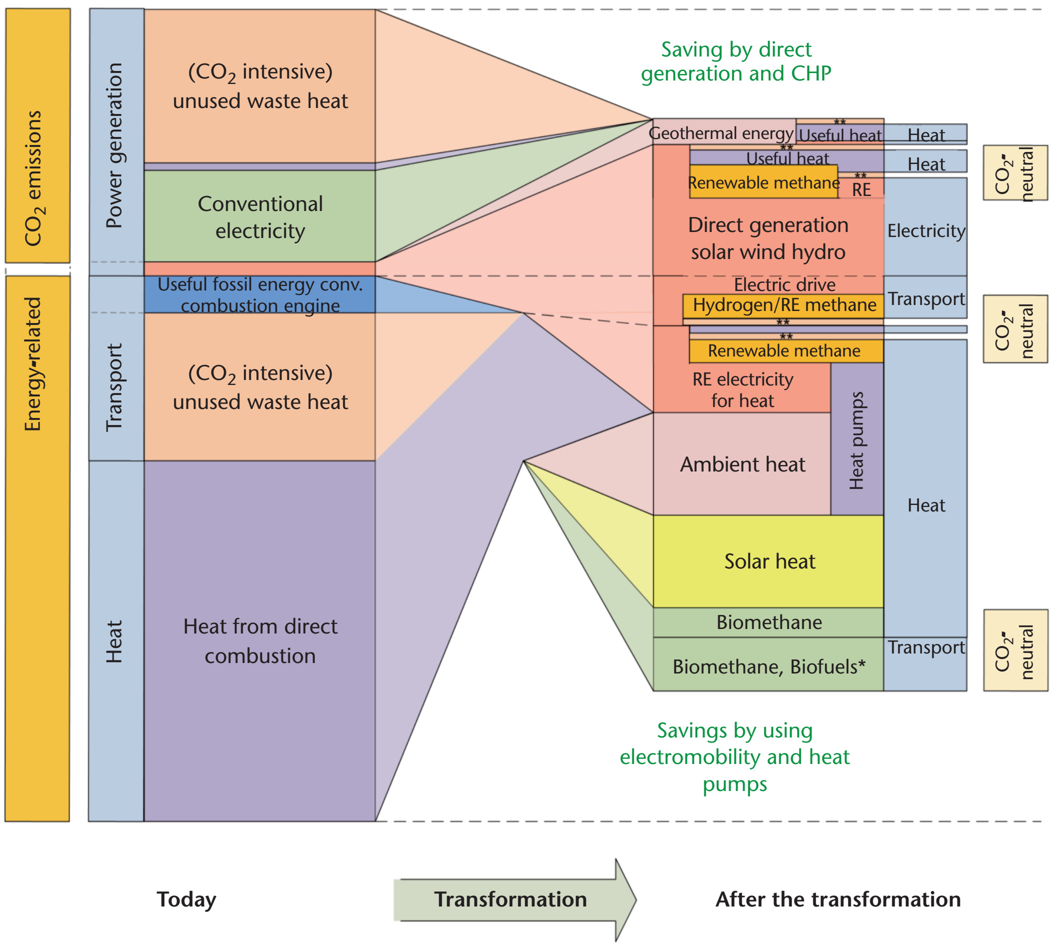
2. Transformation of current energy systems into the Sustainable Energy System 2050

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, -

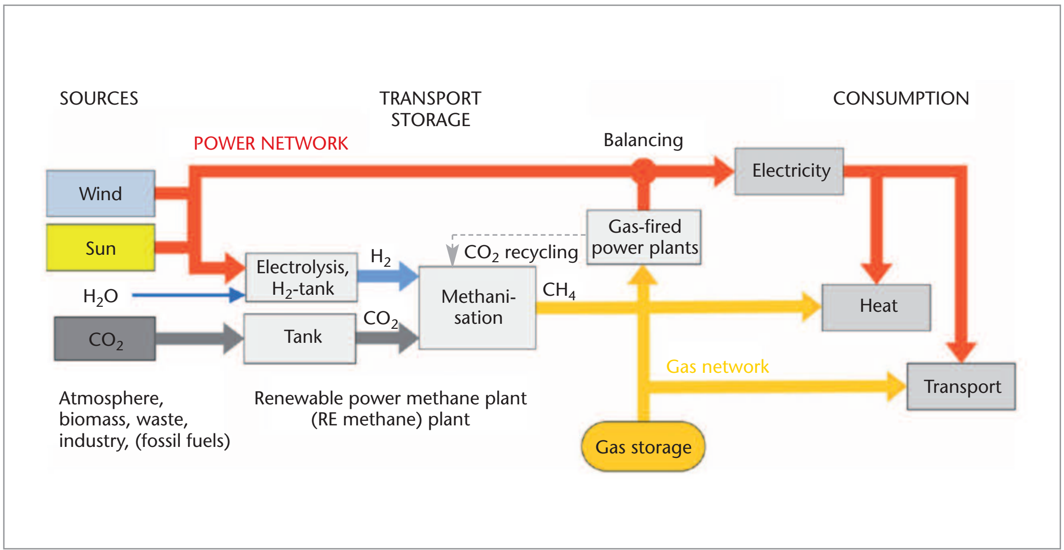


Figure 9
Storage of electricity from the sun and the wind through the production of methane and its subsequentt storage. Using bidirectional coupling of gas and power grids, connected to the mobility consumption sector, methane forms an indirect power storage unit.

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.

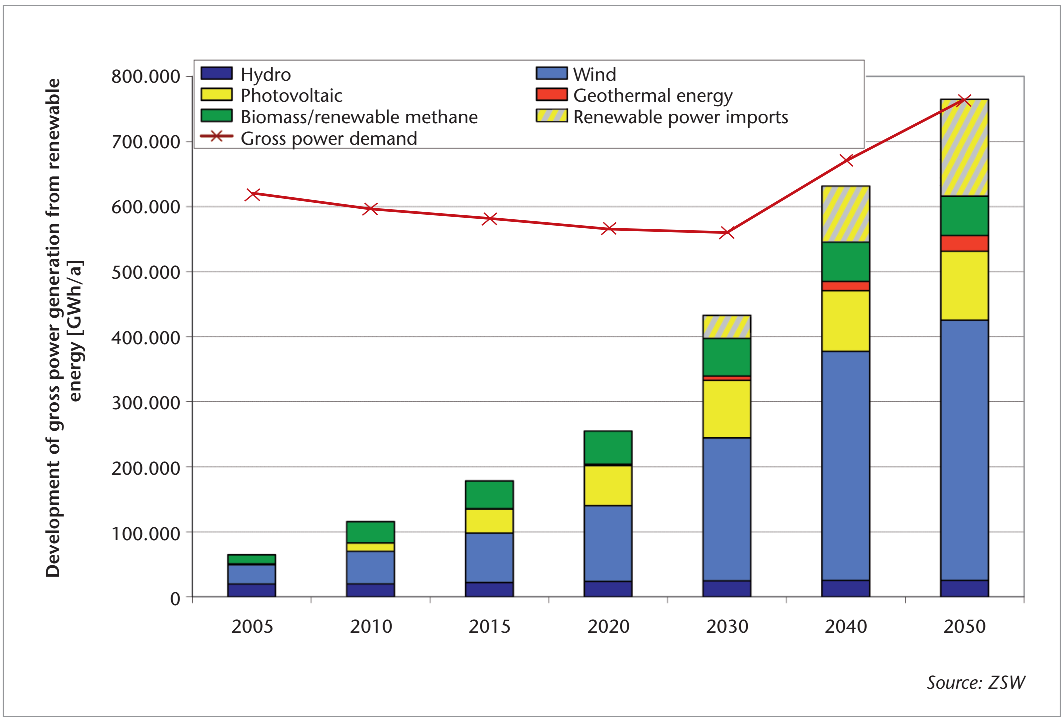
Here, the 100% RE goal is a very robust target, since even if a particular technology in the volume scenario does not reach the given target for expansion, renewable energy has enough technological variety for the missing share to be made up by one or several alternative technologies. The volume scenario 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

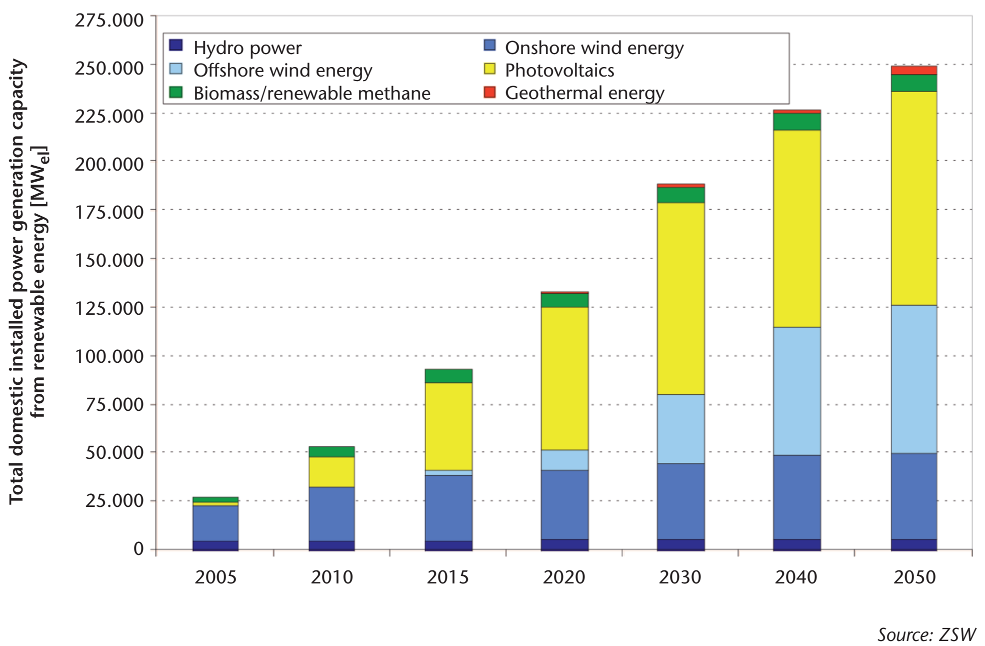
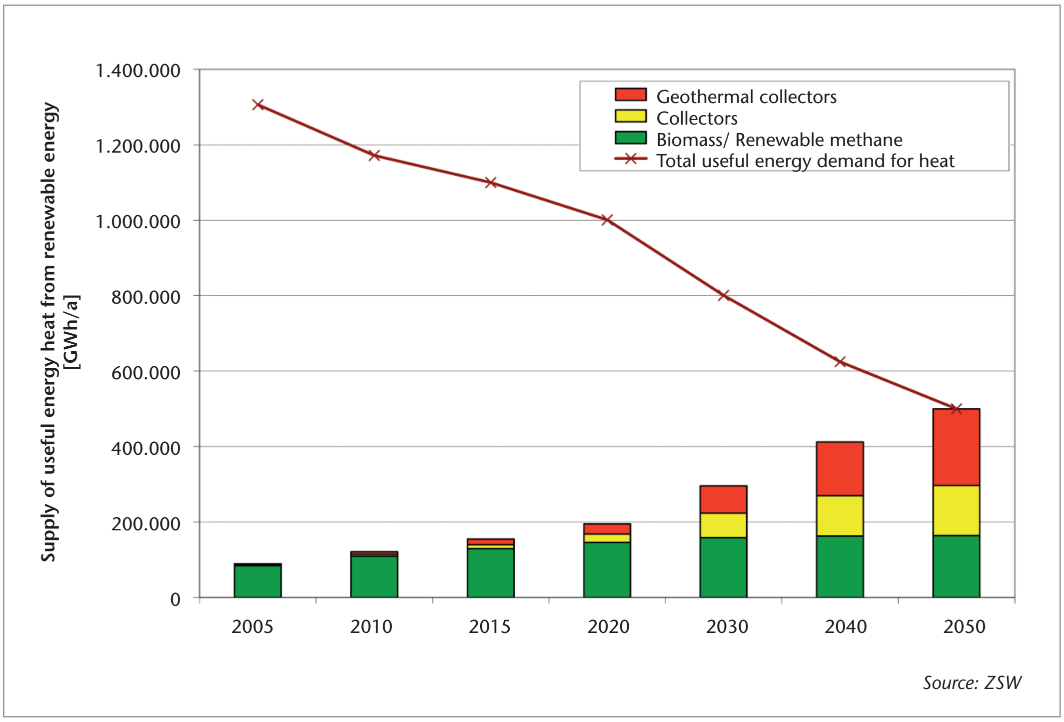


Figure 11
Development in installed power generation capacity in Germany from renewable energy to 2050.

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.

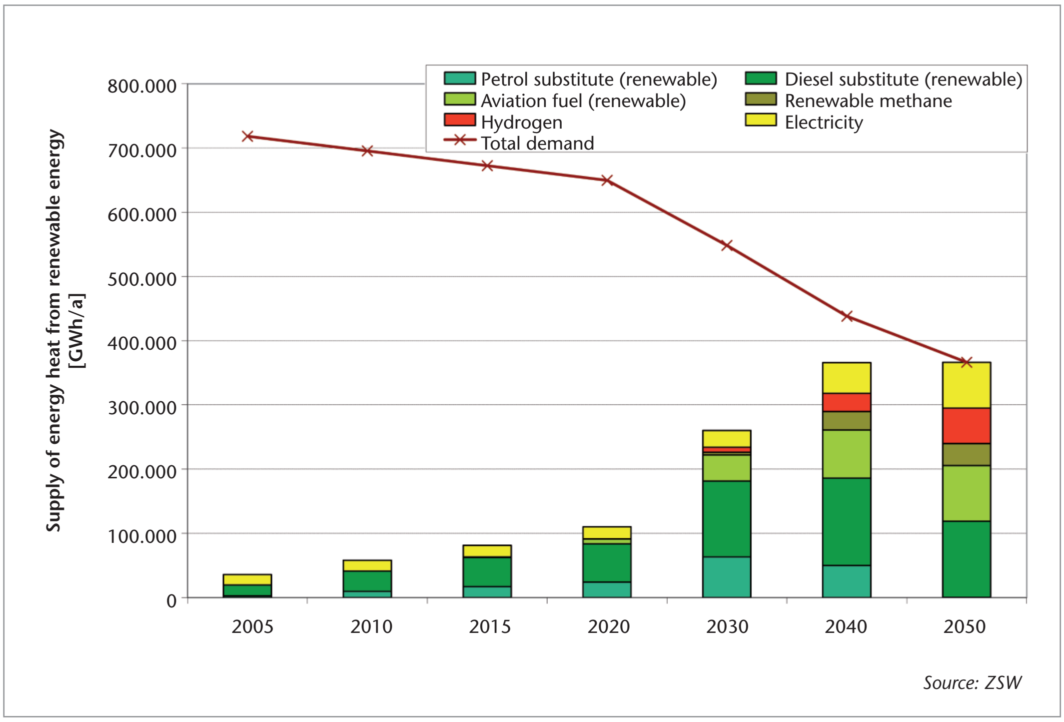


Figure 13
Development in final energy demand for transport from renewable energy and overall final energy demand for transport in Germany to 2050.

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

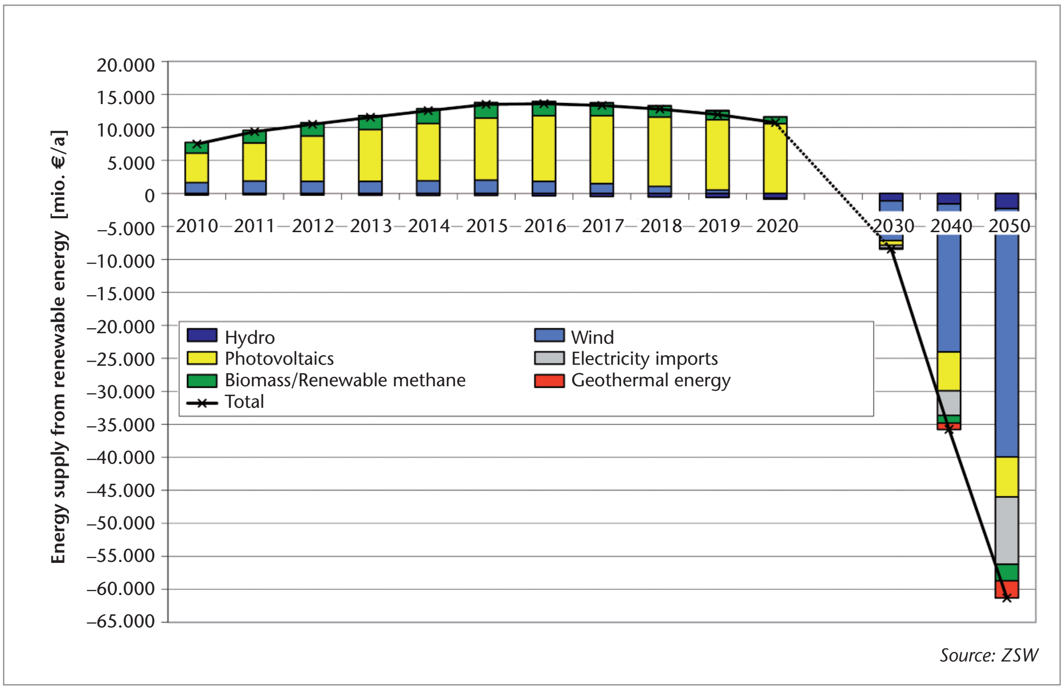
- The differential costs of total RE power generation are calculated on the basis of the power production costs of the individual technologies and their respective share in the renewable power generation mix. The mean electricity costs for a renewable energy generation mix increase on average from 11.5 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



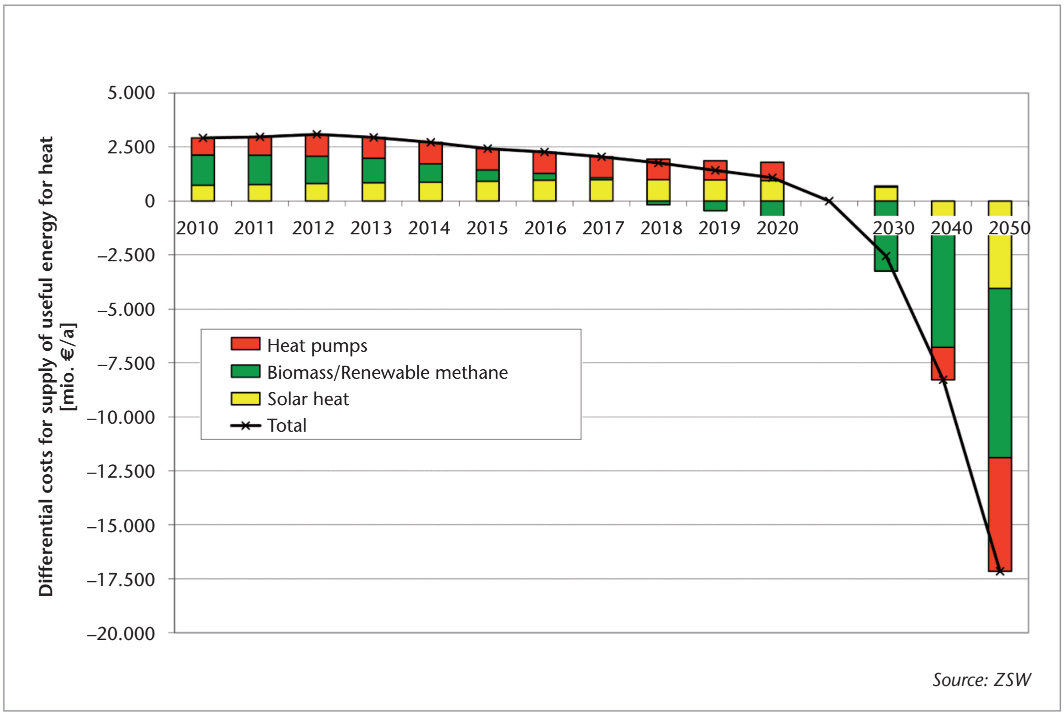


Figure 15
Trend in differential costs of renewable useful heat supply in Germany from 2010 to 2050.

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.

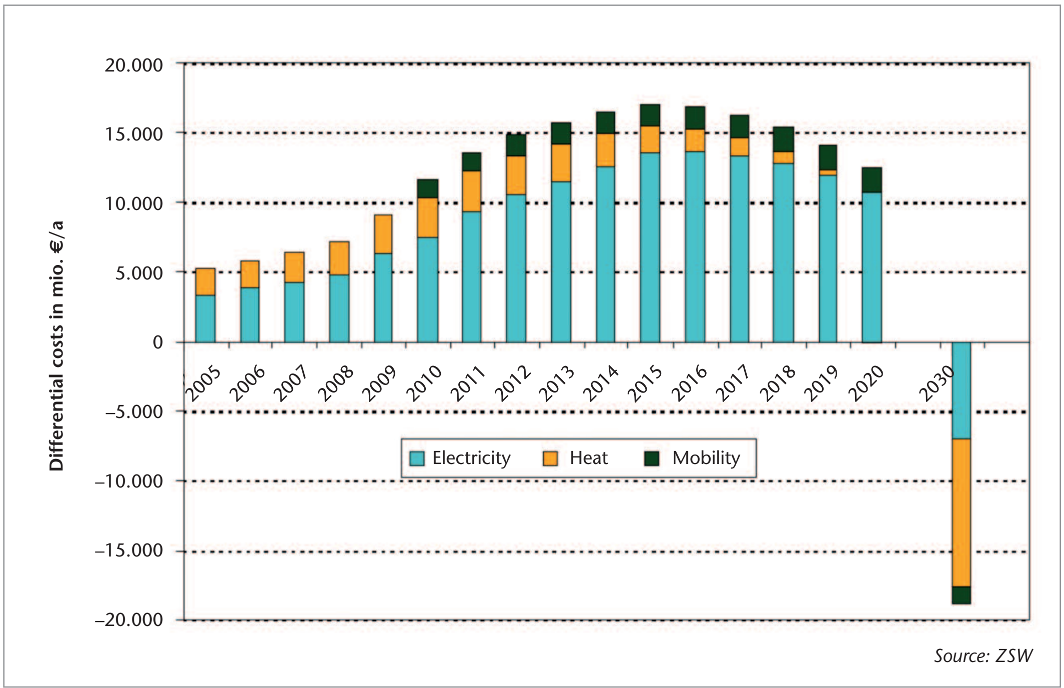


Figure 16
Development in total differential costs in the electricity, heat and transport sectors to 2030.

Source: ZSW

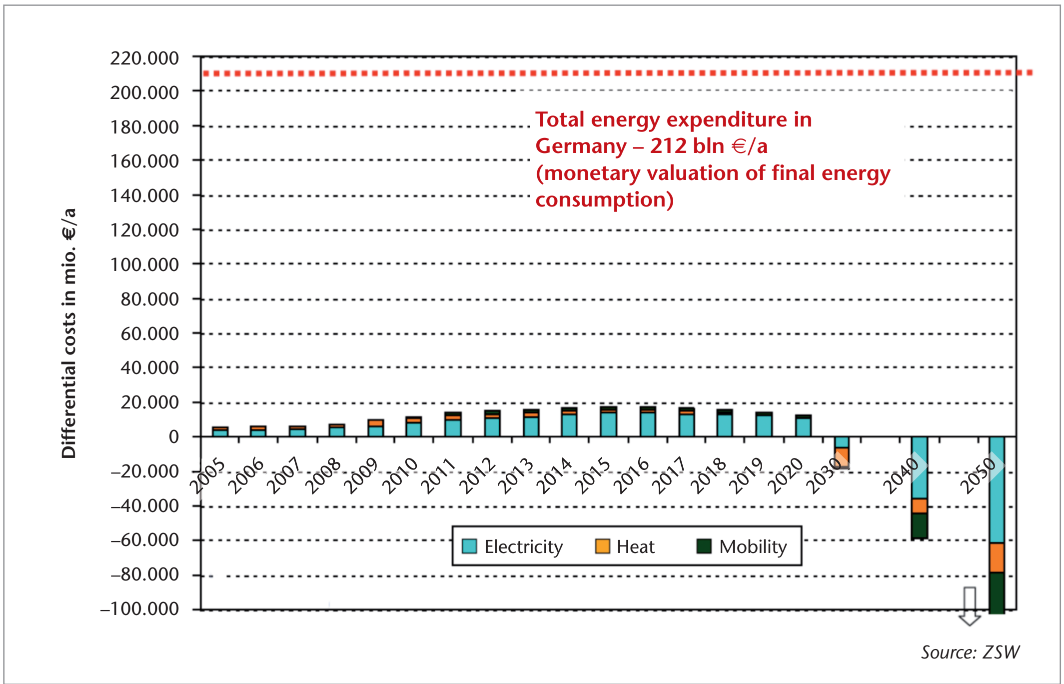


Figure 17
Differential costs to 2050 in relation to total energy expenditure in Germany.

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.

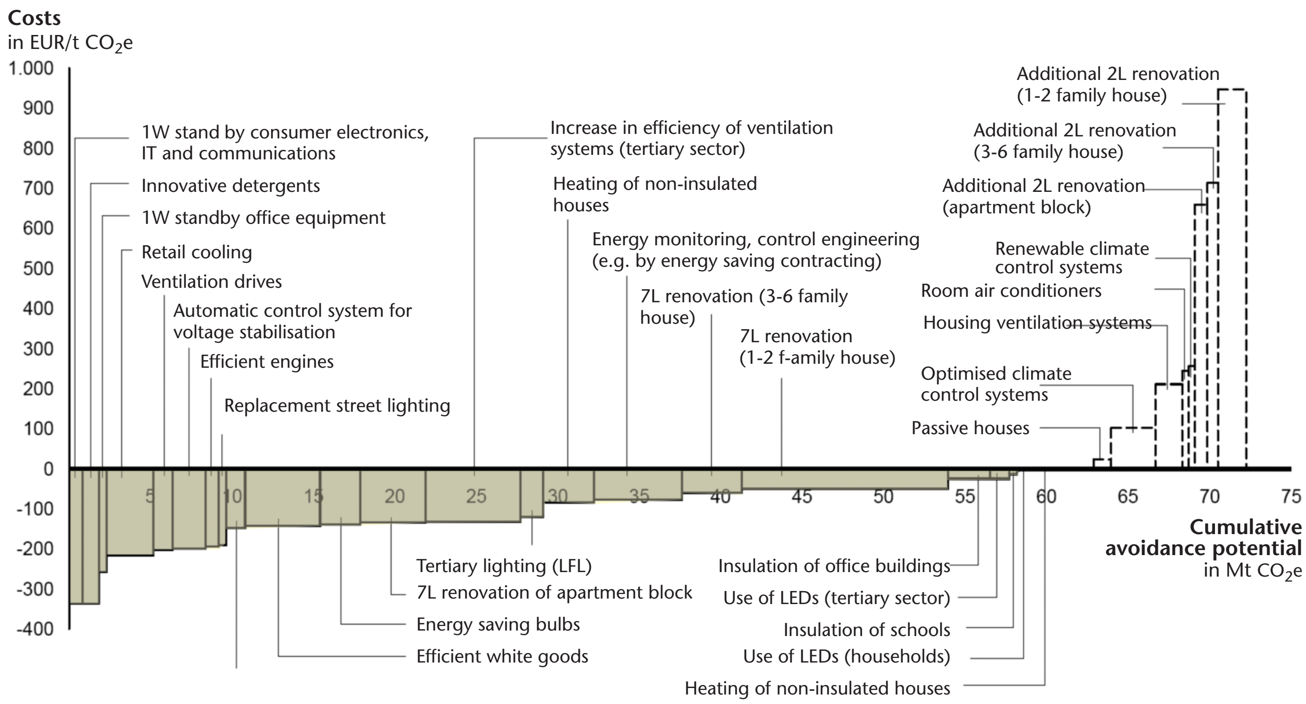
This is added to the increasing significance of building renovation throughout the building sector, as about 70% of the total building construction volume in Germany is subject to renovation measures. Consequently the improvement in the energy performance of buildings can also be seen as a supporting 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