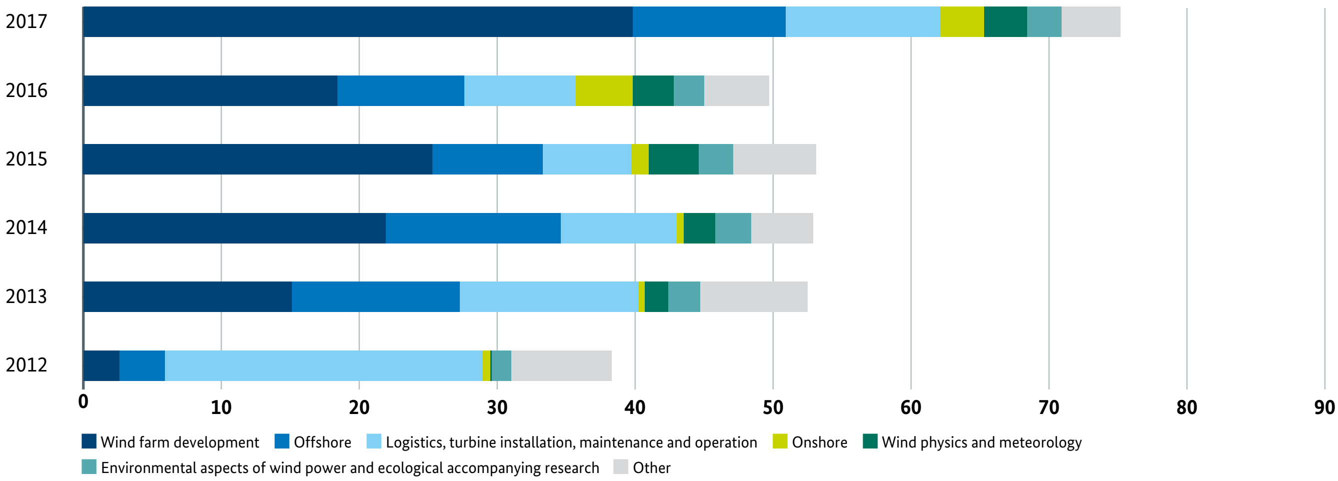
The Federal Ministry of Education and Research is funding basic research in the field of wind energy. In particular its Materials Research for the energy transition call for proposals supports the goal of increasing the lifetime of wind energy installations and cutting costs.

The WEA-GLiTS collaborative project is one example. More reliable wind energy installations are being developed in order to cut failures and down times resulting from damaged anti-friction bearings. Scientists are testing novel material concepts for coatings for sliding bearings. They are developing a separable bearing with replaceable sliding parts. If the project is successful, the industrial potential will be considerable. This could be achieved via a new material concept with higher fatigue resistance and a longer lifetime, and a simpler replaceability of sliding parts.

Project funding

In the field of wind energy, the Federal Ministry of Education and Research and the Federal Ministry for Economic Affairs and Energy provided approximately 75.11 million euros in funding for 354 ongoing projects in 2017. Also, the ministries appropriated approximately 95.97 million euros in funding for 86 new research projects in 2017 (see Fig. 3).

Figure 3: Project funding for wind power in million euros
(see table 2 for data)



2.1.3 Bioenergy

The use of biomass as an energy source continues to make a substantial contribution to Germany's energy supply despite the changing regulatory framework and commercial environment. In 2016, various biogenic energy sources generated 1,128 petajoules of primary energy.[1] This means that biogenic energy sources covered approximately 66 per cent of the consumption of primary energy based on renewables.

There are many ways to use biomass for energy production, both still theoretical and already applied in practice, and at present the dominant one is the production of heat from solid biomass. Other large-scale uses include ethanol for motor fuel and electricity generation from biogas, sewage gas and landfill gas.

There is a lot of funding for research, development and demonstration from three Federal Ministries, reflecting the diversity of the current issues relating to bioenergy. The relevant funding measures are presented in the following sections.

Funding priorities and scientific advances

The Federal Ministry of Food and Agriculture contributes to energy research by funding measures based on the Renewable Raw Materials funding programme. The 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 varies from year to year and is therefore only one element of the funding measures funded in the afore-mentioned programme. Since 2000, the Renewable Raw Materials funding programme 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.

Further to this, R&D measures are funded from the Energy and Climate Fund. Most of the projects funded can be categorised as energy research. All of the measures cover aspects of the use of biomass for energy production, and are oriented towards two funding priorities:

- The definition and development of technology and systems to generate and use bioenergy with a view to further improvements in the greenhouse gas footprints of the main areas of use – electricity, heat and fuel.
- Optimisation of the integration of bioenergy into regional and supra-regional energy (infrastructure) systems (heat, electricity, mobility) with a view to improving system stability and energy efficiency.

In 2017, the amount of new funding appropriated under the responsibility of the Federal Ministry of Food and Agriculture stood at 32.58 million euros.

The Federal Ministry for Economic Affairs and Energy's Energetic Use of Biomass programme supports research, development and demonstration projects for a technically, environmentally and economically optimised use of bioenergy. The goals include sensible use of biogenic waste from the waste, agriculture and forestry industry, improved efficiency, and the development of new approaches to by-product and cascaded use. The focus is on the generation of heat and electricity, combined heat and power generation, flexibilisation and the integration of bioenergy applications into the overall system, and particularly also in energy systems with a high proportion of renewable energy.

The ManBio collaborative project was awarded the Biogas Innovation Prize of German Agriculture in 2017. The project partners were *DBFZ Deutsche Biomasseforschungszentrum gGmbH* (German Biomass Research Center) and Awite Bioenergie. The project started from a technical analysis of systems in current use and the main factors influencing the operation of gas storage systems in biogas installations. Building on this, the team has studied various level measurement systems for gas storage units, modified them and integrated them into the automation of the units. In order to enable predictive control of the filling level in the gas storage unit, the factors influencing the available gas storage capacity are mapped in a model. These factors include temperature, wind strength and solar radiation. On the basis of weather forecasts, it is possible to make recommendations for the predictive adjustment of the feed-in or power generation regime in order to avoid underproduction and overproduction. The technical implementation and testing in permanent operation took place at the *DBFZ*'s biogas research facility and at another biogas facility of the project partner.

The programme was given scientific backing by *DBFZ Deutsches Biomasseforschungszentrum gGmbH* with a view to networking and transferring expertise.

1 http://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/erneuerbare_energien_in_zahlen.html.

The provision of networking services is a key aspect of the Federal Ministry of Education and Research's research funding. In this context, the high degree of flexibility of bioenergetic power generation can be exploited for the entire system. In the context of the call for proposals BioProFi – Bioenergy-Process-oriented Research and Innovation of the Federal Ministry of Education and Research, the ABIoLa project optimised and increased the efficiency of an innovative biogas treatment process. This enables smaller biogas installations to feed biomethane into the gas grid. Under the MOST project, an easy-to-use control technology was developed, and new sensor technologies for real-time monitoring of biogas installations were studied. These support flexible operation, and thus make a key improvement in the provision of balancing energy in an energy system increasingly based on intermittent generation sources.

Another priority of the Federal Ministry of Education and Research's research funding is the production of chemical energy sources and basic chemicals. Here, the fossil fuels currently in use are replaced by sustainable alternatives. A successful project called AG-HiPreFer developed a continuous high-pressure laboratory facility. This makes it possible to feed biomethane into existing long-distance gas pipelines without the need to use a lot of additional energy for compression. It permits up to 30 per cent of the energy used for gas treatment to be saved. The project also studies the suitability of biogas from the high-pressure laboratory unit to produce liquid fuels via Fischer-Tropsch synthesis. The Mekomat project pursues a similar goal. The various elements of an electro-synthesis reactor are optimised in order to permit efficient production of basic chemicals and fuel in anaerobic conditions. This enables not only improved production of bio-based liquid fuels, but also an influential new tool for the bio-economy.

Project funding

In the field of bioenergy, the Agriculture, Economic Affairs and Research Ministries provided approximately 33.04 million euros in funding for 562 ongoing projects in 2017. Also, the ministries appropriated approximately 38.61 million euros in funding for 177 new research projects in 2017 (see Fig. 4).

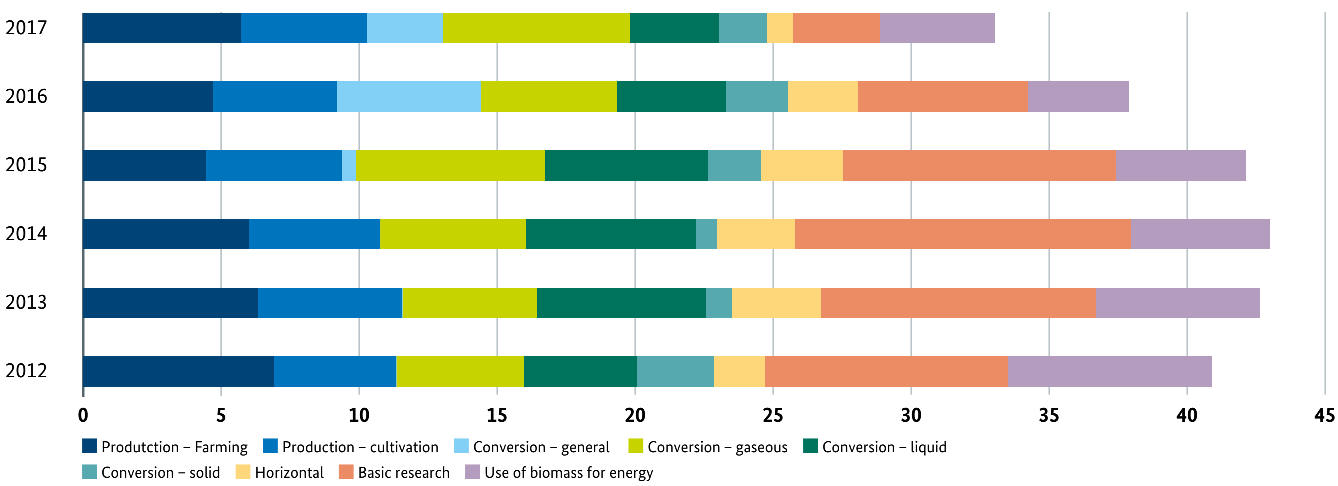
2.1.4 Deep geothermal energy

Research in the field of deep geothermal energy is mainly focused on open systems – as opposed to near-surface geothermal energy, which comprises closed-loop geothermal probes working at a shallow depth. In open systems, hot water is extracted directly from deep below ground and used to generate heat or electricity. According to statistics from the German Geothermal Association (BVG), Germany has 33 regional geothermal heating plants in operation, and the number is growing. The Association also noted eight geothermal power plants in Germany producing electricity for the grid.

Funding priorities and scientific advances

The necessary technology and the processes needed for the operation of a geothermal energy installation with an open-loop hydrological cycle were initially adapted from the oil industry. Teams of scientists and engineers at German higher education institutions, research establishments and in industry have kept adapting these over the last few years to bring them into line with the needs of geothermal energy. They have made particular progress in the field of plant technology. Examples include high-capacity deep pumps. The researchers have also been able to make clear improvements in reservoir, process and risk management. The last 20 years of research and development in this field have helped German plant and machinery companies to

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



become world leaders in the field of geothermal energy. This results in a lot of potential for exports, in the fields of both heat extraction and electricity generation.

Current projects cover all stages of the construction of a geothermal energy installation: from exploration of the deposit to drilling and the subsequent operation of the installations. The common objective of all the funded research projects is to use innovative approaches throughout the value chain to achieve further cuts in the costs of geothermal energy, thereby making geothermal energy a sustainable and commercially attractive alternative for heat production in Germany. In the Horstberg research project, for example, scientists are studying the extent to which an artificially created underground fissure can be used as a heat exchanger. The idea is to feed cold water below ground, let it heat up and then remove it for use in the heating sector. An important question is whether the system is thermally sustainable, and what extraction rate and pressure would be needed to make it sustainable. The heat generation system aims to ensure the sustainable, use of geothermal heat.

A relatively new approach is based on making increasing use of geothermal deposits as heat storage facilities in order to offset fluctuations in heating systems and thus to support the transformation of the energy system. Underground storage facilities – with both closed and open systems – could in the long term be used in the energy system on a seasonal and a situational basis (i.e. when there are short-term energy surpluses).

Project funding

In the field of geothermal energy, the Federal Ministry for Economic Affairs and Energy provided approximately 16.49 million euros in funding for 80 ongoing projects in 2017. Also, the ministry appropriated approximately 8 million euros in funding for 17 new research projects in 2017 (see Fig. 5).

2.1.5 Power plant and CO_2 technologies

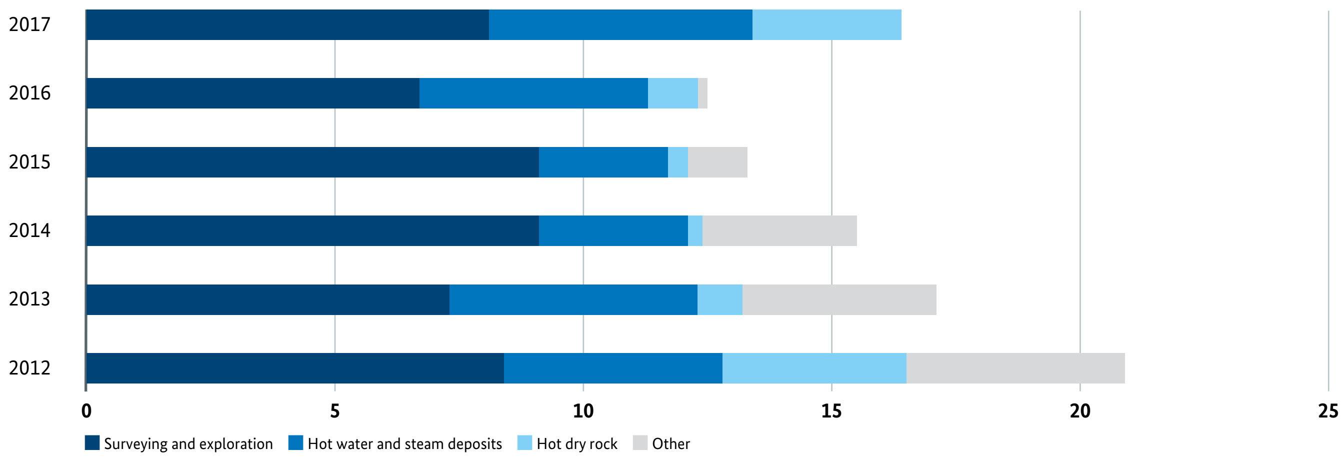
Conventional power plants are needed to be flexible service providers in an age of energy transition. They have to close gaps in supply when weather conditions lead to less electricity being generated from sun or wind. New plant designs and operational processes are required for this, as the power plants have to be ramped up and down frequently, or run on a partial-load basis.

At present, most of Germany's power plants are fired by coal or gas. In future, it should also be possible to use fuels like hydrogen and methane produced using renewable energy. Combined heat and power plants produce not only electricity but also heat for heating public and private buildings, or as process heat for industry.

Funding priorities and scientific advances

The research funding of the Federal Ministry for Economic Affairs and Energy aims to make power plant technology more efficient, cleaner and cheaper. Against the background of Germany's energy transition, the first step is to retrofit existing power plants in order to prepare them for their new role as flexible electricity suppliers. Furthermore, a lot of the retrofitting serves to cut the power stations'

Figure 5: Project funding for deep geothermal energy in million euros
(see table 2 for data)



greenhouse gas emissions. In addition to this, the Federal Ministry for Economic Affairs and Energy funds innovative research projects working on carbon capture, storage and use. For example, CO_2 can be used in cooling units and air conditioning, or be further processed and converted into fuels or chemicals. As part of the CODY project, for example, scientists have developed a process for dynamic methanol synthesis. To do this, they use both CO_2 from power plant processes and hydrogen generated using renewable energy.

In order to adapt operating processes and components to flexible power plant operation, further research and development work is necessary, for example on the materials used. In the THERRI research project, for example, the project partners have studied the impact of the frequent and rapid ramping up and down of the power plants on the materials used, and how to calculate their residual lifetime. The outcome is an innovative fracture mechanical assessment concept for steam power-plants operating at varying loads. Amongst other things, the findings recommend inspection intervals for the reliable, economic and safe operation of these power plants.

Further to this, combined-cycle turbines need to be optimised and developed for applications like combined operation in combined-cycle power plants or combined heat and power plants.

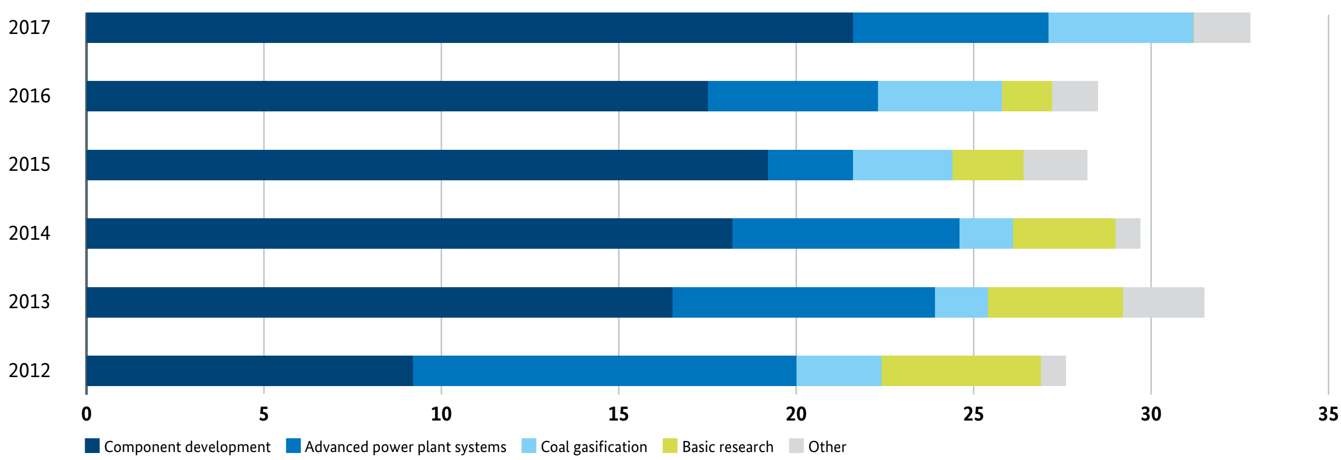
In its funding of basic research on power plant technologies, the Federal Ministry of Education and Research is also supporting solutions to make power plants more flexible and align them to the requirements of the energy transition – using them as a bridging technology. The projects funded under the Materials Research for the Energy Transition call for proposals are therefore studying the characteristics and behaviour of innovative materials under extreme conditions. In addition to high-temperature resistant steam-generation materials, novel ceramic materials for use in gas turbines are being researched. Here, the focus is on boosting the efficiency, operating with flexible loads, and using regenerative fuel cells in combined-cycle power plants and in micro gas turbines which can be used on a distributed basis. In particular, the studies looked into the manufacture of corresponding gas turbine components and the aptitude of different ceramics and composites.

The CeramTurbo project is developing innovative ceramic components for use in micro gas turbines with a view to raising the turbine inlet temperature. This could significantly improve energy efficiency and make it possible to use regenerative raw materials. The micro gas turbines can be used in block-type thermal power stations and biogas installations.

Project funding

In the field of power plant technology, the Federal Ministry of Education and Research and the Federal Ministry for Economic Affairs and Energy provided approximately 32.82 million euros in funding for 326 ongoing projects in 2017. Also, the ministries appropriated approximately 25.34 million euros in funding for 51 new research projects in 2017 (see Fig. 6).

Figure 6: Project funding for power plant technology in million euros
(see table 2 for data)



2.1.6 Fuel cells and hydrogen

Automotive fuel cell systems are a highly promising option for the mobility sector, offering a long range coupled with brief refuelling times and various potential uses. Daimler was the first German manufacturer to present a fuel cell vehicle, in 2017. Stationary fuel system heating systems to generate electricity and heat show what the energy supply of the future can look like for the home. The first fuel cell heaters and vehicles are already on the market, but research and development work is still needed to improve the maturity of the technology. The Federal Ministry for Economic Affairs and Energy's supports a programme that aims to establish fuel cell heating on the market.

Funding priorities and scientific advances

Fuel cells are on the cusp of being introduced to the market. However, they need to become even more long-lasting and cheaper if they are to be widely used in the energy, consumer goods and commercial vehicle sectors. The Federal Ministry for Economic Affairs and Energy is funding research and development work into the next generations of fuel cells, and aims to create the basis for internationally competitive fuel cell technology in Germany.

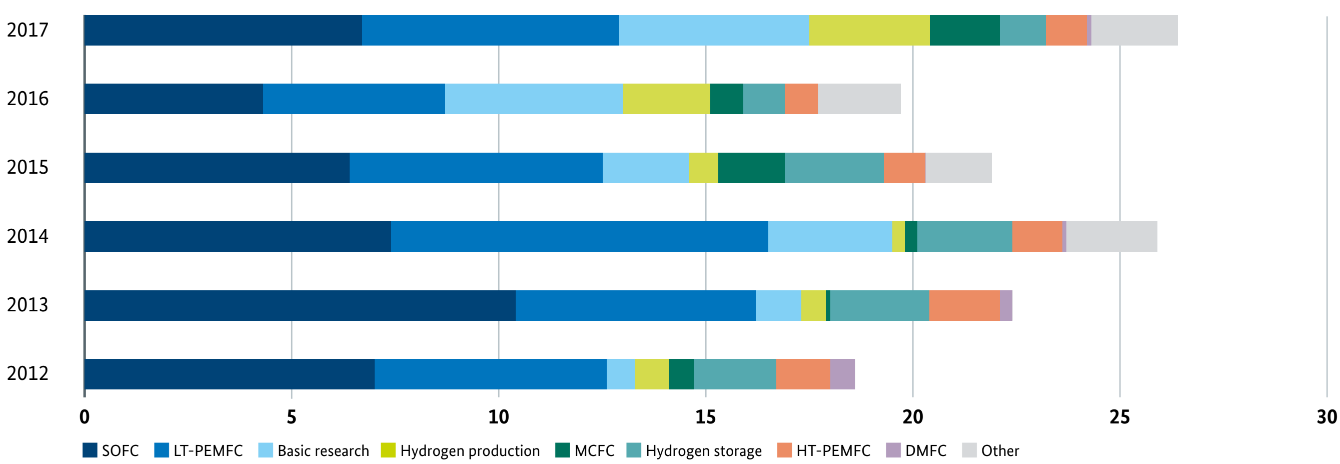
In the Thermelin research project, scientists have developed a micro block-type thermal power station to supply homes with energy, based on a solid oxide fuel cell (SOFC), with a high electrical efficiency rate of at least 50 per cent. The team of researchers has taken the existing micro block-type thermal power station technology and developed it further, integrating a steam reformer into the fuel cell. The internal steam reforming directly oxidises the natural gas. This makes the SOFC more efficient than other fuel cell systems with upstream reforming. Thermelin aims to use the fuel cells to improve energy efficiency.

The goal is to make compact, robust, long-life fuel cell systems at reasonable cost which meet the needs of applications. Their use is closely linked to technologies to generate and store hydrogen. In terms of hydrogen generation, the focus of the funding is on conversion efficiency. With regard to hydrogen storage, the priority is to boost the storage density and to reduce costs.

The Federal Ministry for Economic Affairs and Energy's research funding is technology-neutral in order to allow the different types of fuel cells (SOFC, polymer-electrolyte technology (PEMFC) and other types) to play to their respective strengths depending on the use cases. The Federal Ministry for Economic Affairs and Energy funds projects for hydrogen technologies, the integration of fuel cells in the energy supply system, and overarching activities. In the status seminar on the fuel cell in 2017, for example, experts from research and industry discussed the short-term and medium-term need for research in the field of fuel cell technology.

The funding from the Federal Ministry for Economic Affairs and Energy for research and development in the field of fuel cell and hydrogen technologies is tied to the National Hydrogen and Fuel Cell Technology Innovation Programme (NIP). The Federal Government's NIP2 programme, which runs from 2016 to 2026, builds on the maturity of technology and market availability attained in the first generation of equipment (see chapter 4.3).

Figure 7: Project funding for fuel cells and hydrogen in million euros
(see table 2 for data)



Basic research projects, funded by the Federal Ministry of Education and Research provide solutions for the next generations of technology. The funding from the Federal Ministry of Education and Research covers specific aspects of all types of fuel cells. In the field of hydrogen technology, projects funded by the Federal Ministry of Education and Research are improving the efficiency of the overall system, for example via innovative storage materials or innovations for the electrolysis of water. For example, the POWER-MEE project has attained initial success in improving the performance of PEM electrolysis via printable materials in the active heart of the electrolysis cell. The MANGAN cluster project is studying the technical potential of manganese as a catalyst for parts of the conventional water splitting process. The element and its compounds are readily available and cheap, meaning that expensive noble metal catalysts could be replaced. This would be a key step towards making a success of the power-to-gas storage concept. In order to make the results of the project easily accessible, a comprehensive database of the compounds which have been studied is being set up.

Project funding

In the field of fuel cells and hydrogen, the Federal Ministry for Economic Affairs and Energy and the Federal Ministry of Education and Research provided approximately 26.5 million euros in funding for 156 ongoing projects in 2017. Also, the ministries appropriated approximately 32.23 million euros in funding for 48 new research projects in 2017 (see Fig. 7).

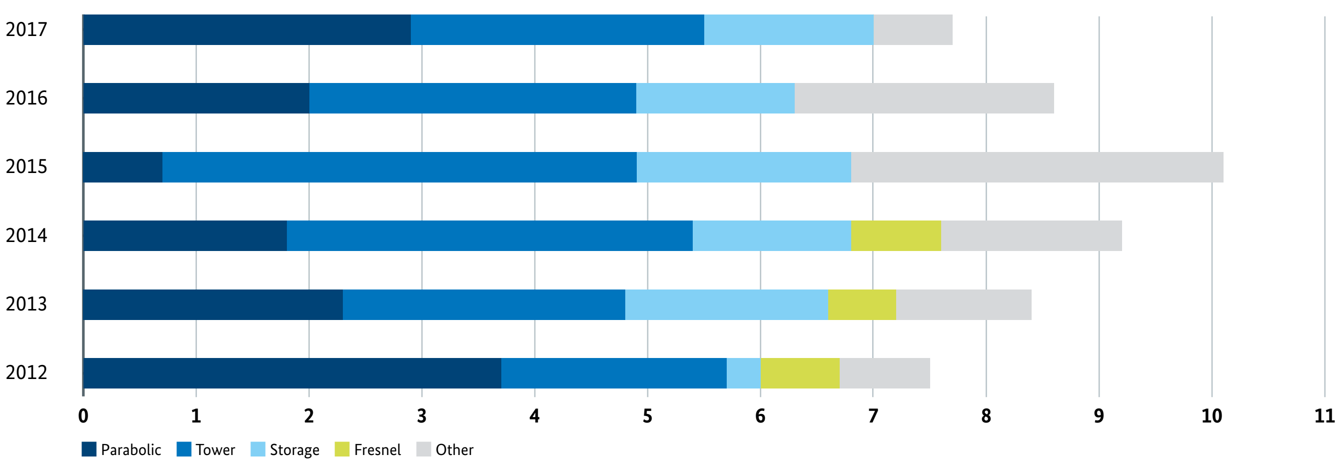
2.1.7 Solar thermal power plants

Solar thermal power plants can generate electrical energy at sunny locations with a high level of direct solar radiation such as Morocco, Spain and South Africa. At present, more than 5 gigawatts are connected to the grid around the world, and the amount is continuing to rise. The International Energy Agency (IEA) expects some 8 per cent of electricity demand to be met by solar thermal power plants by 2050. In view of its geographical location, Germany is not a suitable site, as there is too little direct solar radiation. The focus is therefore on exports – German companies are much in demand due to their expertise in project planning and implementation.

Funding priorities and scientific advances

The Federal Ministry for Economic Affairs and Energy's strategic research funding continues to aim at supporting the role of German firms as world leaders in this field of technology. Research and development work aims to help cut electricity generation costs further and to improve operating efficiency. The main focus of the research is on developing new and improving existing components and systems, particularly of solar tower installations and line-focusing systems, the latter mainly using molten salt and other high-temperature fluids as thermal transfer media. In the SITEF research project, the project partners have studied the characteristics of silicon thermal transfer oils to see whether they are suitable for use in parabolic trough power plants. This type of thermal transfer media can attain comparatively high operating temperatures, improving the efficiency of the power plants.

Figure 8: Project funding for solar thermal power plants in million euros
(see table 2 for data)



Another aspect of research covers the development of standards via robust measurement and testing processes in order to assess the quality of components. Under the Synlight research project, the world's largest artificial sun commenced operations this year; it is operated in Jülich by the German Aerospace Center (DLR). The new research facility can be used to test, for example, components from solar tower technology on a comparatively large scale.

One major field of research relating to solar thermal power plant technology is the development of storage facilities so that electricity can also be fed into the grid at night. Higher education institutions, academic institutions and industrial companies are working intensively on cross-technology concepts and pilot projects with a view to developing the interplay between different renewable energy technologies and storage facilities. Further to this, innovative use of digital technologies can help to optimise operating procedures via modern data evaluation. Solar thermal power plants contain a large number of individual components distributed across a large area. The use of optical measuring technology – for example fitted to drones – can survey and evaluate the operating, pollution and degradation statuses of entire solar fields.

Project funding

In the field of solar thermal power plants, the Federal Ministry for Economic Affairs and Energy provided approximately 7.73 million euros in funding for 66 ongoing projects in 2017. Also, the ministry appropriated approximately 5.62 million euros in funding for 21 new research projects in 2017 (see Fig. 8, p.21).

2.1.8 Hydropower and marine energy

The main source of hydropower in Germany is the running water in rivers. The technology is well established and is used in many places. Around 80 per cent of hydroelectric power stations in Germany are run-of-river installations. The other 20 per cent of hydroelectric power stations are reservoir power stations. In addition to onshore hydropower, it will be possible in future to generate electricity from marine energy. Unlike the established hydropower technologies, however, the marine energy installations are still at a developmental or test phase.

Funding priorities and scientific advances

Fresh potential in the field of hydropower is mainly to be found in the replacement or modernisation of existing installations at present. This 'repowering' sees existing installations refitted with new, more efficient turbines. Also, research and development work can help run-of-river systems to work even where gradients are slight and rates of flow are moderate. This would permit new sites to be developed. The Federal Ministry for Economic Affairs and Energy therefore promotes projects of higher education institutions, academic institutions and industrial companies active in the field. The research must respect all environmental interests.

The future potential of marine energy sources for Germany's coastal areas is believed to be rather small. Nevertheless, the Federal Ministry for Economic Affairs and Energy funds research projects which optimise the necessary plant technology and its components and which develop them for commercial sales abroad. In the Tidal Power research project, experts are working on an innovative marine energy installation with the potential to significantly cut both investment and maintenance costs. In many cases in the field of marine energy, a megawatt turbine is used which is firmly anchored to the seabed; within the Tidal Power project, a semi-submerged floating platform is to be used instead. This TRITON platform is only attached to the seabed by a swivel joint, so that it can follow the tidal currents.

Project funding

In the field of hydropower and marine energy, the Federal Ministry for Economic Affairs and Energy provided approximately 2.15 million euros in funding for 17 ongoing projects in 2017. Also, the ministry appropriated approximately 1.21 million euros in funding for 21 new research projects in 2017. (See table 2 for data)

2.2 Efficient use of energy

2.2.1 Energy efficiency in industry and commerce, trade and services

With a share of 29 per cent of final energy consumption, the industrial sector is the largest consumer of energy in Germany. The sector of commerce, trade, and services accounts for around 15 per cent. Growth, employment and competitiveness are becoming ever more closely linked to the issue of energy efficiency. If there is to be a successful energy transition both in industry and in commerce, trade and services, it will be necessary to systematically use all of the existing potential for energy efficiency. The Federal Ministry for Economic Affairs and Energy funds research and development of energy-efficient and resource-conserving technologies in both sectors, thus strengthening Germany's position in international competition.

Funding priorities and scientific advances

Accounting for around two-thirds of total industrial final energy consumption, waste heat is by far the most important research topic in industry from an efficiency perspective. Several studies put the potential of waste heat in Germany at between 88 and 260 terawatt-hours a year. This waste heat can be used directly as heat, or returned to the process. If it is converted into electricity, conventional coal-fired power plants could be replaced by a carbon-free source of electricity. This highlights the importance of the issue for the energy sector. In the Energy in Industry and Commerce Research Network, the Federal Ministry for Economic Affairs and Energy has pooled all the effective and efficient research into this key issue in the research field Waste Heat. The priority fields of tribology, manufacturing technology, high-temperature superconductivity, iron and steel and chemical process technology are also pooled together in separate research fields.

In the total of seven research fields, the Federal Ministry for Economic Affairs and Energy facilitates a scientific dialogue, long-term research cooperation and programmatic developments under the umbrella of the Energy in Industry and Commerce Research Network. Key topics in research and development in industry, commerce, trade and services can be pooled for a period of several years, and niche topics can also be mapped via the network.

In the EniGlas research project, researchers have developed an innovative project for melting special glass. The key finding: in order to improve efficiency further, the current process, which mainly takes place in a single melting tank, must be divided into steps which are kept as separate as possible, and then the energy input must be optimised for each step. It seems likely that the findings made by EniGlas can also be transferred to the manufacture of soda-lime glass, i.e. the mass-produced glass from the hollow and plate glass industry.

Digitalised production is increasingly coming to the fore in the industrial sector. It can ensure a high level of transparency and can flexibly control processes, including in the context of new business models.

In the PHI Factory research project, scientists at Technische Universität Darmstadt (Darmstadt Technical University) are researching how an energy-efficient factory with demand side flexibility can reduce the burden on the power grid. They are developing new solutions in which the amount of energy obtained by factories can vary over time and adapt to the current grid capacity. The aim is to control the factory electricity grid in a flexible manner, making it possible to regulate the input of energy in line with the needs of future distribution grids with high proportions of regenerative energy, and increasing energy efficiency across the system. In addition to demand side management, the team of researchers is developing and studying ways to improve grid quality and to integrate distributed generation and storage systems into energy management.

Cross-system solutions need to be further developed in research and development work on complex processes. Simulation and deeper scientific understanding can replace certain test series so that new processes, closer to the energetic optimum, can be found more quickly and more cheaply.

The SynErgie Kopernikus project also highlights the opportunities of digitalisation in industry (see chapter 2.4.2). In this project, companies, research establishments and civil society stakeholders are working together to increase the flexibility of industrial processes. Targeted production control adapts the energy demand of factories to the fluctuating generation from renewable sources. Suitable ICT enables this control to function automatically and in line with the needs of companies and the electricity market. This results in a stabilisation of the electricity grid, an increase in the share of renewable energy, and new business models for energy-intensive companies.

Project funding

In the field of industry, commerce, trade and services, the Federal Ministry for Economic Affairs and Energy provided approximately 44.59 million euros in funding for 434 ongoing projects in 2017. Also, the ministry appropriated approximately 55.03 million euros in funding for 130 new research projects in 2017 (see Fig. 9).

2.2.2 Energy in buildings and cities

In Germany, buildings account for about one third of total energy consumption and carbon emissions. The aim of a virtually climate-neutral building stock by 2050 can only be achieved through a dovetailing of energy efficiency measures and renewable energy. Over 4.6 million homes have been built or modernised to be energy-efficient since 2006, representing nearly 271 billion euros in total investment. 13 per cent of heat consumption was covered by renewable energy in 2015 – the 2014 figure was 12 per cent. This means that the 2020 target (14 per cent) will soon be attained.

The Federal Government's Energy Efficiency Strategy for Buildings shows how the building stock can be made virtually climate-neutral by the middle of the century via improvements in energy efficiency and the use of renewable energy. Buildings and cities must become an integral element of the sustainable, smartly controlled energy system of the future which minimises energy consumption, optimises the supply of electricity, heat, cooling and mobility from renewable sources, and strengthens interactions between the sectors.

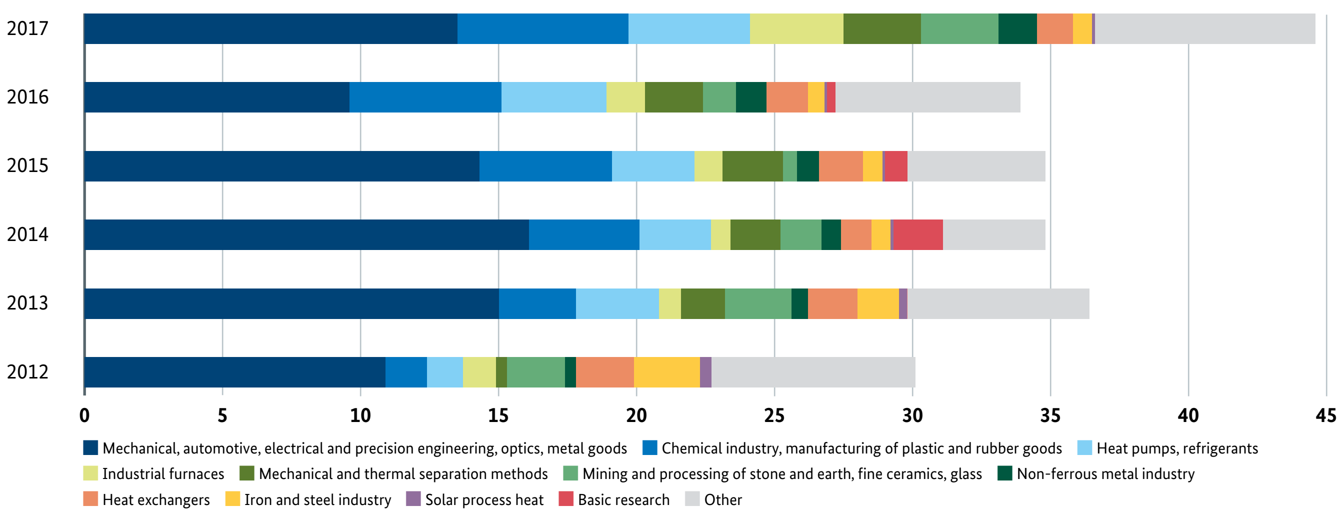
Funding priorities and scientific advances

If buildings and cities are to be able to interact with the grids flexibly and in line with their needs, and to deliver generation, energy storage and distribution functions in the energy system, further supportive advances in technology and research and development work will be needed. The focus of the research funding is on the areas of energy-optimised construction, low-temperature solar thermal energy, thermal storage, research on energy-efficient heating and cooling networks, the integration of solar energy into heating networks, and research into energy-efficient cities. Here, the work is increasingly concentrating on the integration of the sectors of electricity, heating and transport, and the systematic interaction of different energy technologies.

An example is the project entitled *EnEff:Stadt Energienetz Berlin* (energy efficient city Berlin energy network), which brings heating, cooling and regenerative electricity together in a smart way and thus makes it possible to build up a forward looking and flexible supply structure at Europe's largest high-tech centre. By 2030, primary energy consumption for the Adlershof technology park is to be cut by 30 per cent. The networked flows of energy make it possible to build up a forward looking and flexible supply structure, a smart grid alliance, which has been optimised in a targeted manner using forward looking and sustainable technological planning.

Cross-sectoral energy research has long played a crucial role in the field of buildings and cities. The study of integrational ideas and concepts, and the participation of all the relevant stakeholders, for example in living labs, are

Figure 9: Project funding Energy efficiency in industry, commerce, trade and services in million euros
(see table 3 for data)



therefore key elements of *ENERGIEWENDEBAUEN* ('energy transition construction'). This research initiative pools all the activities for research, development and demonstration in the field of buildings and cities.

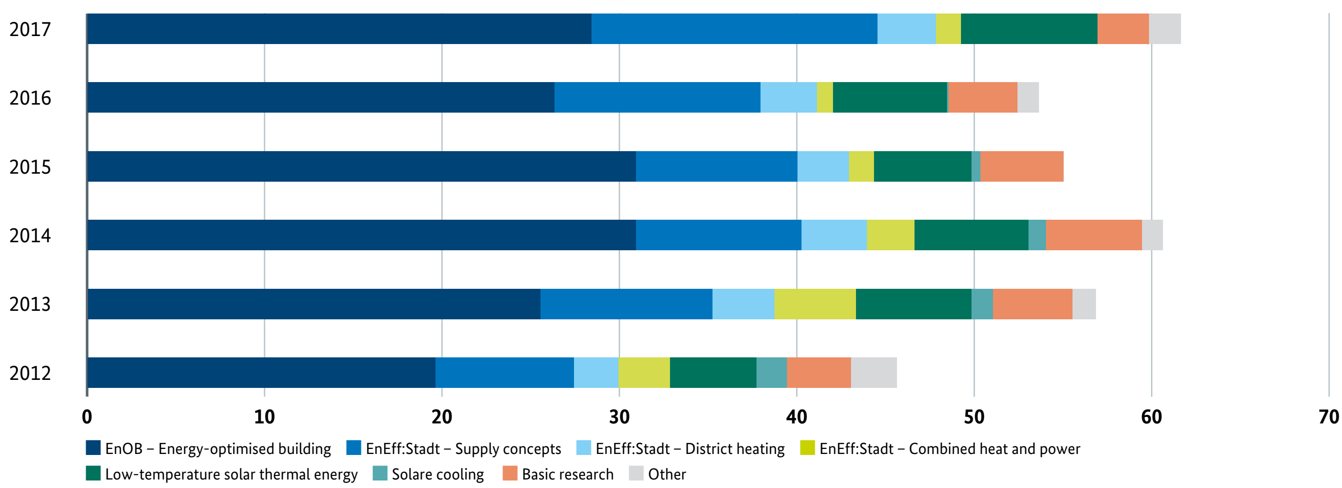
The *ENERGIEWENDEBAUEN* research network (previously called Buildings and Cities) brings together all the stakeholders in the sector. Analyses and conclusions from all the ongoing projects, and new fields of research, trends and potential are being made transparent in the digital 'map of projects'. Further events under the umbrella of the research initiative, such as think tanks, symposia and workshops, are establishing links between the research, industry and policymaking communities.

The joint call for proposals of the Federal Ministry for Economic Affairs and Energy and the Federal Ministry of Education and Research entitled Solar-powered Buildings/ Energy-efficient Cities has made it possible to launch six systematically designed flagship projects at neighbourhood level. These projects aim to show how innovation and smart integration of energy systems can help to create highly energy-efficient and liveable houses and neighbourhoods. The living lab projects, which have been set up to last five years, aim to pursue holistic energy concepts from research to implementation, and to involve all the relevant stakeholders in the work. In the former Pfaff AG factory compound in Kaiserslautern, nine partners are showing how the energy transition can successfully be implemented in urban neighbourhoods whose energy supply is based on a high share of locally generated renewable energy, and which have new buildings as well as listed buildings in need of renovation. In Heide (Holstein), the Quarree 100 consortium with its twenty partners is developing solutions in order to avoid the curtailment of renewable energy and to make local use of this energy. In Oldenburg, the ENaQ – Energetic Neighbourhood project aims to connect not only power, heat and electric mobility, but also local stakeholders and end users. In Zwickau, a consortium of 13 partners is implementing a zero-emission neighbourhood in the ZED project, which is intended to show how apartments based on electrical, thermal interconnected systems can be supplied with energy in a sustainable and affordable way. In Esslingen, a climate-neutral urban neighbourhood called ES-West-P2G2P will enable cross-sectoral use to be made of regenerative electricity surpluses through a combination of innovative technologies.

The Federal Government is providing more than 100 million euros for the interministerial Module II of the joint call for proposals. In addition to this, in Module I of this call for proposals, the Federal Ministry for Economic Affairs and Energy is providing approximately 20 million euros in funding for the demonstration of concepts to retrofit and build new multi-storey apartment blocks. Eight collaborative projects within Module I began in 2017.

In addition to the activities in the joint call for proposals, the Federal Ministry of Education and Research is also funding basic work for long-term research fields. Little attention has been paid so far to the energy performance of the many historic monuments which are an essential element of our cultural heritage and are of great interest to tourists. The project launched in 2017 entitled Maintenance and Management of Castles, Palaces and Monasteries in Central Germany in the Light of Changing Energy and Climate Factors is the first one to take both a broad and a deep approach to addressing this issue. Long-term retrofitting concepts for these types of buildings are being drawn up, technical solutions developed and work equipment provided for owners of historic monuments, architects, engineers and authorities.

Figure 10: Project funding for energy efficiency in buildings and cities in million euros
(see table 3 for data)



In addition to this, the Federal Ministry of Education and Research is providing targeted funding for innovation at the material level for applications in the building sector. The Thermostop research project is developing a composite of various nanoparticles to serve as thermal insulation for buildings. This material will possess the insulating properties of commercially available pore-based thermal insulation (for example glass wool or PU foam) whilst also being highly robust in mechanical terms and can therefore be used in the future as a substitute for conventional facade elements.

Project funding

In the field of energy in buildings and cities, the Economic Affairs and Research Ministries provided approximately 61.76 million euros in funding for 655 ongoing projects in 2017. Also, the ministries appropriated approximately 129.96 million euros in funding for 205 new research projects in 2017 (see Fig. 10, p. 25).

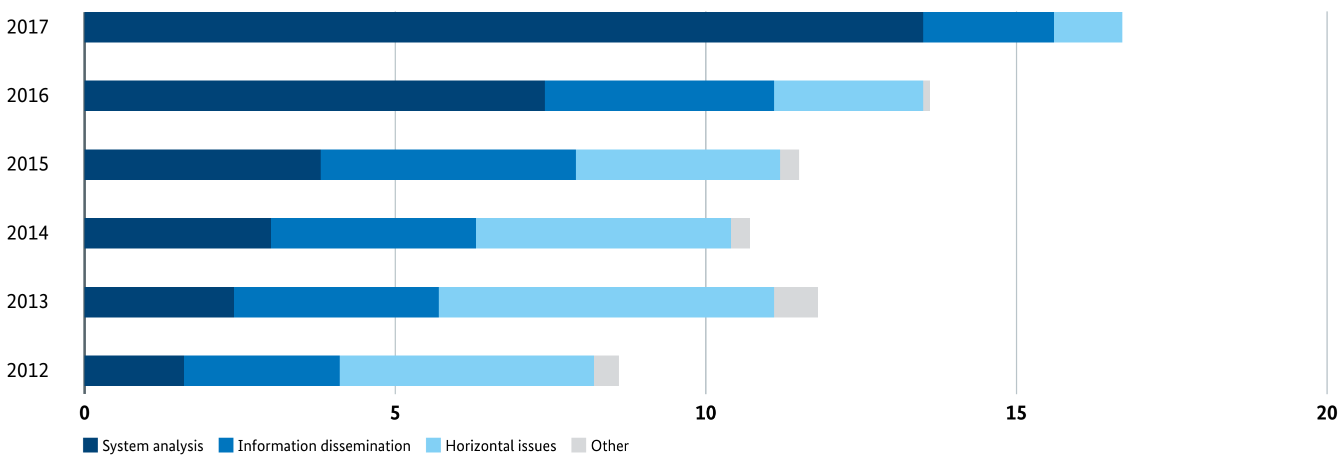
2.3 System-oriented energy research

2.3.1 Energy systems analysis

The generation and distribution structures of the energy supply are becoming increasingly complex. This means that the interplay of all the relevant stakeholders and levels poses corresponding challenges. In the systems analysis, researchers are drawing up answers to how the future system might be designed so that it will be reliable, affordable and environmentally compatible. To this end, scenarios are modelled and simulated, and possible future scenarios are played out on the basis of long-term analyses and a holistic view of the energy system. This permits the analysis of ecological, economic, technical, social and legal repercussions of the introduction of new technologies and makes it possible to evaluate technologies in macroeconomic terms.

With a view to delivering results that are as robust as possible, systems analysis also draws on other scientific disciplines. Against this background, the Federal Ministry for Economic Affairs and Energy provides funding under the systems analysis priority of the 6th Energy Research Programme to a broad base of projects – encompassing engineering, economics, social sciences, mathematics and information technology. The ErdgasBridge and SciGrid_Gas projects are moving the natural gas infrastructure into the focus of systems analytical research – which is believed to offer great potential in terms of coupling the transport, heating/cooling and electricity sectors. SciGrid_Gas aims to develop a freely available model of the German gas grid which can be used by other researchers in systems analytical simulations. The Szenarien_DB project takes a similar line, aiming to create a freely available database of energy scenarios. The aim is to further boost the transparency and comparability of the findings of different energy system models by providing and presenting scenario data in a standardised format. The InNOSys project follows the general trend of focusing more and more on people as a major variable in future energy systems. The intention here is to create a generic tool which can be used to analyse energy scenarios within the three sustainability dimensions of economy, ecology and social aspects. Not least, the systems analysis must also bear in mind that the European neighbours are strongly interlinked and accordingly trade electricity and exchange it across national borders. For this reason, research funding is also devoted to the European energy system. An example is the energy transition Germany EU collaborative project. Possible interactions between Germany and its European neighbours are being studied in various scenarios up to 2050.

Figure 11: Project funding for horizontal issues and system analysis in million euros
(see table 4 for data)



Open source software will continue to play a central role, as it offers great potential in terms of helping people to understand findings, improving individual systems, and establishing standards and interfaces. Sector coupling is also playing an increasingly significant role. For example, consideration is already being given to how gas grids can function as storage facilities for surplus electricity – in an energy system in which renewables will cover a relatively high share.

Project funding

In the field of energy systems analysis, the Federal Ministry for Economic Affairs and Energy provided approximately 13.54 million euros in funding for 118 ongoing projects in 2017. Also, the ministry appropriated approximately 17.19 million euros in funding for 39 new research projects in 2017 (see Fig. 11, p. 26).

2.3.2 Energy storage

Energy storage covers a broad range of technologies and applications for all areas of the energy system. There are therefore many different developments for stationary and mobile solutions in the various areas of deployment; many different types of storage will be used in future. Storage offers possibilities for electric mobility and the coupling of the electricity, heating/cooling and transport sectors. Home storage facilities for photovoltaic installations support higher self-consumption of renewable energy. Also, storage facilities make it possible to cope with grid congestion and create flexibility options in a supply system into which renewable energy is fed intermittently depending on current weather conditions. Energy storage can already offer the answer to local factors, for example where up to 80 per cent of the electricity in the grid of distribution system operators derives from renewable sources. Finally, in the energy system of the future, storage can generally play a central role if, overall a high proportion of renewable energy is integrated into all sectors of supply. If that is the case, it will be possible to accumulate large amounts of surplus electricity from times when there is a lot of wind and sun, and then to use it at times when the opposite is the case.

Funding priorities and scientific advances

In 2017, 33,500 home storage systems for photovoltaic installations were newly installed in Germany, and the market is growing rapidly. Most systems use lithium-ion batteries. However, it has so far been difficult or impossible even for expert fitters to assess the safety of the systems, particularly in terms of their long-term behaviour. In order to close this gap, the Federal Ministry for Economic Affairs and Energy has been funding the SPEISI and SafetyFirst collaborative projects since 2014 and 2015 respectively. A major outcome was achieved in 2017, with the publication of guidelines. These provide comparative criteria for the safety of photovoltaic storage systems for the first time and are to be adapted to fit the situation in other countries in the near future.

Going much further than direct storage of electricity in homes with photovoltaic installations, there is also the conversion of electrical energy into hydrogen or natural gas and the use of the energy content in various sectors, for example the gas industry or mobility. The Federal Ministry for Economic Affairs and Energy funds various projects in which the technologies needed for efficient sector coupling are being developed. The Energiepark Mainz project to develop and demonstrate flexible PEM (polymer electrolyte membrane) electrolysis was completed successfully in 2017. It was launched under the energy storage call for proposals, which has since expired, and shows that the technology can be used to provide system services for the electricity grid.

A post-electrolysis methanisation stage is required if the hydrogen is to be converted into methane. Biological methanisation is one possible process. The ORBIT project network was launched in July 2017 and will study and optimise the use of a bio-trickling filter for biological methanisation.

In future, research into energy storage will focus more on the issue of power-to-fuel: some 20 new projects on alternative fuels are starting from 2018 in the context of the call by the Federal Ministry for Economic Affairs and Energy entitled Energy Transition in Transport published in 2017. These include methanol, ethanol, OME, kerosene, synthetic natural gas and biogas containing hydrogen.

The Federal Ministry of Education and Research funds projects of applied basic research to pave the way for the energy storage of tomorrow. The funding is broad-based, ranging from batteries to thermal storage and concepts for hydrogen, methane and synthetic fuels. In addition to participation in the Energy Storage call for proposals, storage is also covered by the Materials Research for the Energy Transition call for proposals. One example is the R2R project's research into an aluminium solid state battery, which could achieve four times the charge density of lithium. This would potentially enable a car to travel two to six times as far compared with commercial lithium-ion batteries. In view of the mature production and recycling industry, costs could be cut by a fifth compared with lithium systems. The project also shows how applied basic research can create options for the future, because the potential of this battery concept was identified in the predecessor project called ChryPhysConcept. Energy storage is also covered by large-scale Federal Ministry of Education and Research projects such as Carbon2Chem and Kopernikus P2X. Other research into storage can be found in, for example, the programme entitled From Material to Innovation.

A characteristic of the Federal Ministry of Education and Research's funding is the focus on providing groups of young scientists with up to five years' funding, enabling outstanding young scientists to build up their own research. Success stories in the field of energy storage also bear witness to the importance of this funding instrument: Prof. Volker Presser and Prof. Fabio La Mantia are now working as professors at Saarland and Bremen Universities.

Project funding

In the field of energy storage, the Ministry for Economic Affairs and Energy and the Ministry of Education and Research provided approximately 49.7 million euros in funding for 429 ongoing projects in 2017. Also, the ministries appropriated approximately 54.89 million euros in new funding for 116 research projects in 2017 (see Fig. 12).

2.3.3 Electricity grids

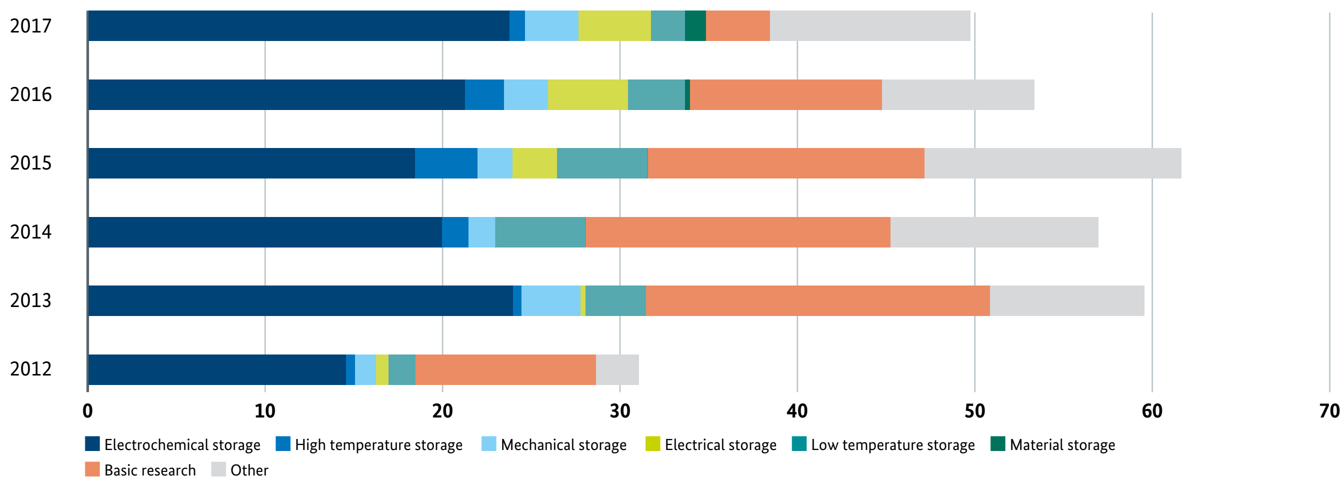
Due to the energy transition, controlling the energy system is becoming more and more complex. The system will be radically restructured in the coming decades. The demands placed on transmission and distribution system operators are also rising. Above all, the electricity grids need to become flexible and proactive in order to safeguard the electricity supply in future. The grids need to become more flexible in particular because, given an ongoing rise in electricity from renewable energy sources, they are having to cope with more and more intermittent feed-in of electricity. This is because the wind and the sun do not deliver a constant supply of energy, but one which depends on the weather. Also, electricity is being fed in from more and more distributed installations of different sizes. The grids need to become proactive so that they can remain stable in this context, and maintain frequency and voltage. A particularly important role here is played by solutions for extended possibilities for control and by information and communication technology. The operation of smart grids will require both innovative technology and new business models. Flexible operating strategies and smart demand-side management can make it possible to integrate more renewable energy whilst maintaining grid stability. Also, there is a need for further research, for example into a safe and efficient use of the enormous quantities of data deriving from an increasingly flexible and automated energy system.

Funding priorities and scientific advances

The building of new renewable energy installations goes hand in hand with increasingly intermittent feed-in and less precise forecasts. For this reason, a priority in the Federal Ministry for Economic Affairs and Energy's applied project funding is placed on coping with the increasing dynamism in the electricity grid. It is forcing control centres to respond more rapidly and precisely to events in order to maintain system security.

The "DynaGridCenter" project is focused on the next generation of grid control centres and smart HVDC control technology. This makes it possible to monitor operational statuses in real time and for the system to self-regulate. Grid operations can be kept stable because this type of smart control technology detects problems or faults quickly and automatically and responds accordingly. In March 2017, the researchers opened a unique test lab in which it will be possible to test prototype control centre functions in future.

Figure 12: Project funding energy storage in million euros
(see table 4 for data)



Another major challenge is posed by the distance between the locations of electricity generation and consumption, which can often be considerable. Direct current technology permits low-loss and economic transport of electricity at the high voltage level across large distances and makes it easier to integrate electricity transport routes. It is also easy to control.

The E²HGÜ project aims to optimise various technical elements of high voltage direct current (HVDC) transmission. The team of researchers is therefore developing and evaluating innovative equipment for use in transeuropean HVDC grids. At the site of TU Dortmund, a partner in the project, a HVDC test centre is under construction as part of this project. The groundbreaking ceremony took place in March 2017. In future, it will be possible to improve and verify HVDC components, equipment, test patterns and models. The results of the research work are to feed into new components which make it possible to optimise the design of HVDC equipment.

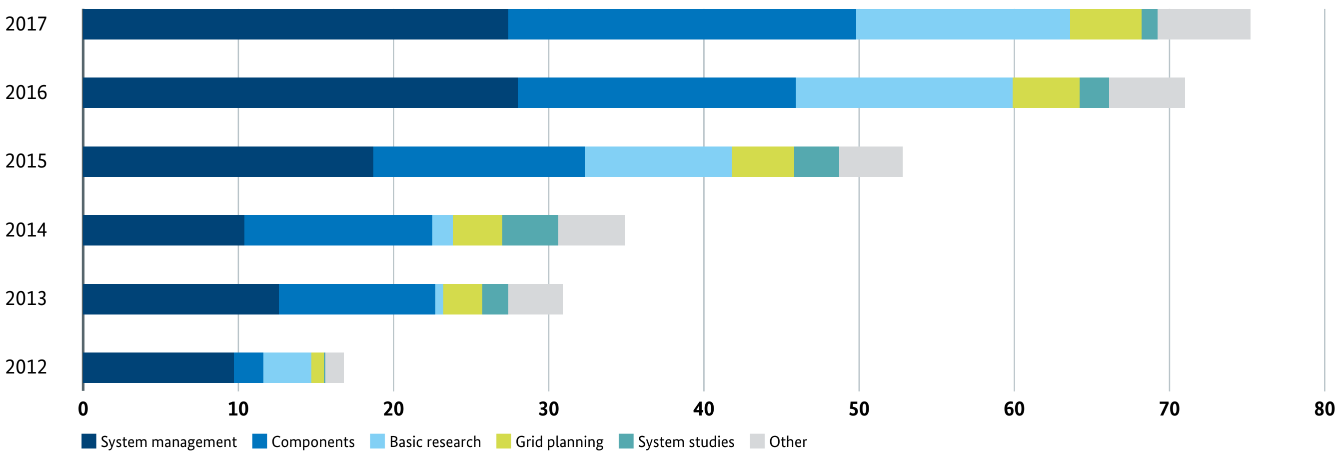
Intensive funding is also going towards cooperative projects at EU level, for example in the context of the Smart Grids Plus ERA-Net, an example of successful cooperation with European partners on smart electricity grids.

Electricity Grids for the Future

In order to optimise the grids, the Federal Ministry for Economic Affairs and Energy and the Federal Ministry of Education and Research launched the Electricity Grids for the Future call for proposals as part of the 6th Energy Research Programme. In this call for proposals, the Federal Ministry for Economic Affairs and Energy is funding 242 projects with a total amount of up to 104 million euros. The funded projects cover the priority areas of grid planning, operational grid management, and the development and integration of components and equipment into the energy system. One of the projects funded by the Federal Ministry for Economic Affairs and Energy is Star-StroP, a collaborative project, which is devoted to maintaining frequency stability in the grid. The increasing amount of renewable energy is leading to a growing number of inverters in the overall system which convert electricity from DC sources like wind energy installations into alternating current before it is fed into the grid. However, the inverters need assistance if they are to meet stability requirements on a very small time scale. At present, the only established solutions are for certain time scales and downtimes lasting several seconds. Solutions are now to be developed for very rapid responses at the microsecond or millisecond level, optimised for the parallel operation of inverters.

As part of this call for proposals, the Federal Ministry of Education and Research is funding research projects in the fields of simulation/modelling, grid expansion planning, operational management and monitoring, and materials and component development. The overarching goal is to make optimal use of the grid infrastructure in order to minimise the necessary grid expansion. The focus is on various aspects, such as system stability, protecting the grid, and automation.

Figure 13: Project funding for power grids in million euros
(see table 4 for data)



One example from the field of components is the HV-SiC project, which studies the use of silicon-carbide (SiC) transistors. The focus is on converters which are attached directly to the medium voltage grid without 50/60 Hz transformers. The use of new SiC semiconductors permits clear improvements in efficiency to be achieved along with reductions in costs. SiC transistors can be used at higher operational voltage levels, with lower switching resistances, shorter switching times and higher operating temperatures. In order to demonstrate the advantages of SiC-based power electronics, the project is using the optimised components to build a three-phase 100kW converter offering power factor correction.

In the field of simulation-based projects, SwarmGrid aims to use a novel, collective balancing approach ('swarm behaviour') to intensively involve distributed systems in operational grid management. The provision of system services to improve system stability is to entail minimal communicative effort.

The Ministry of Education and Research's funding in the field of electricity grids is being continued in the Kopernikus project ENSURE (New energy grid structures for the energy transition, chapter 2.4.2) and in the Flexible Electrical Grids Research Campus (chapter 4.3.4).

Project funding

In the field of electricity grids, the Federal Ministry for Economic Affairs and Energy and the Federal Ministry of Education and Research provided approximately 75.23 million euros in funding for 621 ongoing projects in 2017. Also, the ministries appropriated approximately 55.17 million euros in funding for 92 new research projects in 2017 (see Fig. 13, p. 29).

2.4 Horizontal issues

2.4.1 Energy Transition Research Alliance of Industrial Community Research

The possibilities offered by the Energy Transition Research Alliance, which is part of the programme cooperation of Industrial Community Research (IGF), are targeted at small and medium-sized enterprises (SMEs) in industrial value chains, permit access to practical research findings, and support research cooperation in sectoral and cross-sectoral networks. The findings from the assisted projects are available to all companies at the same conditions.

Funding priorities and scientific advances

The programme cooperation of the Energy Transition Research Alliance of the Industrial Community Research is designed to develop orientational knowledge and technological platforms for entire sectors or for cross-sectoral use. Based on the project results, companies can develop company-specific solutions for new or markedly improved products, processes and services and thus improve their competitiveness. The spectrum of research topics is diverse, ranging from supply of district heating to flexible lithium-ion cells or innovative facade elements for energy-efficient buildings. There is particular interest in projects to digitalise the energy transition and for smart sector coupling.

Project funding

In the field of the Energy Transition Research Alliance of Industrial Community Research, the Federal Ministry for Economic Affairs and Energy provided approximately 2.52 million euros in funding for 23 ongoing projects in 2017. Also, the ministry appropriated approximately 8.71 million euros in funding for 21 new research projects in 2017.

2.4.2 Kopernikus projects

The Kopernikus projects, which are mission-oriented and scheduled to last ten years, cover the key issues of storage, grid structures, industrial processes and system integration. They develop medium-term to long-term prospects for the energy transition in these fields. In this way, they help to make the move from basic research into applications. At present, more than 250 research facilities, companies and associations are working in the four Kopernikus projects.

In the Kopernikus project entitled ENSURE, new grid structures are being developed and tested which deliver robust energy security even when there are great fluctuations in the amount of electricity generated by wind and solar energy. A key goal of ENSURE is to find out how central and distributed supply components can best work together in an overall system in terms of technical, commercial, ecological and social aspects, and how large the respective shares should be. The main focus in the first year of the project was on identifying technical challenges which will face the electricity grids of the future.

The P2X Kopernikus project aims to make it possible to store peak electricity from renewable energy in a chemical form. The project studies both how fluctuating electricity can be turned into hydrogen and synthetic gas via electrolysis, and also how this synthetic gas can be used to make chemicals. The findings will be demonstrated in real life in the course of the project, for example in a test facility which combines carbon sequestration from the air, electrolysis and fuel manufacturing. Nature Catalysis[2] has already published findings from the project. The chemical processes described in it also form the basis for the Rheticus satellite project. This project aims to build a test facility which can produce 'green' chemicals from carbon dioxide and renewable electricity at low cost and in an environmentally friendly manner, making it possible to store renewable energy for long periods of time.

In parallel to P2X, the two Kopernikus satellite projects PiCK and SPIKE have been launched. PiCK is developing – as an alternative to electrolysis, which is being studied in P2X – a combined plasma membrane process to sequester carbon dioxide. In the course of this, carbon monoxide is created, which can be used correspondingly to manufacture fuels or useful chemicals. SPIKE analyses various PtX technologies and is assessing their potential for integration into industrial processes. It also addresses central issues like the potential for climate change mitigation and the economic viability of PtX processes.

The SynErgie Kopernikus project aims to make industrial electricity demand more flexible in order to bring energy consumption into line with intermittent power generation. It identifies, develops and demonstrates the technical possibilities for increasing flexibility and their social and economic implementation. The smart and automated control of energy-intensive processes stabilises the electricity grids and makes it possible for them to absorb large quantities of renewable energy. A marketing of flexibilities and the optimisation of energy purchasing improves the future prospects of energy-intensive industry in Germany and helps to safeguard jobs. The DisConMelter satellite project is studying an electrical glass melting tank with a flexible energy demand. In addition to the numerous technical challenges, the project is also looking into the social aspects of changes to production such as a shift in working hours. Commercial considerations are being worked on in a dialogue with the SynErgie project partners, and these will feed into recommendations for the future design of the electricity market.

The ENavi Kopernikus project is taking a broad approach to studying social, economic and institutional aspects relating to the transformation of the energy supply. In this way, with the intensive participation of citizens, industry representatives and policy-makers, detailed strategies are being quickly drawn up for the transformation of the electricity system which can be regarded as effective and efficient, as well as acceptable for all sides. ENavi is the largest collaborative social sciences project ever carried out in Germany.

The Federal Ministry of Education and Research has allocated 130 million euros up to the end of 2019 for the first phase of the Kopernikus initiative.

2.4.3 Carbon2Chem

In the Federal Ministry of Education and Research's Carbon2Chem project, leading German companies from the chemical, steel, energy and automotive sectors are joining with leading universities and research institutes to achieve significant cuts in greenhouse gas emissions in the steel industry for the first time. The concept aims not only to use the blast furnace gases created in steel production for electricity generation, but also to convert them into chemical products via cooperation between different industrial sectors. 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 the technical implementation in the steelworks. The initial findings, including on the linking of different plant components in distributed co-simulations, were presented in November 2017 at the first conference on sustainable chemical conversion in industry. In the same field, the Federal Ministry of Education and Research's MACOR project is undertaking a comprehensive technical and commercial evaluation of an alternative concept for large-scale integration of direct reduction facilities in an existing smelting process.

2.4.4 Transformation of the energy system in a socially acceptable manner

The energy transition is resulting in far-reaching consequences not only for the energy system, but for the economy and society as a whole. However, the energy transition will only be a success if the population's needs and expectations – not least in terms of aspects of participation and fairness – are reflected appropriately and the needs of the market are considered. For this reason, the Federal Ministry of Education and Research provided approximately 30 million euros from 2013 on for 33 projects in which scientists worked with practitioners to develop specific solutions for an environmentally and socially compatible energy transition. All of the projects developed recommendations for policy-makers, industry representatives and citizens or provided consumers and municipal decision-makers with the tools for an optimised approach to the new challenges. For example, the DZ-ES project produced key ideas and insights for the study 'What's next for the expansion of wind energy?' by Agora Energiewende. The last groups completed their work in 2017.

2 T. Haas, R. Krause, R. Weber, M. Demler, G. Schmidt, „Technical photosynthesis involving CO_2 electrolysis and fermentation", Nature Catalysis 2018, 1, 32-39. https://doi.org/10.1038/s41929-017-0005-1.

2.4.5 Materials research for the energy transition

The development and improvement of materials for use in energy generation and utilisation is of key significance for the energy transition, as it forms the basis for innovative energy technologies. The new materials are to improve the efficiency of energy generation and open up applications for renewable energy sources, for example through load flexibility or the use of renewable fuels. It continues to be important to use energy more efficiently. For this reason, the Federal Ministry of Education and Research successfully launched the priority field of Materials Research for the Energy Transition in 2013. This call for proposals, which is oriented to basic research, is technology-neutral and covers all aspects of the energy sector. The focus of the funding is on photovoltaics, wind energy installations, power plant technology, energy storage, insulation materials, fuel cells and electrolysis. As a result, this call for proposals covers a broad range of fundamental projects working on the basic materials for a large number of further developments in the field of technologies for energy generation and utilisation for the energy transition.

To support the development of upcoming scientists, seven groups of young scientists are being funded within this call for proposals. Dr Lars Borchardt, the director of the Mechanocarb group of young scientists, was recognised as one of the top ten innovators under 35 in Germany by the magazine 'Technology Review' for his research into an environmentally friendly process permitting the manufacture of porous carbons which serve as electrodes for batteries and condensers, making use of materials like renewable raw materials and waste products. The materials offer great potential as electrode materials for forward looking technologies like supercapacitors, lithium-sulphur batteries and fuel cells.

The Max Planck Society's PSUMEA-2 project, which aimed to develop a high-performance membrane for HT-PEM fuel cells, was successfully completed in 2017. The new membrane already reaches comparable power densities and efficiencies to the membranes which have been optimised over many years and are established on the market. In combination with the new processing technology, the new membrane material offers the potential to combine better characteristics with lower manufacturing costs. The PSUMEA-3 follow-up project is continuing the highly promising work into this highly innovative membrane in collaboration with other partners from science and industry starting 2018 with funding totalling around 877,000 euros.

2.4.6 Dissemination of information (BINE Information Service, FONA)

The BINE Information Service

The BINE Information Service fosters the transfer of innovations via specialised information for energy experts. New concepts and technologies from outstanding, applied energy research projects are being processed and disseminated: major findings and experience are being passed on to architects, planners and decision makers in the construction industry, in the real estate industry and in municipalities, to the many different stakeholders in the energy sector and in industry and commerce, as well as to higher education institutions and specialist media.

Major issues, projects, news and events relating to research in a wider context are communicated in an informative and easy-to-understand way in various formats. All of the BINE information service's publications can be obtained via www.bine.info and are also actively distributed by newsletter (currently around 20,000 subscribers), mailshots, media work and social media.

The websites about specific research priorities and research initiatives of the Federal Ministry for Economic Affairs and Energy and interministerial calls for proposals of the Federal Government can present these to the respective audiences, industrial sectors and research communities in targeted ways. The websites on research relating to the energy transition in building, energy efficiency in industry, power plant research, energy storage and electricity grids are designed and edited by the BINE Information Service.

Suggested links:
- www.energiewendebauen.de
- www.eneff-industrie.info
- www.kraftwerkforschung.info
- www.forschung-energiespeicher.info
- www.forschung-stromnetze.info

Fona.de

The Federal Ministry of Education and Research's framework programme Research for Sustainable Development (FONA) draws up innovative solutions for current challenges and provides a basis for decision-making for forward looking action. There are three main initiatives – energy transition, green economy and the city of the future – and energy research enjoys political priority in them. The spectrum ranges from basic research to the development of applications ready for deployment. The website www.fona.de offers information about sustainability research along with the various measures and their results, addressing a specialist audience, science journalists, and the interested public.

2.5 Nuclear safety research

The highest safety requirements apply to the operation, decommissioning and disposal of nuclear power plants and research reactors, and also to the final storage of radioactive waste. For this reason, Section 7d of the Atomic Energy Act requires that the 'advancing state of the art of science and technology' must apply. To achieve this, the law attaches outstanding importance to research and development in these fields.

The nuclear safety and waste disposal research assisted via the project funding of the Federal Ministry for Economic Affairs and Energy undertakes targeted investment in research and development to help create the basis and to keep developing the state of the art and thus to make a substantial contribution towards the creation, development and maintenance of scientific and technical expertise. This remains the case despite Germany's decision to phase out nuclear power generation by 2022, since after that time Germany will still require nuclear technology applications in industry, research and medicine. Similarly, the maximum degree of specialist expertise and the availability of advanced evaluation methods continue to be indispensable preconditions for a science-based safety assessment of nuclear power plants and final storage systems in Germany and abroad.

The Federal Ministry of Education and Research is providing targeted support for the maintenance and expansion of expertise in the fields of nuclear safety and disposal research and radiation research. The focus is on encouraging young scientists. At the same time, the basic research is continuing to network science and industry.

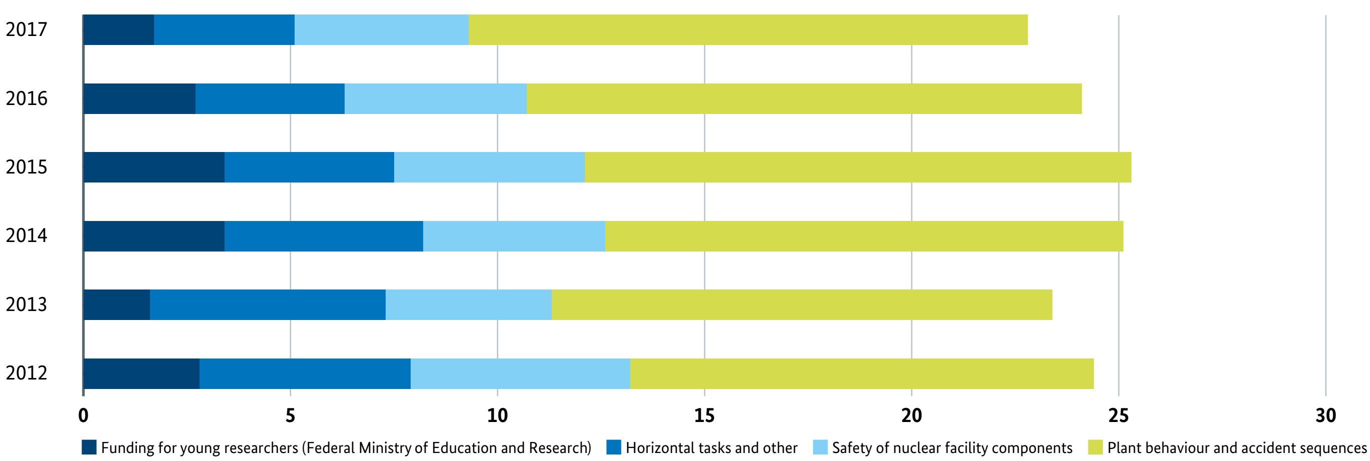
2.5.1 Reactor safety research

Reactor safety research forms part of the state's precautionary activities to protect the population and the environment from the dangers of possible releases of radioactive substances from nuclear facilities. It aims to safeguard the safety concept for German nuclear power plants, also in view of the nuclear phase-out, and to engage in international cooperation to help keep developing the safety standards for nuclear power plants around the world.

The Federal Ministry for Economic Affairs and Energy's initiative Maintaining Expertise in Nuclear Technology (KEK) has been funding young scientists since 1996, and is thus helping to retain scientific expertise in the field of reactor safety. In 2017, the Federal Ministry for Economic Affairs and Energy focused a thematic priority of the KEK initiative on the Safety of Components of Nuclear Facilities. This work involves research into the structural mechanical behaviour of components and structures. The funding is going towards experimental and numerical work including the development of suitable test methods to identify states of damage.

It is of essential importance to have a realistic description of operational processes, faults and accidents in nuclear power plants for the technical safety assessment and for further improvements in precautionary measures to prevent damage. In the field Plant Behaviour and Accident Sequences, the Federal Ministry for Economic Affairs and Energy is funding both experimental and analytical work. In particular, the work is studying the behaviour of the core and the behaviour of faults and accidents in the cooling cycle and reactor containment. In many cases, the funded research is highly integrated with international research, for example in the context of multilateral OECD/NEA activities or the Euratom research programme.

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



Probabilistic safety assessments (PSAs) serve to analyse the course of transients and incidents, taking into account the likely event of different potential factors influencing them. Continuing the development of the methodology forms part of the cross-sectoral tasks within reactor safety research. A number of projects were successfully completed in 2017. These include, for example, innovative work to take account of the way people act, and this is to be covered in greater depth in follow-up activities.

The Federal Ministry of Education and Research backs up the research funding from the Federal Ministry for Economic Affairs and Energy with projects corresponding to funding priorities of the Federal Ministry for Economic Affairs and Energy which deepen and develop scientific expertise in the field of reactor safety research and serve in particular to provide training. The projects focus on issues relating to the metering characterisation of fluid-structure interactions, the design of passive safety elements and the wet storage of spent fuel elements. No new projects were approved in 2017.

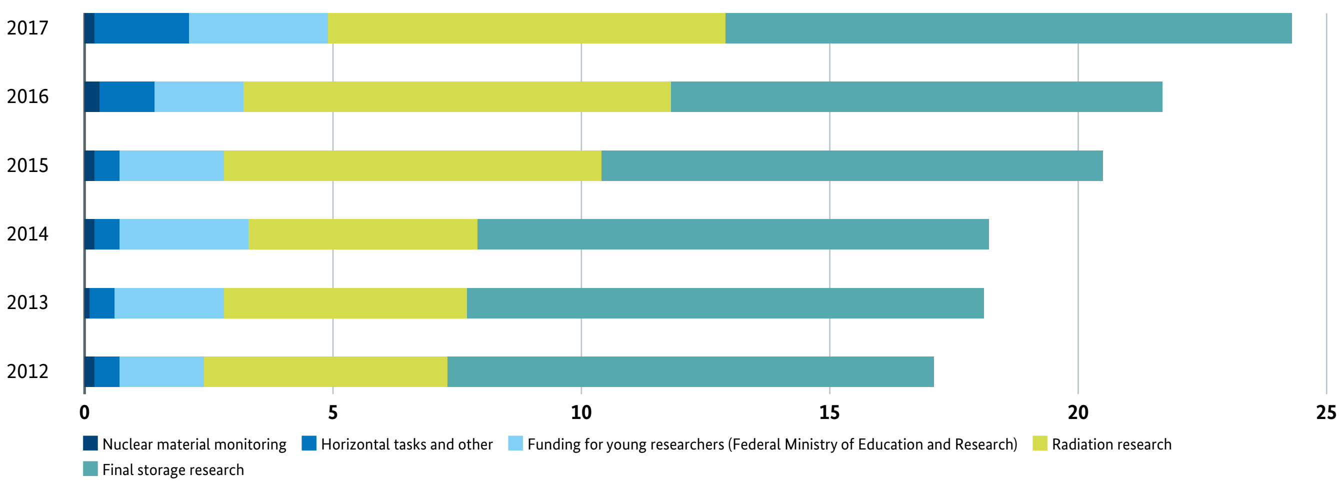
In the field of reactor safety research, the Economic Affairs and Research Ministries provided approximately 22.76 million euros in funding for 159 ongoing projects in 2017. Also, the ministries appropriated approximately 22.52 million euros in funding for 36 new research projects in 2017 (see Fig. 14, p. 33). In 2017, the Federal Ministry for Economic Affairs and Energy funded some 190 scientists (full-time equivalents), and the Federal Ministry of Education and Research funded 13 young scientists.

2.5.2 Research into final storage and disposal of nuclear waste

The lead responsibility for project funding for research into a final repository and disposal rests with the Federal Ministry for Economic Affairs and Energy, and is oriented to the ministry's regularly updated funding concepts. At present, the research is based on the funding concept entitled Research into the Disposal of Radioactive Waste (2015–2018). The concept also reflects the content of the Repository Site Selection Act, the National Nuclear Waste Disposal Programme and EU Directive 2011/70/Euratom. The objectives of the funding are to establish a scientific basis, to develop methods and technologies in line with the state of the art, and to provide knowledge and expertise. The implementation takes place in defined R&D fields in the form of applied, generic R&D projects covering all host rock formations of relevance to Germany (salt, clay and crystalline rock). A significant role in the funding is played by international cooperation and support for young scientists.

The Federal Ministry for Economic Affairs and Energy has consistently expanded R&D field 1, 'Impact of Longer Interim Storage on Waste and Containers'. Six new projects have been approved with a funding allocation of 2.42 million euros, not least as a priority area of the Maintaining Expertise in Nuclear Technology initiative (see also chapter 2.5.1). These are studying a broad spectrum of safety-related issues to assess the long-term behaviour of containers, spent fuel elements and waste, and to improve the management of ageing intermediate storage sites.

Figure 15: Project funding nuclear waste final storage and disposal research[3] in million euros
(see table 6 for data)



3 In previous years, radiation research has been displayed in a separate figure.

In R&D field 2, 'Scientific principles Governing Site Selection', methods and a scientific basis for a selection of a site for a final repository and for the characterisation of geosystems at potential sites are being drawn up. In 2017, three new projects were approved, with funding totalling 0.61 million euros.

In R&D field 3, 'Final Repository Concepts and Technology', projects are being funded to study conceptual, methodological and technical aspects. In 2017, seven new projects were approved, with funding totalling approximately 4.3 million euros. These include projects relating to sealing and locking systems in clays and rock salt, as well as questions relating to the development of final storage containers.

In R&D field 4, 'Proof of safety', funding is being provided for R&D projects to develop basic knowledge to provide proof of safety. This includes experimental work, theoretical model-based studies and the further development of the instruments to analyse safety. In 2017, eleven new projects were approved, with funding totalling approximately 6.61 million euros.

In R&D field 5, 'Knowledge Management and Social and Technical Issues', methods, instruments, processes and potential solutions are being developed for use in the field of disposal/final storage. In 2017, three new projects were approved, with funding totalling approximately 1.23 million euros.

In R&D field 6, 'Monitoring nuclear materials', the project funding from the Federal Ministry for Economic Affairs and Energy promotes projects relating to conceptual, technical and methodological, as well as political and institutional issues. In view of the global significance of the topic, these are embedded in national and international research networks (Euratom, IAEA). No new projects were approved in 2017.

International cooperation is an important element of the project funding provided by the Federal Ministry for Economic Affairs and Energy, and is also viewed as an important aspect in the Ministry's funding concept. More than a third of all the R&D projects funded in 2017 are directly or indirectly related to international cooperation activities.

Training is another important aspect of the funding provided by the Federal Ministry for Economic Affairs and Energy, with its importance for the maintenance of expertise. At present, around 80 young scientists are receiving funding as part of the ongoing R&D projects of the Federal Ministry for Economic Affairs and Energy.

The Federal Ministry of Education and Research backs up the research funding from the Federal Ministry for Economic Affairs and Energy with projects mapping the subjects in the R&D fields of the funding concept of the Federal Ministry for Economic Affairs and Energy which deepen scientific understanding in the field of waste disposal research and in particular which help to train up young researchers.

One research project (TRANSLARA), which covers experimental studies on the migration and accumulation of radionuclides in near-surface soil and its transferral into plants, has been newly approved, with funding of approximately 2.3 million euros.

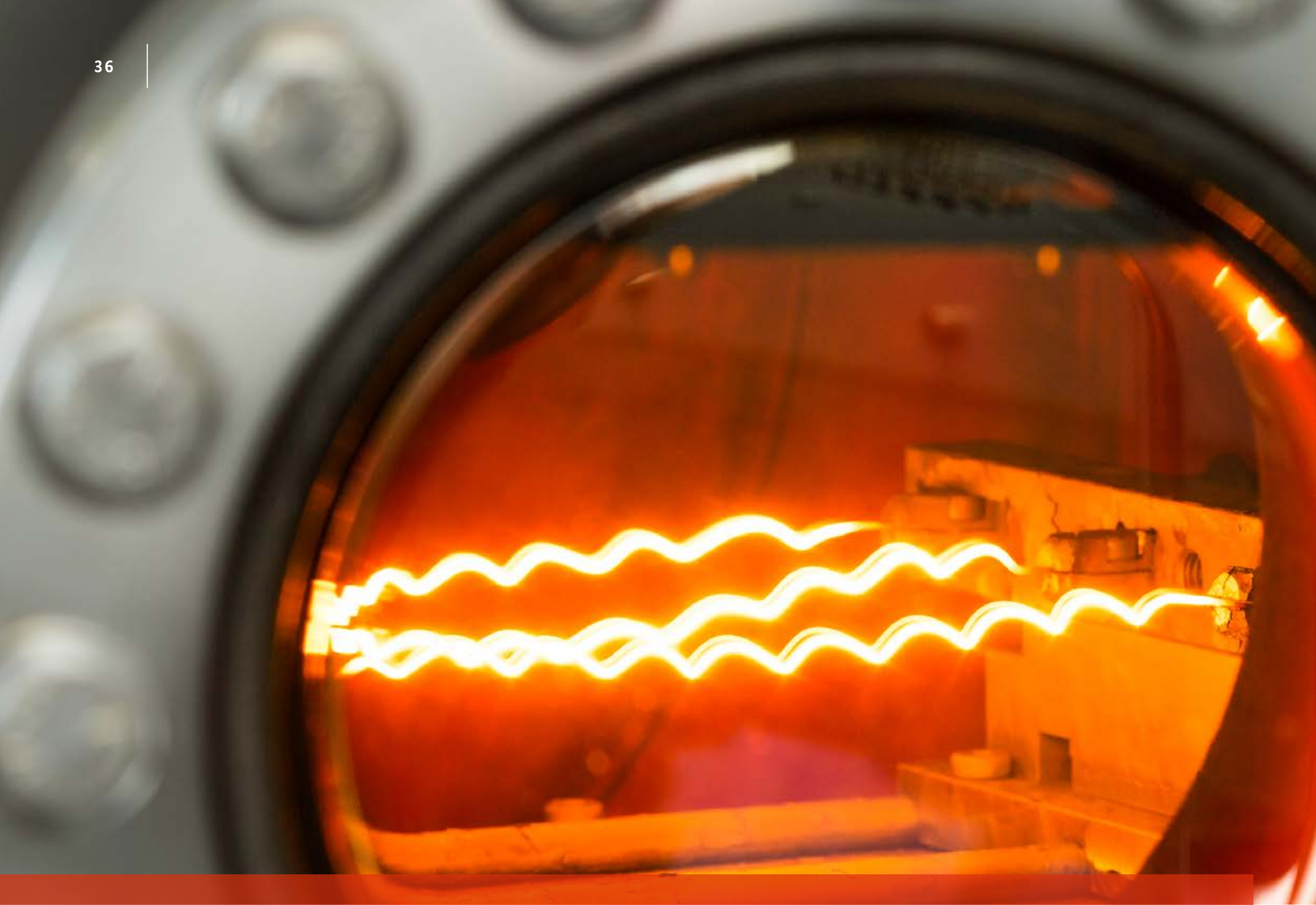
In 2017, the Federal Ministry of Education and Research provided funding to 43 young scientists in the field of waste disposal research.

In the field of final repository and waste disposal research, the Federal Ministry for Economic Affairs and Energy and the Federal Ministry of Education and Research provided approximately 16.33 million euros in funding for 110 ongoing projects in 2017. Also, the ministries appropriated approximately 17.52 million euros in funding for 35 new research projects in 2017 (see Fig. 15).

2.5.3 Radiation research

Under the radiation research priority, the Federal Ministry of Education and Research spent 8 million euros on funding 73 projects in 2017 regarding radiation biology, radiation medicine and radiology (see Fig. 15). A total of 10.1 million euros was appropriated for four new research groups (16 projects).

In 2017, funding went to 140 young scientists.



3. Institutional energy research

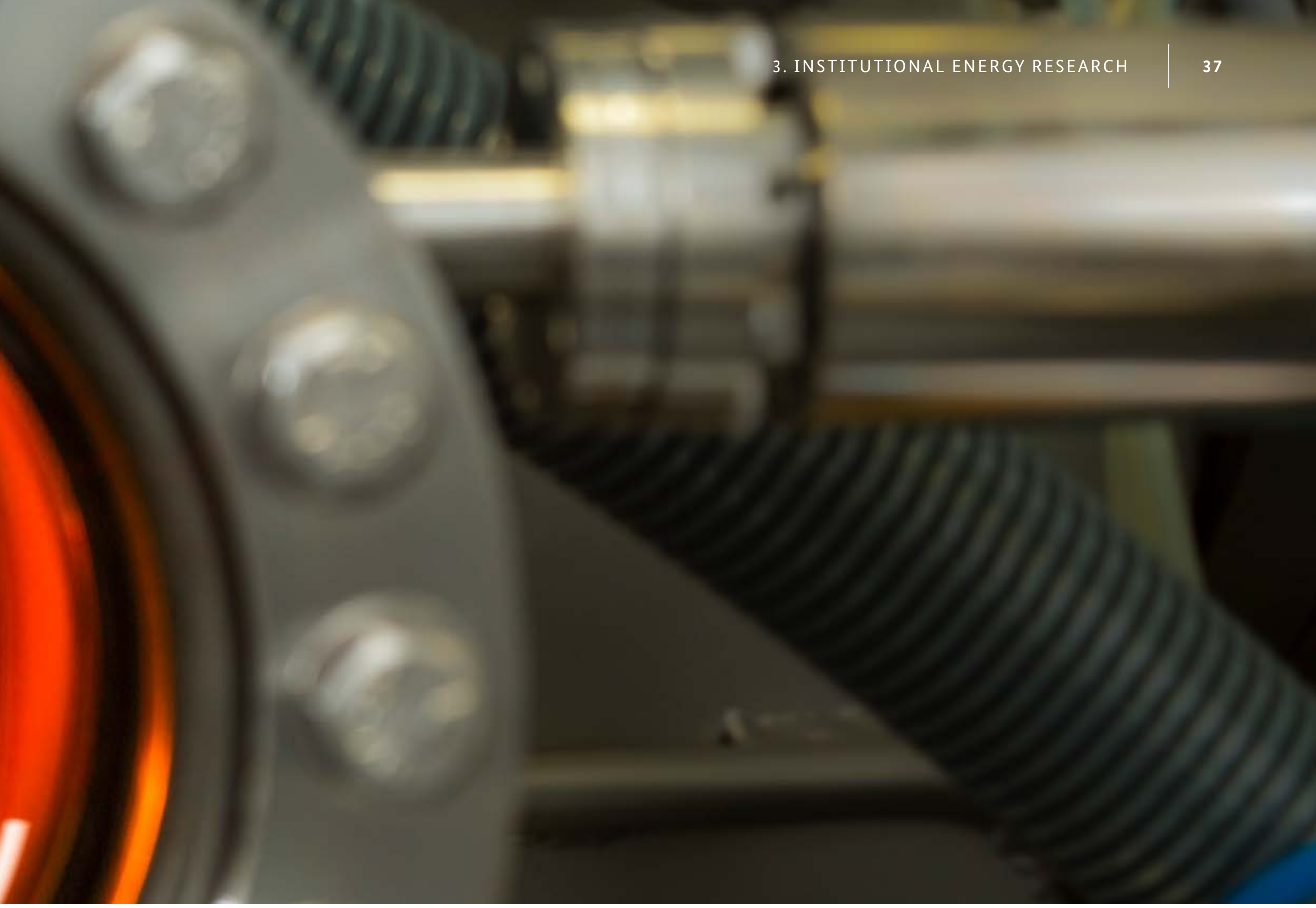
3.1 Energy research by the Helmholtz Association

Energy research at the Helmholtz Association of German Research Centres (HGF) aims to deploy cutting-edge interdisciplinary research to find answers to the great challenges of our time. Advancing climate change is the main challenge addressed by its programme of energy research. Both basic and applied research is undertaken. The strategic orientation of the research field energy is based on a comprehensive and systemic approach to researching and developing energy technology along the entire value chain. In addition, research into energy systems aims to improve understanding of the often complex interactions and thus to the success of the energy transition. The latter particularly takes place as part of the Energy System 2050 initiative.

The work taking place in the context of the current third period of programme-oriented funding (POF III) is structured in seven research programmes: 1. Energy efficiency, materials and resources, 2. Renewable energy, 3. Storage and networked infrastructure, 4. Future information technology, 5. Technology, innovation and society, 6. Nuclear waste disposal, safety and radiation research, 7. Nuclear fusion.

Eight Helmholtz centres are participating in the energy research: the German Aerospace Center (DLR), the Karlsruhe Institute for Technology (KIT), the Jülich Research Centre (FZJ), the Helmholtz Centre Berlin for Materials and Energy (HZB), the Helmholtz Centre Dresden-Rossendorf (HZDR), the Helmholtz-Centre Potsdam – GFZ German Research Centre for Geosciences (GFZ), the Max-Planck Institute for Plasma Physics (IPP) and the Helmholtz Centre for Environmental Research (UFZ).

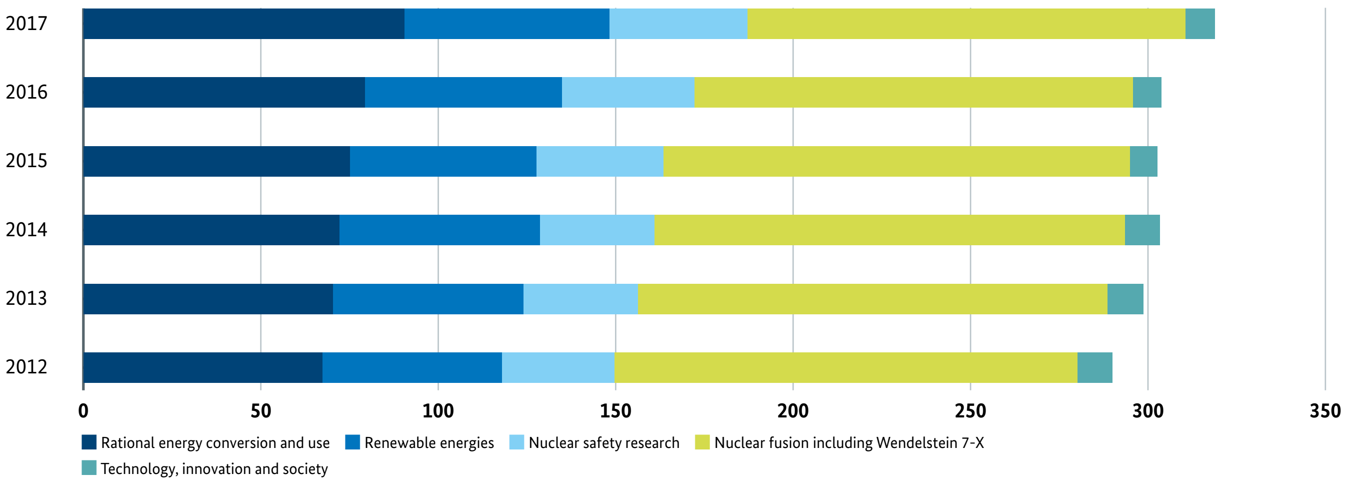
With a total of more than 38,000 staff and an annual budget of approximately 4.4 billion euros, the Helmholtz Association is Germany's largest scientific organisation. Around 16 per cent of the staff work in the research field energy, and the annual budget for energy research exceeds 600 million euros. Of this, approximately 200 million euros is third-party funding, with a large proportion of the fund-



ing coming from public-sector project funding. 90 per cent of the institutional funding for the centres is provided by the Federal Government, the remaining 10 per cent coming from the *Länder* in which the centres are based. With the exception of the DLR, the research centres are funded by the Federal Ministry of Education and Research. The DLR is funded from the budget of the Federal Ministry for Economic Affairs and Energy. Figure 16 provides an overview of the funding of various topics in the context of institutional energy research from the federal ministries participating in the 6th Energy Research Programme.

Based on recommendations made by the Council of Science and Humanities in 2015, a new governance structure was developed for the Helmholtz Association in 2017. In future, there will be three governing bodies at the level of

Figure 16: Disbursements for topics of energy research within the Helmholtz Association in million euros (see table 7 for data)



the research programmes. **The Management Board** serves as a communication, information and strategy platform for the centres involved in the energy research programme. In the **Research Programme Platform**, the centres and the grant providers discuss and take decisions in consensus about tasks to be completed in the research programmes. The **Strategic Advisory Council** provides independent external scientific advice for the research programme, the Senate and the President. These measures are intended to further strengthen the programmatic orientation of the research programme as set out in the recommendations by the Council of Science and Humanities.

The Council of Science and Humanities also proposed a retrospective scientific evaluation. This began in the autumn of 2017 and was finished in April 2018. The findings of this evaluation will form the basis for a strategic evaluation along with the research policy requirements of the grant providers and the programme drafts. This will provide the basis for the fourth period of programme-oriented funding (POF IV).

The Helmholtz Association's energy research programme is characterised by large-scale, unique research infrastructure which is developed and used in the various centres and made available to other scientists. These include in particular the Energy Lab 2.0, the Helmholtz Energy Materials Foundry (HEMF), the Helmholtz Energy Materials Characterization Platform (HEMCP), the Dresden Sodium Facility for Dynamo and Thermohydraulic Studies (DRESDYN), the Research Center for Gas Turbines and the Wendelstein 7-X fusion research facility. New facilities opened in 2017 include the Energy Materials In-Situ Laboratory (EMIL), the Living Lab Energy Campus (LLEC) and Synlight, the world's largest artificial sun.

3.2 Fusion research

The Federal Government believes that the growing demand for energy resulting from the rise in the world's population and the need to cut carbon emissions create the necessity to continue research on a technology-neutral basis, including basic research, in long-term energy research concepts.

Most of the funding for research into fusion is provided via the programme-oriented funding of the Helmholtz Association. This programme involves the Max-Planck-Institute for Plasma Physics (IPP), the Karlsruhe Institute for Technology (KIT) and the Jülich Research Centre (FZJ). These research institutes dispose of outstanding scientific expertise in the international comparison. Large-scale equipment like the Tokamak ASDEX Upgrade and the Stellarator Wendelstein 7-X, both at IPP, and the High-temperature Helium Loop (HELOKA) and the testbed for superconductive components (TOSKA), both at KIT, mean that Germany can draw on infrastructure which is unmatched around the world.

The work done by IPP, KIT and FZJ is integrated into Euratom's European fusion research programme. The IPP coordinates the EUROfusion consortium, founded by 29 national fusion centres in 26 EU countries and Switzerland, which provides the new central structure for European fusion research. The IPP itself is one of the world's leading institutes.

At European level, Germany, as a member of Euratom along with all the other EU Member States, is funding the construction of the International Thermonuclear Experimental Reactor (ITER) in Cadarache (southern France). Euratom represents Europe in the ITER Council as one of the seven project partners (Europe, Japan, USA, Russia, China, South Korea and India). German industrial companies are realising technologically challenging contracts for the establishment of ITER, are boosting their international competitiveness, and are profiting from the cooperation with the research centres and universities. German firms and research institutes have so far won contracts for ITER worth around 580 million euros (as of December 2017).

4. Other energy-related funding activities

4.1 Research funding by the German states (*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. All of the reports on this funding can be found online at https://www.ptj.de/ueber-uns/unseregeschaeftsfelder/ energie/arbeitsgruppe-energiestrategie/ laenderbericht-energieforschung.

The latest survey, for 2016, says that spending by the *Länder* on project funding and institutional funding totalled more than 248 million euros (see Fig. 17, p. 40). According to the Federal Ministry for Economic Affairs and Energy, the corresponding funding at federal level amounts to nearly 665 million euros. Total public-sector funding for non-nuclear energy research in 2016 thus amounted to more than 913 million euros.

Research funding for regenerative energy amounted to a total of 110.9 million euros, and is thus at a high level but lower than the volume seen in previous years. Photovoltaics leads the field, at 27.3 million euros, with the highest amounts of funding coming from Baden-Württemberg (13.7 million euros), Bavaria (6.8 million euros) and Lower Saxony (2.7 million euros). Research into biomass (11.8 million euros) is mainly funded in Bavaria (6.6 million euros) and Lower Saxony (2.1 million euros). Compared with the previous year, funding for wind energy technology dropped sharply (from 12.3 to 4 million euros), with the largest amounts coming from Bavaria (1.3 million euros) and Bremen (1 million euros). The field of research of geothermal energy (4.7 million euros) requires the presence of suitable geological conditions, and is generally restricted to Lower Saxony (2.2 million euros) and Bavaria (1.5 million euros).

Figure 17: Spending by the *Länder* on non-nuclear energy research 2008-2016 in million euros
(see table 8 for data)

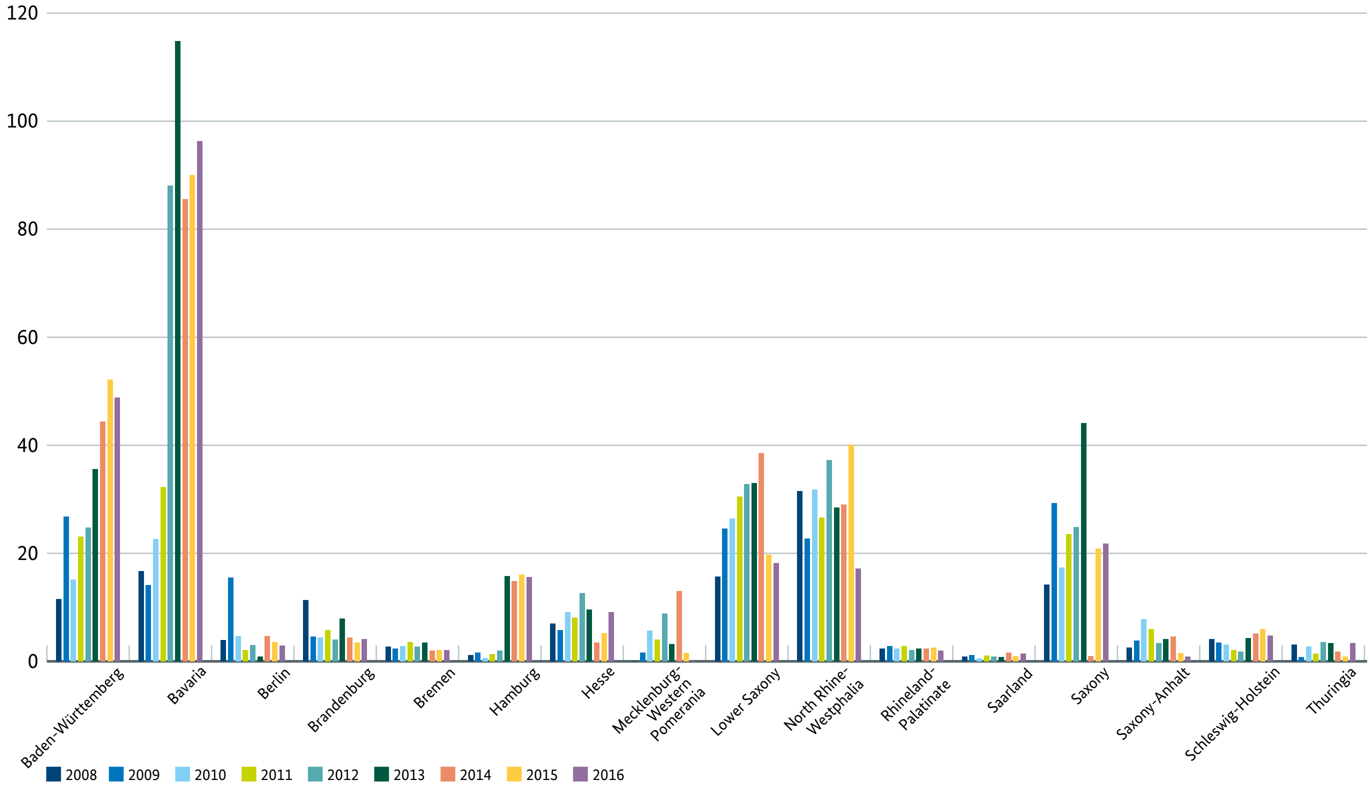
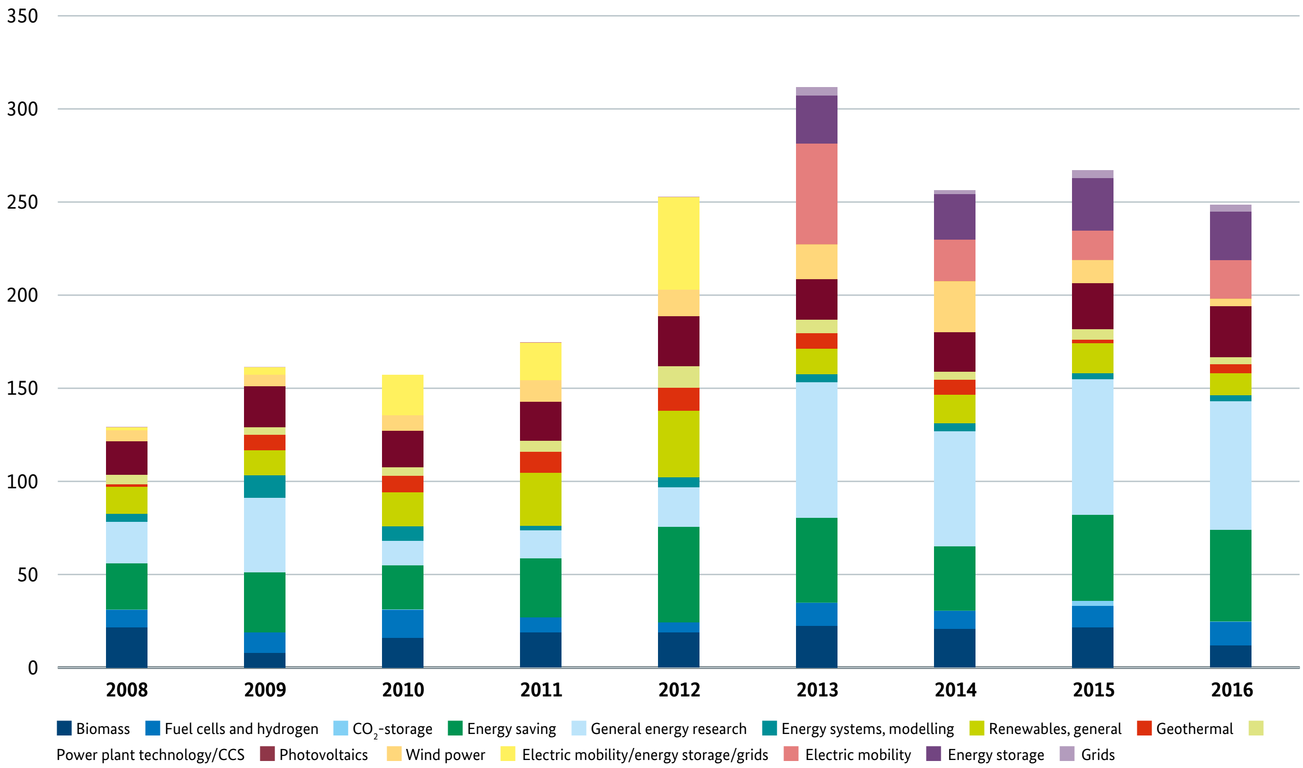


Figure 18: Spending by the Länder on non-nuclear energy research by topic 2008-2016 in million euros
(see table 9 for data)



A breakdown of the figures for other energy technologies shows that funding for energy storage research (26.3 million euros) maintained the 2015 level, whilst more funding went into electric mobility (20.7 million euros) and slightly less into electricity grids (3.6 million euros) than in 2015.

Research work into conventional power plant technology is only funded in a few of the *Länder*. Significant funding was provided by Bavaria (1.9 million euros) and North Rhine-Westphalia (1.2 million euros).

Funding for research into fuel cell and hydrogen technology rose slightly from 2015, to 12.8 million euros, and is a major aspect of research funding in Bavaria (5.4 million euros).

Research into energy systems analysis and modelling is mainly focused on the provision of valid energy scenarios, and *Länder* funding for this amounts to 3.3 million euros.

With their funding of more than 248 million euros, the *Länder* are making a major contribution towards the achievement of the energy policy goals relating to the energy transition, and are providing more than a quarter of total public-sector spending in the field of non-nuclear energy research.

4.2 European Union Framework Programme for Research (Horizon 2020)

Aim and scope of EU research funding

In order to increase Europe's economic potential and to safeguard its global competitiveness, the European Union has pooled its efforts to promote research and innovation in the Horizon 2020 multi-annual framework programme. Approximately 80 billion euros are available for the programme, which runs from 2014 until 2020. An important element of the programme is the Societal Challenge Clean Secure and Efficient Energy.

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. The development and implementation of measures to tackle the societal challenge of energy is increasingly linked to other European (Energy Union and Strategic Energy Technology Plan – SET-Plan) and international (Mission Innovation, Sustainable Development Goals – SDGs, IEA, IRENA) strategies in the energy sector. Transnational and interdisciplinary projects involving cooperation with stakeholders from science and industry as well as users of innovative energy technologies will make substantial contributions towards attaining the agreed goals in the field of energy and climate policy. The efforts are concentrated on improving energy efficiency, making increased use of renewable energy sources, integrating energy systems intelligently at regional and international level, improving the orientation to the needs of the citizens, and optimising energy systems and conurbations, towns and cities and communities.

German applicants successful in the field of energy

In total, around 6 billion euros are available for the Societal Challenge Clean Secure and Efficient Energy during the 2014-2020 programming period. In the period from 2014–2017, approximately 2.4 billion euros were spent on promoting selected projects (including the funding for fuel cells and hydrogen). German applicants received 15.7 per cent or approximately 376 million euros of the funding – a very successful result. Applicants from other states were at best four or more percentage points behind.

In 2016, more than 515 million euros were approved for a total of 111 collaborative projects in the main fields of non-nuclear energy promotion alone – 'Energy efficiency', 'Low-carbon energy' and 'Smart cities and communities'. Germany is represented here by a total of 154 project participants which won funding totalling around 74 million euros. That equates to roughly 14.4 per cent of the funding approved. The largest share of funding is going to Germany, roughly 3.3 percentage points more than is going to the UK and 4.7 percentage points ahead of France (see Fig. 19, p. 43).

Grant recipients from Germany are involved with at least one partner in 64 per cent of all approved projects, and the project coordinator is based in Germany in the case of 16 of the 111 approved projects. Around 43 per cent of the German beneficiaries are based in research institutes and higher education institutions. 49 per cent are based in private-sector companies, and the remaining 8 per cent come from public and other institutions.

The proportion of applicants from Germany is particularly high (67 per cent) 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 per cent) and 'Smart cities and communities' (8 per cent)

Priorities of energy research

Figure 20 shows the distribution of funding to recipients from Germany in 2016 broken down by research field. The figures reflect a clear focus (80.5 per cent) on issues relating to low-carbon energy, and particularly on research and demonstration projects in the field of renewable energy – approximately 58 per cent 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 the building sector, Materials Research and production technologies.

4.3 Activities of the Federal Government outside the Energy Research Programme

4.3.1 EnEff.Gebäude.2050 – innovative projects for a virtually climate-neutral building stock in 2050

The EnEff.Gebäude.2050 – Innovative Projects for a Virtually Climate-neutral Building Stock in 2050 call for proposals fosters the transfer of results from energy research into broad applications. Model innovation and transformation projects aim to show how technology and concepts that are available but not yet established on the market can cut primary energy demand and realise a large number of virtually climate-neutral buildings and cities. The projects draw on current research findings and try out new approaches and ambitious concepts to boost energy efficiency and to use renewable energy in buildings and cities. Within this call for proposals, the Federal Ministry for Economic Affairs and Energy is providing funding of up to 54 million euros for innovation and transformation projects. Competitions which recognise particularly promising concept developments are also part of the call for proposals. In 2017, 10 innovative ideas were awarded prizes totalling 280,000 euros. These included ideas for an international energy competition for buildings and neighbourhoods which present an interesting test area and offer concepts to sustainably integrate the proposed competition sites into the urban environment as living labs.

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

The National Innovation Programme on Hydrogen and Fuel Cell Technology (NIP) has been implemented since 2007 as an interministerial programme together with industry and science. Under the lead of the Federal Ministry of Transport and Digital Infrastructure, the NIP is now being continued in a second phase (NIP 2) from 2016 to 2026, ensuring continuity of the research and development and addressing market activation. NIP 2 aims to make technically mature products and applications competitive. Up until 2019, the Federal Ministry of Transport and Digital Infrastructure is providing approximately 250 million euros in funding for hydrogen and fuel cell technology. The Federal Ministry for Economic Affairs and Energy is continuing to provide approximately 25 million euros a year towards applied research and development in this field under the 6th Energy Research Programme.

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

Within the SINTEG showcases, five large model regions and more than 300 partners are developing and demonstrating scalable model solutions for a safe, efficient and environmentally compatible energy supply with high proportions of electricity being generated from intermittent renewable energies. The programme places a clear focus on building smart networks linking up the energy supply and demand sides, and on the use of innovative grid technology and operating strategies. It thus addresses key challenges of the energy transition including the integration of renewables into the system, flexibility, digitalisation, system security, energy efficiency and the establishment of smart energy systems and market structures. The showcases were selected in a competition and were launched at the end of 2016 or early 2017. The Federal Ministry for Economic Affairs and Energy is providing more than 200 million euros across four years for the projects. Together with more than 300 million euros from companies, more than half a billion euros is being invested in the digitalisation of the energy sector. The programme aims to gather practical experience so that the existing legal framework can be updated. To this end, the Federal Government adopted the SINTEG Ordinance, with temporary experimental options in June 2017. This makes SINTEG a living lab for the smart energy supply of the future.

4.3.4 Research Campus – public-private partnership for innovation

The Federal Ministry of Education and Research's call for proposals 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 euros 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.

Figure 19: Country participation of project partners in the field of Challenge Energy / Horizon 2020 (year 2016)

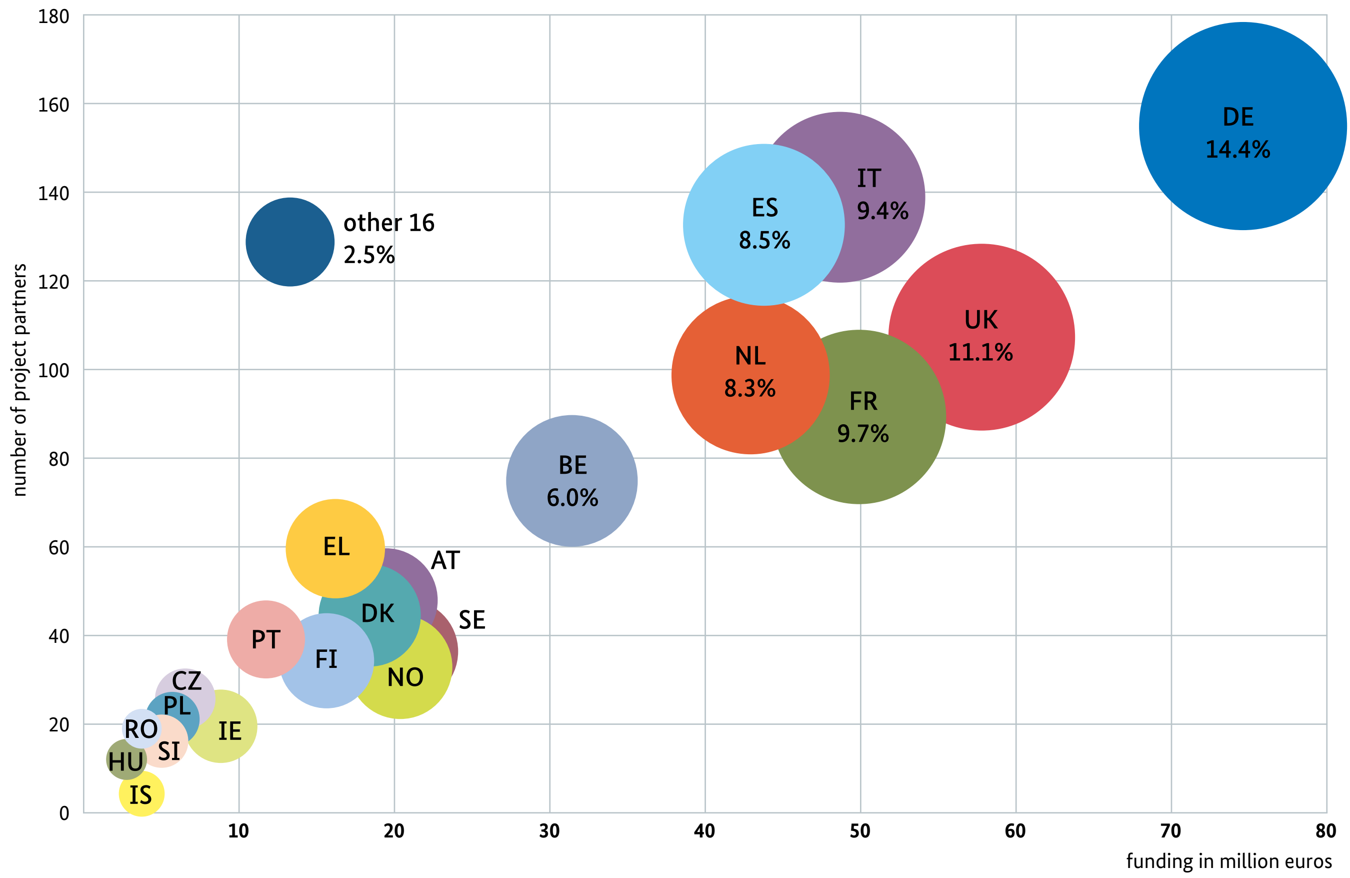
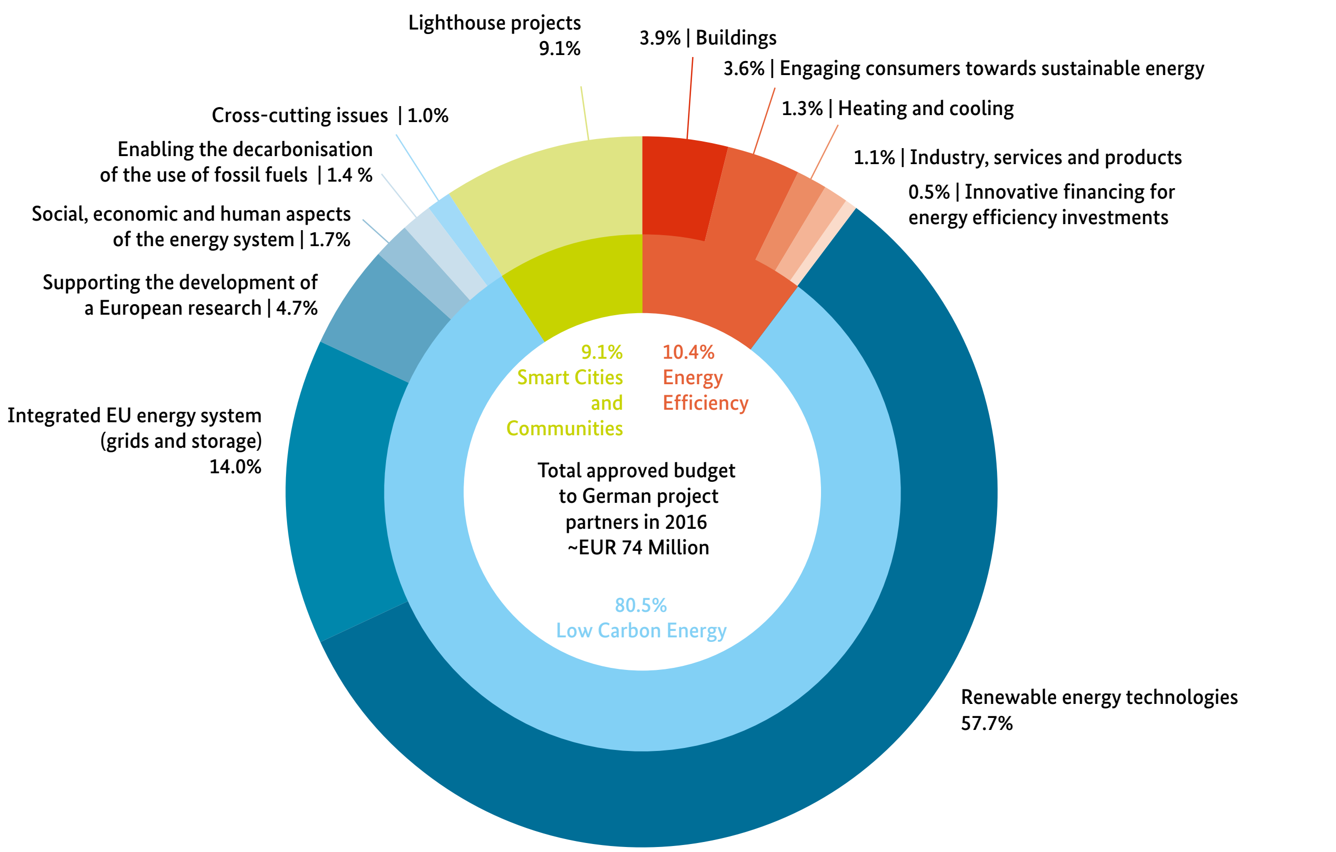


Figure 20: Budget allocation to German project partners in the field of Challenge Energy / Horizon 2020 (year 2016)



4.3.5 From Material to Innovation

The From Material to Innovation funding programme contributed to energy research in 2017. The main focus was on work on electrochemical energy storage facilities, and particularly on secondary lithium-ion batteries and future battery systems. In the second phase of the Battery 2020 call for proposals, new research and development projects have been launched into materials and processes for use in electric mobility. In addition, work intensified in the area of battery cell manufacturing as part of other research and development projects. This addressed both new manufacturing processes and concepts for lithium-ion cells in new cell formats and material and process technologies for solid state batteries. In the From Material to Innovation programme, funding of approximately 53 million euros was granted for research and development projects into electrochemical storage.

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 for the individual funding areas. The data was collected in January 2018.

In addition to this, the number of ongoing projects (including those not yet completed) and the newly approved projects are presented for 2017, as well as the stipulated amounts of funding distributed amongst the following years in line with a typical multi-annual project.

Table 1 | Overview of topics in the 6th Energy Research Programme of the Federal Government

Funding topic	Actual outlays (in million euros)											
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Energy efficiency	110.34	133.95	151.55	189.31	206.13	215.14	239.06	296.64	300.80	317.26	336.09	381.97
Renewable energy	120.23	126.47	152.86	202.01	210.61	221.91	258.85	298.10	303.30	323.33	328.82	418.25
Nuclear safety and waste disposal	54.33	57.58	62.59	70.41	71.93	73.03	74.74	75.62	76.95	82.92	84.44	87.48
Fusion	114.41	121.52	125.58	142.65	131.03	137.44	133.10	138.72	138.14	139.22	126.63	125.73
Total	**399.31**	**439.52**	**492.58**	**604.37**	**619.71**	**647.52**	**705.75**	**809.09**	**819.20**	**862.73**	**875.98**	**1,013.43**

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

Funding topic	Actual outlays (in million euros)						Number of projects		Total funding (in million euros)
	2012	2013	2014	2015	2016	2017	ongoing in 2017	new in 2017	appropriated in 2017
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)	**449**	**104**	**90.71**
Crystalline silicon	30.40	30.51	26.72	36.74	36.99	52.92	248	48	47.75
Thin-film technologies	15.33	12.69	11.31	10.45	8.78	10.69	76	21	16.86
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)	25	1	1.40
Other	5.73	5.53	5.31	12.47	12.05	17.33	100	34	24.70
Wind Power	**38.42**	**52.57**	**53.06**	**53.04**	**49.69**	**75.11**	**354**	**86**	**95.97**
Wind farm development	2.62	15.07	21.93	25.26	18.40	39.80	135	40	36.99
Onshore	0.62	0.51	0.50	1.29	4.10	3.23	13	7	1.79
Offshore	3.34	12.23	12.72	7.98	9.18	11.09	71	14	40.14
Wind physics and meteorology	0.12	1.73	2.33	3.62	3.03	3.06	20	4	1.02
Logistics, turbine installation, maintenance and operation	23.00	12.88	8.39	6.39	8.10	11.18	70	6	1.28

Funding topic	Actual outlays (in million euros)						Number of projects		Total funding (in million euros)
	2012	2013	2014	2015	2016	2017	ongoing in 2017	new in 2017	appropriated in 2017
Environmental aspects of wind power and ecological accompanying research	1.43	2.33	2.64	2.46	2.23	2.48	19	2	3.72
Other	7.29	7.82	4.54	6.04	4.65	4.27	26	13	11.04
Bioenergy	**40.86**	**42.61**	**42.97**	**42.10**	**37.88**	**33.04**	**562**	**177**	**38.61**
(incl. other programmes)	(48.59)	(48.68)	(44.11)	(43.92)	(37.88)	(33.04)			
Production – farming	6.91	6.31	5.98	4.43	4.69	5.70	85	26	7.27
Production – cultivation	4.43	5.25	4.77	4.92	4.49	4.58	83	30	7.44
Conversion – general	–	–	–	0.53	5.22	2.73	51	18	3.30
Conversion – gaseous	4.61	4.87	5.27	6.84	4.92	6.79	103	27	5.22
Conversion – liquid	4.11	6.12	6.19	5.92	3.97	3.21	35	7	1.28
Conversion – solid	2.78	0.94	0.73	1.92	2.23	1.77	33	9	1.78
Horizontal	1.86	3.22	2.85	2.97	2.53	0.94	35	17	6.29
Basic research	8.81	9.99	12.16	9.89	6.17	3.13	20	–	–
(incl. other programmes)	(16.53)	(16.06)	(13.30)	(11.72)	(6.17)				
Use of biomass for energy	7.36	5.91	5.03	4.69	3.66	4.18	117	43	6.04
Deep geothermal energy	**20.82**	**17.10**	**15.55**	**13.38**	**12.54**	**16.49**	**80**	**17**	**8.00**
Surveying and exploration	8.39	7.28	9.13	9.12	6.67	8.06	40	5	2.28
Hot water and steam deposits	4.36	4.97	3.03	2.59	4.61	5.34	14	6	3.08
Hot dry rock	3.69	0.91	0.33	0.45	1.02	3.04	26	6	2.63
Other	4.37	3.94	3.05	1.22	0.23	0.05	–	–	–
Power plant technology and CCS technologies	**27.54**	**31.62**	**29.60**	**28.20**	**28.52**	**32.82**	**326**	**51**	**25.34**
(incl. other programmes)	(28.58)	(35.09)	(30.96)	(28.20)	(28.52)	(32.90)			
Advanced power plant systems	10.76	7.45	6.36	2.41	4.84	5.54	51	9	7.62
Component development	9.18	16.52	18.19	19.19	17.53	21.59	256	42	17.71
Coal gasification	2.39	1.54	1.46	2.80	3.52	4.14	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)			
Other	0.68	2.32	0.74	1.82	1.27	1.55	11	–	–
Fuel cells and hydrogen	**19.47**	**24.88**	**27.16**	**22.32**	**19.69**	**26.50**	**156**	**48**	**32.23**
LT PEMFC	6.15	6.68	9.92	6.43	4.42	6.24	59	11	6.64
HT PEMFC	1.30	1.75	1.21	1.01	0.77	0.99	6	5	3.13
MCFC	0.55	0.14	0.30	1.64	0.82	1.72	2	–	–
SOFC	7.40	11.10	7.84	6.53	4.27	6.73	31	7	5.10
DMFC	0.56	0.34	0.06	-	-	0.14	4	4	1.19
Hydrogen storage	1.98	3.16	2.25	2.36	0.99	1.12	8	14	11.18
Hydrogen production	0.83	0.63	0.30	0.59	2.14	2.86	14	4	1.33

Funding topic	Actual outlays (in million euros)						Number of projects		Total funding (in million euros)
	2012	2013	2014	2015	2016	2017	ongoing in 2017	new in 2017	appropriated in 2017
Basic research	0.71	1.08	3.04	2.10	4.28	4.58	20	3	3.66
Other	–	–	2.23	1.67	2.01	2.12	12	–	–
Solar thermal power plants	**7.45**	**8.41**	**9.25**	**10.09**	**8.58**	**7.73**	**66**	**21**	**5.62**
Parabolic	3.67	2.25	1.84	0.74	2.04	2.90	29	9	2.75
Tower	2.01	2.50	3.59	4.23	2.86	2.63	27	12	2.87
Fresnel	0.68	0.63	0.82	–	–	0.00	–	–	–
Storage	0.30	1.79	1.41	1.85	1.37	1.52	2	–	–
Other	0.78	1.24	1.59	3.28	2.32	0.68	8	–	–
Hydroelectric and marine power	**0.98**	**1.25**	**1.21**	**1.68**	**2.01**	**2.15**	**17**	**2**	**1.21**
Total	**222.62**	**242.02**	**237.14**	**242.06**	**222.90**	**278.30**	**2,010**	**506**	**297.69**
(incl. other programmes)	**(249.99)**	**(269.15)**	**(246.23)**	**(246.22)**	**(224.57)**	**(278.47)**			

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

Funding topic	Actual outlays (in million euros)						Number of projects		Total funding (in million euros)
	2012	2013	2014	2015	2016	2017	ongoing in 2017	new in 2017	appropriated in 2017
Energy efficiency in buildings and cities	**45.81**	**56.76**	**60.55**	**54.86**	**53.60**	**61.76**	**655**	**205**	**129.96**
(incl. other programmes)	(47.74)	(58.94)	(63.53)	(54.86)	(53.72)	(61.80)			
EnOB – Energy-optimised building	19.65	25.50	30.95	30.86	26.33	28.44	322	85	38.42
EnEff:Stadt – Supply concepts	7.85	9.69	9.28	9.06	11.62	16.10	160	65	46.05
EnEff:Stadt – District heating	2.50	3.53	3.75	2.87	3.16	3.35	44	12	3.02
EnEff:Stadt – Combined heat and power	2.93	4.61	2.65	1.39	0.89	1.39	11	–	–
Low-temperature solar thermal energy	4.90	6.47	6.36	5.54	6.43	7.71	70	8	5.87
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	39	35	36.60
(incl. other programmes)	(3.63)	(4.49)	(5.36)	(4.65)	(4.00)	(2.96)			
Research Initiative: The Building of the Future (Environment Ministry) (other programme)	(1.93)	(2.18)	(2.98)	–	–	–	–	–	–
Other	2.62	1.25	1.19	–	1.17	1.85	9	–	–

Funding topic	Actual outlays (in million euros)						Number of projects		Total funding (in million euros)
	2012	2013	2014	2015	2016	2017	ongoing in 2017	new in 2017	appropriated in 2017
Energy efficiency in industry, commerce, trade and services	**30.01**	**36.38**	**34.70**	**34.85**	**33.70**	**44.59**	**434**	**130**	**55.03**
Mechanical, automotive, electrical and precision engineering, optics, metal goods	10.90	14.97	16.07	14.30	9.57	13.54	110	42	17.85
Iron and steel industry	2.42	1.54	0.69	0.67	0.55	0.69	23	14	3.22
Mining and processing of stone and earth, fine ceramics, glass	2.05	2.41	1.45	0.54	1.20	2.76	17	1	1.43
Heat pumps, refrigerants	1.28	2.99	2.58	3.02	3.83	4.45	23	8	6.59
Industrial furnaces	1.19	0.83	0.67	0.99	1.41	3.36	39	14	4.98
Mechanical and thermal separation methods	0.39	1.57	1.79	2.23	2.05	2.82	32	6	2.43
Chemical industry, manu-facturing of plastic and rubber goods	1.52	2.79	4.05	4.81	5.46	6.25	81	26	8.76
Non-ferrous metal industry	0.44	0.56	0.72	0.79	1.09	1.40	10	4	1.38
Heat exchangers	2.11	1.82	1.13	1.61	1.46	1.26	10	–	–
Solar process heat	0.35	0.25	0.10	0.10	0.09	0.08	1	–	–
Basic research	–	–	1.76	0.79	0.32	0.00	1	–	–
Other	7.35	6.64	3.68	5.01	6.68	7.98	87	15	8.39
Total	**75.81**	**93.14**	**95.25**	**89.70**	**87.30**	**106.35**	**1,089**	**335**	**184.99**
(incl. other programmes)	**(79.80)**	**(97.73)**	**(99.68)**	**(90.25)**	**(88.63)**	**(109.14)**			

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

Funding topic	Actual outlays (in million euros)						Number of projects		Total funding (in million euros)
	2012	2013	2014	2015	2016	2017	ongoing in 2017	new in 2017	appropriated in 2017
Horizontal issues and system analysis	**8.60**	**11.70**	**10.82**	**11.46**	**13.67**	**16.79**	**140**	**41**	**20.20**
System analysis	1.57	2.38	3.03	3.75	7.42	13.54	118	39	17.19
Information dissemination	2.49	3.27	3.33	4.09	3.74	2.10	11	1	2.01
Horizontal issues	4.10	5.38	4.13	3.35	2.42	1.15	11	1	1.00
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**	**429**	**116**	**54.89**
(incl. other programmes)	(38.90)	(61.46)	(57.26)	(61.76)	(53.34)	(49.70)			
Electrochemical storage	14.48	23.87	19.86	18.41	21.24	23.71	176	78	41.04
High temperature storage	0.47	0.47	1.52	3.51	2.16	0.92	21	3	2.35
Mechanical storage	1.19	3.26	1.53	1.97	2.48	3.01	26	4	1.10

Funding topic	Actual outlays (in million euros)						Number of projects		Total funding (in million euros)
	2012	2013	2014	2015	2016	2017	ongoing in 2017	new in 2017	appropriated in 2017
Electrical storage	0.74	0.28	0.05	2.48	4.54	4.11	44	9	2.40
Low temperature storage	1.53	3.37	5.13	5.14	3.19	1.86	33	7	3.22
Material storage	–	–	–	–	0.34	1.15	20	11	3.70
Basic research (incl. other programmes)	10.20 (18.08)	19.37 (21.53)	17.21 (17.48)	15.61 (15.77)	10.79 (10.79)	3.60	33	–	–
Other	2.41	8.67	11.70	14.48	8.61	11.34	76	4	1.09
Power grids	**16.74**	**30.95**	**34.88**	**52.85**	**70.93**	**75.23**	**621**	**92**	**55.17**
Components	1.93	10.15	12.12	13.60	17.87	22.44	169	44	25.16
Grid planning	0.78	2.51	3.24	4.00	4.26	4.62	40	6	1.62
System management	9.74	12.62	10.40	18.72	27.98	27.38	259	25	18.01
System studies	0.06	1.68	3.60	2.94	1.90	0.99	5	–	–
Basic research	3.06	0.49	1.26	9.46	14.02	13.77	94	1	0.21
Other	1.17	3.50	4.26	4.12	4.90	6.03	54	16	10.16
Industrial Community Research	**–**	**–**	**–**	**–**	**0.05**	**2.52**	**23**	**21**	**8.71**
Total (incl. other programmes)	**56.35 (64.23)**	**101.95 (104.10)**	**102.69 (102.96)**	**125.90 (126.06)**	**137.99 (137.99)**	**144.23 (144.23)**	**1,213**	**270**	**138.96**

4 In previous years, energy utilisation and energy distribution were listed together. From this year, the issues of energy storage and grids are categorised as system-oriented energy research. The individual figures for the preceding years remain unchanged.

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

Funding topic	Actual outlays (in million euros)						Number of projects		Total funding (in million euros)
	2012	2013	2014	2015	2016	2017	ongoing in 2017	new in 2017	appropriated in 2017
Socio-ecological research (incl. other programmes)	**–** –	**1.18** (3.08)	**3.25** (8.58)	**3.95** (11.11)	**2.64** (4.42)	**0.36** (2.07)	**8** –	**–** –	**–** –
Energy materials	**–**	**–**	**0.72**	**10.41**	**27.87**	**26.68**	**143**	**4**	**0.88**
Kopernikus projects	**–**	**–**	**–**	**–**	**0.40**	**40.16**	**173**	**18**	**4.50**
Carbon2Chem	**–**	**–**	**–**	**–**	**8.64**	**11.84**	**35**	**9**	**2.55**
Project-related fusion research	**2.58**	**6.29**	**5.55**	**7.70**	**3.12**	**2.23**	**1**	**–**	**–**
Other project funding of the Federal Ministry of Education and Research (incl. other programmes)	**7.11** (7.11)	**2.35** (3.23)	**3.93** (3.93)	**3.23**	**4.19**	**5.27**	**13**	**8**	**2.54**
Total (incl. other programmes)	**9.69 (9.69)**	**9.82 (12.61)**	**13.45 (18.79)**	**25.29 (32.46)**	**46.86 (48.63)**	**86.53 (88.24)**	**373**	**39**	**10.46**

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

Funding topic	Actual outlays (in million euros)						Number of projects		Total funding (in million euros)
	2012	2013	2014	2015	2016	2017	ongoing in 2017	new in 2017	appropriated in 2017
Nuclear waste final storage and disposal research	**12.30**	**13.23**	**13.58**	**12.95**	**13.09**	**16.33**	**110**	**35**	**17.53**
Final storage research	9.84	10.39	10.25	10.06	9.94	11.43	74	21	11.52
Horizontal tasks and other	0.54	0.53	0.53	0.54	1.06	1.90	15	9	3.65
Nuclear material monitoring	0.18	0.15	0.19	0.24	0.26	0.21	1	–	–
Funding for young researchers (Federal Ministry of Education and Research)	1.74	2.17	2.61	2.11	1.83	2.78	20	5	2.35
Reactor safety research	**24.38**	**23.43**	**25.10**	**25.22**	**24.06**	**22.76**	**159**	**36**	**22.52**
Safety of nuclear facility components	5.28	4.01	4.38	4.55	4.38	4.20	46	14	6.27
Plant behaviour and accident sequences	11.25	12.09	12.51	13.22	13.37	13.46	73	18	13.35
Horizontal tasks and other	5.08	5.72	4.81	4.05	3.63	3.37	20	4	2.90
Funding for young researchers (Federal Ministry of Education and Research)	2.77	1.62	3.39	3.39	2.68	1.73	20	–	–
Radiation research (Federal Ministry of Education and Research)	**4.91**	**4.95**	**4.61**	**7.58**	**8.58**	**8.05**	**73**	**16**	**10.14**
Total	**41.59**	**41.61**	**43.29**	**45.74**	**45.73**	**47.13**	**342**	**87**	**50.19**

Table 7 | Disbursements in institutional energy research

Funding area	Actual outlays (in million euros)					
	2012	2013	2014	2015	2016	2017
Rational energy conversion and use	67.34	70.34	72.09	75.08	79.34	90.39
Renewable energies	50.75	53.74	56.52	52.46	55.59	57.88
Nuclear safety research	31.64	32.22	32.26	35.76	37.27	38.84
Nuclear fusion including Wendelstein 7-X	130.52	132.43	132.59	131.52	123.51	123.51
Technology, innovation and society	9.92	10.05	9.95	7.75	8.07	8.32
Total	**290.17**	**298.78**	**303.41**	**302.57**	**303.78**	**318.95**

5.2 Funding in energy research by German states (*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. No figures for 2017 are available yet. In 2016, Mecklenburg-Western Pomerania did not spend any of its own money on non-nuclear energy research.

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

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

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

Topic	Disbursements (in million euros)								
	2008	2009	2010	2011	2012	2013	2014	2015	2016
Biomass	21.48	7.79	15.90	18.73	18.71	22.44	20.56	21.53	11.78
Fuel cells and hydrogen	9.47	10.86	15.14	8.11	5.40	12.29	9.82	11.46	12.83
$C0_2$-storage	–	0.11	0.24	0.07	0.21	–	0.02	2.77	0.02
Energy saving	24.86	32.19	23.74	31.66	51.35	45.58	34.73	46.10	49.27
General energy research	22.21	40.20	12.97	14.96	21.01	72.81	61.73	73.03	69.02
Energy systems, modelling	4.48	12.02	7.87	2.46	5.37	4.53	4.33	3.13	3.33
Renewables, general	14.45	13.38	18.09	28.28	35.83	13.50	15.34	15.96	11.94
Geothermal	1.27	8.41	8.86	11.27	12.52	8.43	8.09	2.09	4.70
Power plant technology/CCS	5.09	3.87	4.84	6.09	11.35	7.12	4.25	5.52	3.78
Photovoltaics	18.12	22.17	19.62	20.84	26.95	21.85	21.31	24.81	27.34
Wind power	5.89	6.12	8.26	11.61	14.48	18.60	27.29	12.25	3.97
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
Energy storage	–	–	–	–	–	25.84	24.16	28.12	26.34
Grids	–	–	–	–	–	4.58	2.40	4.33	3.60
Total	**128.87**	**161.14**	**157.11**	**174.39**	**252.78**	**311.74**	**256.56**	**266.99**	**248.63**