Energy Concept 2050

for Germany with a European and Global Perspective

A vision for a sustainable Energy Concept based on energy efficiency and 100% renewable energy

Contribution by the following Institutes:
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Preamble

At the beginning of 2010, the ForschungsVerbund Erneuerbare Energien (FVEE) [Renewable Energy Research Association] was encouraged by the German Federal Environment Ministry to devise a concept for a German energy supply system in the year 2050, which is 100% based on renewable energy. The Energy Concept 2050, which has been developed by 7 of the research association's member institutes, is a contribution to the Federal Government's Energy Concept which is scheduled to be adopted in October 2010. It includes the future energy demand of all areas of use: electricity, heat and fuel.

This Energy Concept should also form the basis for an FVEE paper which will be prepared subsequently, with recommendations on the 6th German Energy Research Programme which should be adopted by the Federal Government at the beginning of 2011.

Chapter 1 introduces the Energy Concept 2050 and shows which technological components are required to facilitate a sustainable, low-cost, secure supply using 100% renewable energy.
Chapter 2 explains which technological transformation processes are needed to implement the Energy Concept 2050.
Chapter 3 describes the importance of research and development for this process.
Chapter 4 provides recommendations for political action which can initiate the process of transformation and/or which can speed this up.

Terminology

- **"Renewable":** The Energy Concept 2050 defines an energy source as "renewable" either if it renews itself in the short-term, or if its use does not contribute to resource depletion. These are then called sustainably available energy resources. This definition applies to all direct solar energies, to indirect solar energies such as wind, hydro power and biomass, and also to geothermal energy and tidal power. According to this definition, nuclear fusion is not a renewable energy.

- **"Sustainability":** The term sustainability is described as a triad of ecology, economics and social acceptability. It is based on the definition of the 2002 final report of the German parliament Enquete Commission "Sustainable energy supply against the background of globalisation and liberalisation", which primarily gave the ecological dimension a certain precedence.

The following points characterise the Energy Concept 2050:

- **A range of options to guarantee supply reliability:** The Energy Concept 2050 describes a reliable, secure, low-cost and robust energy supply on the basis of a variety of renewable energies. Even with lower input or the temporary failure of a technology, this range of renewable energies, whose potential is very much higher than total energy demand, ensures that alternatives are available, so that 100%-supply based on renewable energy is guaranteed in every case.

- **Priority is given to energy efficiency:** Increasing energy efficiency is given the highest priority in terms of strategic requirements: The institutes advocate a substantial expansion in decentralised combined heat

and power (CHP), in order to increase the efficiency of energy use in renewable energy conversion technology. The improvement in the energy performance of the current building stock will largely be concluded by 2050 (see Chapter 1.3.7).

- **Electricity as a mainstay:** Electricity supply and consumption from renewable energy has a central position in the Energy Concept 2050.

- **Chemical energy carriers:** Renewable electricity thus becomes a primary energy, so that chemical energy carriers (hydrogen, methane) can also be derived from it, these are needed in particular for the long-term storage of renewable energy, including for the transport sector. The production of “renewable methane” implies a paradigm shift for energy storage.

- **E-mobility:** Transport in the Energy Concept 2050 is largely covered directly by electricity, or indirectly by electricity being converted into hydrogen or methane.

- **Combined cycle renewable power plant:** The “Combined cycle renewable power plant“ principle (Chapter 1.3.6) is rolled out across Germany, with its systems engineering interaction of renewable energy and energy storage.

- **European interconnected electricity network:** The low loss transmission of electricity over long distances and energy balancing at European level play a key role in the use of fluctuating energy sources.

- **Role of biomass:** The use of biomass for energy is treated as a limited resource. In the medium- to long-term, energy crops should mainly be used for the production of synthetic fuels like kerosene for planes and ships, as well as the production of raw materials for the chemical industry. Energy recovery from biomass waste supplements this concept.

- **Solar heat:** in the Energy Concept 2050, solar thermal collectors make a major contribution to heating drinking water, to space heating, process heat and cooling supply in domestic buildings, and in local, district heating and cooling systems.

- **A high level of use with costs remaining relatively constant:** with optimal design, the Energy System 2050 is economically no more expensive than the current system. This is because of the link between the technological components described in the Energy Concept 2050, with the effects of learning and experience, and a cost/benefit analysis (Chapter 2.5).

Introduction

Renewable energy has the greatest energy and technical potential of all known sources of energy. It is environmentally- and climate-friendly, it can be used worldwide, in a few years time it will be the cheapest source of energy, and it enjoys an extraordinarily high social acceptance. Renewable energy is a domestic source of energy and can gradually reduce the use of coal, oil, natural gas and nuclear energy in the power and heat market, and in the long term it can replace these completely and permanently. For this reason it reduces dependence on energy imports, increases the country's energy added value, and creates jobs.

In the last two decades, technological achievements in research and development, based on an energy policy framework which ensures a high degree of investment security for the market introduction of new technologies, has made the use of renewable energy in Germany more efficient and more sustainable.

While transforming the current energy system into a sustainable energy service economy based on renewable energy, electricity, as the central component of this economy, is becoming more and more "green". This is linked to a paradigm shift in power plant operation and the market, integrating renewable energy into the network and the system: away from the previous base load philosophy, based on large centralised fossil and nuclear power plants, to an increasingly large share for decentralised, fluctuating energy from renewable sources, which can be supported by a variety of measures: gas-fired power stations that can react quickly, combined heat and power plants linked to virtual power stations, load and generating management processes linked to smart grids, and efficient storage technologies.

Efficiency technologies become much more important when linked to renewable energy. This is because the goal of a high share of renewable energy in the overall energy supply can only be achieved if in the medium-term more of the existing technical and economic efficiency potential is developed. In the area of space heating, this includes the construction of low-, passive or even energy-plus houses.

In the transport sector, in the medium- and long-term, electromobility will become an important element in climate-friendly mobility, if the electricity for this is completely supplied by renewable energy. If car batteries are integrated bi-directionally into the power network, these can be used to increase security of supply. Electromobility is supplemented by using hydrogen and methane, and fuel for cars and planes which is derived from this.

These developments are happening because politics gives climate protection a high priority. In particular, the targets and requirements set by the EU and the Federal Government have significantly improved opportunities to develop renewable energy and energy efficiency technologies.

In the last 20 years, the consistent policy of market introduction in Germany, together with a long-term research and development policy, has led to a quicker than expected market and technological developments. This remarkable progress shows that if the innovation dynamic is sustained, by 2050 an energy system can already be realised in Germany which is 100% based on renewable energy and energy efficiency.

Examples of technological advances in recent years

- **Energy efficient construction:** significant reduction in demand for heating, cooling, ventilation and lighting in buildings by increasing efficiency in civil and systems engineering (low energy, 3-litre and passive house).

- **Combined Heat and Power:** Increase in efficient energy supply and use by the possible combination of renewable energy technology with combined heat and power (CHP), or with heat pumps.

- **Photovoltaics:** Continuous cost reduction by an average of 7% per year in the last 10 years by increasing efficiency, the more efficient use of materials and new production technologies [1].

- **Solar thermal power plants:** Development and construction of solar thermal power plants with large energy storage [2].

- **Electromobility:** Developing electromobility and the related opportunity to be able to also use renewable energy efficiently in transport.

- **Biomass:** Development of the polygeneration process to use energy from biomass, to produce electricity, heat, cooling and fuel.

- **Hydrogen:** hydrogen production by high temperature electrolysis with efficiencies of up to 80% [3].

- **Fuel cells:** fuel cells are being tested in large-scale field tests for use in energy supply in buildings, in private transport and in local public transport.

- **Renewable methane:** New conversion technology, to produce renewable methane from renewable electricity and CO_2. The gas network can thus be used directly as a large store for renewable energy. (see Chapter 1.2.3.3).

- **Combined cycle renewable power plant:** the development of combined cycle renewable power plants for the coordinated interaction of different RE technologies.

- **Offshore wind power plants:** the development of the use of offshore wind energy with a new generation of installations and improved forecasts of wind power output based on energy and meteorological methods.

- **Network integration:** the development of inverters, which will increasingly take over system services for network stabilisation. Accurate forecasts for predicting the output from wind and solar power plants.

- **Smart Grids:** The development of smart grids in conjunction with smart metering: Intelligent distribution grids for power linked to time-of-use tariffs for load management [4].

- **Solar heating and cooling:** increase in the efficiency of solar thermal collectors and systems for supporting space heating. Development of the use of process heating and solar thermal cooling.

- **The solar active house:** development of a solar active house, which is 50% to 100% heated by thermal solar collectors [5])

The successes of innovative technological development have contributed towards constant advances in the energy policy objectives of the Federal Government, EU member states and the European Commission.

Examples of economic and political advances in recent years

- As mentioned above, costs fell more quickly and there was a more rapid market introduction than expected for renewable energy for power generation.
- Enactment of the EU directives with the 20-20-20 targets, which make it economically worthwhile to think of a European interconnected electricity network.
- The social acceptance of renewable energy has developed quickly and favourably. Survey results show 80%-90% approval.
- The EEG [Renewable Energy Act] was supplemented in Germany by a Renewable Energy Heat Act (EEWärmeG).
- The BMU [Federal Environment Ministry] has currently set a target of completely converting energy supply in Germany to renewable energy by 2050.
- The BMWi [Federral Ministry of Economics and Technology] has set a target of reducing CO_2 emissions by 80%-95%, compared with 1990 levels.

Similarities and differences in existing energy scenarios and reports

a) WBGU [German Advisory Council on Climate Change] report

In its basic structure, the outline of how the energy supply system 2050 will function (see Chap. 1.3) is similar to the WBGU report "Transformation", which is currently being prepared [6]. In the WBGU 2008 report "A world in transition – future bioenergy and sustainable land use" [7], the potential for saving primary energy by changing to energy supply using renewable energy is convincingly described. For this reason this publication, whose technical aspect was covered by the Fraunhofer IWES [Institute for Wind Energy and Energy System Technology] (Schmid, Sterner), was the basis for the diagrams for transforming the current energy system to that of 2050. In addition, in the Energy Concept 2050, reference was made to the ambivalence towards using biomass for energy use, as is also discussed in the WBGU 2008 report: on the one hand, bioenergy has a significant sustainable potential, on the other hand, the risks for food security, biological diversity and climate protection cannot be ignored.

b) DLR [German Aerospace Centre] lead scenarios

2008 and 2009
The Energy Concept 2050 has a productive relationship with the BMU's 2008 and 2009 lead scenarios [8], [9], and with the preliminary work carried out by the DLR and the Fraunhofer IWES on the 2010 lead scenario. For many, these scenarios provide evidence for a system-analytical basis of the Energy Concept 2050 on transformation (Chap. 2), and above all for an economic consideration of this (Chap. 2.5). Until 2020, the papers are very similar in their most important assertions. However, the following differences should be pointed out:

- The Energy Concept 2050 takes into account the BMU's request to devise a concept for energy supply with 100% renewable energy to 2050. In contrast, the last lead scenario to be published, in 2009, only had a target of 50% renewable energy for the year 2050, but in the 2010 lead scenario, which is currently being prepared, for the first time two 100% targets are also being analysed: one version with hydrogen and one version with methane as long-term storage.
- The 2009 lead scenario was not yet able to take account of the new potential of renewable energy - as listed above – and the significant expansion in PV.
- In contrast to the lead scenarios, the Energy Concept 2050 does not take into account the short-term pragmatic implications, but sees its task as to draw up a coherent Energy System 2050 on the basis of new technolo-

gical knowledge, and to specify the energy and research policy requirements that are associated with this.

c) SRU [Advisory Council on the Environment]-May 2010 report

The Advisory Council on the Environment (SRU) has published a report with the title "100% renewable energy power supply to 2050: climate-friendly, secure, affordable" [10], which largely agrees with the views of the FVEE's group of authors on electricity. However, the Energy Concept 2050 expects higher electricity demand, as it includes the expanded use of heat pumps and electromobility. As much of the information in the SRU report is presented in a more detailed, analytical way, the concept refers to this report in some chapters, with the agreement of the SRU and colleagues in the DLR.

d) WWF study of October 2009

The study "Blueprint Germany – a strategy for a climate safe 2050." [11] is a study which covers all energy demand sectors. It relates to the Energy Concept 2050, as it also derives from the question of how an energy supply that is completely based on renewable energy could look in 2050.

When calculating the volume scenario for energy demand in 2050, the Energy Concept is particularly oriented towards energy demand in the transport sector, which is analysed in the WWF study. However, the difference is that as far as possible, the Energy Concept 2050 abandons the use of biomass as a fuel.

Executive Summary

Limiting the increase in temperature to a maximum of 2° C requires a reduction of at least 90% in energy-related carbon dioxide emissions in the European Union and Germany, and thus the complete reorganisation of the entire energy system. Achieving the target is possible by using different technological paths.

In this Energy Concept, an energy scenario is presented which is based on a significantly more efficient use of energy resources, and for all residual energy to be supplied by renewable energy. The scenario has many advantages: there is enough potential available in Germany, Europe and in neighbouring countries, the operating risks of renewable energy are low, and the scenario is sustainable, as renewable energy is always available.

The following shows how such a system of energy supply, distribution and consumption, based on 100% renewable energy, would look and how it can function in 2050, how a high degree of supply security can be guaranteed, and for such a system to be cost-effective.

Implementing the Energy Concept 2050 means that the energy system must be transformed from a centralised, load-optimised system to a decentralised, intelligent, load and supply-oriented energy supply structure. Decentralised production will be supplemented by the construction of a high voltage direct current transmission network (HVDC) in Europe and North Africa. The networks require intelligent control, which allows energy demand and supply to be balanced on a regional and Europe-wide basis (Smart Grid).

An important element of the Energy Concept is a clear increase in energy efficiency by reducing energy demand, for example using very good thermal insulation, and through the efficient conversion and use of energy, for example by the use of electric motors instead of combustion engines, or by using heat from combined heat and power.

In order to devise as robust an energy supply system as possible, this consists of a mix of all renewable energy, in other words wind and hydro power, photovoltaics, solar thermal power plants (in southern Europe and North Africa), solar thermal heat production, the utilisation of biomass waste, geothermal energy and wave energy. In Germany and Europe the potential for renewable energy is significantly higher than energy demand, although solar energy and wind have the greatest potential. Biomass is mainly used as a material, and in the Energy Concept there is only marginal energy use, mainly in the form of biomass waste, because of the limited resources and the current competition for use with food production.

Electricity, as a universally applicable and easily transportable energy source, is a mainstay of future energy supply, as new power applications such as electromobility emerge, and at the same time, heat demand is significantly reduced by efficiency measures. In the Energy Concept 2050, power production is mainly undertaken by wind and photovoltaics. This is supplemented by combined heat and power plants, which are powered by biogas, as well as by methane or hydrogen, which is produced using renewable energy.

Heat demand is significantly reduced by using efficiency measures, which require the renovation of the entire building stock by 2050. Residual demand is supplied by solar thermal plants, by heat pumps using renewable power and by combined heat and power. Demand for cooling will increase because of the climate, and the supply of cooling will increasingly take place via cooling grids.

In 2050, mobility is above all electromobility, as electric motors are very efficient and primary energy consumption can thus be reduced by a quarter by using renewable-generated electricity. Biofuels, which have only limited availability, are mainly used in long-distance and freight transport, and in aviation. Renewable fuels from wind and solar energy offer an alternative to biofuels. In addition, electromobility makes available storage capacity for the entire energy system.

The construction and integration of large storage capacity in the energy supply system is a basic requirement for a large share of fluctuating energy sources. Here, storage capacity is kept as low as possible by a mix of different renewable energies, by balancing temporary regional over- and under-capacity at European level, as well as by the intelligent control of supply and demand.

For residual storage demand, different power storage is available. Electro-chemical power storage in particular balances short-term fluctuations. Medium- to long-term energy storage takes place chemically, either using hydrogen or synthetic methane, which are both produced using renewable energy. Heat storage is used as short-, medium and seasonal

storage. It is installed in individual buildings and is integrated as a large storage unit in heat and cooling grids, and allows full renewable heat supply and energy recovery from combined heat and power. The current water storage tanks will in the future be supplemented by latent-heat storage and chemical storage.

Synthetic methane is also used as a storage medium, produced by renewable energy from hydrogen and CO2. This allows the storage of renewable-generated electricity which is not required when it is produced, and which can be used as a fuel, for power generation in combined heat and power plants and to provide high temperatures. Synthetic methane is a substitute gas for natural gas, it can be mixed with natural gas in the transformation phase, and it allows the use of the existing gas infrastructure, such as gas grids and storage.

Economic calculations show that in the next few decades, transforming the energy system will lead to additional costs, but that from 2030 it will be cheaper than the comparable fossil-nuclear system.

Essential points of the Energy Concept

1. **100% renewables are possible:** Technologies for using renewable energy and energy efficiency have developed more quickly than expected. The remarkable advances show that if the trend towards innovation continues, an energy system which is 100% based on renewable energy can already be realised in Germany by 2050.

2. **A range of options as a guarantor for supply reliability:** The Energy Concept 2050 outlines a reliable, secure, low cost and robust energy supply based on a variety of renewable energies. This range of renew able energies, whose potential is much higher than total energy demand, also ensures that there is a supply of alternatives, if there is a lower contribution or even a "failure" of a technology, so that in any case, supply based on 100% renewable energy is guaranteed.

3. **Energy efficiency is given priority:** The increase in energy efficiency is given the highest priority as a strategic requirement: The institutes advocate a substantial expansion in decentralised Combined Heat and Power (CHP) to increase the energy consumption efficiency of renewable energy conversion techniques – together with the need to further develop incentives for such systems in conjunction with local heating systems. Improving the energy performance of the current building stock will be essentially completed by 2050.

4. **Electricity as a mainstay:** The generation and use of electricity from renewable energy has a central position in the Energy Concept 2050.

5. **European interconnected electricity network:** The transmission of power over long distances by using HVDC, and energy balancing at European level, play a key role in the use of fluctuating energy sources. This wide-ranging balancing via a European power network secures the supply of renewable energy. In addition, the fluctuating supply of wind and solar energy is adjusted to particular demand using energy storage. Renewable-generated electricity thus becomes a primary energy, as chemical energy carriers (hydrogen, methane) are derived from it.

6. **Chemical energy carriers:** In order to form a bridge in longer periods when supply is too low, during these transitional periods these chemical energy carriers can be made available in long-term storage units on a seasonal basis, which amongst other things are needed for the transport sector. The production of"renewable (synthetic) methane" implies a paradigm shift for energy storage.

7. **E-mobility:** Transport in the Energy Concept 2050 is largely supplied either directly or indirectly by electricity, as electricity is converted into hydrogen or methane.

8. **Combined cycle renewable power plant:** The principle of a "combined cycle renewable power plant", with its technical interaction of renewable energy and energy storage, is expanded across Germany.

9. **Avoiding system conflicts:** Today's large power plants are not suitable for balancing fluctuating power from renewable energy, as they cannot cope with the major changes in output that are required for this.

If the priority given to renewable energy during feed-in is retained, then conventional base-load power stations will be increasingly unsuited to supplying residual load. This not only means that neither nuclear power plants, nor fusion power plants, nor coal-fired power plants, can then be used, but also that the current approach of CO_2 capture and storage for coal-fired generation (CCS) is moving in the wrong direction, not only from purely economic but also for system-related reasons.

10. **Role of biomass:** The use of biomass for energy is treated as a limited resource, which means that material and energy applications must be developed. In the medium- to long-term, energy crops should mainly be used to produce synthetic fuels like kerosene for planes and ships, as well as producing raw materials for the chemical industry. Recovering energy from biomass waste supplements this concept.

11. **Solar heat:** In the Energy Concept 2050, solar thermal collectors make an important contribution to heating drinking water, to space heating, process heat and cooling in domestic buildings and for local/district heating and cooling systems.

12. **Costs and use:** With optimum design, economically, the Energy System 2050 will at least be no more expensive than the present system. This is because of the link between technological elements which are described in the Energy System 2050, with their learning and experience effect, and cost/benefit analysis:

    - To begin with, the expansion of renewable energy generates additional costs, both in power and heat production and also in the transport sector. However, with calculations which relate to one specific year, the maximum additional cost is already achieved in 2015, with an amount of approximately 17 billion euro. This only equates to about 8% of total energy expenditure in Germany, which totals 212 billion euro, according to the monetary evaluation of final energy consumption. The argument which says that renewable energy would mean that energy system costs would increase significantly is rejected as a result of this comparison.
    - A calculation of the differential costs of renewable energy from all three sectors clearly shows that the transformation into an energy system which is completely based on renew able energy by the year 2050 is also economically favourable. In the electricity and heat sectors alone, in the period 2010 to 2050, total costs of 730 billion euro can be saved.

13. **Research funding:** The allocation of public R & D expenditure to the different energy technologies must be geared towards their long-term importance. In line with the governing coalition's target and the Energy Concept which has been proposed, the priority should be placed on renewable energy and efficiency in research funding. Research and development should also be used as an industrial policy measure. Only then, when German manufacturers in the field of renewable energy and energy efficiency are global technological leaders, is there the possibility of keeping production of the elements of the new energy supply system in Germany.

1. The Energy System 2050 based on renewable energy

1.1 Developments in global energy demand

In order to limit global warming to a maximum of 2 °C, energy-related carbon dioxide emissions in Europe must be reduced by at least 80 – 95% by 2050. This makes a massive reorganisation of the global energy systems necessary. All global energy scenarios generally assume that above all, renewable energy must be expanded. Because of the clear increase in the global population, as well as the growth in prosperity in developing countries and emerging markets, global energy demand, particularly electricity, will rise significantly. *Figure 1* shows total energy demand to 2030 in megatonnes of oil equivalent (dotted line), based on an IEA forecast. Amazingly, the IEA assumes that the finite fossil and nuclear energy sources will meet this increasing energy demand. However, this is not possible because of the global climate protection goals, which is why this scenario must be regarded as highly unlikely.

In contrast, the Energy Concept 2050 shows how the increased demand for energy services does not have to lead to a further rise in primary energy demand, by consistently applying measures to increase efficiency, and, if growth continues, that renewable energy can meet this demand to the middle of the century.

This means for Germany's energy supply that primary energy demand for power generation can be reduced by about a third of current levels by completely replacing conventional power plants by wind, solar and hydro power plants. This is because every kilowatt hour of electricity from these renewable sources replaces about three times the amount of primary energy that would otherwise be required [13]. For example, the waste heat losses from power generation, which in coal-fired and nuclear power plants cause about 2/3 of primary energy costs, are avoided by using wind and solar power plants.

In industry, there is a particular need for thermal energy at different temperatures.

Part of primary energy demand is avoided by the consistent use of waste heat using thermal storage and heat pumps with a high annual coefficient. Energy storage units are able to

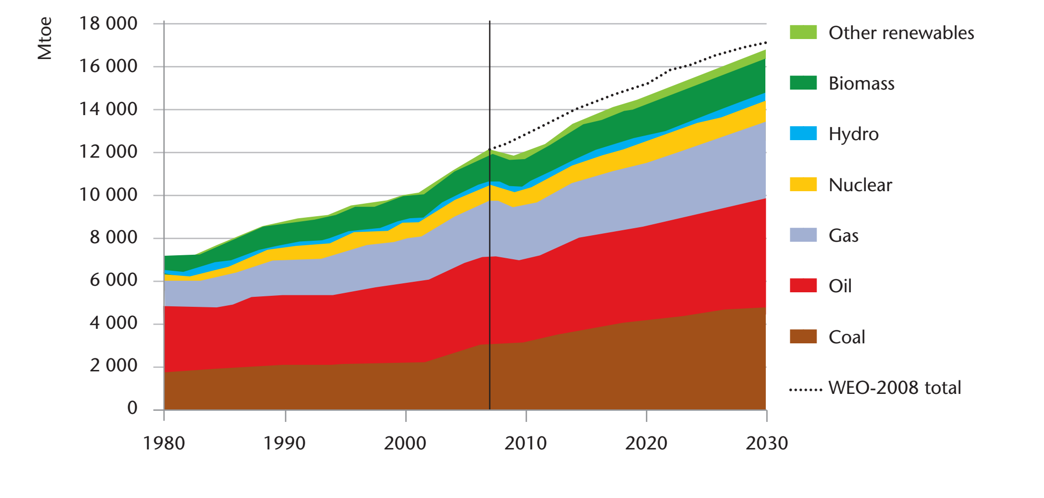


Figure 1
Forecast for growth in global energy demand to 2030 (IEA) and assumptions on possible energy sources to meet demand [12] (12,000 Mtoe = about 500 EJ)

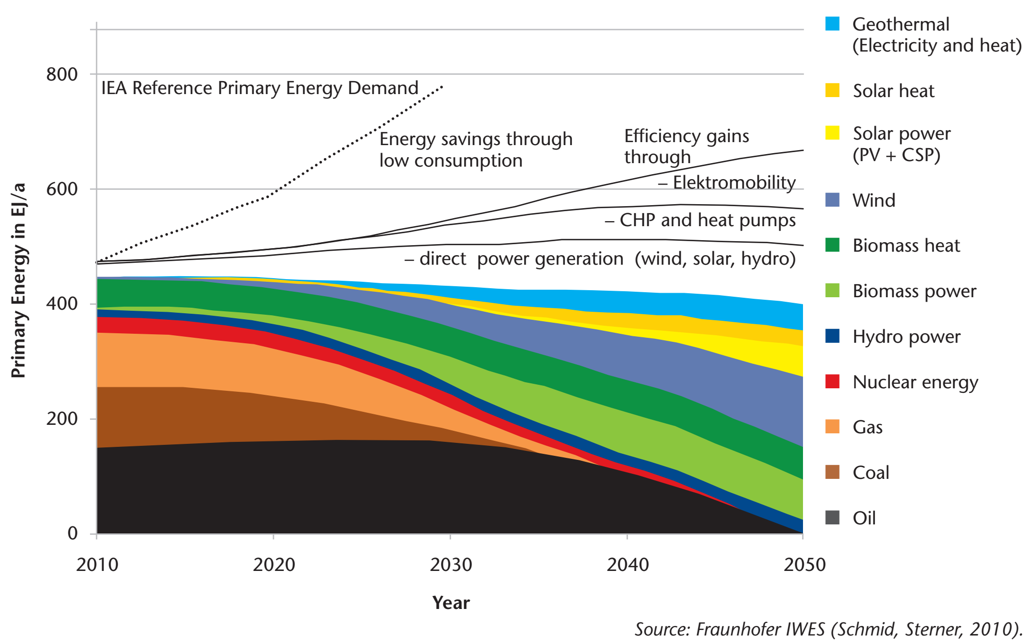


Figure 2
Global scenario for 100% renewable energy: global primary energy demand to 2050 by efficiency method. Energy savings primarily in construction.

PV = Photovoltaic; CSP = concentrated solar power – solar thermal power production).

Source: Fraunhofer IWES (Schmid, Sterner, 2010).

absorb the power peaks in the industrial process. Process heat with temperatures of up to 250 °C can also be supplied proportionately by solar thermal energy.

Figure 2 shows an example for a scenario to meet global primary energy demand to 2050 using 100% renewable energy by efficiency method1 and based on the following assumptions: the goal is to develop a pathway to decarbonisation which conforms to the 2 °C limit based on renewable energy without the use of nuclear energy and CCS. Efficiency measures reduce demand for heating and cooling by 1% p.a., and growth in the volume of traffic and demand for electricity is also limited to 1% p.a through efficiency measures.

1 Efficiency methods and replacement methods are used for the primary energy balancing of electricity from renewable energy sources. For fossil energy sources, calorific value is used as a conversion factor, which is a measurement for the useable energy content of a fuel. Then 1 kWh of electrical energy, which is produced in a conventional coal-fired power plant with an efficiency of h = 40%, ismultiplied by a factor of 1/h = 2.5, and is valued in terms of primary energy at 2.5 kWh. Both efficiency methods are valid for 1 kWh of electrical energy, which is produced using hydro power, wind energy or photovoltaics, a plant efficiency of 100%; this energy is therefore valued at 1 kWh in terms of primary energy. For a nuclear power plant with a typical efficiency of 33%, however, 1 kWh of electrical energy is valued at 3 kWh of primary energy.

This means that overall, primary energy demand to 2050 does not rise to above 700 EJ p.a.. Depending on the technology, thehistoric rate of increase in renewable energy (up to 20% p.a.) will continue for a maximum of 20 years. The expansion of technologies with very extensive resources (wind, solar) is managed to saturation, and technologies with limited resources (bioenergy, hydro power) are reduced to zero and therefore restricted in their maximum sustainable potential. The expansion of biomass is limited to a sustainable potential of 150 EJ, and in 2050 it will only be used in the most efficient application for bioenergy, in combined heat and power. The traditional use of biomass in developing countries is also replaced by modern RE technologies [7]. There is only a slight expansion in hydro power. The most difficult sector to decarbonise is the transport sector, which still shows a high dependence on oil. Bio fuels are abandoned for reasons of efficiency and sustainability. [7]. Instead, electromobility is introduced very quickly, as does the use of renewable fuels from wind- and solar-surpluses for special segments of the transport sector (long-distance vehicles, planes, ships, etc.). In 2050, two thirds of energy demand in the transport sector will be met purely by electricity, the remaining third will be met by renewable wind and solar fuels (hydrogen,

methane or other renewable-generated combinations of H_2 and renewable CO_2).

The savings and efficiency gains in *Figure 2* result from:

- avoiding waste heat in power generation using direct renewable generation (wind, solar, hydro power)
- efficient drive design for electromobility and expansion in public transport
- Use of ambient heat by means of electric heat pumps
- Use of waste heat in power generation by replacing power plant capacity with combined heat and power capacity
- Implementation of measures to save energy, particularly in relation to heating (insulation, etc.)

1.2 The technological components of the Energy System 2050 and their energy potential

In the future, the technological components of the desired sustainable energy supply, based on renewable energy sources, will, for economic reasons, no longer be divided, according to the previous system plan, into electricity, heat and fuel. Instead, they will increasingly transcend system boundaries. Depending on the systems engineering and systems solutions, the available sources are converted into the energy forms required: heat or fuel is derived from electricity, electricity is produced from heat, and electricity and heat are produced from fuel. When the respective conversion happens depends on the systems solutions requested and the economic conditions..

1.2.1. Energy efficiency technologies

The increase in energy efficiency in primary energy use is given a decisive role because in this way, energy consumption can be substantially reduced without cutting industrial activities or having to give up on comfort, for example in the home.

Heat pumps are an example of such an energy efficiency technology, which offers the possibility, together with renewable power, of supplying buildings with heat sustainably. A further example is electromobility, which can be an efficient and emissions-free alternative, when in operation, for private transport.

Even when the technical energy potential of renewable energy amounts to a multiple of energy demand and therefore savings in consumption do not appear to be necessary, the conversion technologies are linked to costs. However, the reduction in energy demand not only has priority for economic reasons, but also because, particularly in the building sector, lower energy demand has advantages for the use of renewable energy sources [15].

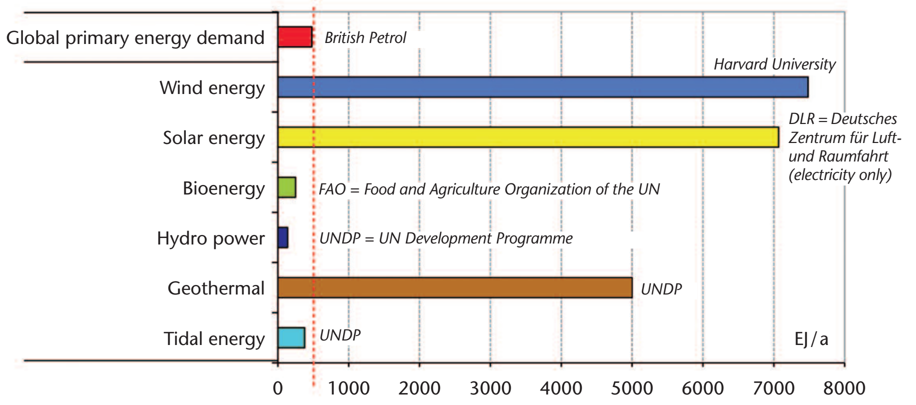
1.2.2. Technologies for using renewable energy

There is sufficient potential from renewable energy to meet current global primary energy demand, *(Fig. 3)*. Just in terms of quantity, the sun and the wind could each meet demand alone, even, but they have a high spatio-temporal variability, there are to a certain extent strong local fluctuations, and they are geographically not adequately available everywhere. The task for research and development is to prepare, technically and economically to develop all renewable energy sources, particularly also with the goal of reducing costs, as well as their integration into energy supply structures and the transformation of energy systems.

A robust Energy System 2050 should ensure that the individual renewable energy potential can largely be covered reciprocally. For this reason it is necessary that the sum of the individual shares of the renewable energy mix amounts to more than 100%. The energy and

Figure 3
Global technical potential of renewable energy (Primary energy by replacement method [2]).

Sources: s. key to diagrams and [18 – 22]



All the technical potential shown, with the exception of bioenergy and geothermal enegry, applies only to power generation. Solar energy is therefore rated somewhat lower than wind energy, as in recent years the potential for wind energy has continued to be adjusted higher in different studies (because of higher hub heights, larger diameters and in particular broader coastal areas for offshore wind). Bioenergy potential (mainly energy crops) is reduced as a result of the assumption of increasing competition for use (food and animal feed, use as a material).[3]

technical potential for Germany and Europe is substantial enough for this. On this basis, the Energy System 2050 can be robust and reliable in order to offset faults and outages caused by fluctuating energy, and ensure full energy supply security.

Electricity, heat and fuels are obtained using different technological options, which can complement and replace each other, as shown for example in *Table 1*.

1.2.3 Energy storage technologies

While fossil and nuclear energy exist in stored form and consequently are always available and can be used flexibly, as part of supply capacity, to meet variable energy demand, apart from biomass and geothermal energy, a renewable system is largely dependent on meteorological and geographical factors.

A wide-ranging balance of renewable energy production achieved by networking secures the supply of renewable energy, and load management can bring together the periods of energy demand with the periods of energy supply. However, for example in the power sector, even when there is a perfect balance using power transmission throughout Europe and load management, there is still a residual demand for storage [23].

1.2.3.1 Storage technologies for electricity

The demand for power storage for energy supply that comes 100% from renewable energy is substantially higher than the storage capacity which is currently available. In Germany, in the winter months, there can be periods with a very low supply of renewable energy (not much solar energy, calm wind conditions because of a Europe-wide Siberian high) [23].

Electromobility also assumes a storage function in a 100% renewable scenario, but even theroetically, it can only meet a small part of demand:

2 Replacement methods value electricity from conventional and renewable sources as comparable: a kilowatt hour (kWh) of wind power replaces the primary energy cost of a kWh of coal-fired electricity (Figure 4).

3 A comparative description and update of the potential of renewable energy will be finallised by the DLR in a study for the UBA in high spatial resolution in 2010.

Energy source	Technology	Primary energy mode	Secondary energy
Wind energy	• Onshore • Offshore	Power generation	Heat Fuel
Photovoltaics	• Silicon wafer-PV • Thin film-PV • Concentrated solar power	Power generation	Heat Fuel
Solar thermal power plants	• Parabolic trough power plants • Tower power plants • Dish technologies • Fresnel collector power plants	Power generation	Heat Fuel
Hydro power	• Barrage technology • Run-of-river technology • Ocean energy	Power generation	Heat Fuel
Biomass	• Polygeneration process	Power generation Heat production Fuel production	
Geothermal energy	• Heat pumps • Deep geothermal energy	Heat production Power generation	
Solar heat	• Passive solar energy use: Transparent heat insulation • Active heat insulation: Solar thermal hot water production and heating • Solar active house, solar local heating systems, process heat and solar cooling	Heat production	

Table 1
Renewable energy sources and the energy demand. If required, power can also be produced again again fuels.

if every 45 million cars have a useable storage output of 10 kWh, only 0.45 TWh would be available, however [24].

The only large storage that exists with the required scale are natural gas storage facilities with an existing thermal capacity of 217 TWh (underground gas storage) and a planned expansion of 79 TWh in the next few years [14]. This technology of long-term storage is proven, safe and established and can be used for chemical energy carriers derived from renewable-generated electricity in two ways: on the one hand direct through the storage of a natural gas substitute in the form of renewable methane, or by adjusting the infrastructure using hydrogen or a mixture (hythane) [25].

- **Electrochemical energy storage**

Electrochemical energy storage takes on increased significance when renewable energy sources are used, as, because of its high energy efficiency, it is ideally suited for buffering fluctuating renewable sources of power such as photovoltaics or wind energy. It absorbs voltage fluctuations, flattens load and demand profiles, allows the use of cable-free or off-grid components and facilitates mobility based on electrical energy. In this context, in the future large stationary batteries, such as for example redox flow batteries, assume an important role.

1.2.3.2 Chemical energy storage

For bridging longer periods when the supply of wind or solar energy is too high or too low, long-term storage is needed, using chemical energy carriers such as hydrogen or methane.

- **Hydrogen**

For the storage of large surpluses, long-term storage technologies (several days or weeks) are necessary. On a large scale, electrical buffering is developed using electrolysis and hydrogen storage in caverns, with downstream power generation by gas turbines. The “surplus“ renewable-generated electricity can be stored as chemical energy using electrolysis.

The central point of a hydrogen economy is the ecological and economically justifiable production of hydrogen using different processes:

- Electrolysis from renewable electricity
- thermal water splitting
- Reformation of hydrocarbon fuels (renewable methane)

Renewable electricity can be stored in transportable chemical energy carriers in such as way that it can be used in an offset way, chronologically or spatially. The hydrogen that is produced and stored can thus be used for power conversion to support the network, as well as as a fuel for the transport sector. Efficiency factors of up to 45% are indicated for the entire process chain, (Production, storage and power conversion).[4]

Hydrogen can assume an important role in the future as a clean energy source for fuel and energy supply, because it is very versatile and has advantages: hydrogen can be used in fuel cells, gas turbines (for the production of electrical energy), combustion engines (to produce mechanical energy) or catalytic combustion (heat production) and, last but not least, it can also be used as an intermediate product to produce renewable methane or other hydrocarbons.

- **Renewable methane as a chemical energy store**

In addition to the direct production and use of hydrogen, the Energy oncept 2050 also regards the production of renewable methane as a particularly interesting process for the storage of larger amounts of renewable energy. The advantage compared with a hydrogen world is that the existing gas infrastructure, including power stations, gas networks and also gas storage, can be used for this.

Methane can be directly produced by the reaction of hydrogen with CO_2, via the so-called Sabatier process, which can be supplied to power producers via the existing gas networks and storage. Here, the energy efficiency factor amounts to > 60% ($kW_{Re.methane}/kW_{power}$). This assumes added attractiveness, until now in a 30 kW technology demonstrated process[5] using CO_2 as a raw material. The CO_2 balance is therefore neutral in power stations, biogas plants, the production of synthetic gas or also in cement manufacturing, through the link with methane production.

The existing gas network forms a virtual seasonal store, both for heat and for power generation, and also to supply the transport sector with renewable fuel [26]: While today the storage capacity of the power network amounts to only about 0.04 TWh, – with a storage range of under one hour –, the storage capacity of the existing gas network in Germany amounts to over 200 TWh, with a storage range in the region of months.

1.2.3.3 Thermal energy storage

Storing energy can help to provide constant energy when integrating renewable energy sources with fluctuating supply. The possible range of use of thermal energy storage runs from seasonal storage in solar thermal energy to high temperature storage in solar thermal power generation (Concentrated Solar Power). Even renewable-generated power can be stored cheaply and efficiently after it is converted into heat or cooling, although it cannot be fed into the network in the short-term.

A major contribution towards increasing efficient energy use can be expected from the use of heat in combined heat and power, and particularly from waste heat. By using thermal energy storage, where there is high energy consumption in industry, for example in foundries, cement works or during glass manufacture, large amounts of heat can partly be made reuseable in the form of process heat, or in local

4 If during power conversion waste heat from gas-fired power plants is used, the total efficiency rate increases by 10 – 15 per cent.

5 In an initial technical implementation stage, construction of a 10 MW wind to methane plant, coupled to a biogas plant, is planned, in which biogas is made into methane with no CO_2 separation,by adding H2. The target startup date is 2012.

heat networks to heat buildings and in water heating.

Solar thermal heat can be stored locally, both for power plants at temperatures of over 400 °C, and for domestic water heating, and can be released at the required time.

In principle, thermal energy can be stored in the form of sensible or latent heat, or in thermochemical processes:

- **Sensible storage of of sensible thermal energy**

When storing sensible thermal energy, a storage medium is heated or cooled. In most cases water is used, as it has a high specific heat capacity and is very cost-effective. Smaller stores are used as buffer storage in thermal plants solar (water heating) for storage for days or weeks. Large water storage (up to several thousand m^3) is mainly built in conjunction with a local heating network for the seasonal storage of solar heat, for heating in the building sector. About half the total heat demand for larger building units in Germany can be met by solar power, using large seasonal heat storage.

Heat and cold are also stored in the ground. Here, for example, thermal energy with a temperature level of about 10 °C can be used in winter by a heat pump, and in summer directly to cool buildings.

- **Latent heat storage**

Latent heat storage also applies a phase change in the storage medium to raise temperatures (or to reduce these) (Phase Change Materials = PCM). With smaller temperature differences, therefore, substantially more thermal energy can be stored. This is particularly useful in storage for cooling. In PCMs that are integrated into the building structure, for example, with a fusion temperature of 25°, the ambient temperature can be kept at comfortable levels: When ambient temperatures are over 25°, these materials absorb the surplus energy and thus offer protection against over-heating, when ambient temperatures are lower, they release the stored energy again. PCMs are available at different fusion temperatures. There is currently increased research into new materials which have a high storage capacity, and which are economically favourable.

With combined heat and cooling plants, latent heat storage allows power-led operations.[6] The high specific storage capacity contributes to a compact storage geometry. The use of industrial heat at high temperatures can also occur, or can be made easier using latent heat storage.

- **Thermochemical storage processes**

Reversible chemical reactions can also be used to store thermal energy. This kind of system has high energy storage density, which can be up to 10 times higher than in water, and is able to adjust temperature levels to current requirements when charging and discharging. Most research in this field is on ad- and absorption processes. Here, steam is normally sorbed into solid, microporous adsorbents (e.g. zeolite or silica gel) or into aqueous salt solutions (e.g. lithium chloride). This releases heat. To charge the store, the heat from the steam must again be desorbed.

Open sorption storage is under investigation for application in the use of industrial waste heat. Here, efficient and economically interesting systems could be developed, particularly in the field of industrial drying processes. As well as storage, open sorption storage also offers the possibility to transform heat into cooling, which for example can be used for solar air conditioning for buildings.

6 Because using latent heat storage heat can be stored for use later.

- **Storage required for power-led CHP operation**

Storage for high temperatures for small combined heat and cooling plants facilitates power-led operation, in which the accumulated heat can be stored for up to a few days if necessary. This is also of interest for an improved use of industrial process heat.

1.2.4 Transmission and distribution networks

A European high voltage direct current transmission network (HVDC) is an important component in the Energy Concept 2050. This safeguards national supply by using renewable energy, by balancing production surpluses and production shortfalls in renewable energy within Europe, and by facilitating imports of renewable-generated electricity from North Africa.

Multi terminal HVDC lines[7] allow renewable-generated electricity from desert regions (solar thermal power plants, as in the DESERTEC project, and photovoltaics), and electricity from European on- and offshore wind farms, in conjunction with Scandinavian pump and hydropeaking power plants[8] to be integrated into a European super power network, in which an expansion to eastern and south-eastern Europe can also be contemplated. Close European cooperation is one of the requirements for the gradual increase in the share of renewable energy in the power grid.

HVDC lines do not have any electro-magnetic fields and can therefore to a large extent transport power without losses over long distances. They are also suitable for burying underground, which avoids visual damage and increases acceptance.

7 Not only point-to-point connections can be realised using HVDC. It is also possible to connect several converters to a voltage circuit. In practice, these systems are mostly called multi-terminal systems. Because of the flexible controllability of the voltage circuit in HVDC Light® Technology – in contrast to the direct current circuit of a network-led HVDC – a multi-terminal system with HVDC Light® is easier to achieve.

8 Hydro power plants in hydropeaking operation to meet peak power demand

Transmission and distribution networks interact both for using energy producer potential, and because of economic considerations, and increase security of supply. The more the cost of renewable energy technologies and smart grids falls in Germany, the more cost-effective is the use of decentralised local energy production and distribution technologies. Importing power from southern Europe, Africa and Norway may not necessarily be more cost-effective, then, but above all it offers an additional energy and technical potential.

Power electronics plays a central role in network control, as the rotary generators in coal-fired and nuclear power plants are not used and the power inverters in wind and PV power plants take over network formation. They control the voltage and frequency of the network through the controlled supply of active and reactive power. If there is a fault on the network, they supply large amounts of short-circuit current to trigger safety devices, and actively participate in rebuilding the network.

1.2.4.1 Decentralised and centralised power and gas distribution networks

The concept is characterised by the following features:

- **Transcending system boundaries:** The different methods of producing methane from renewable energy and the options for use in varying sectors of consumption provide the opportunity for a merger of the energy sectors consisting of the electricity network, the gas network and mobility. Power and renewable methane gas can each be converted to the other in a two-way process, and already have a well-developed infrastructure with seasonal gas storage capacity. In addition, hydrogen can be produced locally from both energy carriers, without being dependent on a large H_2 distribution system with high infrastructure costs.

- **The storage and distribution of temporary surpluses:** in the future there will be increasingly frequent high wind and solar power output because of the further expansion of renewable energy,which cannot be fully incorporated into the power network,

but which can be incorporated into the corresponding distribution grids in the form of renewable hydrogen or methane.

- **Natural gas distribution network:** In the current natural gas infrastructure, the renewable-produced, chemical energy source methane is stored, distributed and used to meet demand. About 50%-60% of electricity can be converted into methane, which can again be converted into electricity and heat in existing gas and steam power plants (GaS) or local combined heat and power plants (LCHP).
- **Stabilisation of the power network:** Through the concept "wind/solar energy to renewable fuel", positive and negative balancing energy can be supplied: when there is surplus electricity, the natural gas substitute (renewable methane) is produced, (negative balancing energy), when there is demand for power, the renewable methane is converted into power (positive balancing energy)[9]

This concept could also be implemented using hydrogen, however, a new infrastructure would have to be installed for this.

1.2.4.2 Distributed heating grids

Despite the decreasing demand for site-specific heat in buildings, heat networks can be developed in compact spaces so that there can also be a high proportion of renewable heat there, as well as facilitating the development of CHP. In Scandinavia, heat networks are used with low network temperatures in medium-sized and larger towns as a centralised heat supply structure. Thus there are various possibilities for use in conjunction with combined heat and power and the feed-in of heat from renewable energy, in particular solar thermal energy, as well as waste heat from industry. The installation of heat networks offers a new degree of freedom in the seasonal and spatial management of heat flows, and also in operating plants which generate both electricity and heat. In association with future chillers which are thermally driven by low temperature heat, heat can also be used for air conditioning and can thus reduce electricity demand.

1.2.5 Components for solar and energy efficient construction

The individual technological components which are required to operate an energy supply system 2050, as described in the next chapter, also form the basic elements for solar and energy efficient construction. The interaction of individual production and conversion technologies thus results in quite new system solutions, which can be adjusted to the building's energy demand, to regional characteristics and to climates. The passive house, the solar active house and the energy plus house are each building techniques which use those components from the range of renewable energy and energy efficiency technologies which are the best for a particular building use or region.

1.3 Functionality of energy supply system 2050

After describing the technological primary components and their energy potential in Chapter 1.2, we should now outline the operation of these technological components within a sustainable Energy System 2050.

1.3.1 Power generation as a mainstay of energy supply

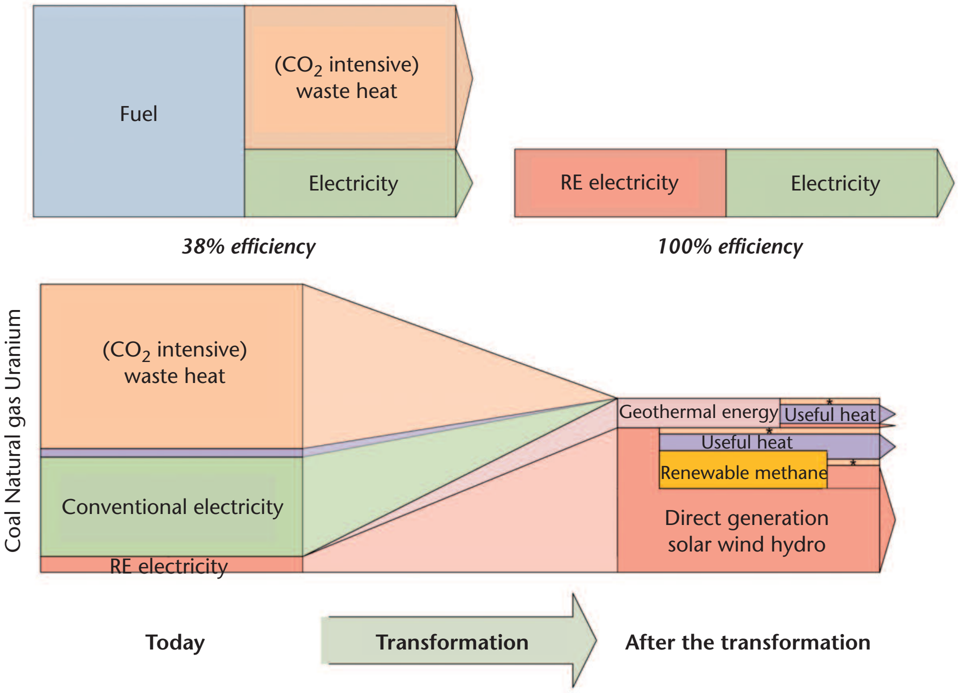
In 2050 wind and solar energy will be the two main sources of power supply, as they have the greatest potential and are amongst the most cost-effective sources of power.

The use of primary energy from purely combustion processes (coal-fired power stations, heating of buildings, the supply of process heat, combustion engines) is replaced by purely renewable electrical systems and renewable generated heat. By using directly produced

9 In 2009, the firms Lichtblick AG and Volkswagen AG started the project "Schwarmstrom", which will network 100,000 gas-fired combined heat and power plants across Germany. These small plants will supply 100,000 buildings with heat and will feed power into the grid. Together they will then form an invisible large 2000 megawatt power plant.

Figure 4
Efficiency gains in the power sector through an increase in direct power generation from renewable energy and combined heat and power (CHP) – an example of transformation.
The diagram is based on the volume breakdown for the 100% RE scenario 2050 (Chapter 2.5.1)
(= CO_2-neutral unused waste heat)*

Source: Fraunhofer IWES



Source: Fraunhofer IWES

With conventional power generation from fossil energy sources without heat extraction, in the global average, only a good third of primary energy can be converted into electricity, while scarcely two thirds remains unused as waste heat. By changing to renewable energy from direct generation, with the same amount of power generation the primary energy demand and energy-related CO_2 emissions thus fall. Waste heat from thermal power generation can largely be made useable by CHP (see also [17]). The stability of power supply is ensured by renewable power generators in a network (combined cycle renewable power plants), energy management (load control) and corresponding storage and backup capacity (mainly pumped storage, gas-fired power plants with hydrogen or with renewable methane).

The illustration is derived from [17, 26].

power generators from wind, hydro and photovoltaic power plants without accompanying waste heat losses, there is a substantial reduction in primary energy demand. This is because in today's power plant mix, every kilowatt hour of electricity from wind, solar or hydro power plants reduces the demand for fossil or nuclear primary energy by about 2.5 kWh.

Solar heat and geothermal energy plants replace fossil heat production. Direct renewable power generation is supplemented by fast reacting gas-fired power plants with combined heat and power, in which the gas used (methane) is obtained from "surplus" renewable generated electricity or from the sustainable use of biomass.

To balance the fluctuations which arise from the direct generation of wind and solar power and for the distribution of energy from the locations with the best generating potential in the consumption regions, both high voltage networks for power (with a share of HVDC) and gas (natural gas and/or hydrogen network) are available [14, 26].

In an overall system which is optimised according to economic criteria, in 2050 the largest share of electrical energy will come from wind power plants, which would be sited in windy locations. In Europe, this is locations along the Atlantic coast, in windy regions inland and in offshore areas. The short- to medium-term fluctuations in wind energy are balanced by a

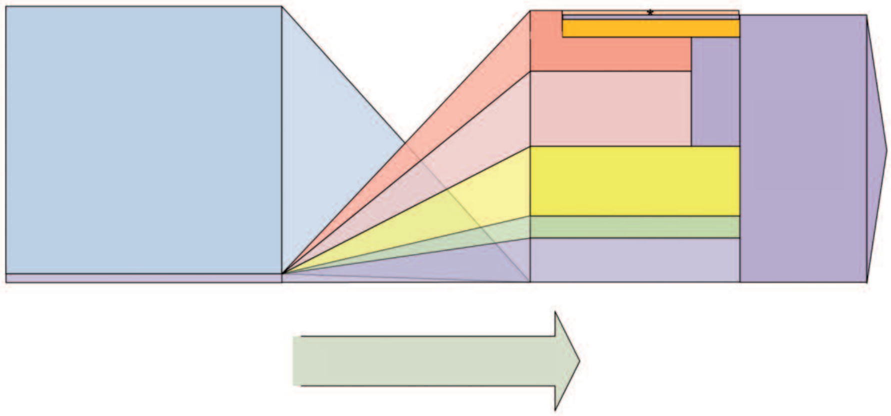


Figure 5
Transformation of the heat sector: by developing combined heat and power, solar thermal energy and the increased use of electric heat pumps, renewable methane/biomethane in condensing boilers and process heat, process and thermal heat demand, which has been reduced by energy saving measures, can in the future be completely met by renewable sources.
The diagram is based on the volume breakdown for the 100 % RE scenario 2050 (Chapter 2.5.1)
(= CO_2 neutral unused waste heat)*

Source: Fraunhofer IWES; the illustration is derived from [17, 26].

European high voltage electricity grid. Seasonal fluctuations are balanced by long-term storage (hydrogen, methane (natural gas substitute)) using the existing gas infrastructure. Wind energy is supplemented by photovoltaics, solar thermal power plants, hydro power plants, which largely exist already today, electricity generated by geothermal energy and combined heat and power.

Solar power plants which operate thermally with heat storage or hybrid supply with the help of chemical energy storage in southern Europe or in North Africa contribute towards balancing fluctuations from wind power generation.

Ocean energy (tidal and wave), geothermal energy power plants for suitable locations, as well as photovoltaic plants that are integrated into buildings, supplement the generation portfolio. Photovoltaic plants take on further functions, in conjunction with combined heat and power and electromobility, to improve security of supply:
If major electrical networks fail, they can enable local networks to operate. For developing and emerging countries, they facilitate the development of decentralised supply networks.

1.3.2 Energy efficiency using combined heat and power

Combined heat and power increases the overall efficiency of conversion techniques and thereby the energy use efficiency of renewable energy. In decentralised energy production, combined heat and power plants will mainly play a supporting role, as will smaller gas-fired power plants, micro-turbines, fuel cells and combined heat and power plants, and fuel cells and micro gas turbines, whose output is adjusted to local heat demand. However, they can also be managed via power demand. With operation at varying speeds, system efficiency rates and life span can be increased. The energy sources deployed come from the use of biomass, hydrogen or methane gas production from renewable energy, solar thermal energy and geothermal energy.

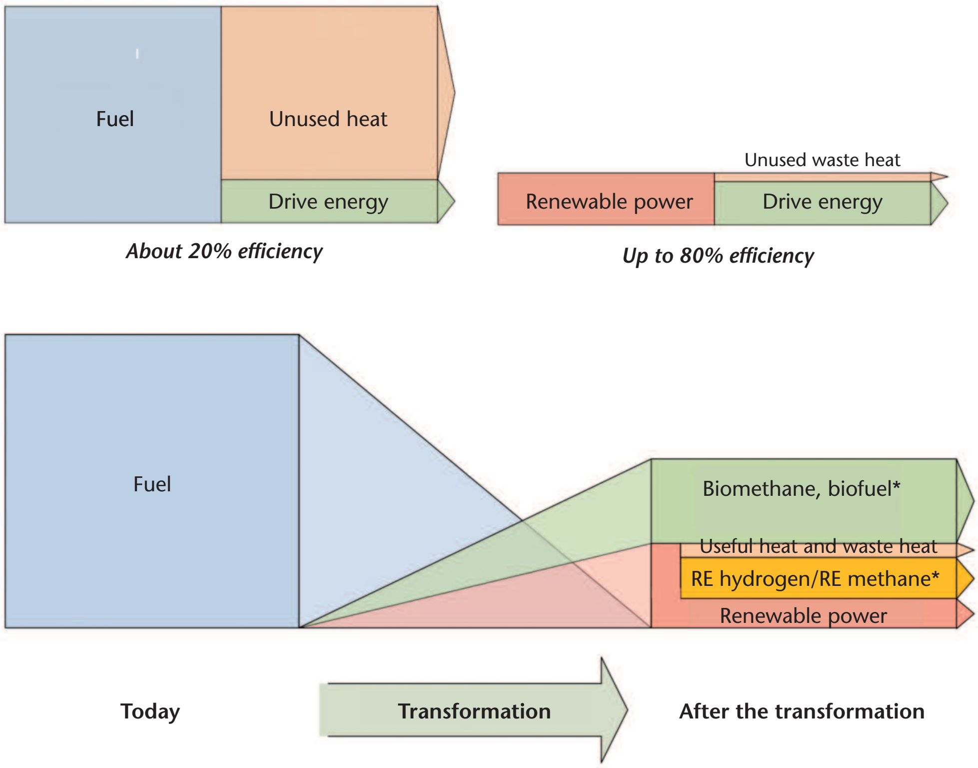
When CHP is combined with solar power generation, both components complement each other extremely well: while in winter CHP produces heat and power, in summer the demand for CHP power is reduced by solar power generation.

The consistent use of CHP, heat pumps and electric drive systems for cars means that overall primary energy demand can be reduced by more than 50% through these three measures alone. These are therefore the most important measures to increase efficiency gains in the energy system. The environmental sustainability

Figure 6
Top: Efficiency gains in the transport sector using electromobility. Comparison between energy cost and efficiency: on the left a conventional drive system using fossil and biogenic fuels, on the right an electric drive system, which uses renewable, directly generated electricity from hydro, solar and wind energy (see also [17]) Below: Example of transformation: a unit of renewable electromobility, renewable methane/ renewable hydrogen (renewable fuels) and bio fuels (biodiesel, biokerosene).

The diagram is based on the volume break-down for the 100 % RE scenario 2050 (Chapter 2.5.1)

Source: Fraunhofer IWES



Source: Fraunhofer IWES

Primary energy demand and greenhouse gas emissions in the transport sector can be substantially reduced. by an increased use of renewable electricity, including a large proportion from direct generation using wind, hydro and solar energy.

* = can also be other renewable fuels such as for example hydrogen or renewable kerosene. The illustration is derived from [17, 26]

of electric heat pumps improves as the share of renewable energy in the electricity mix increases.

1.3.3 Heat production – direct and secondary heat production

The supply of thermal energy is today linked to a very high share of CO_2 emissions. The transformation of heat supply systems therefore takes on a particular importance. Solar heat and geothermal energy plants directly replace fossil heat production and thus avoid the emissions which arise from burning fossil energy sources.

Heat supply for heating buildings results from the interaction of significantly improved thermal insulation and meeting residual heat demand with renewable energy, such as solar thermal collectors, geothermal energy and biomass plants as well as, via waste heat from industrial processes, using combined heat and power (CHP, fuel cells) and by the combination of heat pumps with renewable energy. The supply of industrial process heat primarily takes place using high temperature solar thermal energy, as well as electricity from renewable energy or renewable methane.

The process heat demand for industry and commerce in the temperature range between 80 and 250 °C can be met by renewables. In some sectors, it runs parallel to the supply of solar radiation and can then be met using process heat collectors or CHP plants.

Production figures, which increase in summer e.g. for the drinks industry and the increased demand for cooling in food production and trading, provide opportunities to meet significant amounts using solar power.

That heat demand can be substantially reduced, amongst other things by significantly better insulated buildings, goes without saying. The BMU 2009 lead scenario [9] shows declining demand for heat to 2020 to 85%, and to 2050 to about half current amounts.

1.3.4 Energy supply in the transport sector

Mobility will increasingly happen electrically and will therefore be 2 to 3 times more efficient than today's cars. This includes purely electrically driven cars using batteries with and without "Range extenders", in which the latter can consist of small combustion engines, as well as fuel cells. In freight transport, on the one hand hybrid technologies are also used, on the other, as much freight transport as possible should be diverted to the railways. Renewable fuels (renewable methane, hydrogen, diesel) from biomass, or using power from wind energy, solar energy and hydro power, are produced for freight and long distance transport, for planes and ships.

Cars, trains and buses draw their energy from overhead lines, batteries or fuel cells, so their environmental sustainability is improved by a growing share of renewable energy in the electricity mix. The batteries are charged by bidirectional chargers at charging points. The storage batteries can also be recharged by contactless charging while driving (inductive transmission).

Planes and ships use renewable fuels from biomass, hydro, solar and wind energy. Here it is possible to produce renewable kerosene as a fuel from surplus power according to the process mentioned (renewable methane).

1.3.5 Information and communications in energy supply

Integrating the Energy Concept into an overall European context secures renewable feed-in and reduces the demand for energy storage. Close agreement between all European member states and coordination, for example by the European Commission, is therefore a requirement for successful implementation.

Changing from a centralised energy supply to a decentralised structure with many small fluctuating plants which feed in electricity requires a technical communication link between electricity consumers and decentralised producers in network operation. Only by deploying information and communications technologies can electricity best be distributed or temporarily stored: the power grids become "intelligent", they are called smart grids because they allow bidirectional energy management through the internet. Broadband communications systems between producers, network operators and consumers mean that an online energy market can be created, which enables a flexible alignment between production and consumption through the use of time-of-use electricity tariffs.[10]

In this way, customer-oriented incentive systems can be developed, so that, for example when winds are strong, the batteries of electric vehicles can be charged, or to favour the operation of chillers or heat pumps. The development of current power networks and energy supply structures into smart grids is at present, as part of the so-called E-energy initiative supported by the Federal Government, being promoted and demonstrated in six trial regions.

To balance the sharply increasing fluctuations in power generation from the sun and the wind which will occur in the future, the following elements can be integrated into the online market:

- Decentralised power plants which react quickly – particularly combined heat and power plants or gas, and gas and steam

10 However, data protection must also be taken into account.

power plants, which are supplied via natural gas networks from biomass gasification plants or with methane produced from power surpluses.

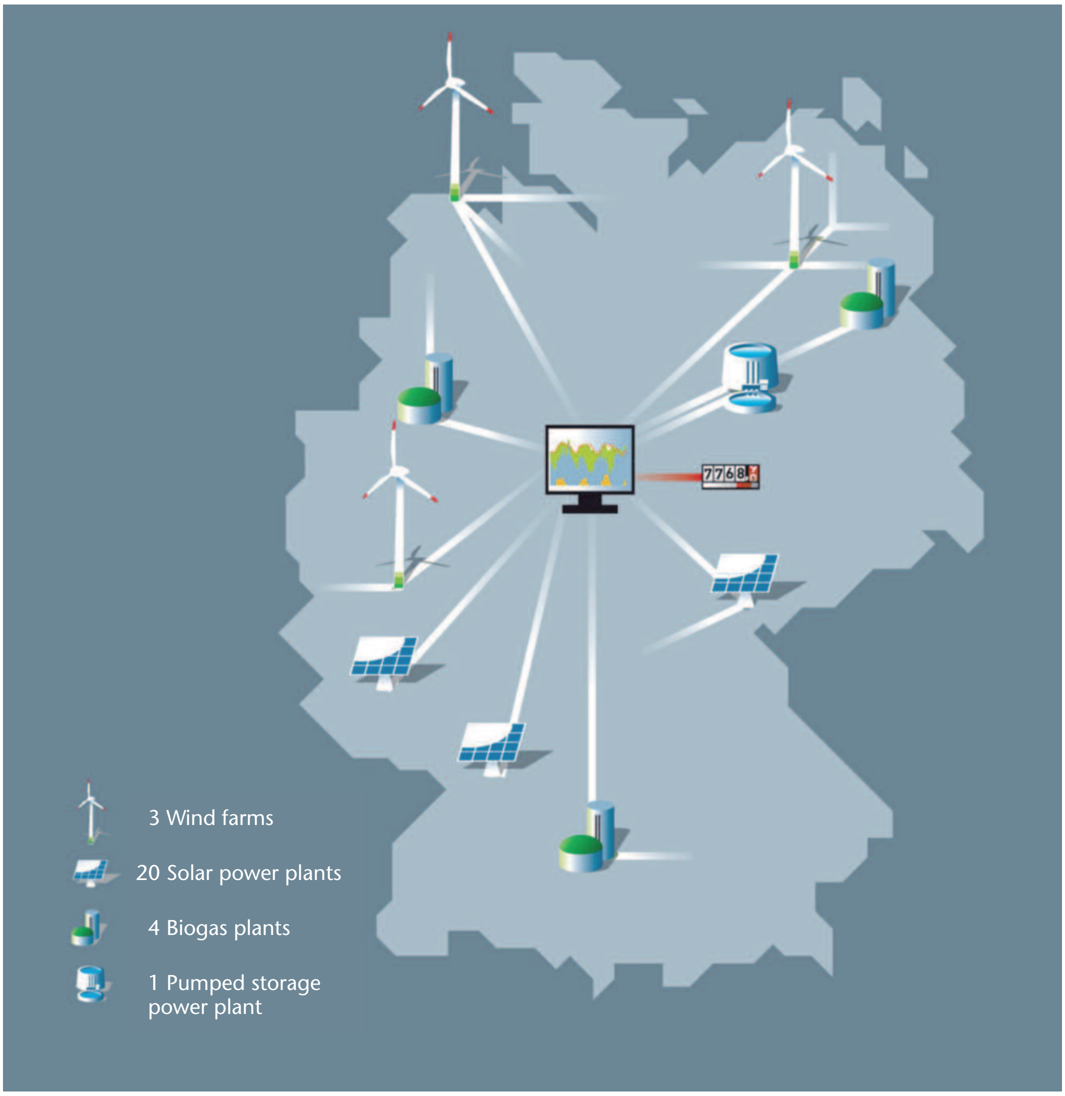
- Interactive networks for electricity, gas and also for heat/cooling (smart grids) in conjunction with smart metering for load and feed-in management (renewable combined cycle power plants).
- Combined cycle renewable power plants for demand-led production from different renewable energy sources, and for the supply of system services for voltage and frequency control.

1.3.6 Combined cycle renewable power plant

The "combined cycle renewable power plant (RKKW)", which was presented at the Energy Summit on July 3rd 2007, showed that a power supply that meets demand from renewable energy is possible through an intelligent link between supply-dependent, producers (wind, PV) which have limited controllability, with controllable producers (biogas-driven combined heat and power plants, micro gas turbines) and pumped storage [27]. This makes a secure energy supply using renewable energy possible at all times and in all locations, particularly if in the future renewable methane is also available in the gas network.

Figure 7
The combined cycle renewable power plant

(schematic diagram)



The combined cycle power plant connects and controls 28 wind, solar and biomass plants which are scattered throughout Germany, with a total output of 23.2 MW [27]. Each individual renewable energy producer has its strengths and weaknesses. Intelligent connection for individual producers, coupled with effective forecasts and combined with storage and flexible consumers, allows output availability which meets the requirements for security of supply. The combined cycle power plant has met Germany's power demand in real time at the ratio of 1:10.000 to the second, and demonstrates that renewable energy is capable of securing Germany's power supply, if it is expanded accordingly.

However, the project has also shown that, for a future energy supply based on renewable sources, installing substantial over-capacity is absolutely essential, so that production surpluses can be generated which can meet temporary generating shortfalls.

The ability of renewable energy to provide reliable supply and to meet total power demand is further strengthened through current research activities as part of the E-Energy Project [28].

1.3.7 Buildings, towns and communities as energy system components

Up to 2050, the passive house, the energy plus house and the solar active house should each in turn become a new building standard. In the long-term, there must be a decoupling of heat energy demand from the per capita living space.

- **Passive houses** are primarily powered by electricity, which is partly produced by a photovoltaic system on the roof, and have a thermal solar power plant for heating drinking water. The remaining energy demand can mainly be met in a highly efficient way through heat pumps supplied by renewable generated power, which can if necessary be used in summer in combination with the PV plant to cool the house. The demand for heat energy in a passive house is up to 15 kWh pro m^2 and per year, the total energy demand amounts to 30 kWh/(m^2a) [9].
- As an annual average, **energy plus houses** can even produce more final energy than they themselves use.
- **Solar active houses**, like passive and energy plus houses, feature good heat insulation and meet their residual heat demand using 100% solar heat, whereby part of the solar heat from the summer can be stored until winter using a seasonal heat storage unit.

In new buildings there is already a movement towards this energy efficient and solar construction method. However, in order to reduce the total level of energy demand in the home, the energy performance of the old building stock must also be improved, which should largely be completed by 2050. This goal would be achieveable with a renovation rate of 2 to 3% a year.

Energy demand in old buildings whose energy performance has been improved is reduced by up to 90% [16]. This can be met by renewable energy. In towns, and in densely populated areas, network and interconnection solutions for the sensible linking of heat sources and heat sinks should be used. In historic monuments, district-based solutions will in particular be used to resolve the situation.

The technology of using local and district heating – possibly coupled with transportable heat stores – takes on a key role in urban centres for the efficient use of waste heat from industry and CHP. Furthermore, synergies can develop by linking old and new buildings, higher flow temperatures are first used in the old building stock for heating, and then new buildings can, for example, always have an adequate supply from the return flow from these systems (cascade use of heat).

1.3.8 Dynamic interaction of technology components

In order to integrate very large amounts of renewable energy, besides the specified high power transmission networks, flexible and interactive distribution and low voltage networks are also needed. These so-called smart grids first facilitate the interaction between generation and consumption and thus open up the opportunity for consumers to adapt to current supply, e.g. via variable tariffs. The first projects to demonstrate the efficiency of so-called smart grids are currently being carried out as part of the E-Energy programme.

Integrating solar thermal power plants into national energy supply offers clear advantages, both in relation to competitive supply and security of supply, as for example described in the "DESERTEC" initiative [29]. On the one hand, operating solar thermal power plants requires a high share of direct solar radiation, which can only be found in southern Europe or in North Africa. On the other hand, this kind of power plant can adapt to particular demand by adding storage units or by operating auxiliary burners, which use renewably produced fuels. However, in each case, these require very efficient long-distance transmission networks. Geothermal power plants must be adjusted to meet demand through optimal use.

If there is no integration of the national power supply using renewable energy into the overall European network, the costs of power supply will rise – also because of the additional power storage units which are required.

So-called residual load power plants will be required in the future to supply balancing energy and control energy to electrical grids, which cover the difference in demand between fluctuating sources of power and current load. In contrast to the base-load power stations, their operating periods are short (e.g. 1000 full-load operating hours/a). However, the requirements for a time dynamic for output supply are very high. For example, gas turbine peak load power stations are well suited for this. A completely new perspective results from the coordinated production of distributed CHP plants as so-called virtual power plants. Here, using appropriate communications equipment, a multiplicity of small CHP plants are then activated when there is a corresponding need for output in the electrical network. Decoupling heat demand, which differs depending on time, occurs using thermal storage units. In exceptional cases, this kind of virtual power station can also come on stream, if there is no heat demand.

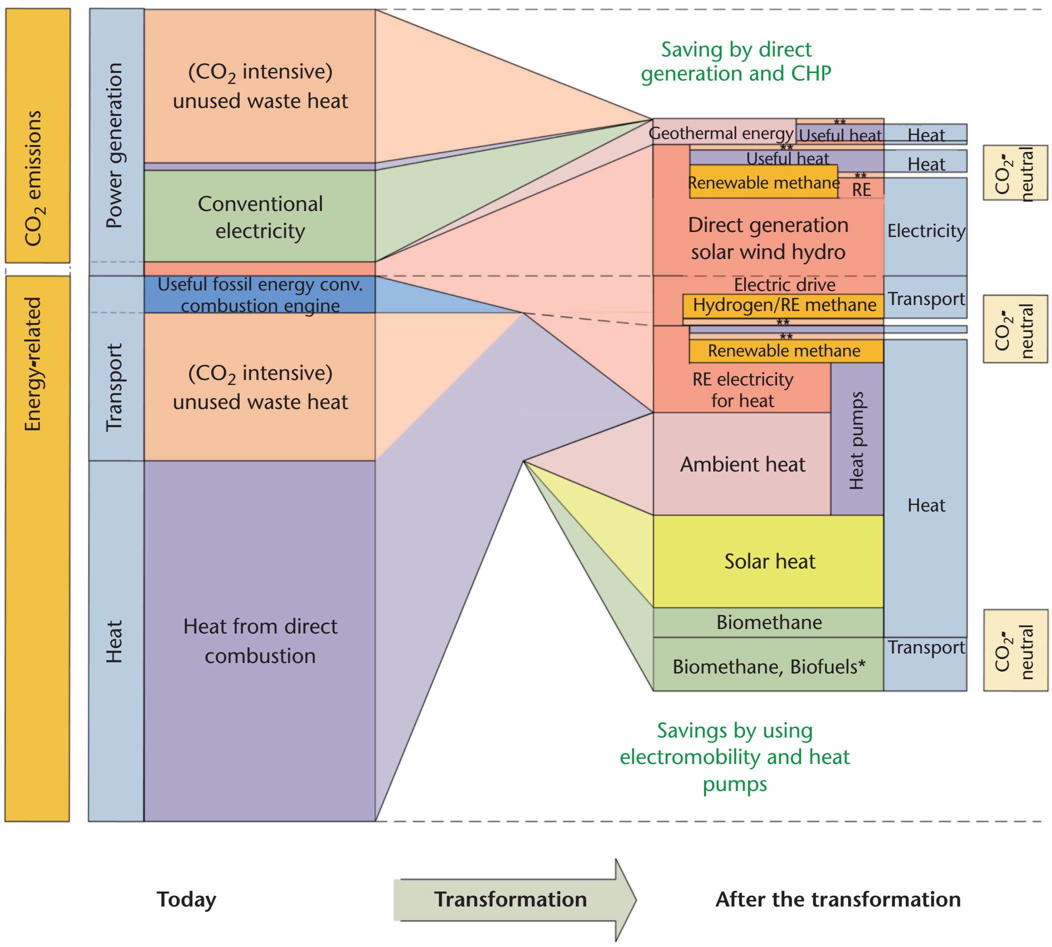
2. Transformation of current energy systems into the Sustainable Energy System 2050

Converting the energy system in Germany and in Europe into a sustainable energy supply implies a profound change in the current industry and service economy, which will extend in an evolutionary way over four decades. Here, the transition from the current energy system to the sustainable and largely emissions-free system which is described in Chapter 1 should be designed in such a way that it avoids technological errors, and that security of supply is also guaranteed during the transformation phase (no regret strategy).

Figure 8 summarises the essential components for transforming the energy system, using the example of the industrialised country of Germany:

In 2005 in Germany, primary energy demand, excluding the non-energy share, (such as crude oil for the chemical industry) amounted to 13.4 EJ, of which 34% was for the electricity sector, 43% for the heating sector and 23% for transport.

If we look at final energy, other relationships emerge: the share of electricity falls (18%) and



Source: Fraunhofer IWES

Figure 8
Diagram of total energy transformation from today to the Energy System 2050. The wedge-shaped areas in the middle of the chart symbolise the gradual transition from today's energy mix to the future mix.

The diagram is based on the volume breakdown for the 100% RE scenario 2050 (Chapter 2.5.1)

** = can also be other renewable fuels, such as e.g. renewable kerosene*
*** = unused CO_2-neutral waste heat*

Adjusted in accordance with [17, 26] and [17], using BMWi data [31] and Chapter 2.6

both the other sectors become correspondingly bigger (heat 54%, transport 28%). Electricity is already used today for transport, but this only amounts to a share of 2% in the transport sector, and has therefore not been included in the diagram.

In the future, direct combustion for heat usage should be replaced by heat from CHP, solar thermal energy and electroheat pumps which are supplied by renewable electricity.

The share of heat which is obtained from electricity, including heat from CHP, is included in the chart under power generation. Electricity should mainly be generated by direct production from solar, hydro and wind energy. For the load management of fluctuating energy sources, as well as a massively expanded electricity transmission and distribution grid and connected storage power plants (Pumped storage, compressed air, hydrogen or renewable methane in the natural gas network), heat pumps should be available both for the transport sector (electrically driven cars) and also for the use of heat, which are linked to a broadly expanded information network (smart grid). Power use in the heat and transport sector amounts to a total of 25% of electrical energy supply. Such a transformation is conceivable by 2050.

2.1 Structural change in the space heating sector

About 40% of final energy consumption comes from building operations, this makes it one of the main sectors for contributing to Germany's energy consumption. In order to achieve the target of a sustainable energy supply and the necessary climate policy goals, there is a need to reduce energy demand for heating and air conditioning in buildings, as well as an increase in meeting energy demand with renewable energy.

As a particularly large amount of energy can be saved in the building sector, it follows that the Federal Government's goals on energy efficiency will mainly be either achieved or missed in the building sector or in the area of space heating [30]. In the short-term, new buildings must be changed into energy plus houses, and the building stock must be brought to the level of a low energy house. This will result in reductions in consumption in Germany, which will exceed the 2008 targeted contribution from renewable energy by a factor of 3 or 4.

The Energy Concept 2050 states that the space heating sector must go through a serious structural change by 2050.

2.2 From natural gas supply to renewable methane

As already stated in section 1.2.3.2, as well as hydrogen, renewable methane can also be produced from surplus renewable energy. A paradigm shift in the philosophy of energy storage can be seen here. Large amounts of renewable electricity can therefore be stored chemically in existing gas networks, and can again be converted into electricity, heat or fuel, depending on demand. Gas and steam power plants with an electrical efficiency rate of up to 60% provide reverse current.

The construction of power plants which will initially operate on gas, and on combined heat and power, can begin immediately. The initial increase in demand for fossil gas will be offset in the medium-term by the reduction in gas-consuming heating for buildings and replacement by combined heat and power and electric heat pumps.

The Energy Concept 2050 assumes that total gas demand will already have fallen by 10% by 2020. [9]. In the long-term, gas demand will move towards zero, increasingly replaced by sustainably produced bio methane and by renewable methane from electrical surpluses. This means that the existing gas networks must also be adapted to the changing location of future energy sources. As with the electrical network, -

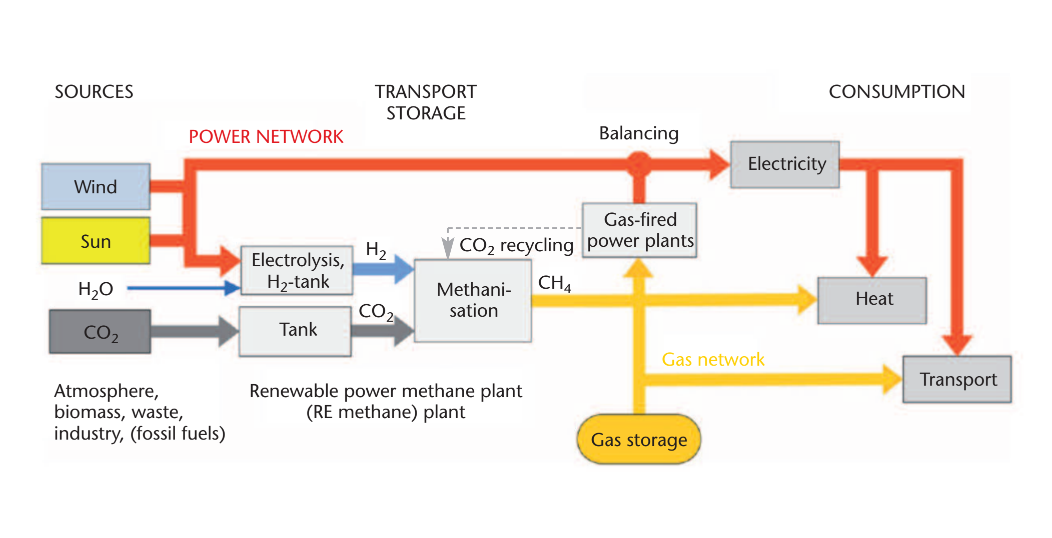


Figure 9
Storage of electricity from the sun and the wind through the production of methane and its subsequentt storage. Using bidirectional coupling of gas and power grids, connected to the mobility consumption sector, methane forms an indirect power storage unit.

Source: Fraunhofer IWES (Sterner) and ZSW (Specht) [14; 26; 32]

in contrast to today - the gas network will be able to handle changing directions in flow. This requires new management strategies (smart grids). The construction of liquefied gas terminals which is now in progress should be speeded up further to allow the inclusion of hydrogen or methane produced at particularly favourable locations from wind and solar power surpluses.

2.3 Flexible energy and substance flow-oriented utilisation strategies for biomass

Biomass can make an important contribution to the future of energy supply, as it has the potential to play a particular role, together with renewable energy. It is a domestic resource and it is available for energy use to meet demand as part of a defined potential. It is therefore one of the energy sources which can balance fluctuating energy flows in various ways, and can thus be used as a balancing energy between supply and demand. Particularly promising in this context are new kinds of conversion technologies, with which electricity and heat (through cogeneration) as well as additional fuels (through polygeneration) are produced. Against this background, using biomass for energy with a supply efficiency of more than 70% is possible. These technologies are therefore essential for the transition from supply using fossil fuels to a future with renewable energy. Inter alia, this is shown by the many projects to construct bio-energy villages.

While biomass waste – admittedly with limited potential – is largely available uncritically and, as part of efficient chains of use, it can also be used for long-term energy, cultivated biomass in the form of energy crops – both nationally and globally – will in the future increasingly compete with alternative uses (food, feed stock for bio refineries etc.). In the future, then, differentiated, substance flow-oriented strategies should be followed in the biomass sector, which should be stringently geared towards efficiency criteria, the development of other renewable energy sources, and the specific demand for resources.

Against this background, the 2009 lead scenario [9] states that “provided that there is a significantly more efficient use of fuels, the introduction of biogenic fuels would then be an advisable transition strategy, if the sustainability criteria are adhered to, which, inter alia, are defined in the biomass strategy of BMU. From the“ecological” domestic potential there is an available cultivation area for bio-fuels of a maximum of 2.35 million hectares for the transport sector, in the area of application used. Against the background of current general conditions relating to biofuel quotas and taxation, a share for biofuels in total fuel consumption of just under 10% has been set for 2020”.

By 2050, biogas can be increasingly replaced by renewable methane gas, which can, for its part, be used in a comparably flexible way. In the long-term, biomass should also be converted into cascade use systems, because of CO_2 commitments, where energy recovery will only ensue when the material options for use have been exhausted.

2.4 Balance between centralised and decentralised energy supply

The rapid development of decentralised regional energy supply concepts in Germany also mobilises regional economic structures. This reorganisation is an engine of change. In order to give the necessary energy policy stimulus, the balance between centrality and decentrality in energy supply must be respected. This balance is mainly formed by future cost structures. The more cost-effective the components and systems for the use of renewable energy, the more decentralised is their use.

2.4.1 Network management of decentralised electricity and heat networks in conjunction with large, national and European networks

For such network expansion to be sustainable, the future development of renewable energy and all the European power plants should be simulated as accurately as possible and this should be analysed. There should also be efficient, Europe-wide monitoring alongside the expansion of the network.

By 2020 "electricity from the European renewable power network will already make a substantial contribution to Germany's renewable energy power generation, at almost 5 TWh/a. Because power production costs are 6.5– 7 ct 2005/-kWh cheaper, power supply from the European power network (wind energy and solar thermal power plants) will grow significantly towards 2020, will already be 41 TWh/a in 2030 and will increase to 123 TWh/a by 2050. This corresponds to 20% of total gross power generation" [9].

If the construction of this trans-European supergrid is not completed to time, or not finished completely, power surpluses from renewable energy must on the one hand be stored nationally, and, on the other hand, gaps in power supply will be contained using residual load power plants. In contrast to the previously used base- and medium-load power stations, these will be fast reacting gas-fired power plants with combined heat and power, and virtual network-structured small systems such as combined heat and power units, microturbines and fuel cells. Electrical energy stores, as they are often proposed, could in principle also provide this balance. However, for the foreseeable future they will probably not be competitive with strong networks or residual load power plants. In the medium- to long-term, however, electrochemical energy storage such as high temperature and redox flow batteries will also make a contribution [33].

2.4.2 How can system conflicts be avoided?

Today's large power stations are not suitable for balancing fluctuating electricity from renewable energy, as they cannot undertake the major changes in output that are required. Frequent and major load changes reduce the operating lifetime of large power plants because of the additional pressure on materials which occurs when this happens, and also their economic efficiency.

In other words, if the priority given to the feed-in of renewable energy is maintained, then the conventional base-load power stations will be increasingly unsuitable for supplying residual load. The types of power plant which are suitable for this are therefore: gas-fired power plants and combined heat and power plants (motor-generators, microturbines, fuel cells), which can be controlled using communications equipment.

The consequences arising from the call for fast-reacting power stations are serious: they mean

that large power plants of all kinds are unsuitable for the future supply structure, if fluctuating renewable energy is to take over the lion's share of supply. This not only means, then, that neither nuclear power stations, nor fusion power stations, nor coal-fired power stations can be used, but also that the current approach of CO2 capture and storage from coal-fired generation (CCS), is leading in the wrong direction, not only for purely economic, but also system reasons.

2.5 Costs and benefits of converting energy supply

This Energy Concept assumes that the transformation to an energy system which is fully based on the use of renewable energy sources will be successful by 2050. The sustainability of this approach is often questioned against the background of the costs associated with transforming the system. It is usually not take into account that fossil energy sources will be increasingly expensive because of shortages of raw materials, while renewable energy is still being developed technologically and its costs will continue to fall further as a result of a substantial learning and experience effect. To show that a 100%- renewable energy scenario for Germany in 2050 is not only possible from the viewpoint of potential, and that it is technologically feasible, but also that the costs of changing are justifiable, the following outlines a possible

volume scenario (2.5.1) and, by examining the differential costs (2.5.2), renewable energy is compared with fossil energy sources. The examination of differential costs is restricted to supply technologies for electricity, gas and heat from solar and geothermal sources. Not included are possible additional costs for the increased introduction of CHP and electric heat pumps. Additional costs for the required expansion of the network are not included in this examination, as well as additional costs from the essential expansion of power storage. However, these additional costs are in any case below the amount for savings that will result from the supply of renewable energy, in comparison with conventional alternatives, to the middle of the century.

2.5.1 Volume breakdown for a 100% RE scenario 2050

The possible volume scenario for the energy scenario 2050 that is outlined here includes the areas of power generation, the supply of useful heat and final energy demand for transport. In all three sectors, up to 2050 a share of l00% renewable energy is achieved. It should be pointed out here that the volume scenario only sets out a possible development pathway to a purely renewable energy supply system, and can be seen as one solution amongst many for a renewable energy supply system.

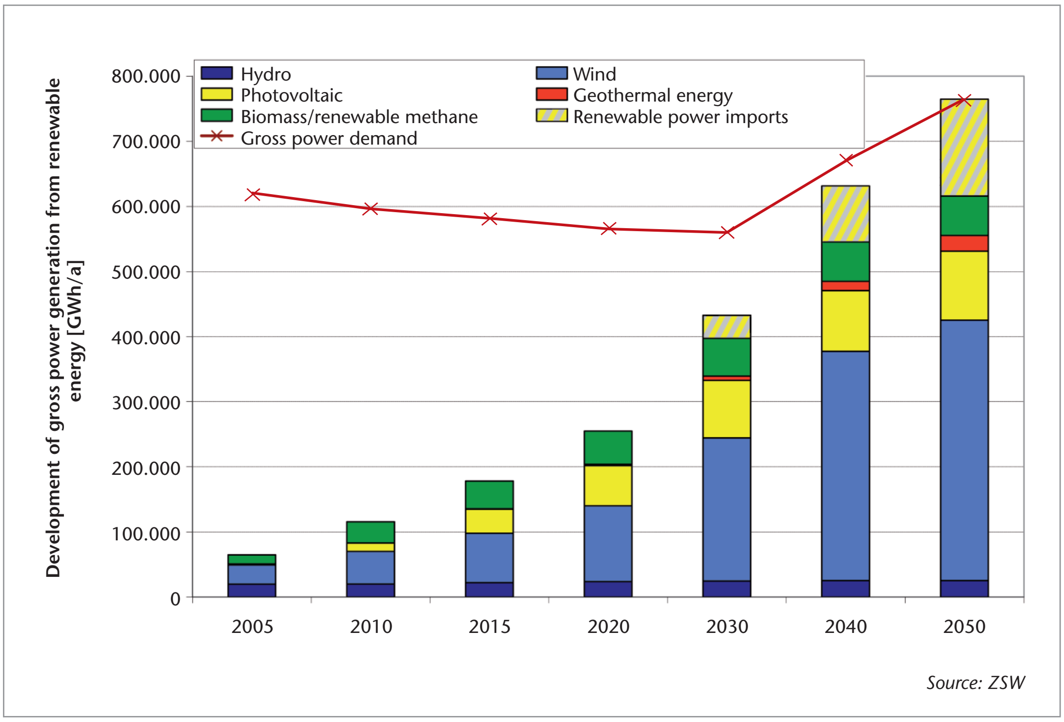
Here, the 100% RE goal is a very robust target, since even if a particular technology in the volume scenario does not reach the given target for expansion, renewable energy has enough technological variety for the missing share to be made up by one or several alternative technologies. The volume scenario which is shown here is formulated in such a way that the whole of Germany's annual energy demand is covered mathematically, but in this context, there is no aspiration for Germany to be self-sufficient in energy supply. Particularly for power supply, Germany should be seen as part of a European power network, whereby the storage capacity and output to be installed can be limited to a minimum. No specification of the storage technologies to be used has been made here.

The DLR's lead scenario [8, 9] initially served as a basis for developing the volume scenario in the power and heat sector, while in the transport sector, on the demand side, the orientation is based on the WWF study [11]. The call for a100 % renewable energy supply makes higher expansion rates for the different technologies necessary, in comparison with the 2009 base lead scenario. This also includes the increase in power demand resulting from the expansion in power supply in the heat and transport sectors.

In comparison with the lead scenario, supplying all useful heat using renewable energy is achieved by a significantly higher penetration rate of electric heat pumps, by a higher share of solar thermal energy, and, last but not least, by assuming a more substantial fall in demand as a result of efficiency measures. However, in contrast to the target values stated in the WWF

Figure 10
Development of gross power generation from renewable energy and gross power demand in Germany to 2050.

Source: ZSW



study for the heat sector, a lower rate of increase is assumed for efficiency and renovation, so that the estimated demand for useful heat in 2050 is between the 2009 lead scenario and the values stated in the WWF study.

In transport, in contrast to the WWF's starting scenario, a much higher electromobility penetration, particularly in passenger transport, is assumed.

The use of surplus electricity from wind and solar power plants takes on an important role: The available power surpluses can be used to produce hydrogen and in the future renewable methane or other renewable fuels, whereby the power surpluses can also be stored over longer periods. Importing wind and solar fuels produced in this way is also conceivable. This link between the power and gas networks and the resulting possibility to use the gas network as a store make attaining the 100% RE target significantly easier. If necessary, power can be re-converted, and used as an energy source to meet heat demand or in the transport sector.

Figure 10 shows developments in gross power generation using renewable energy from 2005 to 2050, as well as the expected development of gross power consumption. Higher power demand must be met in comparison with the 2009 lead scenario. This arises from the increased use of electrically driven heat pumps to supply heat, and from a significantly higher electrification rate in the transport sector. In contrast, the supply of hydrogen for the transport sector corresponds to the expansion path forecast in the 2008 lead scenario 2008 [8]. Surplus electricity is mainly used to supply this. These and other power surpluses are also converted initially into hydrogen and, if necessary, using the further conversion stage mentioned, into renewable methane. If the gas and oil infrastructure is successfully converted into hydrogen, hydrogen can also be used directly.

The higher demand for power is offset by a more intensive expansion of the offshore wind sector and photovoltaics, as well as by increasing the share of imports. Up to the year 2020, expansion can take place solely domestically. Only after this are imports of renewable electricity required. Amongst other things, this creates the necessary leeway in terms of time for the expansion of the European power network. In 2050, about 764 TWh of power will be supplied

from renewable energy, and all the gross power consumption will be met by renewable energy.

The level of electricity demand is slightly above the results of the SRU report [10], which assumes that an electricity demand of 700 TWh, arising from the substantial electrification of the transport sector, which in terms of potential can also be met 100% from renewable energy.

In the volume breakdown that is outlined for the Energy Concept 2050 scenario, which only sets out a possible pathway to a 100% renewable energy supply, wind power generation – including a share of about 38% for offshore wind – has the highest importance. In the same way, photovoltaics also becomes one of the important pillars of power generation, and in 2050 this produces almost 15% of power demand, which means that photovoltaics makes a bigger contribution than the use of on-shore wind energy. Renewable electricity imports can also come largely from photovoltaics and solar thermal power plants (the part of the column that is shaded in yellow and grey – see *Figure 10*), which would mean that up to 25% of the German electricity grid could come from solar power. The great importance of photovoltaics can also be shown in *Figure 11*, from which the installed output that is needed to produce the amounts of electricity that are presented is evident. Power exchanges within the European power network, as well as the import of renewable electricity, also play a key role. Overall, almost 20% of the electricity needed will be imported from abroad in 2050.

In the heat sector, the 2009 lead scenario also assumes that renewable energy will only meet 50% of demand in 2050. In order to be able to achieve 100% supply using renewable energy by 2050, first of all demand for heat energy must be reduced more substantially through greater energy efficiency measures, particularly in the housing stock. The scheduled increase in efficiency is higher than in the 2009 lead study [9], but follows a less ambitious path to growth than is set out in the WWF study in the "innovation" scenario.

In addition to the reduction in useful heat energy demand, the Energy Concept 2050 includes greater expansion of solar thermal energy and electrically driven heat pumps. The use of biomass is gradually replaced, to the level at which hydrogen and renewable

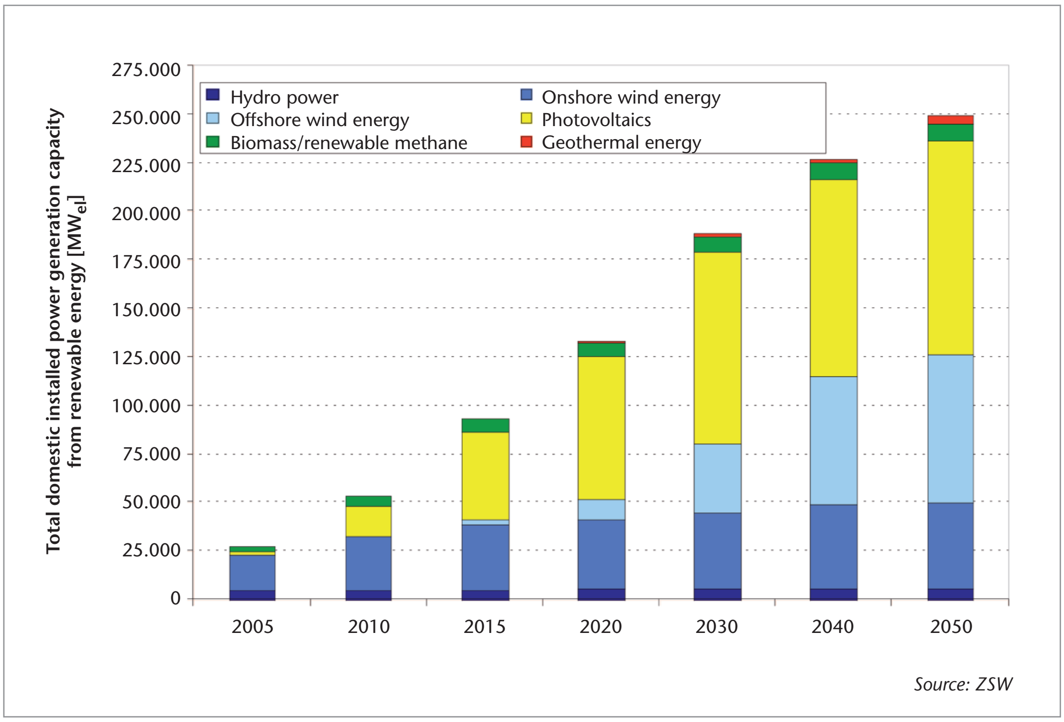


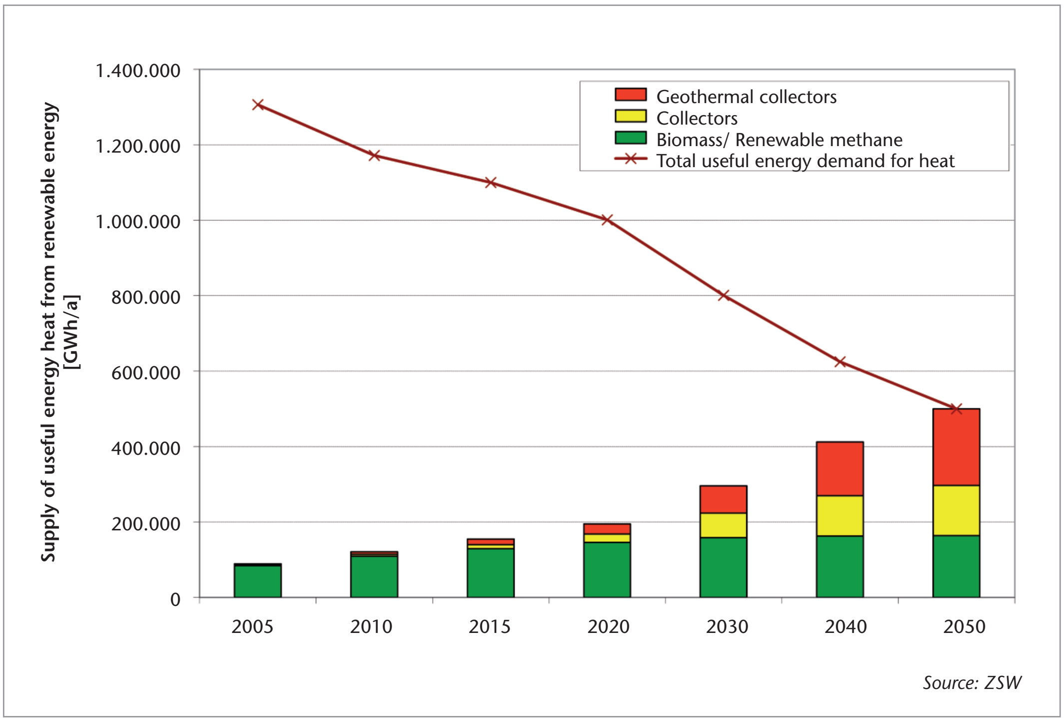
Figure 11
Development in installed power generation capacity in Germany from renewable energy to 2050.

Source: ZSW

Figure 12

Development of supply of useful energy for heat from renewable energy and total useful energy demand for heat in Germany to 2050.

Source: ZSW



methane is available from surplus electricity. Heat production primarily takes place in decentralised combined heat and power plants, which take on an important role in balancing the fluctuations in electricity generation.

In all, in 2050 about 500 TWh of heat will be produced from renewable energy. With a very ambitious, but feasible expansion pathway for solar thermal energy, this will produce about 27% of the required heat in the volume scenario under consideration. Furthermore, to meet heat demand, particularly in existing buildings from 2030, there will be increasing use of heat pumps, so that in 2050 ambient heat will supply about 40% of heat demand. Biomass and renewable methane will have a share of 33%, as shown in *Figure 12*.

The WWF study is used for developments in the transport sector [11] as a basis for the volume scenario: it predicts that in 2050 no more fossil energy sources will be used in the transport sector and that these will gradually be substituted by renewable energy, primarily biomass, (e.g. biodiesel, petrol from biomass, kerosene). The Energy Concept 2050 differs from this insofar as it is assumed, in relation to passenger traffic, that until 2050 it will be completely converted to battery-powered electric cars, and fuel cell cars, which operate using hydrogen and methane. It is assumed here that both petrol and also diesel cars will be replaced. In freight transport as well, individual shares will be replaced by vehicles operating on hydrogen or methane. This is not least also because reserving total German revenue from biomass for the transport sector, as mentioned in the WWF study, does not appear to be realistic from the point of view of the Energy Concept 2050, for reasons of sustainability and the priority use of biomass for material purposes. The remaining fuels that are needed for freight, shipping and aviation transport will be completely substituted by 2050, in line with the WWF study, by fuels of biogenic origin, and by energy sources that are obtained from surplus electricity.

Figure 13 shows a possible development in energy sources in the transport sector to 2050. Developments in the transport sector are particularly difficult to predict, as the domestic production of biomass is subject to restrictions and a not inconsiderable share of this must be imported from abroad. An alternative, or a supplement, using fuels from power surpluses, could be considered.

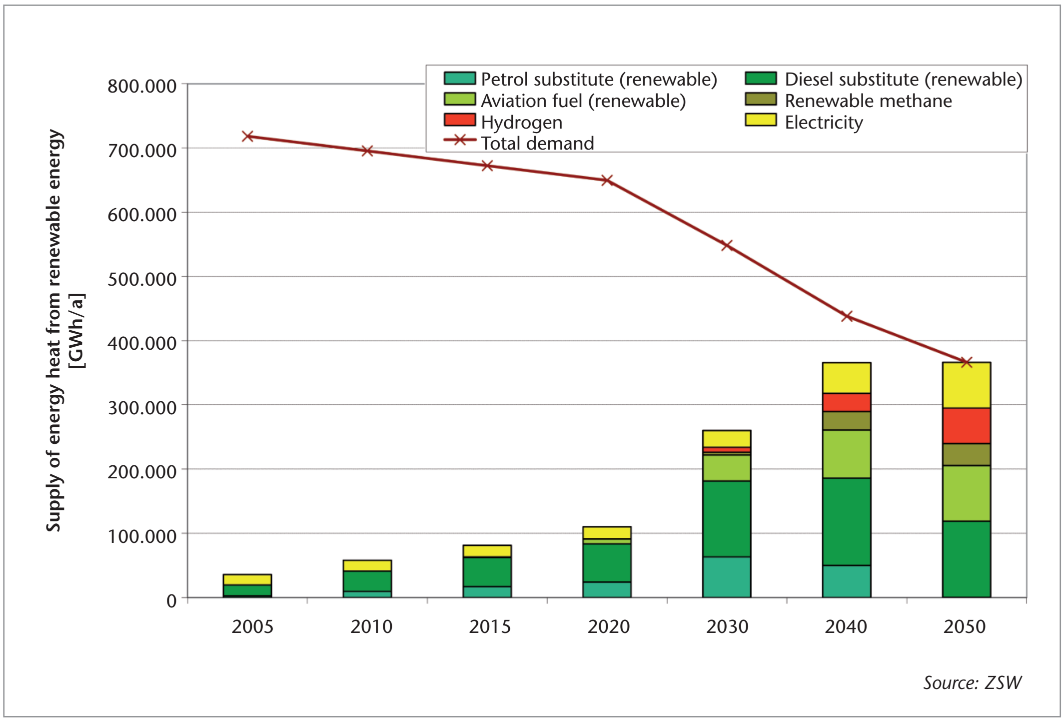


Figure 13
Development in final energy demand for transport from renewable energy and overall final energy demand for transport in Germany to 2050.

Source: ZSW

2.5.2 Differential costs for a 100% RE scenario 2050

The conversion of the three sectors, electricity, heat and transport, to renewable energy initially produces additional costs, in comparison with the applied energy prices, based on conventional energy supply, which are here each shown as differential costs for the individual sectors. The additional costs for renewable energy, which today are still above the prices of fossil energy sources, fall over time as a result of the effect of learning and experience, until finally the break-even point with fossil energy sources is reached. From this point in time, the differential costs become negative, that is, costs can be saved by using renewable energy, compared with the use of fossil fuels.

Calculating the differential costs is done here on a cost basis, that is, the energy production costs for renewable energy are compared with the average electricity production costs of the fossil power plant mix, including heat credits[11], with fossil heat prices and with fuel prices (excluding tax).

11 Payment for waste heat, in particular for biomass CHP plants

In the power sector, these differential costs are slightly higher than the EEG differential costs, and the details vary, as the payment clauses in the EEG are generally not identical to the pure power generation costs. Total energy supply from renewable energy is considered, this means that in particular, "old" hydro power from larger power plants is included.This is one of the cheapest sources of power production, and today it already results in "negative" differential costs in comparison with the established power prices.

The basis for calculating the differential costs is the 2008 lead study [8]: on the one hand, assumptions made for future cost developments in renewable energy technologies, and on the other hand, the local price scenarios for the development of fossil energy prices and the price of CO_2 certificates. Here, in relation to the 2010 lead study, the easy adjustments arising from the current economic situation are currently being worked on, and these have already been included here.

However, these tend to be short-term considerations rather than long-term effects.
When looking at sector-specific costs, the most important underlying assumptions are once

again each presented together, in order to create the necessary transparency.

2.5.2.1 Differential costs of power generation

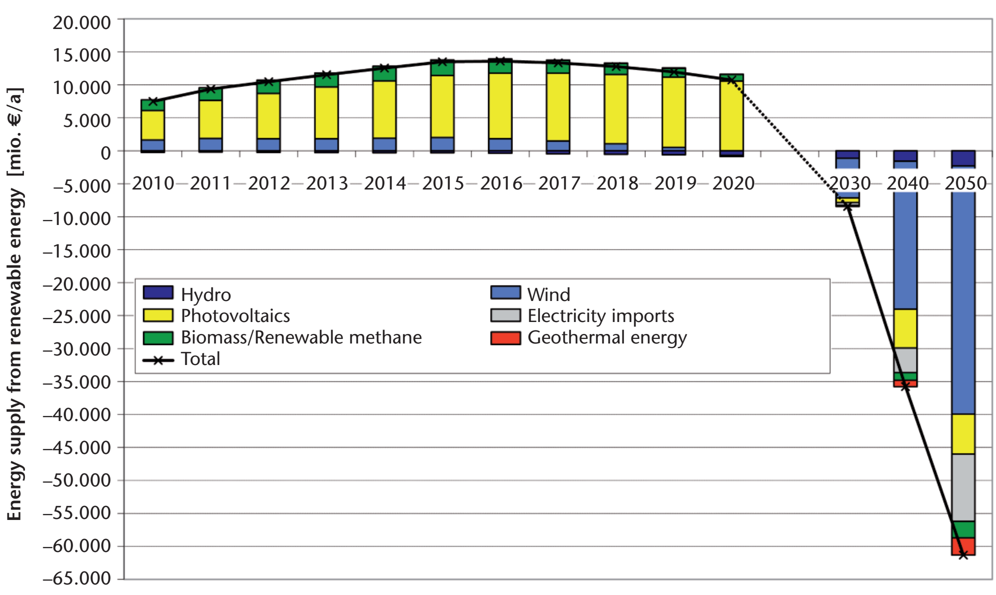
- The differential costs of total RE power generation are calculated on the basis of the power production costs of the individual technologies and their respective share in the renewable power generation mix. The mean electricity costs for a renewable energy generation mix increase on average from 11.5 ct/kWh today, to initially 13.1 ct/kWh in 2015, when they will reach their maximum. After this, they will continue to decrease. In 2020, they are still above today's figure, at 12.1 ct/kWh. They will subsequently fall significantly, to 7.6 ct/kWh in 2030, 6.4 ct/kWh in 2040 and 6.3 ct/kWh in 2050.
- From 2020, price pathway A for the given development in energy prices in the 2008 lead study applies.
- As there are still no reliable data for the new technological pathway for producing renewable methane, the differential costs that arise for this purpose are equated with those of biomass. This gives a certain vagueness to the assessment of costs. As the differential costs of power generation from biomass are comparatively high, this tends to be rather an over-estimate than an under-estimate of the resulting differential costs

Using renewable energy to generate power will probably lead to differential costs in Germany of about 7.5 billion euro in 2010. The increased expansion of renewable power generation will at first increase the annual differential costs further. They will reach their maximum at about 13.6 billion euro in 2016. After this they will decrease. In 2020 they will still amount to 10.7 billion euro. After reaching the maximum differential cost, the annual differential costs will continue to fall.

Between 2020 and 2030, the renewable energy mox reaches the break-even point with fossil energy sources. For individual technologies, the point at which it is reached is very different from the point of intersection with the cost curve of fossil energy sources. So, for example, wind power already achieves cost savings compared with fossil energy sources in 2020, while for photovoltaics, this will not happen until 2030. In 2050, cost savings of about 61.3 billion euro will be achieved.

Figure 14
Development in differential costs of power generation from renewable energy in Germany from 2010 to 2050.

Source: ZSW



Source: ZSW

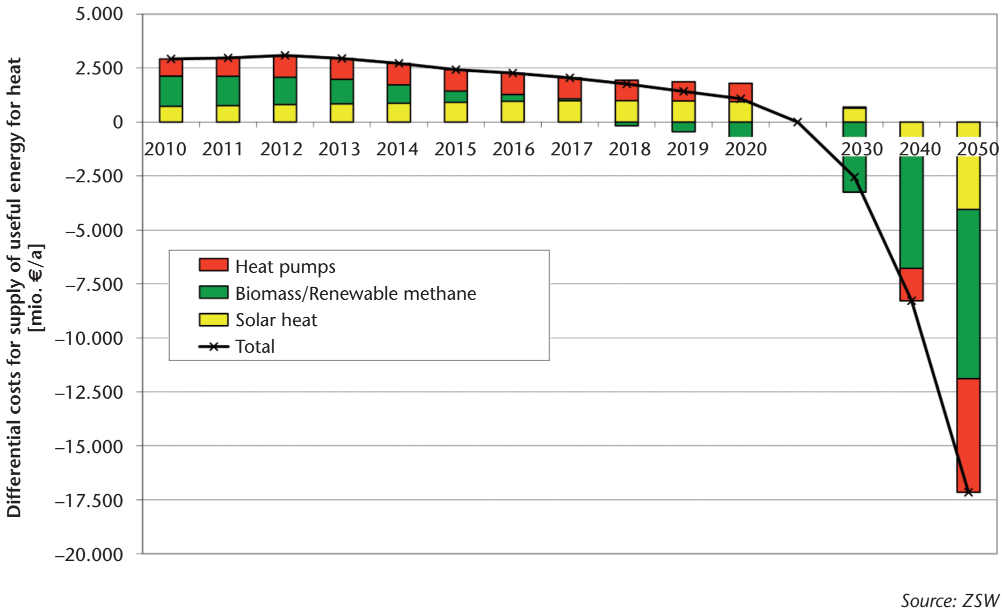


Figure 15
Trend in differential costs of renewable useful heat supply in Germany from 2010 to 2050.

Source: ZSW

Overall, in the period 2010 to 2050, by using renewable energy to generate electricity, costs amounting to 567 billion euro are saved (*Figure 14*). If we look at how differential costs develop over the years, this shows that overall, renewable energy saves more costs than has to be generated in advance payments to reach the break-even point. This means that the expansion in the use of renewable energy not only makes sense in terms of the future direction of energy policy, but also economically.

2.5.2.2 Differential costs of heat production

- The differential costs of the total supply of useful heat from renewable energy are calculated on the basis of the heat production costs of the individual technologies and their respective share in the renewable supply mix.
- From 2020, the energy price trend in price path A included in the 2008 lead study is applied.

In the heat sector, differential costs will probably be about 2.9 billion euro in 2010. If the supply of useful heat from renewable energy develops according to the volume scenario presented, the maximum annual amount for differential costs will already be reached in 2012, at about 3.1 billion euro. After this, the differential costs will continue to fall. In 2020, at 1.1 billion euro, they are still positive, whereas in 2030, at -2.6 billion euro, they are already clearly negative. Here significant cost savings can already be observed. These increase substantially in the period after 2030. In 2050 there are savings amounting to about 17.2 billion euro.

The total differential costs in the heat sector in the period from 2010 to 2050 are negative, that is, the savings outweigh the additional costs, which are to be spent until the break-even point is reached. Total savings for the period from 2010 to 2050 in the heat sector amount to 163.1 billion euro.

2.5.2.3 Differential costs in the transport sector

For a transitional period, additional costs in the transport sector arise from the increased use of biofuels and the introduction of electrically driven cars. Of importance here are the price relationships of the relevant energy sources, the car costs and the amounts of energy in comparison with a business as usual scenario which describes a development under largely unchanged political conditions, in which trends in mobility and efficiency increases continue. In contrast to climate protection scenarios, in this case changes in greenhouse gas emissions are an amount and not a target variable. CO_2 emissions in transport in the reference scenario [11] between 2005 and 2050 thus fall by only 42%.

The important cost factors for the business as usual scenario used here are (in today's prices):

- The oil price in 2020 is 100 US$ a barrel and increases in accordance with [WWF 2009] to 2050 to US$ a barrel.
- The price of fuel increases correspondingly for petrol (as for diesel fuel) to 1.60 euro/Litre to 2020 and about 2.60 euro/Litre in 2050.
- The CO_2 credits for renewable fuels amount to 20 euro/t CO_2 in 2020 and increase linearly to 50 euro/t CO_2 in 2050.

For renewable –generated fuels, it is assumed from this that the differential costs after 2020 fall to zero, as they become competitive with untaxed petrol and diesel fuel [9]. To balance electrically driven cars (Plug-in-hybrids and purely electric cars), it is assumed that they will be mainly in private hands and that the electricity prices for private households will be applied to driving the cars. To conform to the goals of the 100% scenario in the Energy Concept 2050, this power comes exclusively from renewable sources. According to the development of costs in the renewable electricity mix, prices increase to 2020 to 27 ct/kWh and subsequently fall slightly. It should also be borne in mind that the purchase costs of electric cars are significantly higher than cars with combustion engines. This is particularly important in the context of the forthcoming market introduction. In relation to the Federal Government's National Development Plan for electromobility of August 2009 [34], the scenario envisages that a million electric cars will be in use by 2020, and about five million cars by 2030. The additional costs should be reduced as there are further developments in components and through mass production, to below 5,000 euro per car by 2020. However, the significantly lower operating costs compared with cars with combustion engines cannot yet, at this point in time, fully offset the higher purchase costs. This will happen first a few years later. Bearing in mind the significantly higher additional costs when market introduction begins, in 2020 for the complete fleet of electric cars, the differential costs are about 400 mio. euro/a. After this they decrease significantly and by 2030 they cross the base line. However, the advance payments made until then can subsequently be recouped within a relatively short period.

In contrast to purely electric cars, the introduction of hydrogen technology will at first happen via the fossil-based supply of hydrogen. The reasons for this are related to infrastructure, as initially, hydrogen for mobile applications will only be supplied via a decentralised reformation of natural gas.

A change to renewable resources will only happen in the period around 2030. The increasing demand for the storage of renewable surplus electricity in the form of hydrogen or renewable methane will speed up technological development accordingly. The additional costs which arise as a result of using fuel cell technology can be reduced by the introduction of mass production, as well as further developments in components and vehicle technology in the longer-term by 2000 euro per vehicle, in comparison with a petrol-driven vehicle, which means that the fuel cell vehicle would reach the level of the diesel vehicle/GermanHY 2009/. This means, in relation to medium- and long-term costs for renewable-produced hydrogen at the service statio of below 14 cents/kWh H2, that the kilometer-related costs can be reduced to about 30 ct/km. This means that there are no more additional costs as soon as the oil price is above 130 $/bbl.

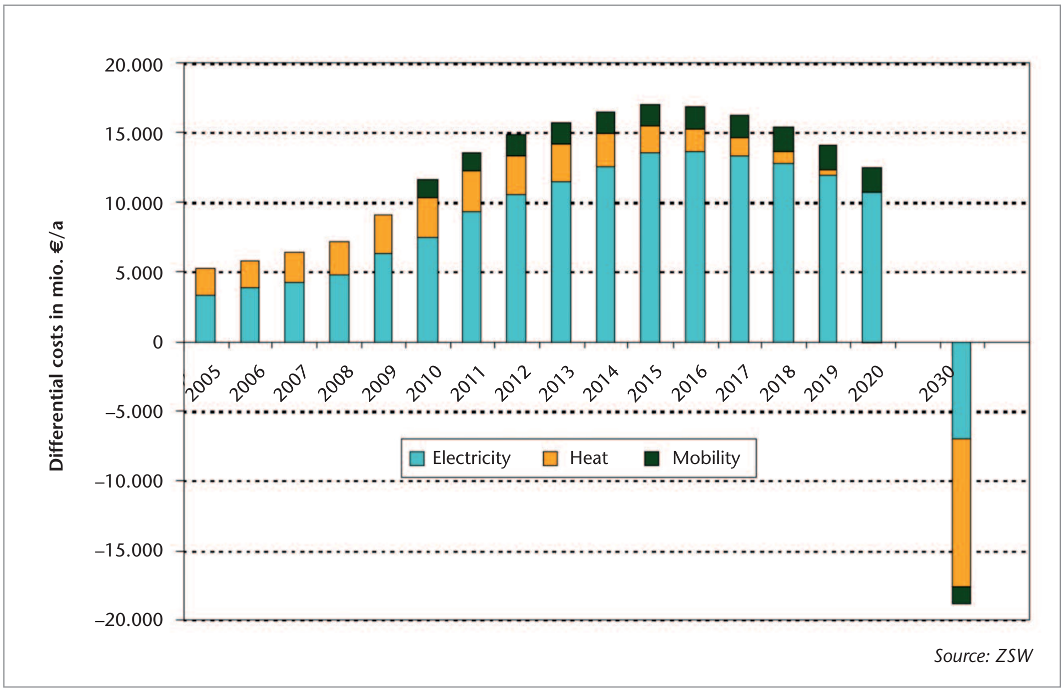


Figure 16
Development in total differential costs in the electricity, heat and transport sectors to 2030.

Source: ZSW

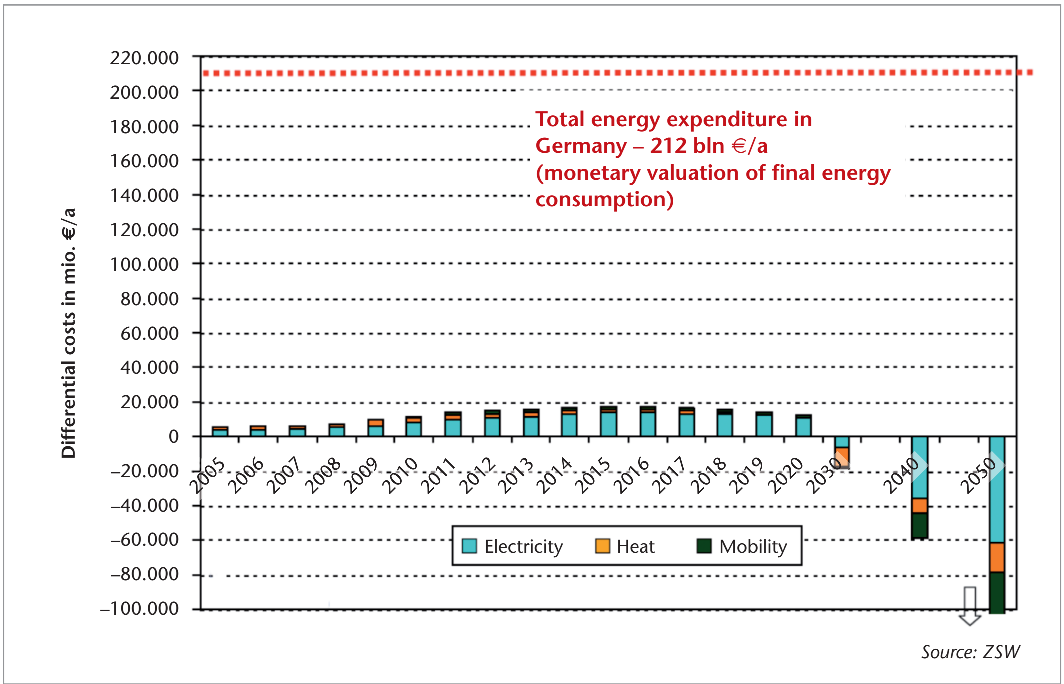


Figure 17
Differential costs to 2050 in relation to total energy expenditure in Germany.

Source: ZSW

2.5.2.4 Differential costs – integration into the general context

The expansion in renewable energy initially results in additional costs, both in electricity and heat production, and in the transport sector. Looking at specific years, though, the maximum additional costs will already be attained in 2015, with an amount of about 17 bln euro (*Figure 16*). For comparison: This corresponds only to about 8% of the total energy expenditure in Germany, which adds up to 212 bln euro, according to the monetary valuation of final energy demand [35] (see *Figure 17*). This comparison means that the argument by which renewable energy would cause significant cost increases for the energy system, can be rejected.

When looking at differential costs of renewable energy for all three sectors, it becomes clear that transformation into an energy system that is completely based on renewable energy by 2050 is also economically beneficial. In the period 2010 to 2050, in the electricity and heat sectors alone, costs totalling 730 bln euro can be saved. The savings from the transport sector are additional to this.

2.5.3 Risks and opportunities of transforming the energy system

A further positive aspect is the reduction in costs from external effects, through lower emissions. On the one hand, via the reduction in costs, for example in health care, this results in a direct economic benefit, and on the other hand, by reducing emissions, there will be a decrease in climate change and therefore lower adoption costs.

At the same time, Germany will reduce its dependence on raw materials from abroad. This dependence presents a particular risk, as a large proportion of fossil raw materials must be obtained from states which can be regarded as politically unstable or undemocratically governed. Without this recommended transformation, dependence on these supplier countries would rise still more in the future, as the raw material deposits in the reliable states of Europe will be increasingly exhausted.

One advantage of using renewable energy, which should not be under-estimated, is a significant improvement in the predictability of economic development. The reliability of forecasts on trends in raw materials, particularly for oil and gas, is markedly low. For example, some studies from 2001 predicted an oil price of about 18-21 US dollars per barrel for 2010. The problem is here less that these forecasts were significantly exceeded, but, much more, the immense volatility of raw material and energy prices. There is no continuous trend, but considerable fluctuations in a very short time. In contrast, the energy supply costs of renewable energy scarcely vary, as they are mainly determined by the level of initial investment and the corresponding capital costs. The only exception is biomass, but here as well a comparably high volatility in prices is not at all to be expected.

Economic structural changes – Germany's position in the global market

A global transformation of the energy system to renewable energy will introduce an overall change in structure. There will thus be opportunities for German firms, but also risks. As an exporting nation, Germany can benefit significantly as a result of the global expansion in the use of renewable energy, if the guidelines are set in time. German firms are, for example, already taking up leading positions in the global wind energy market.

However, whether Germany will be able to benefit in the future from the expansion in renewable energy depends on several factors: a particularly important point is the technology profile. Until now, Germany's strength has mainly been in mechanical engineering and electrical engineering. This is clear, for example, in the development of the German wind energy sector. Because of expansion over the years and the consolidation of know-how and experience in this field, German firms have taken on a leading role in the global market. Innovative developments in the field of system services, which the wind energy plants can provide for the electricity grid and which are also partly attributed to legal requirements, represent competitive advantages for German firms compared with their foreign competitors. This is particularly an advantage for countries with a poor power infrastructure. However, considerable efforts are needed to withstand growing competitive pressure in the global market, to be able to maintain the competitive position, and to expand this still more, as far as possible. Here in particular there is a need for further efforts in research and development at a very high level. A requirement which also fits in with Germany's technological profile as a high-tech location.

The situation is similar for building photovoltaic plants. Germany's technological profile can also be identified by its strong competitive position. Germany's leadership in the global market (50%) in this section of the value chain is shown not least in the high export rates for machinery

and production facilities, up to turnkey plants. The high demand from the Asian region and the resulting provision of high quality facilities, also inevitably increases the competitive pressure on the subsequent stages of the value chain. However, fast growing global competition speeds up the desired cost reduction and poses huge challenges for the German solar cell and module manufacturers. This is not least because the Asian region is a global market leader in the field of electronic mass-produced products, such as for example

LCD screens, and is increasingly keen to also use this experience in photovoltaics. However, Germany is currently also assuming an important role in the global market in the area of PV module manufacturing.

This can be maintained and expanded if, through intensive research and development, exclusive know-how is generated and used by German PV manufacturers that can then be repeated, although initially with a time delay, in plant construction.

With more complex photovoltaic products (in comparison with PV modules), such as inverters or PV production machinery, Germany is a world leader and should also be able to maintain this position in the future.

As well as the production facilities that have already been mentioned, this also includes the field of inverter technology for wind energy and photovoltaics. In 2009, 60% of global PV inverter production originated in Germany. Asian manufacturers are trying to capture this market, however, inverters have become extremely complex, particularly in the field of control engineering. The growing integration in the functions of network creation and stabilisation means that this complexity will continue to grow. For this reason it is to be expected that Germany will be able to retain or even expand its leading position here, if it makes significant efforts on research.

Electromobility

The importance of electromobility in and for Germany should also not be under-estimated. It is true that German industry has long had a competitive automobile industry, but the main components for electric cars will be batteries. And in this field, German firms are at a considerable disadvantage compared with the market leaders from the Asian region, especially Japan, China and Korea. In order to be able to make up this advance, substantial investment linked to major efforts in research and developments is needed.

Moreover, the manufacture of combustion engines by the German automobile industry will decline, because in the future this will in fact only still be allowed to be used for lorries and coaches.

As in the foreseeable future the Asian region will continue to be a leader in battery technology, and demand for combustion engine technology will fall, the expansion in electromobility could lead to job losses for Germany. In order to counteract this development, the German automobile industry must make considerable efforts. However, the activities of the German automobile industry suggest that this risk has already been identified and that the opportunity is being seized to adapt both the company and the technology profile to the changing situation. This also applies to activities in the field of fuel cell development, both for mobile and stationary applications.

Power electronics and electric motors are one part of the German electro-technical industry, and the existing know-how can be transferred to electromobility. So, for example, many functions relating to drive inverters in electric cars are transferred to frequency inverters for industrial applications, and the same requirements are placed on bi-directional chargers for electric car batteries as for PV inverters.

Research and development

In order to achieve the goals mentioned within the time available, substantial efforts are required in research and development. However, active research work produces so called spillover effects, this means, for example, that in Germany the results of research can also lead to advances and improvements in technology for foreign competition. This can mean that German firms invest too little in research in order to minimise the spillover effects, but at the same time also to benefit from foreign spillover effects. Less is therefore invested than would be economically ideal. In order to compensate for this and strengthen Germany as a high-tech location, public funds must be allocated to research, particularly in such fast growing fields as technologies to use renewable energy and electromobility.

Costs and use of building renovation

As well as renewable energy, reducing energy consumption and thereby increasing energy efficiency plays a key role, both in terms of reducing CO_2 emissions (Figure 18) and also adding local value. At the same time, measures on improving the energy performance of buildings also maintain and increase the value of a building.

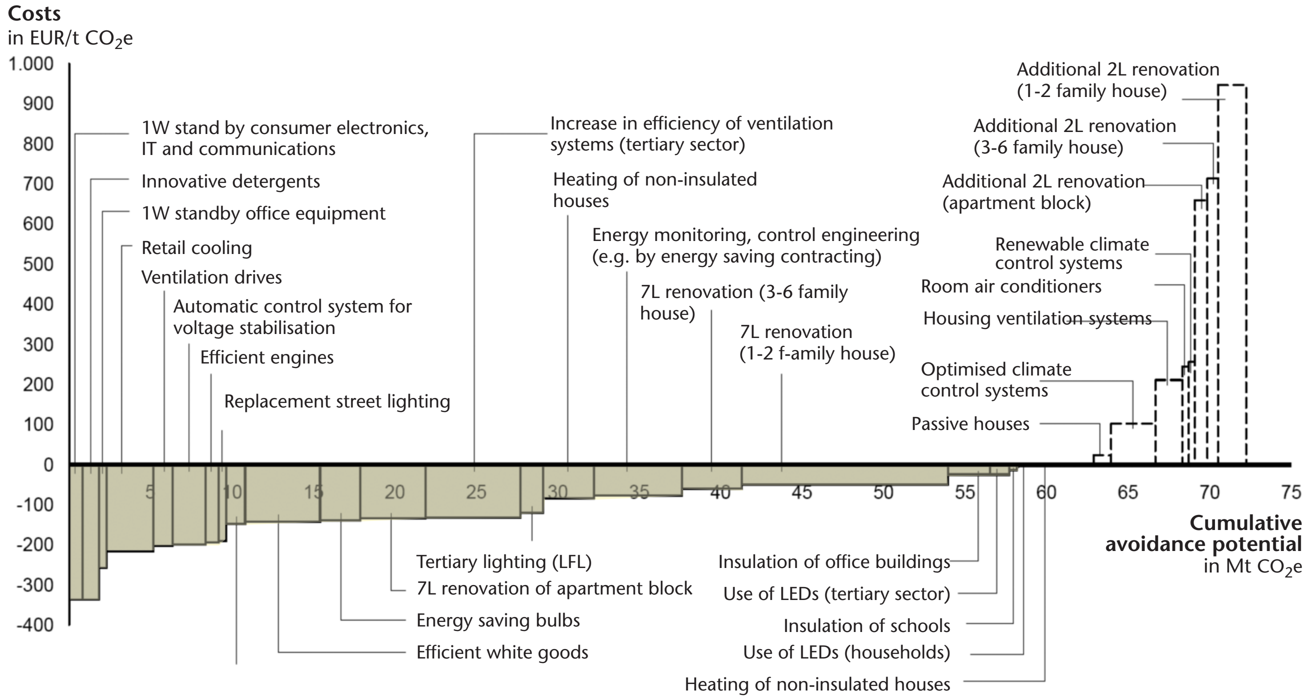
This is added to the increasing significance of building renovation throughout the building sector, as about 70% of the total building construction volume in Germany is subject to renovation measures. Consequently the improvement in the energy performance of buildings can also be seen as a supporting pillar for work and jobs in the building industry. This is because every billion euro invested in the building stock secures or creates about 25,000 jobs in the building trade and building industry. A comparison of the costs and potential to avoid CO_2 in other sectors shows the cost-effectiveness of measures to increase energy efficiency in the building sector (*Figure 18*), which is significantly increased as soon as measures are taken in conjunction with existing renovations. Last but not least, the last few years have shown that that a public programme with comparatively low financial expenditure can instigate substantial willingness to invest in the energy modernisation of buildings.

A comparison of the costs and CO_2 avoidance potential in other sectors (see *Figure 19*) shows the high cost-effectiveness of measures to increase energy efficiency in the building sector, which is significantly increased as soon as measures are taken in conjunction with existing renovations. [Translator's note: the above paragraph is a repeat of the text on the left of the page] [36].

Figure 18
Primary energy demand and CO_2 emissions for individual renovation scenarios: According to actions identified in the different scenarios in the Federal Government's CO_2-building programme, building-related CO_2-emissions to 2020, compared with 2005, will decrease by 40%. Total investment of about 344 bln euro is needed, corresponding to 23 bln euro a year, which produces a fall of 51 bln euro in heating costs [36].

Source: CO_2 building report 27.11.07, p. 72–73

Scenario		Primary energy		CO_2 emissions	
		TWh/a	kWh/m²a	mio. t/a	kg/m²a
Ist	Status Quo 2005	750	226	191	58
1	Up-date to 2020	624	162	157	41
2	only increased EnEV for new building (IEKP-Scenario 30/30)	619	161	156	41
3	Growth to 3 per cent a year full renovation	577	150	145	38
4	Range of measures "CO_2 minus 40 per cent"	458	119	114	30



Source: McKinsey & Company, Inc. on behalf of "BDI initiative – economy and climate protection" – AG Building

Figure 19
Costs and potentials of different measures to avoid greenhouse gas emissions in Germany

3. The importance of research and development

The technological, economic and sociological challenges relating to the transformation towards the Energy System 2050 can only be overcome with research and development.

Moving from the current energy system to a sustainable, emissions-free or emissions-neutral system requires constant advances in renewable and energy efficient technologies, and supplementary social research.

This is because the renewable energy technologies which are available today are not all yet sufficiently developed to meet the challenges of a mass market. New materials to replace expensive or scarce elements, process engineering, systems engineering, communications technology etc. must be developed for the the high level of materials conversion. Technological and infrastructure errors should be avoided and supply security should also be safeguarded during the transformation (no regret strategy).

The transformation phase thus requires both the development of transitional technologies and continued monitoring through system-analytical research and technological assessment.

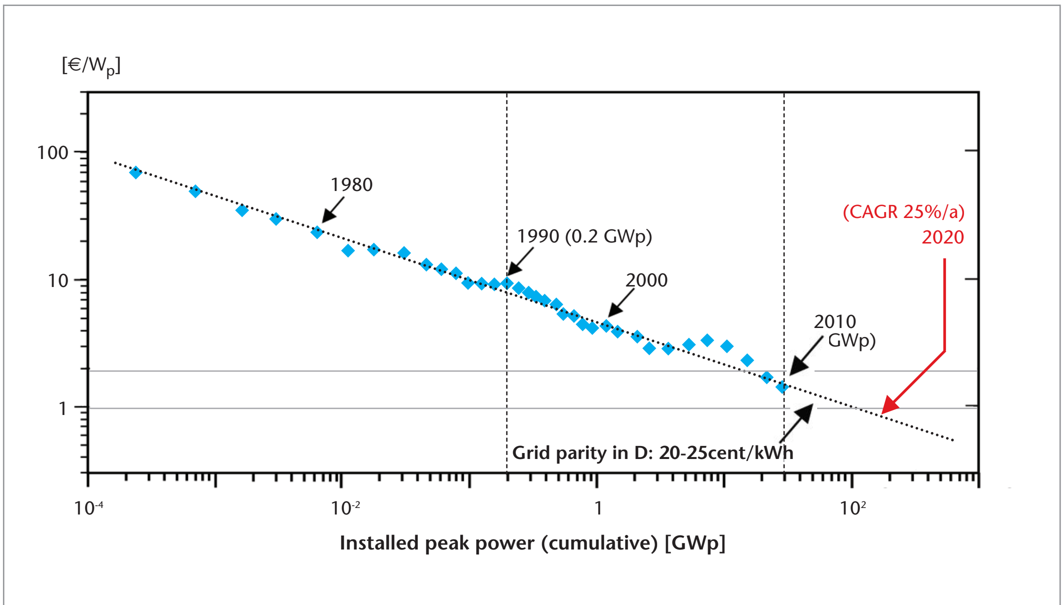
Cost reduction through the learning curve effect

A significant advantage for renewable energy is the fact that, the more it is used, the more its costs decrease.

Figures 20 and *21* show the advances in reducing costs with the example of wafer-based silicon photovoltaic modules and PV inverters. Over a long period, the learning curve shows a reduction of 22% in the cost of modules and inverters when the cumulative number of installations is doubled. This reduction in costs is the result of research and development, together with technological advances such as an increase in efficiency and reduced spending

Figure 20
Price-learning curve of c-Si PV modules (As of September 2009)

Source: G. Willeke, Fraunhofer ISE [37]



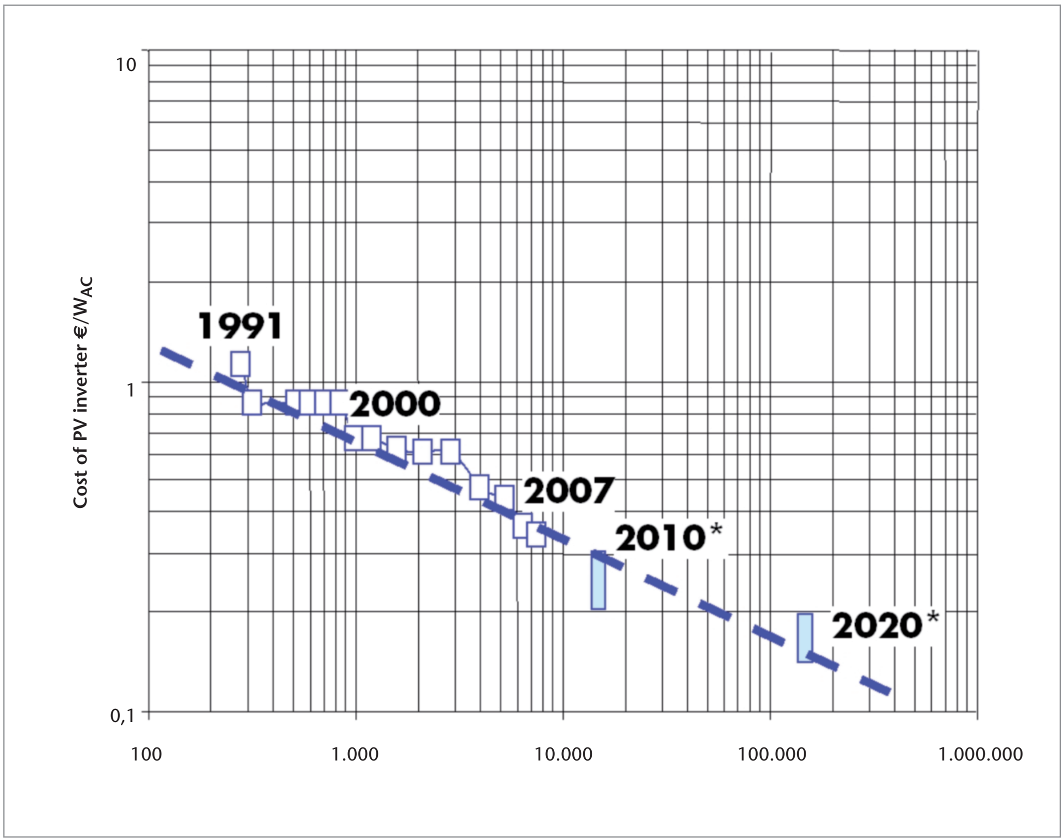


Figure 21
Learning curve for photovoltaic inverter

Source: M. Meinhardt, B. Burger, A. Engler: "PV system technology – Engine for cost reduction for photovoltaic power generation"

on materials, improved production technology, more efficient marketing and other economies of scale. Costs are therefore reduced when research and development takes place in institutes and in industry, in combination with continued market expansion.

Research and development is therefore an important requirement for future cost reductions. The dynamic of technological development also rises significantly with growing market volume, which is why research and development activities must be increased accordingly.

Further learning curves for different renewable energies are put together in *Figure 22*, in which the costs are considered in relation to energy produced. It thus becomes clear that all renewable energies are competitive with conventional fossil energy sources if their overall share is about 10% or more. This applies to all in the same way, cost effectiveness is therefore not a fundamental question, but only a question of time:

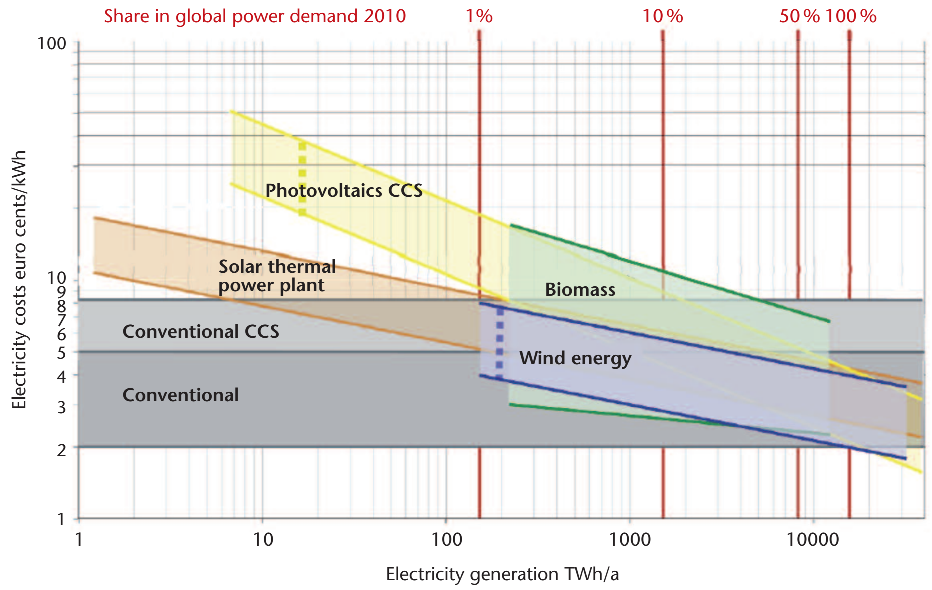
- Photovoltaics currently has a global share of slightly more than one-tenth of one per cent, but its learning curve shows a decrease in costs of 20% if the installed capacity is doubled.
- The global share of wind energy is already about 1.5%. In the last few years annual growth rates for wind energy have been between 30 and 40%. In fact this will turn out to be slightly lower in the next few years, but here as well, the learning curve shows a fall in costs of 10% if installed capacity is doubled.

Triggered by the Renewable Energy Act, research and development has received a significant stimulus from the economy. *Figure 23* shows the costs of electricity and the EEG fee payments for Germany. In the near future, photovoltaics will, with the planned reductions, achieve so-called so grid parity with domestic electricity. From 2020 the electricity costs of fossil power plants will be significantly higher than those of wind and PV. This is also reflected in the differential costs of power generation, in which a transitional period is assumed, between 2020 and 2030.

Figure 22

Potential trends in the cost of electricity from renewable energy – worldwide

Source: J. Schmid, Fraunhofer IWES 2010

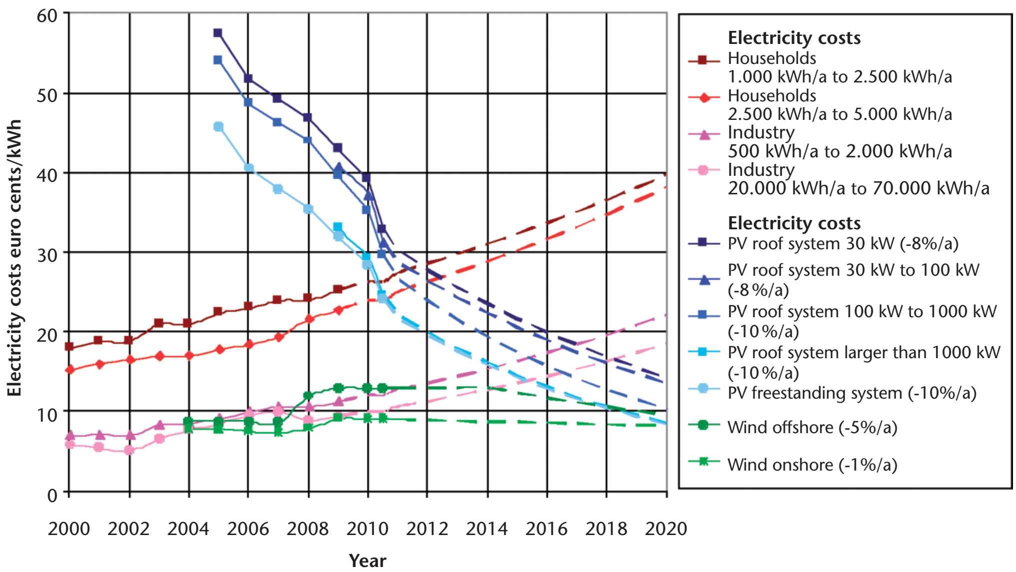


The starting values of the cost bands show currentglobal amounts and costs, the final values correspond to the potential of the pathway shown as an example. Trends in power generation costs in accordance with the learning rates for each technology as a function of global annual power production in double logarithmic application in comparison with (actual) constantly underpriced electricity costs for conventional power plants today and in the future, using CO_2 carbon capture and storage (CCS).

Figure 23

Trends in electricity costs and EEG fee payments in Germany

Source: BMU and BMWi



3.1 Research and development from the viewpoint of the Energy Concept and long-term research goals to 2050

To translate the Energy Concept that is being proposed, extensive research work will also be needed in the future in the field of efficiency increases, supply technologies for renewable energy, systematic improvements and acceptance by users. The most important research fields from the viewpoint of the Energy Concept 2050 are outlined as follows.

3.1.1 Energy efficient and solar construction

A particularly important aim of research and development is firstly to significantly reduce energy demand in the building sector and to supply residual energy demand using renewable energy sources. The building sector can make a substantial contribution to sustainable energy supply through energy plus houses in the new build sector, and the gradual harmonisation of the building stock to the low energy standard. The speed of this harmonisation largely depends on funding for research and development, which is determined by politicians.
Key elements are:

Long-term research and development goals

- Passive houses, energy plus houses and solar active houses become the building standard, depending on the region and demand
- novel, cost-effective heat insulation systems with additional functions, such as ventilation ducts for heat recovery and the inclusion of solar energy, in particular for modernisation
- part-mechanised, demand-led air-conditioning systems with heat recovery, also for modernisation
- glazed sun protection systems which can be automated using a large switch
- thermal component activation for space conditioning without damaging the room acoustics
- full substitution of boilers by heat pumps and CHP
- building control for the optimum integration of fluctuating energy supply and demand
- create commercially useful waste heat recovery using optimal local and district heating to an urban standard, and thus incorporate a district-related supply system which reacts to specific low energy demand
- increased use of low exergy technologies for residual heat demand

3.1.2 Electricity from renewable energy

Electricity from photovoltaics

In power generation in central Europe, solar cells from renewable energy sources have a very high technical potential. In some German states, the share of PV in electricity is currently already between 1 and 2%. The PV contribution to power generation is increasing rapidly worldwide. In the foreseeable future, this will lead to significant contributions to power supply through energy management. In the long-term, photovoltaics will form an important pillar of a sustainable energy supply system. In the last 30 years, prices for photovoltaic modules and photovoltaic inverters have already fallen by a factor of 10 (*Fig. 20* and *Fig. 21*) and this trend can continue further.

Since a final assessment of the different technological approaches with regard to the long-term development of photovoltaics is not yet possible at present, wide-ranging support for different technologies, with a focus on a rapid reduction in costs, is maintained, including crystalline si-photovoltaics (wafer and thin film), the conventional thin film techniques (amorphous silicon, Copper Indium Diselenid), as well as new approaches (organic solar cells and nanotechnology).

Photovoltaic inverters are one of the German PV industry's domains and are manufactured as a mass product. Using new semi-conductor materials such as silicon carbide (SiC) or gallium nitride (GaN), even higher efficiencies can be achieved in the future.

At the same time, costs fall as a result of higher levels of integration and more compact building techniques. As the rotating generators forming the network are increasingly omitted, inverters

takes on more of the network control and stabilisation. They communicate with control centres and receive specifications from these centres for network operations.

Long-term research and development goals

- Photovoltaic module efficiencies achieve an average of 22%
- Increase in the life-span of modules through better understanding of the decomposition mechanisms
- Photovoltaic modules will be connected in an integrated way
- With all thin film materials, the thickness of the material amounts to only a few micrometres, and even with crystalline silicon this is below 30 µm.
- Cell and module production form one unit.
- The processed surfaces amount to several square meters. Thin film techniques (incl. crystalline Si-thin film techniques) achieve 20% efficiency.
  Photovoltaic modules act as a roof covering and thus reduce installation costs.
- Concentrated photovoltaics (CPV) achieve a module efficiency rate of 50%
- Photovoltaic inverters become more efficient, more compact and more cost-effective by using new semi-conductor elements
- Photovoltaic inverters take over network control tasks and are remotely controlled by control rooms
- Reduction in volumes of materials (semiconductors, metals, lamination, glass, connectors, encapsulation
- The costs of photovoltaic-generated electricity, even in Germany, are below the cost of electricity from fossil energy sources

Electricity from solar thermal power plants

Fast growing markets for solar thermal power plants are currently being developed in southern Europe, the USA and in some developing and emerging markets of the sun belt.
German industrial firms are involved in this as leading players. As well as the rapidly growing energy markets in the sunny countries of the world, there are already technical requirements now to also use the electricity produced there in central Europe, if the corresponding network capacity for high voltage-direct current-transmission (HVDC) is built.

In particular, the possibility of being able to integrate cost-effective energy storage or to produce electricity as needed through the co-firing of biogenic fuels, will in the long-term allow solar thermal power plants to meet large proportions of power demand.

Also, in conjunction with sea water desalination plants, solar thermal power plants show interesting potential to meet growing demand for power and water in the southern Mediterranean, in a cost-effective way.

The research themes on parabolic trough systems cover varied aspects of cost reduction and life span, as well as the use of new heat carriers with higher thermal stability and the use of direct evaporation technology, in order to achieve higher efficiencies in downstream power plants by an increase in discharge temperatures. The need for research into solar tower power plants goes much further, in basic work on improved or innovative receivers, and subsequent questions relating to the heat cycle at temperatures of up to 1000 °C.

Long-term research and development goals

The overall goal is to reduce electricity production costs by 50% and more, which should be achieved by following a number of different pathways:

- Enabling an increase in the efficiency of parabolic trough power plants through alternative heat transfer fluids e. g. steam or molten salt at operating temperatures of over 400 °C, increasing the overall efficiency
- Developing high temperature receivers for solar thermal power plants with varying heat transfer fluids (salt, steam, air, particles) for temperatures over 500°C
- Reduction in costs for concentrators using innovative reflectors, a more efficient tracking system and optimised design concepts for wind load
- Further optimisation of the operation and maintenance of solar thermal power plants
- A demonstration of the combined production of electricity and drinking water in North Africa at competitive prices

Electricity from wind energy

The expansion in the use of wind energy is mainly affected by two challenges. The highest growth is expected to be in onshore use. Here, the industry is facing the challenge of global market developments, while at the same time reducing costs, which requires technological developments with an emphasis on standardisation and the highest reliability in large-scale production.

An increase in research and development activities is also needed to expand wind energy use in emerging nations and developing countries. In particular, the specific climatic and topographical conditions (areas that are highly structured) are leading to new challenges.

One of the most important goals of research and development is further cost reduction through fundamental innovation such as, for example, further developments in systems engineering and the development of new materials and compound materials. In parallel to this, the aerodynamics, aeroelastics and aeroacoustics of the plants are further improved by the application of knowledge and instruments from fluid mechanics. Further research themes are an investigation of wind climatology, finding locations in complex terrains, and energy production estimates.

For offshore use there are additional challenges, which derive mainly from the higher loads from the wind and the sea and the more difficult accessibility. Innovative ideas for the overall system, regulations and technical reliability, as well as wind and wave characteristics for offshore applications, must be investigated.

Long-term research and development goals

- Wind energy plants are standardised, modularised and developed as technology platforms for large-scale production.
- The efficiency of wind energy plants is increased by 20%, while at the same time noise emissions are halved
- Wind turbines achieve an output of over 10 MW and have power plant characteristics
- The offshore use of wind energy is established as an important factor in power supply. Technical availability can be increased substantially.
- Accurate forecasting and effective energy management facilitate a reliable power supply from renewable energy sources.

Electricity from geothermal energy

The condition for a wider application of geothermal energy is the development of processes so that drilling can take place cheaply and safely, and the economic return on deposits can be increased in a targeted way. The research challenge is therefore to work on the learning curve towards the cost-effective supply of geothermal electricity. This should particularly include the development of so-called Enhanced Geothermal Systems (EGS). These are predominantly based on hot water deposits and dry geological formations, which are located outside the volcanic or tectonically active areas and are therefore associated with higher exploitation and/or production spending, in relation to recoverable energy. However, these reservoirs represent the main part of global deep geothermal potential and are also available in Germany.

Because the technology is still at an early stage, the preparation and success of the EGS research should in future be updated and expanded in appropriate programmes. In addition, Europe-wide research and development activities, national support programmes and competences should in future be brought together more and networked. The main emphasis for support and further development should be geothermal technologies which are not limited to particularly favourable areas for geothermal energy, and which are therefore transferable to similar situations world-wide, and which are exportable. Because of the existing technological synergies in conventional geothermal systems, the research successes will above all offer further export opportunities in the field of materials research and component selection.

Long-term research and development goals

- The development of cost-effective reservoirs should be achievable with only production and injection drilling, through improved planning and drilling feasibility, as well as a significant increase in the productivity of

geothermal reservoirs through innovative stimulation processes. The needs of the public are at the heart of considerations, so that "public acceptance" can be developed.
- The efficient conversion of geothermal heat into electricity
- Geothermal power production can be better planned economically when drilling costs are foreseeable and efficiencies are improved

3.1.3 Electricity and heat from fuel cells

Fuel cells are efficient energy converters, as they achieve particularly high electrical efficiency rates when there are especially low emissions of pollutants, and a high overall efficiency when there is simultaneous energy recovery. They can be operated using hydrogen, using hydrocarbon containing fuel cells (partly after reformation) or directly using methanol, and are suitable both for decentralised electricity and heat supply, and also for electric vehicle propulsion. Other promising possibilities for use are e.g. auxiliary power units in cars and planes, as well as replacing batteries in electronic equipment.

Long-term research and development goals
- Replacing electrode materials by using cheaper materials
- Alternative cheaper catalyser coating for electrodes
- Avoiding decomposition mechanisms in the stack
- Fuel cells will have a high power density and an operating period of 10 years and more, and offer cost-effective solutions for the stationary and also the mobile sectors

3.1.4 Chemical energy carriers from renewable energy

Energy recovery from biomass

Research and development in biomass is to be complemented by a scientifically based assessment of existing biomass potential, including biogenic waste, in terms of existing conflicts of use, issues of soil and nature conservation, potential production risks, technological restrictions and the social, ecological and economic implications of international biomass trade. In the long-term, as well as energy recovery from biogenic waste, efforts should be made for energy cascade use with (several) upstream materials processes for use in the area of cultivated biomass.

There is a particularly high potential for development for the combined use of biomass with a high overall efficiency: the optimised supply of electricity, heat and fuels through "polygeneration", which also opens up a CO_2-neutral substitution in the transport sector. When biomass is used for the production of synthetic gas, about 75% of the energy that is stored in biomass could already be supplied as hydrogen chemical energy. An important strategic question relates to contact with biomass-based local heat networks, as part of an increased expansion in building and heat insulation. Dynamic models should be developed in this context, which on the one hand would facilitate CO_2 -neutral heat supply as a temporary solution, but on the other hand would also provide sufficient incentives to carry out insulation measures in terms of reducing heat demand.

Long-term research and development goals
- The available biomass will be supplied, using biomass forecasting via satellite monitoring to optimise use, giving priority to the food chain and material use, and only finally to be used as energy (e.g. for fuels).
- Through the use of renewable resources "renewable electricity" and "biomass", biomass carbon is almost completely converted into carbon fuel.

Efficient production of hydrogen

The development of more efficient processes for the large-scale conversion of renewable energy into hydrogen is a requirement either for the establishment of hydrogen, and/or the production of renewable methane and its introduction as an energy source.

Producing hydrogen using electricity through the decomposition of water from renewable energy, seems – at least for central Europe – to be the most sensible option for hydrogen supply. The technologies required for this must primarily be developed for large-scale applications.

Concentrated solar systems offer an increasingly interesting possibility for countries in the sun belt. Here, sunlight is used in a direct thermo-chemical way to produce fuel cells. This process has the potential for very high conversion efficiencies: These so-called thermochemical cycles have the potential to be able to supply hydrogen at the highest efficiencies and the lowest costs. The first pilot plants are under construction. To develop further, materials and components must be available which allow the plants to be operated at temperatures of over 1000 °C.

Implementing direct water splitting using cata - lytic connections is also an important option. Cost-effective materials must be developed for this in order to produce the hydrogen.

Long-term research and development goals

- Replacement of precious metals by cheaper materials for water electrolysis
- Hydrogen production using solar-supported thermochemical reactions supplement hydrogen production by electrolysis, or by high pressure or high temperature electro-lysis.
- Solar fuel cell production, especially using hydrogen with the use of biological conver-ters or nanotechnological tailor-made cataly-tic materials. An electrochemical reduction in CO_2 using methanol and methane is also a worthwhile research aim.
- The storage of hydrogen or 'biomethane' in caverns to smooth out fluctuating renewable energy plays an important role for large-scale energy storage, upwards of several hundred GWh.

Efficient production of methane

For power storage in Germany there are cur-rently almost exclusively pumped storage plants with a storage capacity of 0.04 TWh. However, for full renewable supply, about 20 TWh is nee-ded. These high storage capacities can only be provided using chemical energy carriers. As well as hydrogen, renewable methane as a natural gas substitute (Subsitute Natural Gas) is the most interesting option, as the existing infra-structure and the existing storage capacity of > 200 TWh can also be used for this. This new storage concept should therefore be brought to market by increased research and development.

The process chain for producing renewable methane from electrical energy, water and CO_2 consists of the two main components, water electrolysis and methanation.

Further advances should be made in methane synthesis and the integration of renewable me-thane into the energy system.

Long-term research and development goals

- Electricity and renewable methane can each be converted into the other and have a fully developed infrastructure, so that the storage capacity of the gas network can also be used for seasonal storage in the electricity sector.
- Renewable methane gas and renewable fuels from wind, solar and hydro power are produced highly efficiently; decentralised and centralised plants are available in the market.

3.1.5 Using CO_2 as a raw material

The CO_2 capture and storage which is currently under investigation presents a conventional 'End of pipe'- technology, which does not itself change the production process, but only seeks to reduce environmental damage downstream. Even if successful, only very limited amounts of CO_2 can be kept out of the atmosphere. It is more promising and above all more sustainable to use CO_2 as a raw material for the chemical industry, for the production of renewable methane and subsequently for every kind of synthetic material [38]. More economic, more ecological and more socially beneficial are also global reforestation and the build up of humus, which extracts greenhouse gases from the atmosphere. This can counter soil erosion and damage and thus provides a dual use for growing food and for energy crops.

Long-term research and development goals

- Increase in the supply efficiency of CO_2 methanisation

3.1.6 Energy storage

In almost all areas of energy technology, "energy technology" can be significantly reduced by storing energy, and many worthwhile process improvements are possible for the first time by using storage. Energy storage is thus the central component for a sustainable energy economy, which is relevant for all three strands of energy policy:

- A reduction in final energy consumption
- An increase in energy conversion and supply efficiency
- An increase in the share of renewable energy in the energy mix

In the past, developments in energy storage were scarcely promoted. This applies both to storage for electrical energy (batteries), and to thermal storage and chemical storage (alternative fuels). New fundamental technological approaches must be developed in all areas and new research capacities must be established. The work ranges from very fundamental aspects to applications and require the cooperation of very different scientific disciplines. In parallel with research and development, the market introduction of storage or the implementation of optimal energy systems must be promoted.

Electricity storage

The need for electrical energy storage (fuel cells and batteries), electrochemical storage (high temperature and redox flow batteries) and hybrid systems with batteries and super-condensers with high power densities and long lifetimes will increase significantly in the next few years. This is because the share of electricity from decentralised and fluctuating sources will increase, which will speed up the stationary use of these technologies. At the same time, their mobile application in transport will become increasingly important. Research and development can contribute towards making up the deficit that has arisen here in the last few years.

The challenges lie in a user-friendly cost structure for electrochemical storage and the production of application-oriented system solutions. This applies in particular to stationary electrochemical power storage for the fluctuating feed-in from PV and wind plants. Here a development is emerging by which surplus wind power is directed into large battery systems in order to integrate these into an energy service system, which efficiently stabilises voltage and frequency in the distribution network.

Long-term research and development goals:

- Batteries and cells have a high energy and power density, which helps electromobility to penetrate.
- The decentralised storage of electrical energy in high temperature or redox flow batteries is efficient on the flat
- The number of large compressed air stores will be increased five-fold
- Fluctuating accumulating renewable electricity can be converted by storage in the form of renewable methane as required, thus facilitating planning.

Heat storage

Extensive research and development work is required for new storage techniques. Through the development of new storage materials on the basis of phase transformation and sorption materials, in principle, completely new approaches to heat storage, with low storage losses, are possible, which enable higher energy densities and support the use of decentralised heat supply systems. Reduced energy consumption in modern buildings makes this kind of new approach particularly promising from the viewpoint of system technologies.

New storage materials also open up new opportunities for use in the field of high temperatures for solar thermal power plant technology, and for the improved utilisation of industrial process heat. In this context, storage for small combined heat and cooling plants is of interest, as with these components an optimal power-led operation is possible and the accumulated heat can be stored for up to a few days. With solar thermal power plants, the availability and electricity production costs can be significantly improved by installing heat stores.

Long-term research and development goals

- New materials, components and systems allow heat transmission to be controlled in a targeted way, i. e. to facilitate and accelerate it, or to reduce and delay it.

Seasonal geothermal heat stores

The seasonal storage of thermal energy in aquifers, as well as the integration of storage into energy supply systems, has enormous potential which until now has been insufficiently taken into account. The combination of seasonal heat storage and combined heat and power (CHP) also improves the demand-led power supply of an energy system. By storing surplus heat in times of low heat demand, CHP plants can be operated all year to produce electricity, as the stored surplus heat can be used when there is a higher demand for heat. Here, aquifer heat stores are particularly well suited because of their high storage capacity and high heat recovery rates during seasonal operation.

Aquifer cold storage allows low winter temperatures to be used for cooling in summer. In comparison with conventional cooling supply, significantly higher COP values (Coefficient of Performance) are achieved for cooling supply (factor 5 to 10), which allows the electricity demand for cooling supply to be reduced in particular during the summer months. The use of aquifers as thermal energy stores is determined by geological ratios. In Germany, about 70% of the surface area is generally suitable for the use of stores with a capacity of 5-10 GWh each, as is used for example in the parliament’s building in Berlin. With an assumed number of 2000 plants in Germany, a storage capacity of over 10 TWh is possible.

Long-term research and development goals

- Despite good experience with the previous projects, there are constraints on converting further stores, which is caused by the complexity of the planning process and by systems engineering. Basic technological consolidation is required, from which planning and operating guidelines will be developed, which are based on experience gained from pre-competitive demonstration projects with a recognisable research component. The resulting standardisation of the planning, construction and operation of energy supply systems with aquifer stores is essential to create high potential.

3.1.7 Heat and cooling from renewable energy

Heat and cooling from solar thermal collectors

Solar thermal collectors convert the solar radiation received into heat. It can be used with various technologies in different temperature areas:

- Solar thermal flat plate or vacuum tube collectors heat tap water and drinking water for households and for space heating.
- Concentrated solar collectors (parabolic trough and linear fresnel systems) or high efficiency flat plate collectors provide process heat at higher temperature levels, ready for industrial applications and air conditioning in buildings.

Collector systems to produce heat up to 90 °C must be further developed in order to reduce costs and open up new applications. This is particularly the case for integrating solar collectors into the building envelope. This is a condition for developing systems engineering for the solar active house, whose heat demand is fully met by solar heat, and as an intermediate step for the “Solar house 50+”, over 50% of whose heat demand is met by solar heat.

On the basis of solar thermal collectors, complete systems for combined heat and power are constructed, which in the summer half of the year are largely solar-driven, while in the winter half of the year they produce electricity using renewable methane or biofuels, and feed the waste into a heat network. Economic optimisation – efficient renovation compared with the use of waste in local heating systems – is also an important subject for research.

Long-term research and development goals

- Despite good experience with the previous projects, there are constraints on converting further stores, which is caused by the complexity of the planning process and by

systems engineering. Basic technological consolidation is required, from which planning and operating guidelines will be developed, which are based on experience gained from pre-competitive demonstration projects with a recognisable research component. The resulting standardisation of the planning, construction and operation of energy supply systems with aquifer stores is essential to create high potential.

Heat and cooling from geothermal energy

The important task for research and development is to prepare this technology in a reliable way. For a more cost-effective and efficient supply of geothermal energy, there should be an increase in the seasonal performance factor (ratio of thermal heat to power) of geothermal plants. Depending on the heat source used, in small plants, improvable seasonal performance factors of 3 (ambient air) to over 4 (geothermal probe/water) are achieved – in combination with low-exergy-heating surfaces significantly better values are achievable. Larger supply systems should be improved by the cost-effective seasonal storage of heat and cooling underground. Heat sources deep underground must be developed more economically.

Long-term research and development goals

- Increase in the seasonal performance factors (ratio of thermal heat to power) of geothermal plants
- Development of suitable heat transfer over days, e.g. in low temperature heating networks and the direct use of heat

3.1.8 Mobility

The climate problem requires new methods of mobility. Developing technologies for battery- and fuel cell-supported electric vehicles results in extremely energy efficient electric power systems with efficiencies of up to 80% (from store to drive shaft) and offers the possibility of providing the energy supply for transport from renewable sources such as solar or wind energy.

The Energy Concept 2050 regards electromobility and the development of more cost-effective and reliable stationary electricity storage as an opportunity for Germany to move forward economically and ecologically into a new dimension. With the necessary change in technology in the mobility sector, there is also the opportunity not only to adapt our current energy system, but to structurally transform it.

The future electric car will consist of a technological combination of fuel cells, batteries and super-condensers. For this reason it is necessary to further develop battery and fuel cell technologies in parallel, and to research the potential for the hybrid mode of operation, as only by developing these technology pathways is it possible to transform the mobility sector and to be international leaders in technology. The different storage technologies will be coupled with traction through highly efficient compact power electronics. Intelligent plant management will decide how the load is allocated to the different stores.

As well as research in the field of battery systems engineering, suitable energy systems and system components must also be developed for power electronics and control engineering.

Long-term research and development goals

- The efficiency of electric motors reaches 98%
- Inductive power transmission is installed in many streets
- Passenger cars are largely electrified and charge their on-board energy store with power from renewable energy or hydrogen, methane or other renewable fuels – produced from wind, solar energy and hydro power
- Surpluses from renewable electricity generation are supplied to the transport sector in the form of renewable fuels (hydrogen, methane, dimethyl ether, kerosene, etc.) via the energy infrastructure.
- Super-condensers can supplement systems with low power density in such a way that in the short-term as well, high output can be realised. This allows a particularly favourable system design. However, a broad introduction requires a further increase in energy densities, with power densities that are adapted for use.

- Highly efficient, compact and bi-directional frequency converters must be developed to charge the batteries of electric cars with as few losses as possible, and at the same time to be able to integrate them into the network as quick energy storage. The charging infrastructure and the vehicle network interface should be developed, with the aspects of identification, metering, invoicing and communication (between the vehicle, the network and the user).
- The challenge for safety techniques relating to lithium batteries is the absolute avoidance of a "thermal runaway". At the same time, however, the cells must be able to be charged quickly. This requires a detailed understanding of the thermochemical mechanisms, the best thermal management design, as well as the development of thermally stable electrode materials.

3.1.9 Electrical systems engineering, network management and distributed power plants

The aim of future research and development efforts must be to design changing supply structures in such a way that network stability and security of supply continue to be assured with a growing number of fluctuating suppliers, even without large reserves of power. The inverters of wind and PV plants must take on network creation functions and safeguard security of supply. The network that is today formed of rotating generators will become a power electronics, inverter-led network.

Power transmission and energy balancing at German and European level plays a key role for the use of fluctuating energy sources. The central themes are network expansion, network control and the optimal integration of renewable energy using power electronics energy converters, which are actively involved in network control and which safeguards network stability. Here, efficient communications structures, online- and forecasting processes for network resource scheduling, as well as bi-directional energy management and trading systems, are of particular importance for the dialogue between the energy producer, distributor and consumer.

Renewable producers can therefore take over all the necessary system services for secure network operation from conventional power plants. Here, it is essential to develop modern information and communications technology for improved energy management processes. A key role is played by the dynamic network simulation for the European area and beyond. Only with the help of these simulations can the effect of the planned expansion scenarios for renewable energy in Europe, the varying integration strategies for pumped storage plants and the level of expansion in the European transmission network be analysed in relation to security of supply and the cost of energy supply.

Long-term research and development goals

- Smart grids will be introduced everywhere and will communicate with the smart control devices[12] in the building
- Long-range power transmission using HVDC technology will have become established by 2050 and will help to distribute electricity from renewable energy sources
- Efficient medium and high voltage converters will be developed, to be coupled with direct and alternating current networks
- New control methods for network stability for the power electronics-led network will be developed. The power flows between the alternating current network, the direct current network and energy stores will be controlled intelligently.
- Power transmission with superconductors will be used in areas with high power demand.
- Electricity, gas and heat networks will be optimally networked and expanded as economically as possible

12 Smart control equipment consists of e. g. bi-directional energy management interfaces (BEMI)

3.1.10 Systems analysis and assessment of technological implications for financial incentives and the requirements of political regulation

The development of new energy technologies takes place within a complex environment with numerous technical, economic, ecological and energy policy conditions.

The requirement for a successful market introduction is therefore a preliminary and related analysis of these relationships. Here systems analysis applies. Using analyses of potential, the future prospects for new energy technologies and systems will be explored. Subsequently, scenarios will be drawn up which present possible pathways for development. Converting these scenarios through the targeted use of political instruments, their specific adaptation, modification or reorganisation, and the accompanying political debate, are some of the fundamentally important starting points for system-analytical work to achieve this conversion.

During the conversion phase, energy technologies and systems, as well as the selected funding instruments, are accompanied by monitoring. Systems analysis and an assessment of the results of technology will be needed to adapt political concepts to unexpected developments. This continuous and comprehensive evaluation identifies opportunities and risks, helps to detect possible mistakes in good time, and develops alternative approaches. Consideration should be given to economic aspects – such as the liberalisation and globalisation of the energy markets –, ecological aspects, questions of supply security and also the requirements of international climate protection policy.

3.1.11 Supplementary social research

One of the most important fields of research consists of supplementary social research, in particular, the question of acceptance for new technologies and processes to improve the dialogue between technology and the user must be developed. Consideration of this aspect is especially important for realising a North African-European power network.

4. Recommendations for political action

The 2050 Energy Concept for Germany, which extends to 2050, envisages a complete change in the current fossil-nuclear, climate damaging, centrally-aligned energy supply system, which is also primarily built on energy imports, to a sustainable energy supply system which uses 100% renewable energy, energy efficiency and energy storage, and which is therefore secure, reliable and cost-effective.

The Energy Concept makes the following assumptions for the year 2050:

- Global energy demand for energy services will continue to rise
- Fossil and nuclear energy will no longer be anywhere near sufficient to meet global energy demand,
- There will still be no commercially applicable nuclear fusion power plants available,
- Electricity, heat and fuels from renewable energy will be significantly cheaper than electricity from fossil and nuclear energy sources.
- New technologies will be available which will make an energy supply system which is built on 100% renewable energy more secure and cost-effective.

This assessment concurs with the evaluation of the governing parties, who in the coalition agreement have formulated the goal, “that renewable energy will take over the major part of energy supply.“

Such a wide-ranging Energy Concept needs for its implementation a transformation concept, as set out in Chapter 2. The following recommendations for action are derived from this.

4.1 Market introduction measures

Energy policy has the task of stimulating or speeding up the necessary transformations in the energy system which do not happen by themselves, or not at the desired speed.

Energy efficiency measures and renewable energies have for years been ready for use, and the transformation process with a continuously increasing share of renewable energy in energy supply has already begun. To some extent some unexpected major successes have been achieved, e.g. in wind power and photovoltaics.

But implementing the Energy Concept requires political support for continued market introduction, where this is successful, and for extending and strengthening this, where the pace of transformation has so far been inadequate. Technological leadership happens above all through consistent and early market introduction, as most innovative ideas originate in the production of technology and its application in practice.

4.1.1 Stimulating energy efficiency measures

Until now, stimulating energy efficiency measures has proved to be particularly difficult. So, for example, the renovation rate in the building stock, at below 1% a year, has so far lagged well behind the political goals. The stimulation of efficiency measures must be encouraged by a range of different measures:

- Implementation of the European Energy Performance of Buildings directive (EPBD) and strengthening the Energy Saving Regulation (EnEV)
- Implementation of the European Energy End-Use Efficiency and Energy Services Directive

- Conversion of the building energy certificate into a compulsory demand-led energy pass
- Expansion of the building renovation programme
- Clear expansion of CHP by increasing support for local and regional district heating networks
- Reduction in legal constraints and problems of acceptance in implementing local and district heating networks
- Increase in efficiency of electricity use e.g. through the Top Runner Programme
- Implementation of the EU directive on Energy End Use Efficiency and Energy Services (EDL) [39][13]
- Establishment of an energy efficiency fund to finance efficiency programmes

4.1.2 Stimulating the market introduction of RE power generation

The greatest successes in the market introduction of renewable energy have so far been achieved in the power sector, where the Renewable Energy Act EEG has proved to be extremely effective.

The continued market introduction of RE power production requires the following measures:

- The maintenance and continued development of the EEG
- Conserving rules on giving priority to the feed-in of renewable electricity into the power grid
- Compensation payments for regulated renewable electricity only as an interim arrangement until the network and storage has been expanded
- A bonus for demand-led energy supply (Combined cycle renewable power plants)
- The introduction of a seasonal energy storage bonus as an incentive to develop energy storage technologies and systems

As a result of the great success of the EEG, the FVEE is advocating that the German Federal Government should support the Europe-wide introduction of instruments that are similar to the EEG.

4.1.3 Stimulating the market introduction of RE heat production

Although more than 50% of energy use occurs in the heat sector, and in many areas of heat use efficiency and renewable energy technologies are available and advantageous, so far the speed of transformation in this sector has not been nearly adequate enough. With the Renewable Energy Heat Act (EEWärmeG) a start has been made which must now be pursued forcefully.

The following measures are suitable for accelerating market introduction in the RE heat sector:

- Strengthening the Federal Emission Control Regulation (BImSchV)
- Amendment to the Heating Cost Regulation
- Continuation of the market incentive programme (MAP) with adequate financial provision, particularly to stimulate new market segments like solar housing, heat networks using renewable energy etc.
- Extension of the obligation to use renewables in the EEWärmeG in the building stock
- Possibility of allocating renewable energy when fulfilling the requirements for renovating old buildings

4.1.4 Stimulating the market introduction of RE mobility concepts

The transformation of the transport sector is very expensive and protracted, also because the electric vehicles and mobility systems that are required are not yet available today.

As well as the increased research and development in the field of biofuels and electromobility, the following market introduction measures make sense:

- Pilot projects to introduce electric vehicles
- Pilot projects to convert innovative mobility concepts

13 The EU member states have agreed on a common directive with an ambitious energy saving target: the EU directive on Energy End-Use Efficiency and Energy Services (2006/32/EG, EDL-Richt- linie) was adopted on April 5 2006. Under this EDL directive, in 9 years, 9% of end energy should be saved in comparison with a reference period, using targeted measures.

4.2 Increasing resource productivity

A sustainable energy supply must not only have regard to power generation, but also the materials cycle that is required. A condition for realising the Energy Concept 2050 is a radical improvement in the resource productivity of elements and materials, which play a role in a mass market for renewable energy technologies, such as, for example, elements for ferrous alloys, copper, platinum and lithium. However, all other materials that are used should be included in a materials cycle, from an efficient use of materials to, if possible, complete recycling. Both the more economical use of materials, and recycling processes to reuse materials, are linked to research and development, which must become an interdisciplinary subject, and which is an integral component of all plans.

4.3 Infrastructure and general conditions

4.3.1 Converting and expanding networks

The condition for increasing efficiency and the integration of growing amounts of fluctuating renewable energy is the conversion and expansion of our supply networks. Amongst other things, this requires the following measures:

- The rapid and systematic expansion of the power network to receive and transport renewable electricity to population centres
- Support programmes for measures to adjust power consumption to fluctuating power generation, e.g. through the personal use bonus in the EEG
- Further development of centralised to decentralised power networks
- Introduction programme for ITC-technologies
- Targeted expansion of local and district heat and cooling networks in centres of population to achieve the expansion goals for CHP and renewable energy
- Pilot programmes to introduce intelligent grids (Smart Grids)

4.3.2 Integrating storage

In the medium-to long-term, high shares of fluctuating energy sources require the integration of short-, medium- and long-term storage in the power-, heat-/cooling and gas networks. Even if many storage technologies are still in the research and development phase, a start should be made today with the gradual integration of existing storage technologies. Amongst other things, the following measures would be good for this:

- Expansion of pumped storage power plants and other electrical storage
- Expansion in seasonal heat storage in heat networks

4.3.3 Expanding gas-fired power plants with CHP

In order to replace coal-fired and nuclear power plants during the transformation phase, gas-fired power plants and gas and steam power plants that can be quickly adjusted – preferably with combined heat and power and decentralised small combined heat and power plants (engines, microturbines, fuel cells) – should be widely introduced.

4.3.4 Integration into a European energy concept

An important requirement for a Sustainable Energy System 2050 is the compatability of national strategies with a pan-European approach. Here, above all, national expansion targets for renewable energy should be identified for their effect in relation to the resulting load flows into the electricity and gas networks. A European strategy for expanding these networks can be derived on this basis.

An important element of a European network is a new, very intelligent and very efficient power transmission network, which balances the fluctuations which arise in local power generation within a large area. This is because it is beneficial from an energy and an economic viewpoint to connect decentralised energy supply structures with each other via “Backbone” networks. Through these networks, using information and communications technologies,

load fluctuations or demand fluctuations can also be balanced over long distances and additional power suppliers can be incorporated (e.g. hydro power from Scandinavia, wind energy from Portugal or solar power from North Africa).

4.3.5 Training and continuing education for specialists

A successful transformation of energy supply requires specialists to implement this technically. These will only be available if the training of specialists for a renewable energy supply system is specifically expanded in all fields of application, in cutting edge research, product development, planning, distribution, installation and energy advice, as well as for the authorities which have corresponding planning duties. These include the establishment of Bachelor and Masters study programmes in the field of renewable energy, as well as more integration into professional training.

4.4 Increasing acceptance and strengthening public relations for renewables

The complete transformation of the energy supply system in a few decades requires the acceptance and active participation of the population, both as investors, e.g. in building insulation, as well as consumers, operators and as political sovereigns. For this reason it is essential that the Energy Concept and the transformation concept should be communicated and explained in detail by intensive and continued public relations work for the relevant target groups. Generally speaking, the social and sociopolitical constraints in the transformation process should be investigated and overcome. The following communications goals should be followed in particular:

- Understanding of the absolute need for sustainability criteria for a future energy supply (ecological, economic and social)
- Clarification of the potential for energy efficiency and renewables which safeguard security of supply
- Information on technical-scientific innovations, which facilitate the new energy efficiency techniques and conversion techniques and make well-known technology more cost-effective
- Clarification measures to persuade building owners to implement energy saving measures and to join local heating networks.
- Information on the economic potential of energy efficiency and renewables: the potential to reduce costs, create jobs, export potential, advertising for young acadmics for research and development for renewables.

4.5 Developing technologies through research and development

Every new energy supply system requires many developed and new technologies, which is why energy research must be significantly expanded. The focus of research and development in the coming years will be described in the 6th Energy Research Programme, which should be adopted in 2011.

The challenge in energy research consists of keeping open different possible development pathways, and at the same time using the scarce financial and research resources in a sufficiently targeted way to achieve the necessary successes.

The Energy Concept 2050 advocates that funding for research and development should be divided up between the different technologies in terms of their long-term importance. In line with the goals of the ruling coalition and the proposed Energy Concept 2050, priority should be given in research funding to renewable energy and energy efficiency.

Research and development is also to be understood as an industrial policy measure. This is because only there, where German producers are global technology leaders in the field of renewable energy and energy efficiency, is there an opportunity to keep production of the components of the new energy supply system in Germany. For this reason, market introduction and research policy must go hand in hand.

References

[1] Rolf Brendel: Entwicklung neuer Produktionstechnologien für die Solarenergienutzung, FVS-Themenheft 2007 „Produktionstechnologien für die Solarenergie“

[2] Robert Pitz-Paal: Strategische Ausrichtung des DLR für die Qualitätssicherung solarthermischer Kraftwerke, l12. Kölner Sonnenkolloquium, 9. Juni 2009

[3] Cerbe, G. (2008): Grundlagen der Gastechnik. Gasbeschaffung – Gasverteilung – Gasverwendung. 7., vollst. neu bearb. Aufl. Deutsche Vereinigung des Gas- und Wasserfaches (Hg.). München: Hanser

[4] David Nestle: „Dezentrales Energiemanagement im elektrischen Verteilnetz – was kann Gebäudeautomation beitragen?“, FVS-Themenheft 2008

[5] Gerhard Stryi-Hipp: Die Forschungsstrategie der Deutschen Solarthermie-Technologie-Plattform (DSTTP), Solarthermie Technologie Konferenz 26./27.1.2010

[6] WBGU-Gutachten 2010 „Transformation“ (noch in Arbeit – unveröffentlicht)

[7] WBGU-Gutachten 2008 „Welt im Wandel – Zukunftsfähige Bioenergie und nachhaltige Landnutzung“

[8] Leitstudie 2008, Weiterentwicklung der „Ausbaustrategie Erneuerbare Energien“ vor dem Hintergrund der aktuellen Klimaschutzziele Deutschlands und Europas. Dr. Joachim Nitsch, Stuttgart, in Zusammenarbeit mit der Abteilung „Systemanalyse und Technikbewertung“ des DLR-Instituts für Technische Thermodynamik

[9] Nitsch, J., Wenzel, B., Langfristszenarien und Strategien für den Ausbau erneuerbarer Energien in Deutschland – Leitszenario 2009; Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit; Berlin; August 2009 und weiterführende Arbeiten.

[10] Sachverständigenrat für Umweltfragen (SRU): „100 % erneuerbare Stromversorgung bis 2050: klimaverträglich, sicher, bezahlbar“ Vorläufige Fassung vom 5. Mai 2010

[11] Kirchner, A.; Matthes F.; Modell Deutschland – Klimaschutz bis 2050: Vom Ziel her denken; WWF; Basel/Berlin; Oktober 2009.

[12] IEA-Prognose 2008

[13] Bundesministerium für Wirtschaft, Arbeitsgemeinschaft Energiebilanzen, Endenergieverbrauch nach Anwendungsbereichen, Berlin 2008

[14] Specht, M.; Baumgart, F.; Feigl, B.; Frick, V.; Stürmer, B.; Zuberbühler, U.; Sterner, M.; Waldstein,. G. (2010): Speicherung von Bioenergie und erneuerbarem Strom im Erdgasnetz. Themenheft 2009 „Forschen für globale Märkte erneuerbarer Energien“ FVEE Jahrestagung 2009.

[15] Dr. Rolf-Michael Lücking, Prof. Dr. Gerd Hauser „Nachhaltige Energieversorgung von Gebäuden“, TAB-Technik am Bau, Zeitschrift für Technische Gebäudeausrüstung, 10, 2009, S. 62

[16] Prof. Dr. Gerd Hauser: Energieeffizientes Bauen – Umsetzungsstrategien und Perspektiven in „Energieeffizientes und solares Bauen“ FVEE-Themenheft 2008

[17] Sterner, M.; Schmid, J.; Wickert, M. (2008): Effizienzgewinn durch erneuerbare Energien – der Primärenergiebeitrag von erneuerbaren Energien. BWK No. 60, 08/2008. Düsseldorf: Springer-VDI-Verlag.

[18] (Harvard) Lu, X.; McElroya, M. B.; Kiviluomac, J. (2009): Global potential for wind-generated electricity. In: PNAS. www.pnas.org/content/early/2009/06/19/0904101106

[19] (UNDP) Goldemberg, J. (2000): World Energy Assessment.Energy and the Challenge of Sustainability. 1. print. New York, NY: UNDP/UN-DESA/World Energy Council

[20] (DLR) Teske, S.; Schäfer, O.; Zervos, A.; Beranek, J.; Tunmore, S.; Krewitt, W. et al. (2008): energy [r]evolution. A Sustainable Global Energy Outlook. Greenpeace und European Renewable Energy Council. Berlin. www.energyblueprint.info/

[21] FAO (2008b): The State of Food and Agriculture 2008: Biofuels – Prospects, Risks and Opportunities. Rome: FAO.

[22] BP (2009): BP Statistical Review of World Energy June 2009. London: BP.

[23] Von Bremen, L.; Hofmann (2009): Storage and Transport Capacities in Europe for a full Renewable Power Supply System. Fraunhofer IWES Studie für Siemens AG. Präsentation auf der ewec 2009 (European Wind Energy Conference). Marseille.

[24] Sterner, M.; Pape, C.; Gerhardt, N.; Jentsch, M.; Saint-Drenan, Y.M.; von Oehsen, A. (2010): Modellierung einer 100-Prozent erneuerbaren Stromerzeugung in 2050 – das UBA Szenario Regional. Unveröffentlichte Studie, Fraunhofer IWES, Umweltbundesamt: Kassel, Dessau.

[25] Sterner, M.; Specht, M.; Gerhardt, N.; Saint-Drenan, Y. M.; Stürmer, B.; Zuberbühler, U. (2010): Erneuerbares Methan – Eine Lösung zur Integration und Speicherung Erneuerbarer Energien und ein Weg zur regenerativen Vollversorgung. Solarzeitalter 01/2010. Eurosolar, Berlin. www.eurosolar.de/de/images/stories/pdf/SZA%201_2010_Sterner_farbig.pdf

[26] Michael Sterner. Bioenergy and renewable power methane in 100% renewable energy systems. Limiting global warming by transforming energy systems. Dissertation, Universität Kassel 2009. www.upress.uni-kassel.de/publi/abstract.php?978-3-89958-798-2

[27] Mackensen, R.; Rohrig, K.; Emanuel, H. (2008): Das Regenerative Kombikraftwerk; Abschlussbericht. ISET e. V. Kassel.

[28] Sterner, M.; Gerhardt, N.; Saint-Drenan, Y.M.; von Oehsen, A.; Hochloff, P.; Kocmajewski, M.; Lindner, P.; Jentsch, M.; Pape, C.; Bofinger, S.; Rohrig, K. (2010): Energiewirtschaftliche Bewertung von Pumpspeicherwerken und anderen Speichern im zukünftigen Stromversorgungssystem. Fraunhofer IWES, Kassel. www.schluchseewerk.de/105.0.html

[29] Robert Pitz-Paal, Henner Gladen, Werner Platzer: Solarthermische Kraftwerke – Exportschlager ohne Heimatmarkt, FVEE-Themenheft 2009

[30] Dr. Knut Kübler (BMWi), „Der Schlüssel für mehr Energieeffizienz in Deutschland: Neue Technologien für energieoptimierte Gebäude“, FVEE-Themenheft 2008 „Energieeffizientes und solares Bauen“

[31] BMWi – Bundesministerium für Wirtschaft und Technologie: Energiezahlen (2008). Berlin, BMWi.

[32] Jürgen Schmid, et al. „Integration der erneuerbaren Energien in die Strom- und Wärmeversorgung" Themenheft 2009 „Forschen für globale Märkte erneuerbarer Energien"

[33] Forschungsstrategie des FVEE für elektrochemische Stromspeicher und Elektromobilität (April 2010) Link: www.fvee.de/fileadmin/politik/10_04_strategie_stromspeicher_kurzfassung.pdf

[34] Nationaler Entwicklungsplan Elektromobilität der Bundesregierung, August 2008

[35] Bundesministerium für Wirtschaft und technologie (BMWi): Trends und Hintergründe zur Energieversorgung in Deutschland. Berlin. April 2009.

[36] Friedrich, M., Becker, D., Grondey, A., Laskowski, F., Erhorn, H., Erhorn-Kluttig, H., Hauser, G., Sager, Ch. und Weber, H: CO_2-Gebäudereport 2007. Bundesministerium für Verkehr, Bau und Stadtentwicklung, Berlin (2007).

[37] Eicke R. Weber, Der globale Forschungsmarkt für erneuerbare Energien: Wettbewerb und Technologiepartnerschaften, FVEE-Themenheft 2009 „Forschen für globale Märkte"

[38] Patent DE102006034712 A1, Verfahren zur Reduzierung der CO_2-Emission fossil befeuerter Kraftwerksanlagen, Anmelder: Steag-Saar Energie und IZES gGmbH

[39] EU-Richtlinie über Endenergieeffizienz und Energiedienstleistungen (2006/28/EG, EDL-Richtlinie) vom 5. April 2006

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