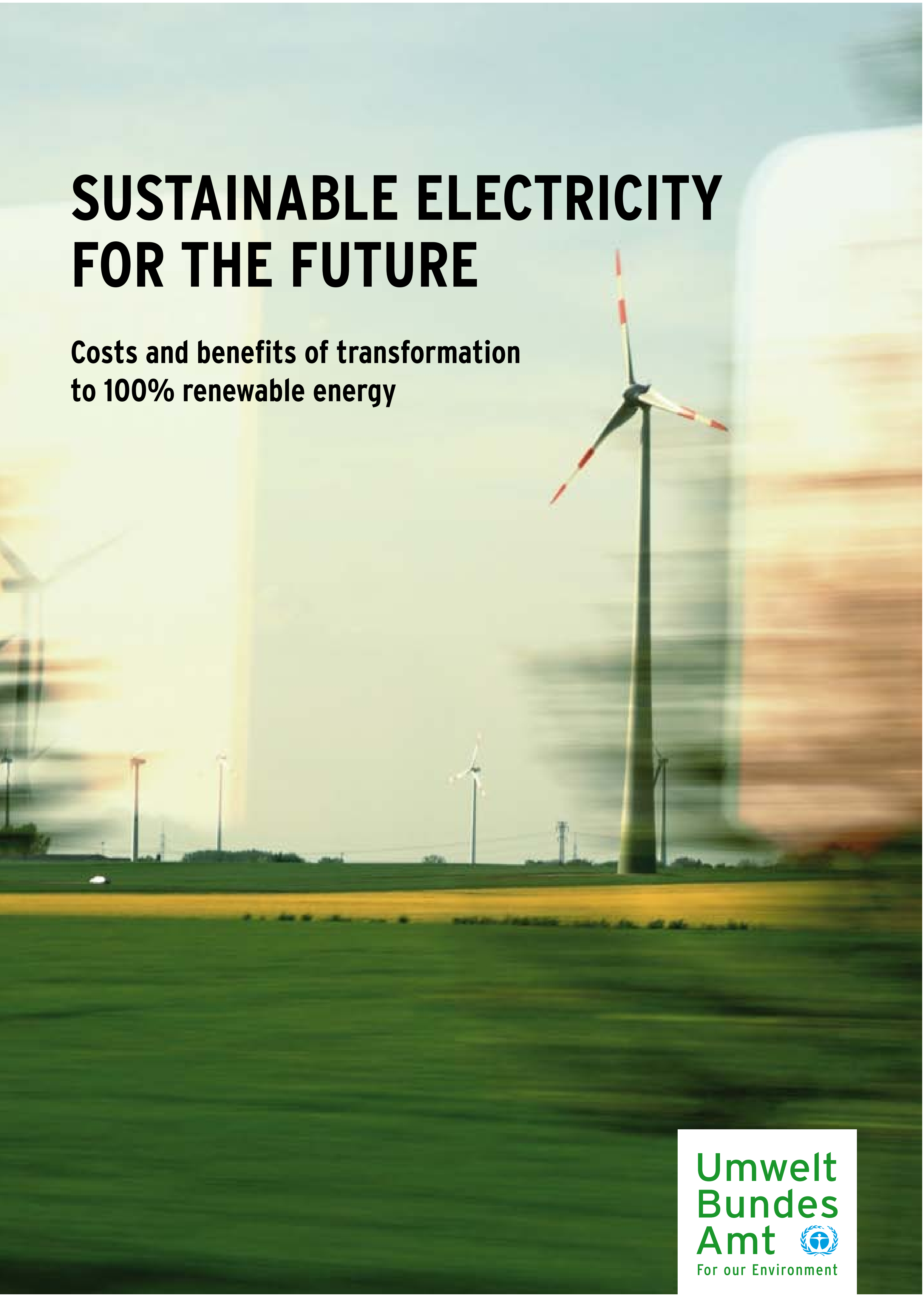
SUSTAINABLE ELECTRICITY FOR THE FUTURE

Costs and benefits of transformation to 100% renewable energy



Umwelt Bundes Amt

For our Environment

Imprint

Published by:	German Federal Environment Agency Press Office Wörlitzer Platz 1, D-06844 Dessau-Roßlau, Germany
E-Mail:	pressestelle@uba.de
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Date:	**August 2012**
Design:	UBA
Cover photo:	© designritter / photocase.com

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Summary

Sustainable electricity supply calls for transition to a system using 100 percent renewable energy sources.

- Important criteria for sustainable electricity supply are its compatibility with health, nature and the environment, and also its low risk. Our present electricity supply system does not satisfy these criteria. At a global level, electricity generation gives rise to about 26 percent of greenhouse gas emissions.[1] This makes it one of the principal causes of climate change. The use of nuclear energy involves high risks and social costs due to accidents and disposal of the radioactive waste.
- In order to meet the two-degree climate target, the industrialised countries will have to reduce their emissions by between 80 and 95 percent by 2050, compared with 1990. Since the agricultural sector and a number of industrial processes will continue to cause a residual quantity of underlying emissions even if extreme climate control efforts are made, there is a need to reduce greenhouse gas emissions from electricity generation to virtually zero. Sustainable electricity supply thus calls for a transition to a system using 100 percent renewable energy sources.

Electricity supply based entirely on renewable energy sources is technically possible by 2050. In all ambitious expansion scenarios, electricity from wind and solar energy plays the central role.

- The technical potential exists for worldwide electricity supply based entirely on renewable energy sources.
- An analysis of ambitious long-term expansion scenarios up to 2050 for Germany, the European Union and the world as a whole shows that electricity from solar and wind energy dominates the production mix in all studies.
- The expansion of renewable energy sources has to be paralleled by their integration in the electricity supply system. Grid expansion, load management and storage solutions make indispensable contributions here.
- Studies show that by 2050 an electricity supply system based entirely on renewable energy sources can guarantee reliable electricity at all times.

The costs of electricity generation from renewable sources have already fallen considerably – and this trend will continue. Since conventional electricity generation will become more expensive as time goes on, renewable energy will increasingly become a paying proposition.

- The cost of one megawatt-hour (MWh) of electricity from photovoltaic and onshore wind energy systems has fallen substantially in the last two years, by around 44 percent for photovoltaic and around 7 percent for onshore wind power. In the same period the cost per MWh of electricity from coal-fired power stations increased by 9 percent.
- The foreseeable depletion of fossil fuels will lead to further price increases. This is another reason for reducing our dependence on fossil fuels and looking ahead to pave the way for renewable energy sources in electricity supply.
- A comparative analysis of numerous studies on the expansion of renewable energy in Germany, the EU and the entire world shows that the costs of renewable energy will continue to fall because of “learning-curve effects”. By 2050 the investment costs for photovoltaic systems will fall by 75 percent and for offshore wind installations by 50 percent.
- In 2030 the average cost of producing electricity from renewable sources in Germany will probably be around 7.6 ct/kWh. By then, electricity from new gas-fired and coal-fired power plants will probably be costing over 9 ct/kWh. This does not take any account of system integration costs.
- In many regions of Africa, India, Southeast Asia and parts of the Middle East the use of photovoltaic systems is already economic compared with electricity from diesel generators.

1 Wheeler and Ummel (2008).

Environmentally harmful subsidies and failure to take account of external environmental costs arising from electricity generation from fossil fuels and nuclear power result in a massive distortion of competition to the disadvantage of renewable energy.

- In Germany, the environmental costs of electricity generation from lignite, at around 11 ct/kWh, are higher than the cost of electricity production from onshore wind turbines, at around 7.5 ct/kWh.
- Around the world, subsidies for fossil fuels totalled 409 billion USD in 2010, and 122 billion USD of this was due to electricity generation. By contrast, financial assistance for the market launch of renewable energy sources came to only 44 billion USD in 2010.

The transformation of the energy system makes economic sense at national level. Assistance for renewable energy avoids environmental costs arising from harmful effects on health and the environment, creates jobs and increases regional value added. It also improves the country's competitive position on the growing global markets for renewable energy technologies.

- By 2050 the cost of unchecked climate change could amount to 14 percent of worldwide consumption, with a continuing upward trend. By contrast, the cost of drastic restrictions on greenhouse gas emissions is put at only around one percent.
- German experience with the expansion of renewable energy is very favourable. Over the last 10 years the share of electricity supplies due to renewable energy sources has tripled to around 20 percent in 2011. Between 2004 and 2011 the number of jobs in the renewable energy sector more than doubled from 160,000 to around 382,000. There was a net increase of between 70,000 and 90,000 new jobs in 2009.
- Around the world, some 5 million people are employed in the renewable energy sector – and the upward trend continues. Estimates indicate that by 2020 the targeted expansion of renewable energy in Europe will result in slightly positive growth effects and will on balance create 400,000 new jobs.
- By 2025 the global market for green energy is set to grow to 747 billion EUR. Renewable energy sources play a central role here. As key technologies for the energy supply of the future, they are of great economic relevance. Countries that push ahead with the expansion of renewable energy have competitive advantages on these markets.

Electricity supply based entirely on renewable energy sources is an intergeneration task and a global innovation project. Research and development, innovation assistance and instruments for promoting market diffusion are important to speed up the expansion of renewable energy and the reduction of costs in that sector.

- The greater the growth of renewable energy markets, the greater are the cost reductions due to learning effects. Because all countries reap the benefits, promoting renewable energy is a global task. Its expansion therefore needs to be advanced rapidly everywhere.
- Market-based assistance mechanisms are of central importance for the expansion of renewable energy. Feed-in payments for renewable energy create planning certainty for investors, reduce the investment risk and hence finance costs, and speed up the market diffusion of renewable energy through learning-by-doing and economies of scale.
- Distortions of competition at the expense of renewable energy must be abolished. This calls for the discontinuation of climate-harmful subsidies and the internalisation of external costs in the electricity generation sector.

1 INTRODUCTION

1.1 A fundamental reconstruction of the electricity supply system is needed

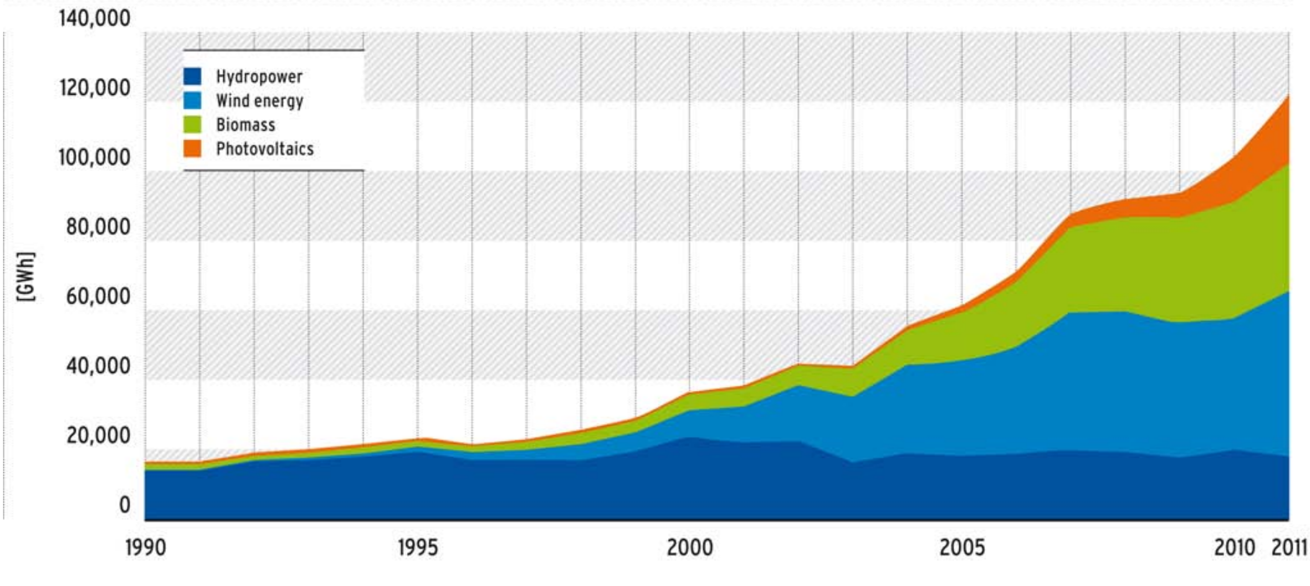
The existing electricity supply system based largely on fossil fuels and nuclear energy is not compatible with sustainable development. At a global level, electricity generation gives rise to about 26 percent of greenhouse gas emissions.[2] This makes it one of the principal causes of climate change. Without massive expansion of renewable energy sources it will be impossible to achieve the two-degree target for limiting global warming. High social costs, for example due to rising sea levels and persistent droughts, would result from unrestrained climate change in many sensitive regions of the world. Nuclear disasters like Fukushima in 2011 and Chernobyl in 1986 show that nuclear power involves great risks and social costs, not only for the present generation, but also – because they are irreversible – for all future generations. To this must be added the considerable environmental pollution caused by the extraction of uranium and fossil fuels. There is thus an urgent need to switch to an electricity supply system based on renewable energy sources.

Expanding renewable energy pays off, not only because of the environmental risks and external costs that it avoids. The costs of electricity generation on the basis of renewable energy sources have fallen sharply in recent years – in some cases they are already competitive today. In future the resource prices for fossil fuels and uranium will probably continue to rise and be subject to large fluctuations, while the cost of renewable energy will fall. As a result, electricity generation from renewable sources will be cheaper in the foreseeable future. There are also industrial policy arguments for expanding renewable energy. The global markets for renewable energy technologies are booming, and the race is already on for leading positions in these markets. Countries that provide assistance for renewable energy at an early stage are in a good position here.

1.2 Economic impacts of renewable energy expansion in Germany

In the wake of the Fukushima nuclear disaster, Germany decided to phase out nuclear energy completely – eight nuclear power plants were shut down before the end of 2011. This would not have been possible without the rapid expansion of renewable energy in the years before. With a renewable energy share of around 20 percent of gross electricity consumption in 2011, Germany is already on the road to a greenhouse-gas-neutral energy supply system (see Figure 1).

Figure 1: Renewable energy contribution to electricity generation in Germany

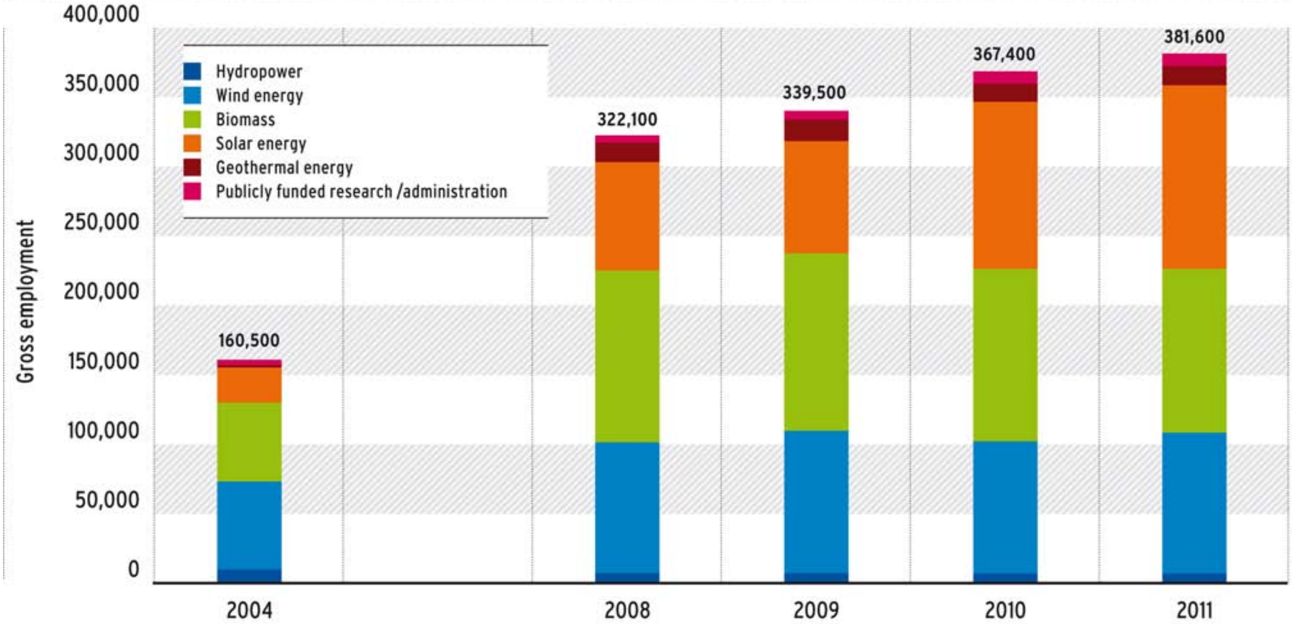


Source: BMU (2012a), Slide 13

2 Wheeler and Ummel (2008).

The rapid expansion of renewable energy affects employment. Between 2004 and 2011 the number of jobs in the renewable energy sector more than doubled from 160,000 to around 382,000.[3] Even during the financial crisis of 2009 there was a slight rise in employment (cf. Figure 2). Model calculations show that on balance – i.e. after taking account of parallel job losses in the fossil fuel sector, for example – renewable energy has a positive impact on employment. In 2009 the net increase in employment due to the expansion of renewable energy came to between 70,000 and 90,000 jobs.[4]

Figure 2: Employment impacts of the expansion of renewable energy in Germany



Source: BMU (2012) p. 5, 8 and Breitschopf et al. (2011) p. 16.

Moreover, the use of renewable energy sources for electricity generation saved imports of fossil fuels to the value of 2.9 billion EUR in 2011. At the same time this avoided environmental costs (due to climate gases and air pollutants) of 8 billion EUR.[5] Furthermore, the promotion of renewable energy sources made a major contribution to improving the competitive position of German companies in the renewables sector. They are outstandingly well represented on the global market for renewable energy technologies, as evidenced by the large world market and patent shares of German companies and the considerable increases in renewable energy exports in recent years.[6]

The expansion of renewable energy is to continue in the decades ahead. By 2050 at the latest, at least 80 percent of electricity in Germany is to come from renewable energy sources. This is part of the transformation of the energy system (German: Energiewende) – a comprehensive climate protection strategy with the aim of reducing German greenhouse gas emissions by between 80 and 95 percent compared with 1990 levels. The energy turnaround is a great challenge and the subject of lively discussion. Surveys indicate that around 90 percent of the population are in favour of a rigorous transition to renewable energy sources.[7] However, in some sections of the population and industry there are also sceptical voices, especially as regards technical feasibility, security of supply and the costs of large-scale expansion of renewable energy sources.

3 BMU (2012), p. 8.
4 Lehr u.a. (2011), p. 214.
5 Breitschopf (2012a).
6 BMU/UBA (2011).
7 BDEW (2012).

As a first step, the following chapter therefore examines whether expansion of renewable energy with the aim of full coverage is possible. Chapters 3 and 4 then look into the question of the resulting costs and benefits. One important basis here is the meta-study conducted by the Potsdam Institute for Climate Impact Research (PIK) for the Federal Environment Agency (UBA) on the costs of renewable energy expansion.[8] This analyses the main existing scenarios for long-term transformation of the energy system in which renewable energy meets at least 80 percent of electricity consumption by 2050. The selection includes not only scenarios for Germany, but also for Europe and the world.[9]

2 IS IT POSSIBLE TO EXPAND RENEWABLE ELECTRICITY SUPPLY TOWARDS 100 PERCENT?

In the first place, electricity supply from renewable sources calls for adequate technical potential.[10] Chapter 2.1 looks into this question and describes the technical expansion potential that exists in relation to energy requirements. Secondly, it is necessary to clarify the contributions that the various renewable energy technologies can usefully make. Chapter 2.2 summarises findings from the relevant scenarios developed for the global, European and national levels. Thirdly, there is the question of how to ensure grid stability and supply security in the expansion of renewable energy. This is the subject of Chapter 2.3; here the remarks are confined to Germany.

2.1 Technical expansion potential for renewable energy worldwide

Analyses by the Intergovernmental Panel on Climate Change (IPCC) for 2050 show that the technical potential in all regions of the world is sufficient to meet energy supply requirements entirely from renewable energy sources (cf. Figure 3).[11] In fact, the technical potential is in most cases several times higher than energy demand. For example, in the USA or India the technical renewable energy capacity in 2050 is 7.6 to 10 times higher than the primary energy consumption of 2007, and in South America or Africa it is as much as 25 to 50 times higher. In the countries of the southern hemisphere, solar energy is of outstanding importance, and even in some northern countries it offers the greatest technical potential. Here, however, other renewable energy sources such as wind energy and hydro power play an important role.

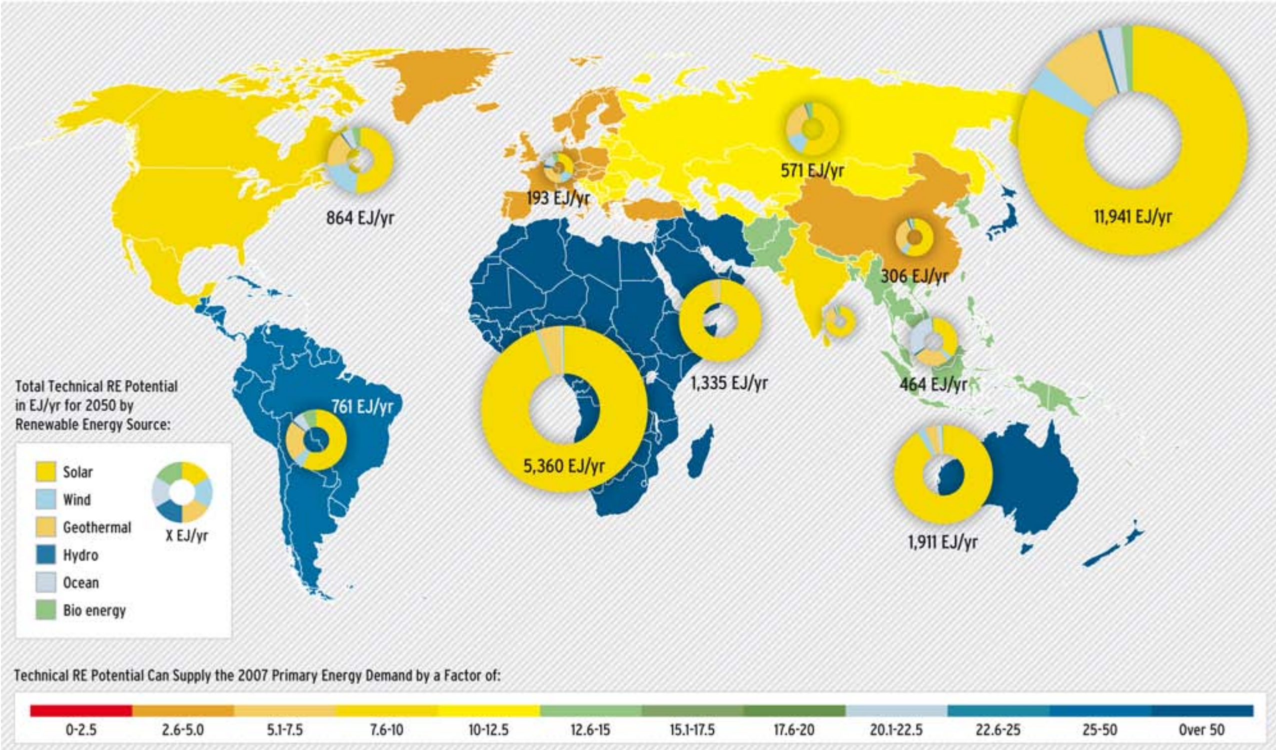
8 PIK (2012).

9 The sources analysed were: Lead Study (2010), SRU (2011), WWF (2009), Greenpeace(2009), EWI/GWS/Prognos(2010), WI/PIK(2010), EC(2011), ECF (2010), EREC (2010), PWC/PIK/IIASA/ECF (2010), EWI/Energynautics (2011), PIK/IIRM/IfE (2011), Greenpeace(2010), WWF(2011), IEA (2010a), Energy Watch Group (2008).

10 The technical potential is that part of the theoretically possible total potential of renewable energy sources which is technically possible to harness. The relationship between the two is usually expressed as efficiency. For example, the technical potential of a photovoltaic installation with an efficiency of 20 percent is one fifth of the theoretical solar potential. The technical potential may be reduced by ecological restrictions (e.g. land take, adverse effects on flowing waters, adverse changes in the landscape). Similarly, the technical potential may also be reduced by restrictions on use due to the site-specific geography of geothermal energy.

11 IPCC (2012). The figures relate to entire energy requirements (including heat and mobility)

Fig. 3: Technical potential 2050 compared with primary energy consumption 2007

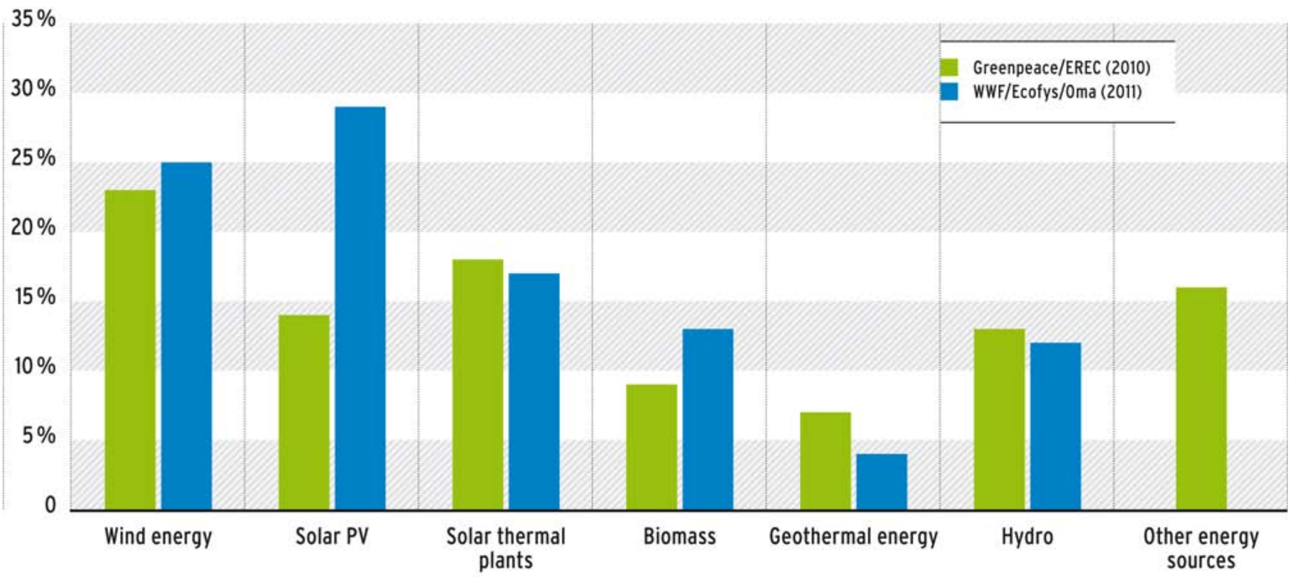


Source: IPCC (2012), Special Report on Renewable Energy Sources and Climate Change Mitigation, Fig. 10.19 (top part). Cambridge University Press.

2.2 Expansion scenarios for renewable energy sources in electricity generation

The global technical potential is also reflected in the findings of global energy scenarios. In the studies analysed with large renewable energy shares up to 2050, the global energy mix in 2050 is dominated by solar energy (photovoltaic and solar thermal power plants), well ahead of wind energy (see Figure 4).[12] Wind and solar energy together amount to between 55 and over 70 percent of the global electricity mix.

Fig. 4: Electricity mix in global studies (in 2050, figures in percent)

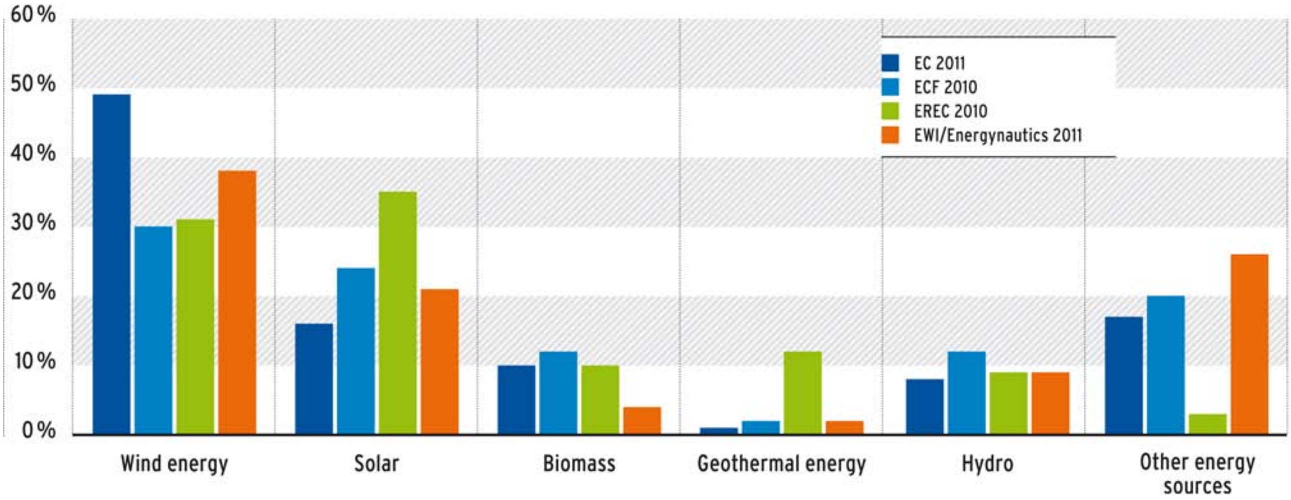


Source: Own diagram, data from PIK (2012), p. 15

12 Greenpeace/EREC (2010) does not show separate figures for onshore and offshore wind energy. The graphic results for wind energy are therefore shown in aggregated form. Electricity generation from fossil and nuclear fuels is summarised under "Other".

The studies focusing on Europe show that wind energy will probably be the most important component for the future electricity mix (cf. Figure 5). According to the findings of the studies, the wind share of the European electricity mix is between 30 and 49 percent in 2050, and thus exceeds the solar energy contribution to electricity generation in almost all studies, which is put at between 16 and 35 percent.[13] Biomass and hydro power, with a maximum of around 10 percent each, are well behind. In this respect the studies present a relatively uniform picture. In some cases, however, the scatter is considerable, especially for geothermal energy, which is still in its infancy. The scatter of the biomass shares is due to differences in the assumptions made about limits to expansion.[14]

Fig. 5: Electricity mix in Europe (in 2050, figures in percent)



Source: Own diagram, data from PIK (2012), p. 15

FFor Germany there are numerous studies that use scenario analyses to depict an extensive transition to electricity supply from renewable sources. The long-term scenarios commissioned by the Federal Environment Ministry analyse how the German government's targets for the expansion of renewable energy up to 2050 can be achieved.[15] By way of example, Figure 6 shows the results of one of the three long-term scenarios (Scenario 2011 A). Here the renewables share of electricity generation rises to 41 percent by 2020 and to around 85 percent by 2050. Annual growth of electricity generation from renewable sources up to 2020 averages 8.2 percent.

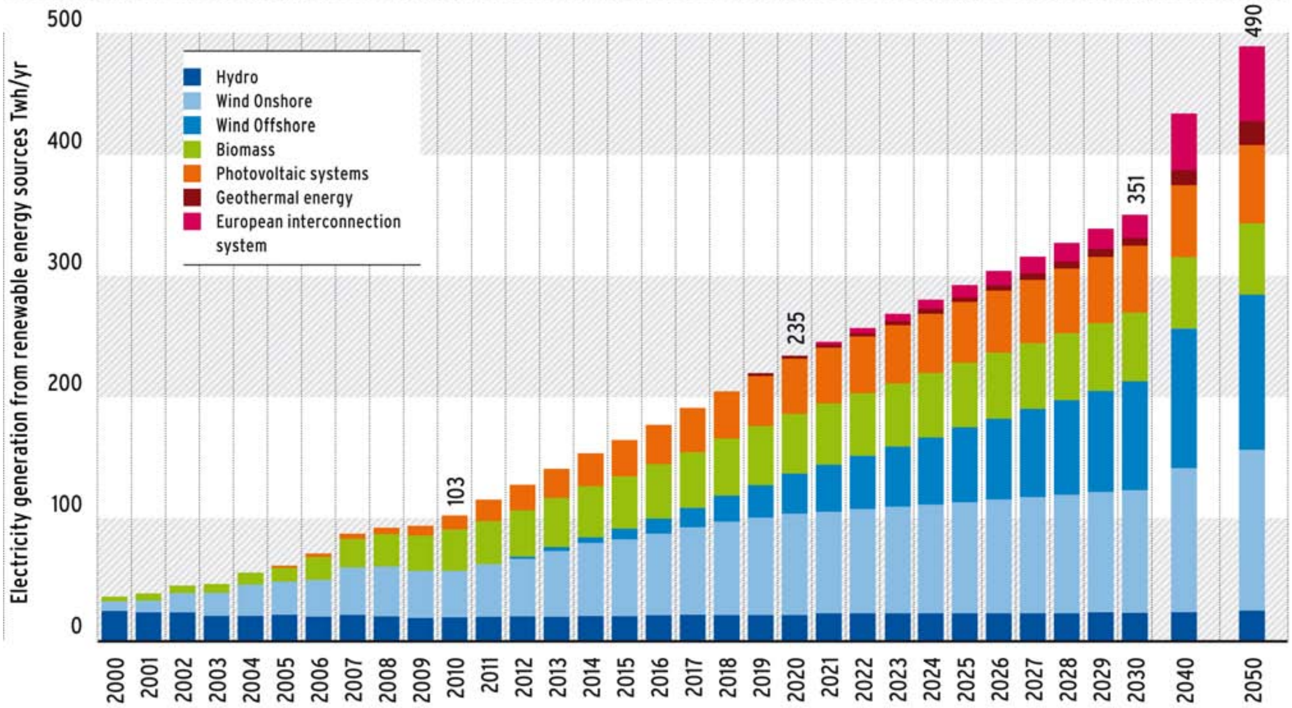
The largest absolute contribution is made by wind energy. At 11 percent per annum it is growing very fast, and only the growth of the photovoltaic sector is more dynamic with 13.5 percent up to 2020. Between 2020 and 2050 the renewables share of electricity supply grows by an average of 2.5 percent a year. The expansion of offshore wind energy plays a central role here. Imports from the European interconnection system also become increasingly important in this scenario. In view of the high installed capacity in the photovoltaic sector, growth of the European interconnection system and of the less volatile offshore wind energy will tend to be reinforced from 2030 onwards. By contrast, the growth of the photovoltaic sector will slacken off.

13 The studies by EC (2011) and EREC (2010) do not show separate figures for onshore and offshore wind energy. Moreover, EC (2011) does not show separate figures for photovoltaic systems and solar thermal power plants. The graphic results for wind energy and solar energy are therefore shown in aggregated form.

14 Examples of the limits to expansion are limited availability of land and competition for use between energy uses of biomass and other forms of use (food and animal feeds, use as material).

15 DLR/IWES/IFNE (2011) The German government's expansion targets according to Section 1 (2) of the Renewable Energy Sources Act are at least 35 percent renewable-based share of gross electricity supply by 2020 and at least 80 percent by 2050.

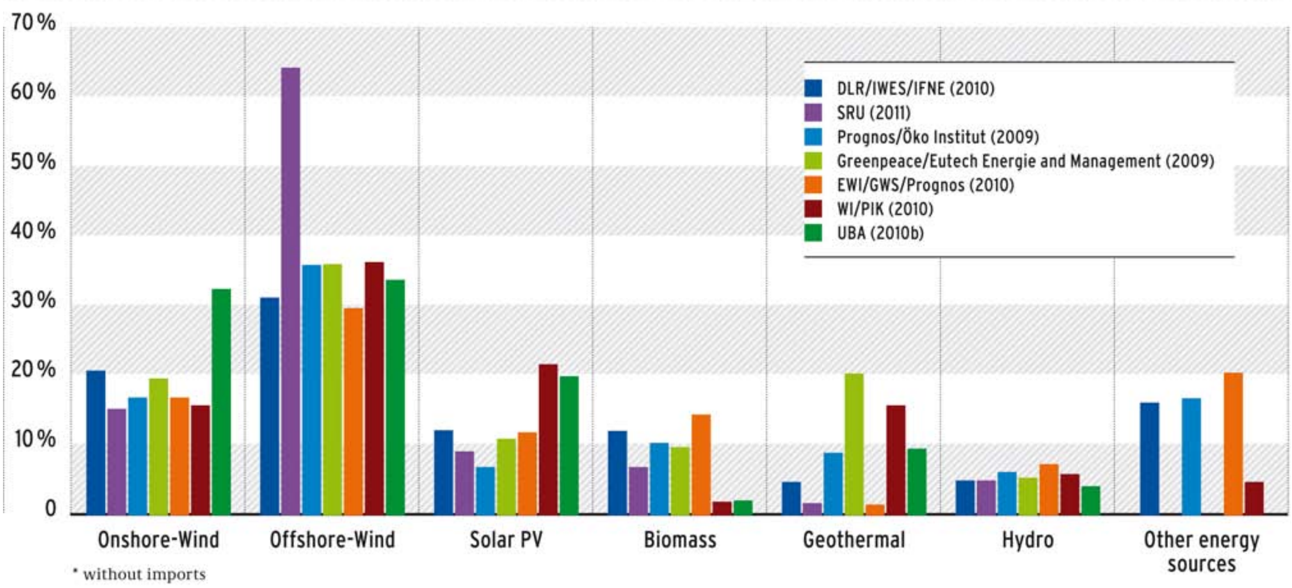
Fig. 6: Development of electricity generation from renewable sources in Scenario 2011 A, broken down by renewable energy sources



Source: DLR/IWES/IFNE (2011), Scenario 2011 A

The other studies on renewables expansion in Germany up to 2050 also show wind energy as dominant, with shares of between 45 and 78 percent of the electricity mix (cf. Figure 7).[16] A striking feature is the large share of electricity generation accounted for by offshore wind energy. All in all, wind energy has a much larger share of the electricity mix in Germany than in the EU expansion scenarios. Wind energy and photovoltaic,[17] as forms of generation that depend on the available supply, have a share of not less than 57 percent of electricity supply in all studies.

Figure 7: Electricity mix in Germany (in 2050, figures in percent)*



* without imports

Source: Own diagram, data from PIK (2012), p. 15 and UBA (2010b)

16 Cf. DLR/IWES/IFNE (2010), SRU (2011), Prognos/Öko Institut (2009), Greenpeace/ Eutech Energie und Management (2009), EWI/GWS/Prognos (2010), WI/PIK (2010), UBA (2010b).

17 In Germany, solar thermal power plants do not play a role in any of the expansion scenarios.

Box 1: 100 percent renewable energy regions in Germany
The vision of an energy supply system based entirely on renewable energy sources is becoming increasingly attractive in Germany for a growing number of local authorities and regions. Today there are more than one hundred rural districts, communities and regional alliances that are seeking to achieve complete conversion of their energy supply system to renewable energy sources. Under the project "100 percent renewable energy regions" (www.100-ee.de) the Federal Environment Ministry promotes networking of municipalities and regions that want to convert their energy supply systems to renewable energy . These regions already account for 22 percent of the population of Germany.

Important motives for these local and regional initiatives are the general public's commitment to climate protection and the fact that switching to renewable energy sources makes them independent of finite fossil resources. An additional factor is the assistance provided under the Renewable Energy Sources Act. Also a decentralised energy supply system based on renewable sources leads to an increase in regional economic output. This creates additional jobs locally and increases municipal tax revenue.

2.3 Grid stability and supply security

Grid stability and supply security are central requirements in the further expansion of renewable energy. For a secure power supply system, supply and demand must always be in balance. Since large proportions of variable, supply-driven sources reduce the supply-side potential for adapting to demand, renewable energy expansion requires greater system flexibility in the rest of the electricity supply system. The power grid is of great importance here: The better developed it is, the larger the area over which supply and demand can be balanced.

Other means for increasing system flexibility are load management and electricity storage. Load management makes it possible, by time-shifting or switching off non-critical uses of electricity, to minimise peak loads in situations where the load substantially exceeds feed-in from renewables and to shift consumption to situations where feed-in from renewables exceeds the load.[18] In the medium to long term, additional means of storing electricity will be needed on a large scale as the shares due to wind and solar energy increase. Both short-term and long-term storage facilities will be necessary.

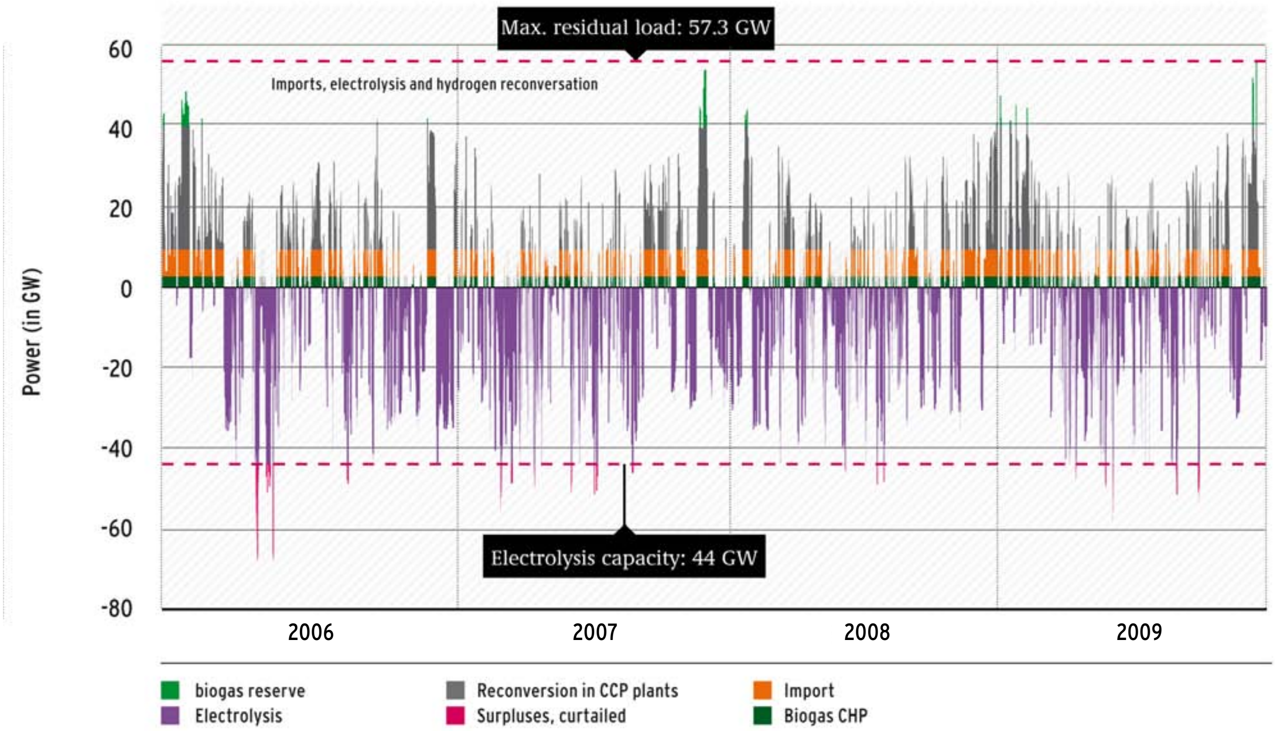
In view of their great complexity, differentiated studies on the need for developing and converting the power grid for the expansion of renewable energy sources are only possible at national level. The following remarks therefore take the situation in Germany as an example. As it stands at present, the Germany grid is not suitable for transmitting large currents over long distances. Transmission grid operators in Germany are bound by law to produce an annual grid development plan setting out the need for optimisation, upgrading and expansion of the transmission grids to ensure safe and reliable grid operation.[19] Starting from the existing grid with roughly 35,000 km of very-high-voltage transmission lines, they have calculated for 2012 that, depending on the scenario, it will be necessary to optimise or upgrade between 4,200 and 4,500 km of the existing lines by 2022 and to construct between 3,500 km and 4,100 km of new lines.[20] The plans include four major "power highways" from the north of Germany to the south. To ensure low-loss transmission, HVDC (high-voltage direct current transmission) is to be used for 1800 to 2400 km of these long distances. The need for this expansion stems above all from the expansion of wind energy in the north and east of Germany, and also from the growing trade in electricity within Europe.

18 UBA (2010b), p. 41ff.
19 ÜNB (2012).
20 The figures also include the lines already laid down in the Energy Lines Expansion Act, projects in progress and measures with approved investment budgets.

These scenarios do not examine the conversion and development of the distribution grids. Here too there is a need for expansion, since in some regions it is already impossible to collect and transmit all the electricity generated from renewable sources. Not only grid bottlenecks, but also large fluctuations in power flows or changes in power flow direction in the distribution network may make it necessary to adapt the infrastructure. In the past the power flow has taken place in one direction only – from the large central generator to many decentralised consumers.

In its study, the Federal Environment Agency shows that if the electricity supply system is fed entirely from renewable sources in 2050 it is possible to ensure security of supply even under restrictive assumptions.[21] The study assumes that only very limited balancing takes place via the European interconnection system. Neither does the scenario take account of major potential storage facilities, such as Scandinavian or Alpine hydro power plants.[22] It describes two alternatives for a long-term power storage system. In both long-term storage systems, surplus electricity production from renewable sources is used to produce hydrogen or methane. The gas produced in this way can be used to generate electricity when needed.[23] Figure 8 shows the hourly simulation result for the storage system on the basis of renewables-based methane for four years with the weather and load characteristics of the sample years 2006 to 2009. The load is fully covered for every hour, and the fluctuation in the renewable energy supply can be reliably balanced at all times.[24] Similar results were obtained for the long-term storage system using renewables-based hydrogen.

Fig. 8: Use of electrolysis/methanation, methane reconversion, power from biogas and imports in 2050



Source: UBA (2010b), Fig. 7-22

21 UBA (2010b).

22 By contrast, the German Advisory Council on the Environment included pumped storage facilities, and especially the potential in Scandinavia, in its report on 100 percent renewable energy by 2050. Cf. SRU (2011), Chapter 4.5.

23 For a detailed description of these systems see UBA (2010b) Chapter 4.1.

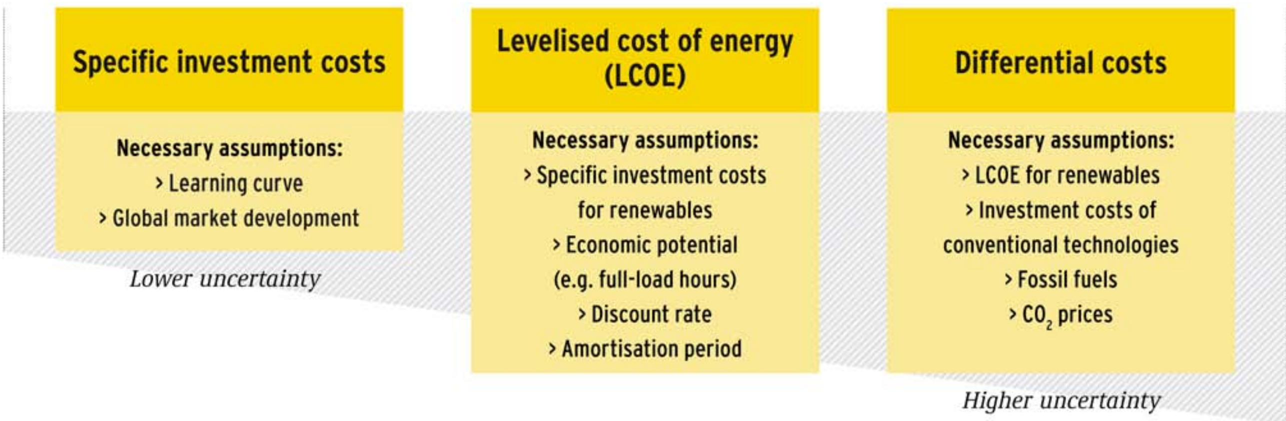
24 To this end the following controllable generating capacity is used as needed: 2.5 GW biogas turbines with combined heat-and-power generation, 9.3 GW imported electricity from renewable sources, 28 GW gas-and-steam power plants for reconversion from methane and 17.5 GW biogas turbines as reserve power plants. Even with improvements in energy efficiency and taking account of load management, the residual peak load of the power supply system is still around 57 GW.

3 COST OF EXPANDING RENEWABLES-BASED ELECTRICITY GENERATION TOWARDS 100 PERCENT

The most important cost factor for many renewable energy sources is the technology-specific **investment costs**, which are analysed more closely in Chapter 3.1. For a wind energy installation, for example, they comprise the cost of the installation itself, the foundations, grid connection, site development, transport, and assembly, planning and permits. On the basis of the investment costs it is possible to estimate the **levelised cost of energy** (LCOE), which permits cost comparisons between the various renewable energy technologies (Chapter 3.2). For this purpose it is necessary to make additional assumptions, e.g. regarding the site-specific annual full-load hours for a renewable energy technology, depreciation periods and discount rates.

To be able to assess the cost-effectiveness of renewable energy sources compared with conventional power generation, it is necessary to estimate the system-analytical **differential costs** (Chapter 3.3). This requires further assumptions, especially as regards the development of fossil fuel prices, CO_2 prices and tax burdens. It is also necessary to take into account the cost of grid expansion and system integration of the renewables-based electricity (load management, power storage costs). The more complex the estimates, the greater the uncertainty of the forecasts – which can in any case be considerable in long-term scenarios for the future (see Fig. 9).

Fig. 9: Relationship between the various cost headings and uncertainty



Source: PIK (2012)

The system-analytical differential costs comprise all economic costs. However, they disregard the external costs of energy generation for society as a whole, and also distortions of competition which arise from environmentally harmful subsidies to the disadvantage of renewable energy sources. It is therefore necessary to take account of these aspects as well in the context of a comprehensive cost analysis (Chapter 3.4).

Efficient and economical use of electricity is not the subject of this background paper. Energy efficiency is nevertheless of great importance for the cost of a full supply of renewables-based electricity and the question of how to ensure an optimised electricity supply system in terms of the national economy (cf. Box 2).

Box 2: The importance of energy efficiency for the cost of expanding renewable energy
Studies show that many measures designed to save electricity make economic sense.[25] Examples include the use of economical electric motors and pumps in industry or the use of power-saving household appliances. Harnessing this efficiency potential reduces the cost of a full supply of renewables-based electricity. After all, the lower the electricity consumption, the less need there is to use relatively expensive power generation technologies. At the same time savings in electricity consumption also gain more time for the expansion of renewable energy and the necessary infrastructure (power grids and storage).

Sensitivity analyses by the German Aerospace Centre (DLR), which estimate the costs of a wholly renewables-based electricity supply in 2050 for various levels of power consumption, confirm the cost benefits of efficiency strategies. They put the overall cost of electricity generation in Germany at 7 ct/kWh if electricity consumption is 500 TWh, and nearly 10 ct/kWh for a consumption of 700 TWh.[26]

3.1 Investment costs

The scientific findings on the development of the energy system are regularly summarised by the IPCC, most recently in a special report on renewable energy sources. They show that the development of renewable energy costs has a crucial influence on the future energy mix.[27] In the case of renewable energy sources, the investment costs account for a large proportion of total costs; for wind and solar energy the share of total costs is nearly 95 percent. By contrast, the fuels required for generation using fossil fuels sometimes account for as much as 70 percent of total costs.[28]

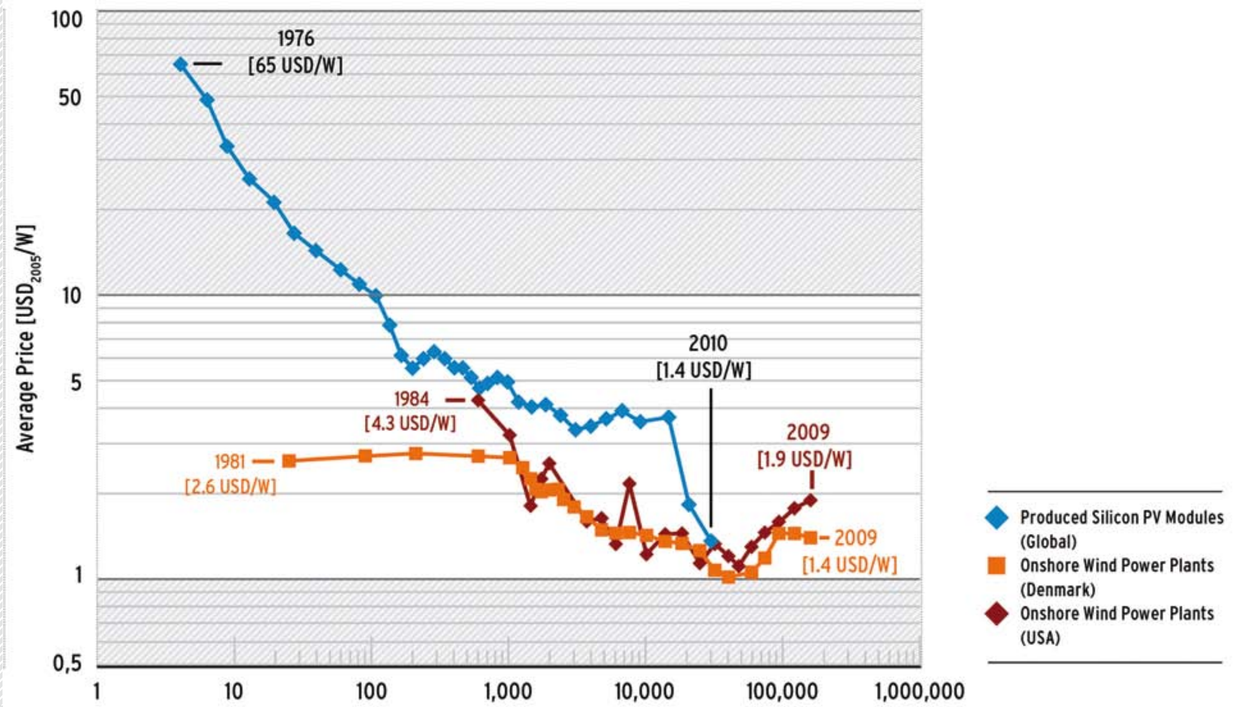
In recent years, costs have fallen rapidly in the solar and wind energy sectors. Between summer 2008 and the beginning of 2012, prices for photovoltaic modules fell by up to 76 percent.[29] Onshore wind energy has experienced a similar, though not so dynamic development. For example, average turbine prices per megawatt fell by around 25 percent from 2009 to 2011. Learning-curve effects which are closely connected with the worldwide expansion of capacity have a critical influence on cost reductions (see Box 3).

Box 3: Learning-curve effects as cost reduction drivers
The learning-curve approach has become a standard for future scenarios in the modelling of the energy system and the expansion of renewable energy sources. It works on the basis that production costs fall by a more or less constant percentage as production quantities increase. This correlation was first discovered in the aviation industry in 1925 and has been empirically confirmed for many technologies in the field of renewable energy. For example, 96 percent of development costs in the photovoltaic sector can be explained by the change in worldwide installed capacity, and the figure for wind turbines is 82 percent.[30]

Important factors for the learning-curve approach are the **development of the global markets** and the **learning rate**. The learning rate is a measure of the percentage reduction in the specific investment costs of a technology when the installed capacity (market development) doubles. Plotting the production costs against installed capacity results in the “learning curve” (see for example Figure 10).

25 Cf. IPCC (2007), p. 632 and Fraunhofer ISI/Ecofys/Öko-Institut (2012).
26 SRU (2011), p.197.
27 IPCC (2012).
28 IEA (2010b).
29 UNEP/Frankfurt School/BNEF (2012).
30 Nemet (2009).

Figure 10: Learning curve for photovoltaic modules and onshore wind turbines in USD_{2005}/W [31]



Source: IPCC (2012), Special Report on Renewable Energy Sources and Climate Change Mitigation, Figure SPM. 6 (left part). Cambridge University Press.

The driving force behind the learning curve is technological learning. This involves learning from production process improvement, research and development, "learning by doing", upsizing of products such as wind turbines, and economies of scale.[32]

The cost of renewable energy will continue to fall in the long term. Fig. 11 shows the results of the meta-study by the PIK for investment costs today and in 2050. It illustrates the expected declining scale of specific investment costs for the various forms of electricity generation from renewable sources. The studies analysed forecast very substantial cost reductions averaging nearly 75 percent for the photovoltaic sector by 2050. The forecasts for other technologies such as solar thermal power plants, biomass and offshore wind energy also show cost reductions of up to 50 percent. Only in the case of onshore wind energy no further major cost reductions are expected by 2050.

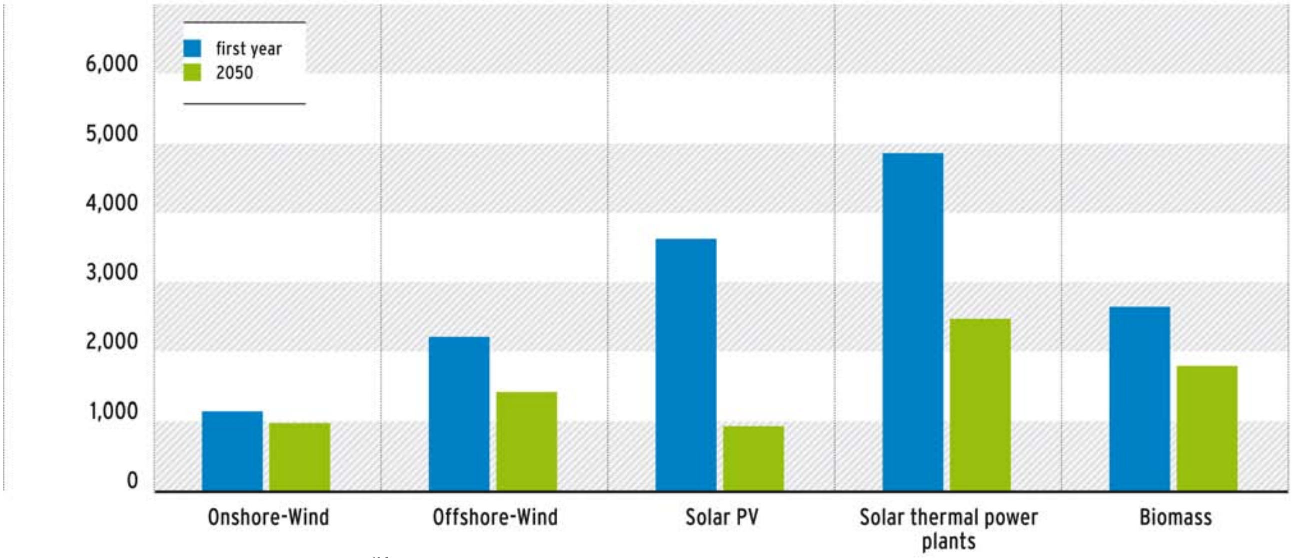
In the first year, onshore wind energy is by far the cheapest renewable energy technology in all the studies.[33] The median of the costs of offshore wind energy and biomass is much higher than the costs of onshore wind energy, followed by photovoltaic and solar thermal power plants. The forecast cost reductions by 2050 result in a slight change in the picture. Onshore wind energy, together with photovoltaic, shows the lowest specific investment costs, followed after a considerable gap by offshore wind energy. Biomass falls back in the investment cost rankings. Solar thermal power plants continue to show the highest investment costs.

31 The axes use a logarithmic scale.

32 For an in-depth analysis of learning curves cf. Junginger et al. (2006) or PIK (2012).

33 The start year of a study is the year on which the relative development in the scenario is based. In the studies analysed, it ranges from 2005 to 2010. In the interests of comparing the values, the cost figures in the studies have been standardised in terms of the reference year and the currency expressed in €2010.

Fig. 11: Median of specific investment costs in the start year and 2050 in $€_{2010}$/kW



Source: Own diagram, data from PIK (2012)[34]

3.2 Electricity generation costs (LCOE)

Partly as a result of lower investment costs, the cost of electricity generation from renewable sources is falling fast in some sectors. A glance at the development from the first quarter of 2011 to the first quarter of 2012 shows that the cost of generating electricity was down by some 31-35 percent for photovoltaic and by 9 percent for onshore wind energy, while the cost of generation from fossil fuels remained relatively constant.[35] Looking at the development of the last two years up to the first quarter of 2012, the result for renewable energy sources is even clearer: While electricity generation costs were up 9 percent for coal-fired power stations, they fell by around 44 percent for photovoltaic and 7 percent for onshore wind energy.[36]

Against the trend, electricity generation costs for offshore wind energy increased by 20 percent. Major factors here were the increase in offshore projects in deep water, and lack of competition in the supply industries, e.g. for connecting cables or offshore installation vessels. From the middle of this century a marked decrease in costs can be expected to result from greater competition among suppliers, increasing experience and know-how in the installation field, and more efficient turbines. Costs for wave energy and tidal power plants have also increased. Many installations of this kind are still at the early prototype stage. Significant cost reductions can only be expected with technological advances and the start of mass production (cf. Fig. 12).[37]

A comparison of the costs of electricity generation from renewables and from fossil fuels shows that many renewable sources are already competitive or only slightly more expensive than fossil fuels.[38] This becomes even clearer if one takes CO_2 prices into account (cf. Fig. 12; the dark green shading in the last two lines of the figure shows the electricity generation costs for coal and gas power plants at a price of 36 USD per tonne of CO_2).

34 The results of the following studies were analysed: Greenpeace/EREC (2010), WWF/Ecofys/Oma (2011), EC (2011), ECF (2010), EREC (2010), EWI/Energynautics (2011), DLR/IWES/IFNE (2010), SRU (2011), Prognos/Öko Institut (2009), Greenpeace/Eutech Energie und Management (2009), EWI/GWS/Prognos (2010), Wuppertal Institut/PIK (2010).

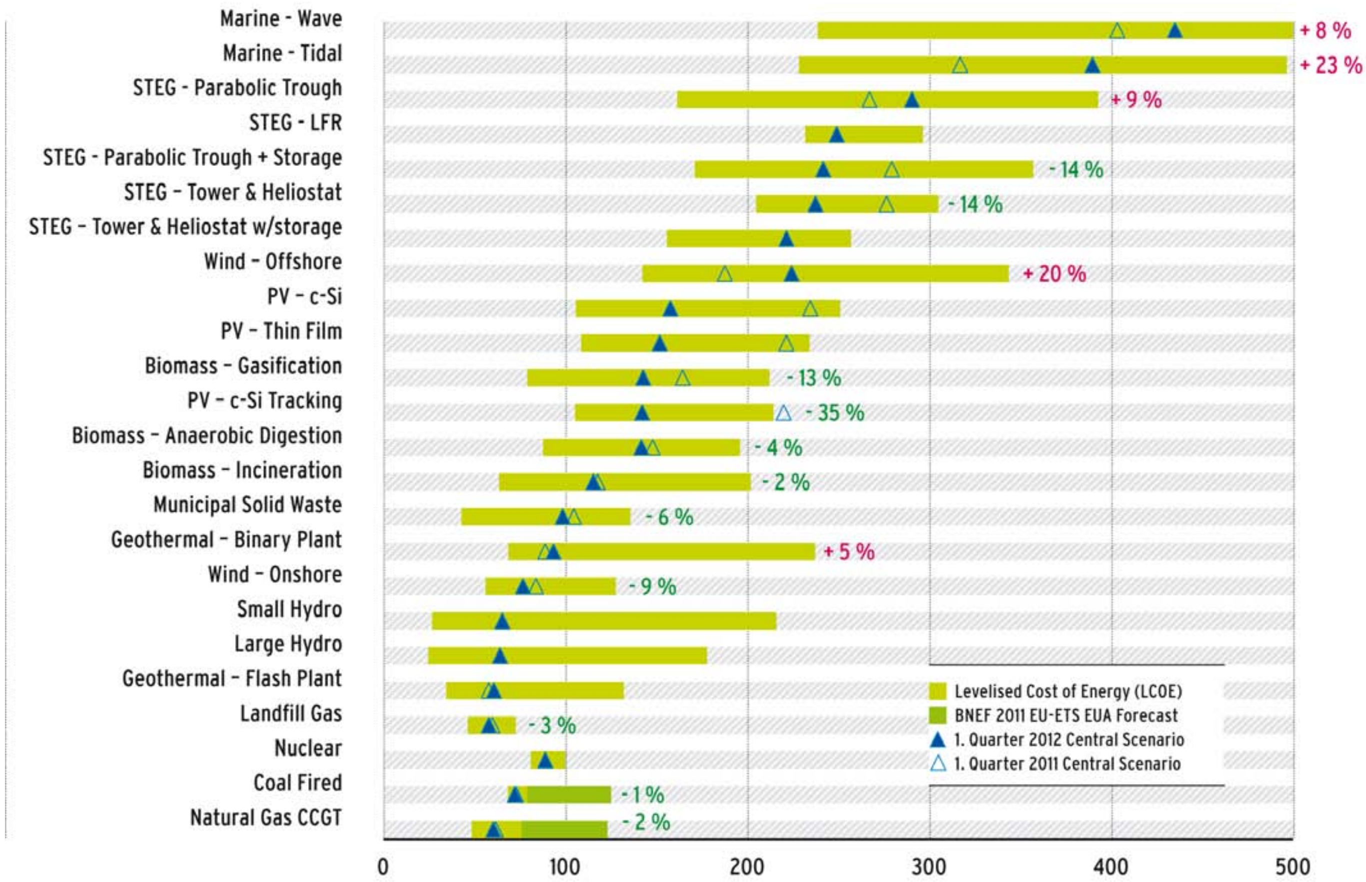
35 UNEP/Frankfurt School/BNEF (2012), p. 33.

36 UNEP/Frankfurt School/BNEF (2012), p. 34.

37 UNEP/Frankfurt School/BNEF (2012).

38 The IPCC (2012) p. 28 arrives at similar results. This does not take account of the cost of system integration of renewable energy sources (cf. Chapter 3.3).

Fig. 12: Electricity generation costs for various technologies for the first quarters of 2012 and 2011 in USD per MWh



Source: UNEP/Frankfurt School/BNEF (2012), p. 33 [39]

Box 4: Cost-effectiveness of small photovoltaic installations

The cost-effectiveness of small photovoltaic systems is frequently compared with that of large-scale installations. However, in the case of households with roof-mounted systems, for example, profitability is not determined by the cost of electricity generation, but by the price of electricity for the final consumer. Even today, roof-mounted photovoltaic systems in some countries are already producing a return of at least 5 percent as a result of the saving in electricity consumption.[40] Examples include Denmark, parts of Australia, Germany, Spain and Italy.[41]

By 2015 – assuming a continuing decrease in photovoltaic costs – this could also apply to France, Japan, parts of the USA, and Turkey.[42] The operation of photovoltaic systems is also economic in many regions of Africa, India, Southeast Asia and parts of the Middle East with or without local networks supplied by diesel generators. McKinsey estimates that by 2020 the worldwide economic potential for installed photovoltaic systems will exceed one terawatt (TW).[43] For comparison: In 2010, worldwide installed capacity amounted to 40 GW[44] – a mere fraction of the economic potential that McKinsey expects by 2020.

39 The light green bars show the range of electricity generation costs depending on site-specific factors or assumed capital costs. The LCOE for nuclear power does not include the full costs of subsequent decommissioning and
disposal of the nuclear power plants or the inadequate insurance cover in the event of a nuclear accident.

40 This return is based on consideration of the individual installation; it does not, for example, include system integration costs. This return is based on consideration of the individual installation; it does not, for example, include system integration costs.

41 Bloomberg (2012).

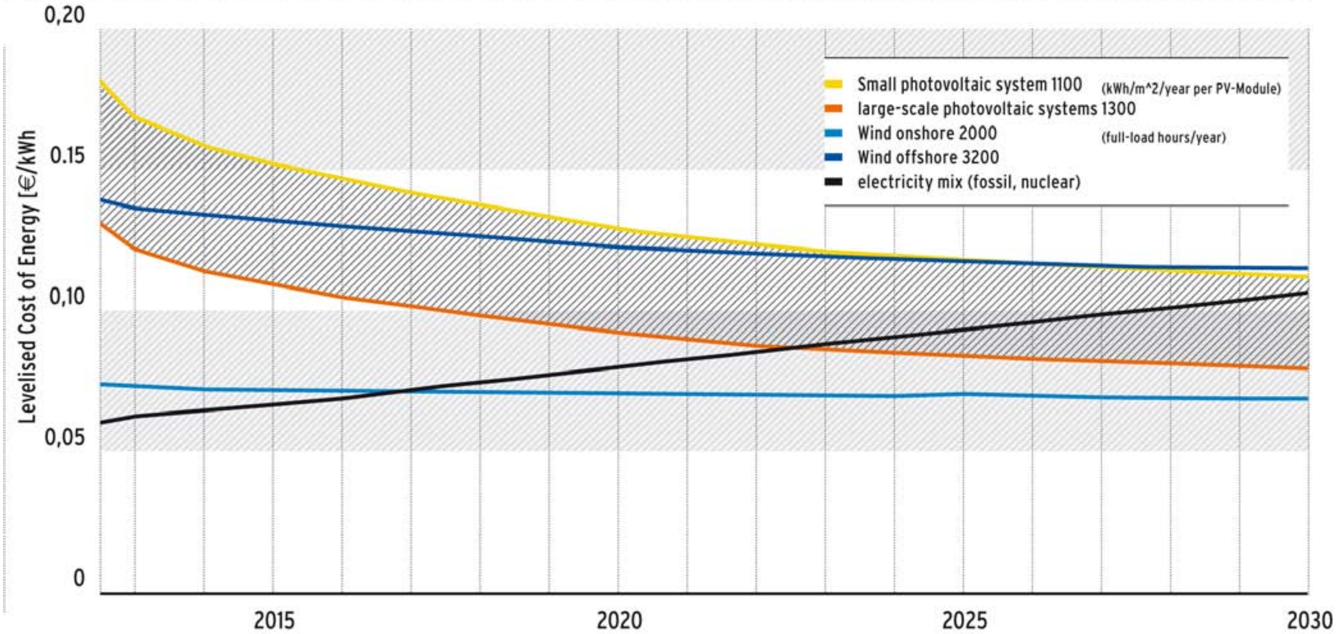
42 Bloomberg (2012).

43 McKinsey (2012).

44 IEA (2011a), p. 42.

Forecasts indicate that electricity generation from renewable sources will show a continued marked decrease in costs in the years ahead, while the cost of generation from fossil fuels will display an upward trend (cf. Fig. 13). The diagram for Germany shows that, assuming incident radiation of 1300 kWh/m² per annum, photovoltaic systems will become competitive by the middle of the next decade, and onshore wind energy as early as the middle of this decade. Today electricity generation costs for onshore wind energy, at 7.5 ct/kWh, are already only marginally higher than for fossil fuels.[45]

Fig. 13: Electricity generation costs for renewable energy sources in Germany compared with fossil fuels



Source: FH ISE (2012) p. 18

3.3 Differential costs

One reason frequently given for rejecting the expansion of renewable energy sources is the considerable extra cost compared with conventional electricity generation based on fossil fuels. It is therefore important to know whether such additional costs arise and on what scale, what they are due to, and how they will develop in the future. An analysis of the system-analytical differential costs makes an important contribution here.

Estimates of the long-term development of differential costs are available for Germany.[46] The differential costs are shown for various possible paths (A, B and C) for the price of fossil fuels (cf. Fig. 14). The reference scenario in the study, which is shown in Figure 14 as the baseline, is a fossil-nuclear power plant portfolio (mix of old and new power plants). The scenario analyses for Germany show that the transformation of the energy system will give rise to maximum annual differential costs of 14 billion EUR. These costs reach their maximum by 2020 and then fall rapidly.

45 FH ISE (2012).

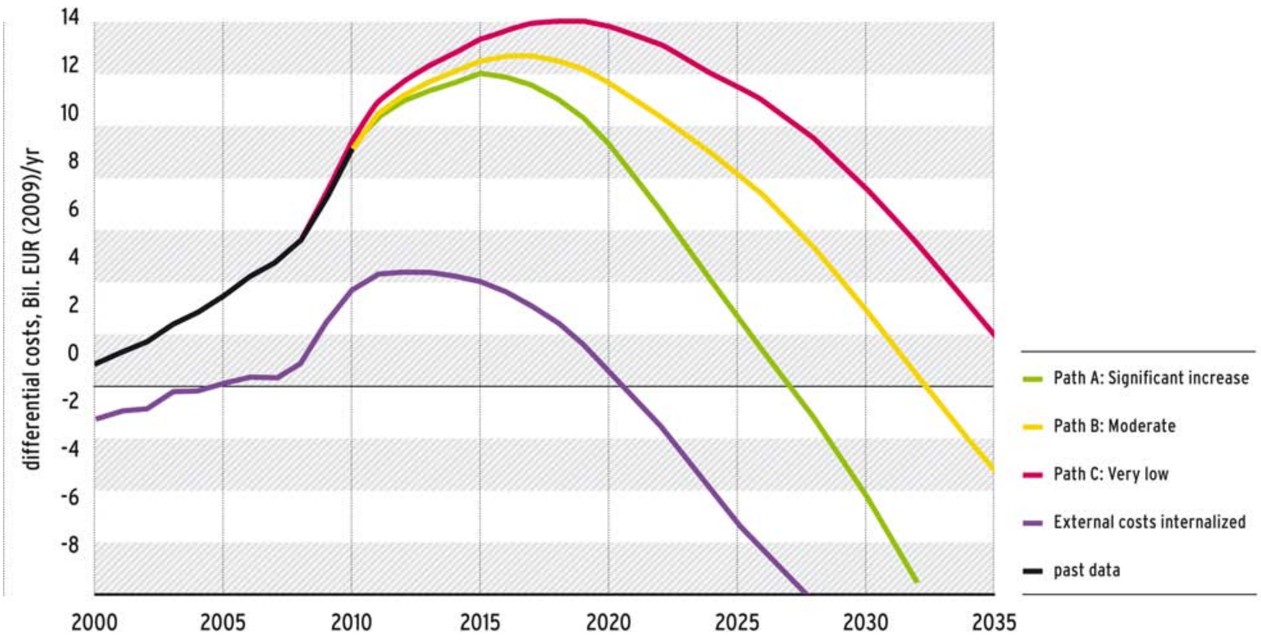
46 DLR/IWES/IFNE (2011).

Box 5: Relevance of existing installations to future expansion decisions
From an economic point of view, investment costs for existing installations for generating electricity from renewable sources are “sunk costs”, and are therefore no longer a deciding factor in future expansion decisions. Only the investment costs and other external costs of new installations count when it comes to economic assessment of the further expansion of renewable energy sources. This is also true in the event that national subsidies continue to ensure the financing of existing installations for years to come.

For example, high costs have arisen in Germany in the past due to the expansion of the photovoltaic sector. This has been reflected in a sizeable increase in the surcharge under the Renewable Energy Sources Act (EEG surcharge). However, further expansion of the photovoltaic sector will only have a minor influence on the development of the surcharge, since the rapidly diminishing cost of photovoltaic systems means that the differential costs are falling fast. In 2012 the EEG surcharge will probably increase by no more than 0.035 cent/kWh for each gigawatt of additional photovoltaic capacity, and by 2016 the increase is expected to be as little as 0.016 $cent_{2012}$/kWh.[47]

Depending on the price path assumed for fossil fuels, the system-analytical differential costs become negative as early as 2027, i.e. from that point onwards renewables are cheaper than fossil electricity generation.[48] This shows that the expansion of renewable energy sources offers cost benefits in the long term.[49] As early as 2030 the average cost of generating electricity from renewable sources in Germany will probably be around 7.6 ct/kWh. By then, electricity from new gas and coal-fired power plants will probably be costing over 9 ct/kWh.[50]

Fig. 14: System-analytical differential costs of renewable energy expansion for electricity generation



Source: DLR/IWES/IFNE (2011). The differential costs are based on Scenario A.

47 Prognos (2012). The findings are to be seen as an indication. They depend among other things on uncertainties regarding the development of the market bonus, the "green power privilege", new hardship rules, the wind and solar energy yield, new payment rates and developments in electricity prices.
48 This does not take account of the cost of grid expansion and system integration of renewable energy sources by means of load management and power storage. These factors grow in importance as the expansion of renewable energy increases.
49 If external costs are internalised (see blue line), the differential costs become negative considerably earlier (see Chapter 4.4).
50 Disregarding costs for grid expansion, load management and storage.

Figure 14 does not take account of the cost of grid expansion. Latest estimates indicate that the upper limit of the grid investment necessary for renewable energy expansion is around 5 billion EUR per annum for the entire grid (transmission[51] and distribution networks). Of this, some 2.3 billion EUR per annum can be classified as additional expenditure due to the construction of new renewable energy installations. If the additional grid expansion were taken into account, the differential costs under price path A would be about 12-13 percent higher.[52] This does not take account of the additions to the European interconnection system which are necessary as a result of renewable energy expansion, or the costs of integrating renewable energy into the system.

3.4 Distortion of competition due to external environmental costs and environmentally harmful subsidies

Electricity generation based on fossil fuels gives rise to considerably higher social costs than generation from renewable sources. Since external environmental costs are not adequately internalised, competition is distorted at the expense of renewable energy. If one includes the external costs of fossil electricity generation in the analysis, this considerably increases the differential costs (dashed blue line in Fig. 14).[53] On this basis, the expansion of renewable energy up to 2005 did not cause any additional costs at a macroeconomic level, but rather net-benefits. Although differential costs arise between 2005 and 2020 when external costs are taken into account, the maximum level they reach is about 4 billion EUR per annum. After 2020 the picture once again changes to net-benefits, which grow larger as time goes on.

Explicit and implicit[54] subsidies for fossil fuels and nuclear power also distort competition to the disadvantage of renewable energy sources, thereby impeding the transition to a sustainable energy supply system. The International Energy Agency (IEA) estimates worldwide subsidies for fossil fuels at 409 billion USD in 2010.[55] Of this figure, 122 billion USD is due to electricity generation. Subsidies for fossil fuels are frequently justified on the basis of social objectives. However, the IEA finds that only 8 percent of the total subsidies benefit the poorest 20 percent of the world's population. The subsidies also prevent businesses and private households from making timely preparations for diminishing supplies of fossil fuels. In 2010 the financial assistance for the market launch of renewable energy sources in the electricity sector came to 44 billion USD – which means that subsidies for electricity generation from fossil fuels were higher by a factor of 3. The advantages enjoyed by nuclear energy – for example the limited liability in the event of accidents in nuclear installations – are very difficult to quantify in monetary terms. They do however favour nuclear power to a considerable extent. For example, nuclear power is only profitable on a microeconomic view in Germany because it receives explicit and implicit subsidies running into billions.[56]

4 NATIONAL ECONOMIC IMPACTS OF RENEWABLE ENERGY EXPANSION IN THE ELECTRICITY GENERATION SECTOR

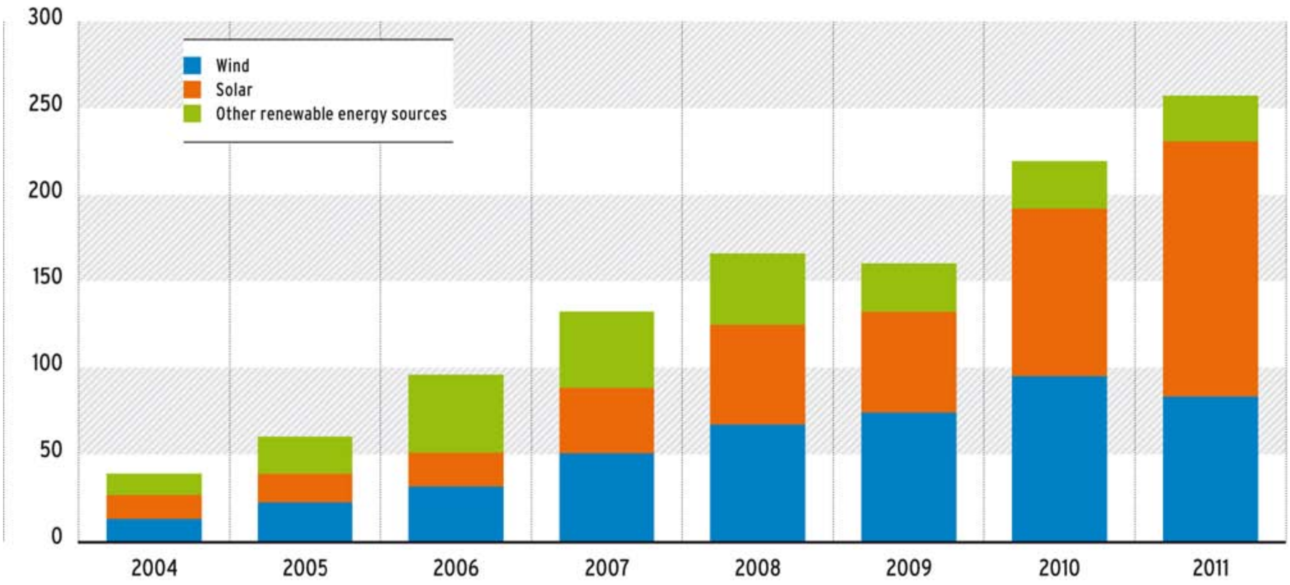
4.1 Investment thrusts and growth effects

Investment in renewables is rising fast. Between 2004 and 2011 it showed a fivefold increase to reach 257 billion USD (see Fig. 15). In the electricity sector renewable energy now accounts for nearly half of all additions to installed generating capacity.[57]

51 According to the latest grid development plan, total investment in the expansion of transmission grids in the next ten years will come to around 20 billion EUR. ÜNB (2012).
52 Cf. DLR/IWES/IFNE (2011), p. 29.
53 Assumed price development of fossil fuels on the lines of price path A.
54 Implicit subsidies are concealed concessions that do not have a direct impact on the budget, e.g. sureties or guarantees. The economic benefits resulting from free allocation of emission allowances also constitute an implicit subsidy.
55 IEA (2011b), Kapitel 14.
56 UBA (2010c) Umweltbundesamt: Umweltschädliche Subventionen in Deutschland (Environmentally Harmful Subsidies in Germany), updated edition 2010.
57 UNEP/Frankfurt School/BNEF (2012), p. 31. In 2011 the renewables share of additional installed capacity came to 43.7 percent.

The world market for green energy, which comprises renewable energy sources, efficient power plant technologies and energy storage, is one of the most important green markets of the future. The current volume of this global market is 313 billion EUR – and by 2025 it is set to rise to 1060 billion EUR. This means an annual market growth of 9.1 percent.[58] Demand for photovoltaic systems is growing particularly fast. Whereas installed capacity worldwide was about 65 GW in 2011, the figure will rise to between 400 and 600 GW by 2020.[59] Renewable energy is therefore not only essential on environmental and climate grounds, but is an important market of the future with great economic relevance for all economies in international competition.

Fig. 15: Global investment in renewable energy 2004-2011 in billion USD



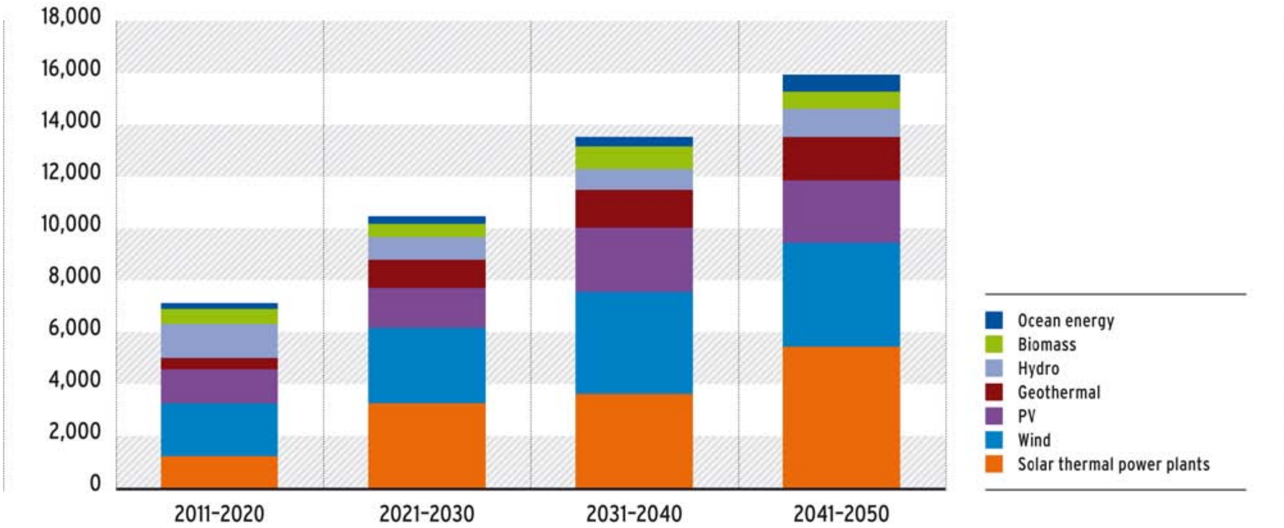
Source: Figures from UNEP/Frankfurt School/BNEF (2012), p. 15.

The global transformation of the electricity supply system calls for substantial additional investment during the decades ahead. This is revealed by climate scenarios aimed at compliance with the two-degree upper limit on global warming. A particularly ambitious expansion of renewable energy is found in the Energy [R]evolution study. In 2050 its climate protection scenario has 94.3 percent of electricity coming from renewable sources. To achieve this, investment of around 50 billion USD is necessary from 2011 to 2050, made up of 47 billion USD in renewable energy, and 3.4 billion USD in generation from fossil fuels and nuclear power. In the reference scenario, by contrast, investment in the electricity sector is less than half as much with a total of 22.3 billion USD, and only half of the total investment goes into renewables.

In the expansion scenario, annual investment in renewable energy averages 1.2 billion USD.[60] Fig. 16 shows the investment required for the various generation methods and decades up to 2050.

58 BMU (2012b), p. 45.
59 McKinsey (2012), p. 2. The European PV industry also forecasts a substantial increase in global capacity. For 2016 it quotes a range of 208 to 343 GW for cumulative global capacity (EPIA, 2012, p. 45).
60 Greenpeace/EREC/GWEC (2012) p. 280.

Fig. 16: Global volume of investment in renewable energy in the electricity sector in the decades up to 2050 in billion USD



Source: Greenpeace/EREC/GWEC (2012, 280).

If the investment needed to transform the energy system is compared with the present situation, this reveals a need for a considerable increase in investment in the energy sector. Especially in the field of research and development there is an investment gap: even today there is a shortfall of some 40-90 billion USD per annum.[61]

For a macroeconomic assessment of the expansion of renewable energy and the associated transformation of the electricity supply system it is necessary to use simulation models to take account of feedback effects, e.g. between energy prices and economic growth.[62] As a rule such analyses cover the entire energy system, i.e. not just the electricity supply sector.

Global simulation models investigate how compliance with the two-degree global warming limit can be assured – mostly on the basis of minimising the avoidance costs. The comparative scenario is a reference development without any climate policy. Models that rely fairly heavily on expansion of renewable energy show a drop of only about one percent up to the year 2100.[63] In this respect they hardly differ from scenarios with large amounts of nuclear power and electricity generation based on fossil energy. At the same time the drop in consumption is marginal: In a growing global economy the delay in reaching the consumption level of the reference scenario without climate protection measures is only a few months, even for major expansion of renewable energy.

For methodological reasons, the simulations usually do not take account of the economic benefits of climate protection. On balance, however, they far exceed the slight drop in the level of consumption (cf. Chapter 5.1).

Furthermore, the positive impacts on security of supply are of great relevance from the point of view of the national economy. This is because renewable energy diversifies the energy supply and reduces the country's need for energy imports and its dependence on sharply fluctuating international energy prices.[64]

61 WBGU (2011), p. 171 and IEA (2010a), p. 480.

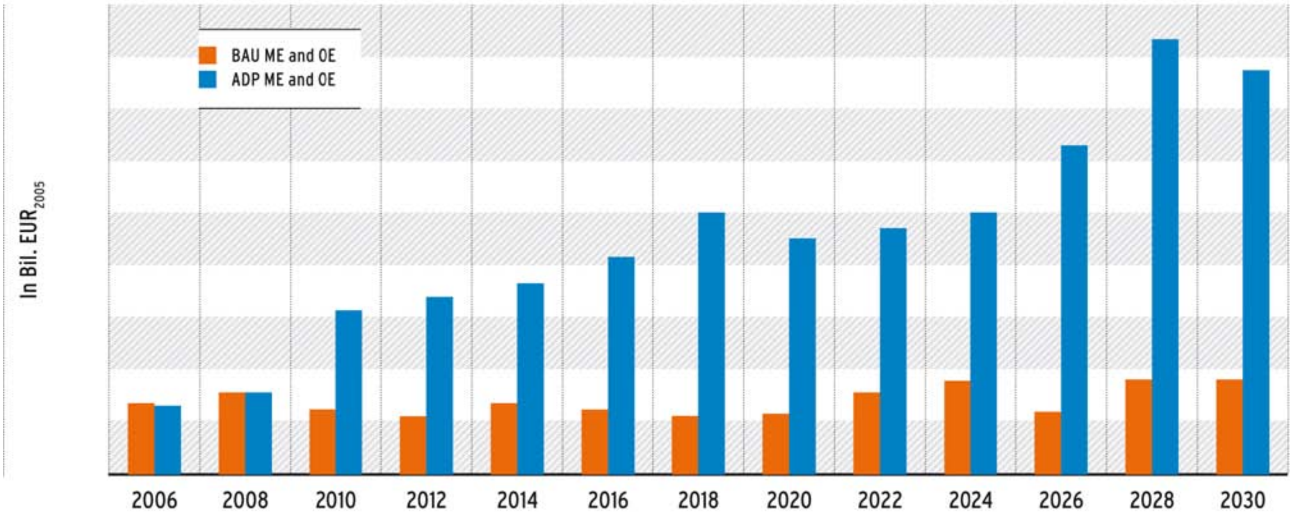
62 To be able to determine the macroeconomic effects of investments in renewable energy, it is necessary to take account of the investments thereby avoided in conventional electricity generation and the fuel savings. These are hardly needed any more in the operation of many renewable energy sources.

63 Edenhofer et al. (2009), p. 25 and IPCC (2012), p. 811. This is based on a comparison of various simulation models and a 450 ppm climate path. The REMIND-R model displays comparatively large contributions for renewable energy, and the associated consumption losses remain well below 1 percent.

64 IPCC (2012), p. 880.

Model calculations on the growth effects of renewable energy expansion are available for the European Union (EU) and Germany. The simulations for the EU arrive at positive growth effects. The estimates are based on the EU target of increasing the renewables share of gross final energy consumption to 20 percent by 2020. Compared with the reference scenario in which there are no subsidies for renewable energy sources, gross domestic product (GDP) shows growth of between 0.23 and 0.25 percent – depending on the simulation model. A factor of central importance here is the strong boost to investment resulting from the expansion of renewable energy sources (cf. Fig. 17). The model calculations assume that the subsidies for renewable energy lead to only moderate export growth in the renewables field – to this extent the estimates of growth effects are on the conservative side.

Fig. 17: Boost to investment due to renewable energy in the EU



Source: Ragwitz et al. (2009) p. 172.

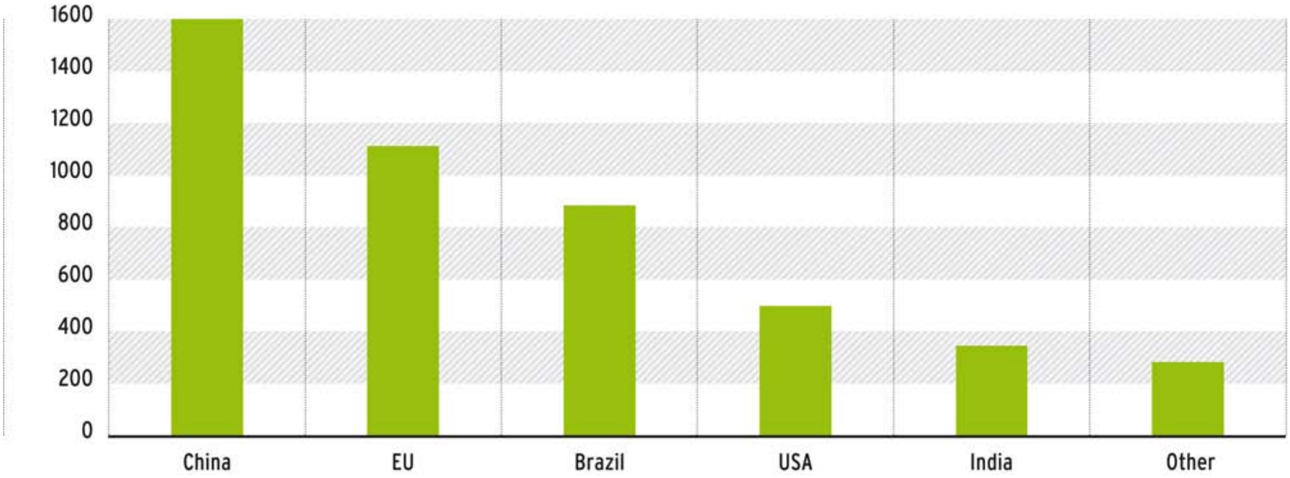
Model calculations also show moderate positive growth effects for Germany. According to the lead scenario 2009, which shows a renewables share of nearly 64 percent in the electricity sector in 2030, gross domestic product rises by between 22 and 29 billion EUR compared with a reference scenario without renewable energy sources.[65]

4.2 Employment effects

In 2011 as many as 5 million people worldwide were employed in the renewables sector (cf. Fig. 18). China, with 1.6 million jobs, has the most people working in this sector, ahead of the EU and Brazil with 1.1 and 0.9 million respectively.[66] These estimates relate to renewable energy sources as a whole, i.e. they are not confined to electricity generation. In view of the growth rates forecast for the renewables sector, the number of workers will continue to rise in the future.

65 Lehr et al (2011), p. 212. For the expansion path, cf. p. 116 and p. 132ff.
66 REN21 (2012), p. 27.

Fig. 18: Jobs in the renewable energy sector in 2011 [figures in thousands]



Source: REN21 (2012), p. 27.

In a rough estimate, the Energy-[R]evolution study comes to the conclusion that the direct employment effects of ambitious renewable energy expansion in the energy system and in upstream processes are positive. Compared with the reference scenario, there would be an increase of about 4.9 million jobs by 2020. Given renewable energy expansion, some 22.6 million employees would be working in the energy system, and about 13 million of these would be in the renewables sector (the figure for the reference scenario is only 6.2 million people).[67]

Model calculations for the European Union (EU) also come to the conclusion that renewable energy expansion creates jobs on a large scale. The EU has set itself the target of increasing the renewables share to 20 percent by 2020. As a result, the number of jobs in this sector throughout the EU will rise by about 400,000 by 2020.[68]

The projections for further ambitious expansion of renewable energy in Germany also arrive at positive effects on employment. According to a study published at the beginning of 2011, employment in the renewable energy sector in Germany can be expected to rise to between 479,000 and 589,000 by 2030.[69] The range quoted is due to different assumptions about developments on the export front. In 2011 there were already 381,600 people employed in the renewable energy sector (cf. Figure 2).

The study shows that renewable energy expansion also creates more jobs on balance. In 2030 there is a net increase of between 143,000 and 182,000 jobs.[70] This also takes account of jobs lost as a result of renewable energy expansion, e.g. because of electricity price increases. There are a number of reasons why renewable energy expansion leads to positive net effects on employment. It tends to be labour-intensive sectors that profit from renewable energy. Renewable energy sources also do a considerable amount to replace imports with domestic value added, by reducing the consumption of fossil fuels such as oil or gas.

67 Cf. Greenpeace/EREC/GWEC (2012) p. 192. The study does not take any account of macroeconomic feedback effects resulting from the transformation of the energy system.
68 Ragwitz et al. (2009) p. 188ff.
69 Lehr et al (2011), p. 199. The figures quoted are based on a scenario with restrained development of energy prices and robust expansion of the photovoltaic sector. The zero scenario involves virtually no expansion of renewable energy since 1995.
70 Lehr u.a. (2011), p. 212.

4.3 External costs avoided by means of renewable energy expansion in the electricity generation sector

The external environmental costs of electricity generation are crucially dependent on the energy sources used. For example, electricity generation from fossil fuels gives rise to considerable carbon dioxide emissions which contribute to climate change. The importance of this aspect for the economic assessment of renewable energy sources is shown by the Stern report.[71] It estimates the cost of unchecked climate change at between 5 and 20 percent of worldwide gross national product per capita.

Moreover, electricity generation from fossil fuels has harmful effects on health and the environment due to other air pollutants such as oxides of nitrogen and particulates. They cause health problems (asthma, coughs or bronchitis) and damage to buildings (external dirt). The health impacts are considerable. Anthropogenic fine particulate emissions ($PM_{2.5}$) alone cause some 3.7 million premature deaths worldwide.[72] In Europe and large parts of Asia, combustion plants for energy generation are responsible for 13 percent of fine particulates.[73] This makes it clear that energy policy decisions fall short of the mark if they are merely based on a comparison of the microeconomic costs of electricity generation.

Estimates for Germany show that electricity from lignite has the highest specific environmental costs, followed by hard coal and oil (cf. Fig. 19). Fourth place– after a sizeable gap – is taken by natural gas. Electricity from renewable sources has by far the lowest environmental costs. For example, the environmental costs of wind energy are lower than those of electricity from lignite by a factor of 40. This makes it clear that switching electricity generation to renewable energy sources offers large overall economic benefits by avoiding external environmental costs for society.

According to recent estimates, renewable energy expansion in Germany in the electricity generation sector alone saved environmental costs totalling 8 billion EUR in 2011. Together with renewable energy expansion in the heat sector, the environmental costs avoided came to well over 10 billion EUR. In 2020 the savings will already be as much as 15.4 billion EUR, assuming that renewable energy expansion meets the political targets.[74]

Fig. 19: Environmental costs of electricity generation [2010 in ct/kWh_{el}]

Electricity generation from	Air pollutants	Greenhouse gases	Total environmental costs
Lignite	2,07	8,68	10,75
Coal	1,55	7,38	8,94
Natural gas	1,02	3,90	4,91
Oil	2,41	5,65	8,06
Renewable energy sources			
Hydro power	0,14	0,04	0,18
Wind energy	0,17	0,09	0,26
Photovoltaic systems	0,62	0,56	1,18
Biomass*	1,07	2,78	3,84

* Average weighted by production shares for solid, liquid and gaseous biomass (households and industry), bandwidth from 0.3 to 7.2 ct/kWh

Source: UBA (2012a)

71 Stern (2006), p. 143.
72 Anenberg u.a. (2010)
73 Umweltbundesamt (2011) Daten zur Umwelt – Emissionen von Luftschadstoffen im erweiterten EMEP-Gebiet
74 Breitschopf (2012a and 2012b). The figures are provisional.

5 CONCLUSIONS AND PROSPECTS

5.1 Renewable energy – the key to sustainable electricity supply

Renewable energy in electricity generation makes an indispensable contribution to climate protection and to a sustainable energy supply system. Delays in the transformation of the energy system present a threat to worldwide economic and social development opportunities.

Ongoing climate change endangers the stability of global ecosystems and gives rise to high social costs. The OECD estimates the cost of unchecked global warming at 14 percent of worldwide consumption as early as 2050, with a continuing upward trend in the second half of the 21st century.[75] The global costs of around one percent of worldwide consumption up to 2100 which, according to existing studies[76], are necessary for comprehensive limitation of greenhouse gas emissions to comply with the two-degree target, are far lower.

Important criteria for a sustainable electricity supply system include environmental and health safety, low risks, error tolerance, resource conservation and comprehensive cost-effectiveness having regard to external costs.[77] Our present electricity supply system does not satisfy these criteria: Combustion of conventional energy resources results in emissions of greenhouse gases and air pollutants such as oxides of nitrogen or particulates, and the use of nuclear power involves high risks and social costs due to accidents[78] and disposal of radioactive waste. By contrast, a transition to renewable energy gives rise to much smaller quantities of greenhouse gas and other harmful emissions, conserves fossil resources and increases supply security.

A full supply of renewables-based electricity is not only necessary, but possible. The industrialised countries should embark on the transformation of the electricity supply system with the emphatic aim of achieving a full supply of renewables-based electricity in the long term.

The technical potential for a full supply of renewables-based electricity exists in all countries. Wind and solar energy are of outstanding importance here and play a central role in all ambitious expansion scenarios.

In order to meet the two-degree target, the industrialised countries will have to reduce their emissions by between 80 and 95 percent by 2050, compared with 1990. Since the agricultural sector and individual industrial processes will continue to cause a residual quantity of underlying emissions despite extreme climate control efforts, electricity generation needs to become virtually climate-neutral in the long term. Sustainable electricity supply thus calls for a transition to a system using 100 percent renewable energy sources.

Financial assistance for renewable energy sources in industrialised countries has made a substantial contribution to the fact that costs in the photovoltaic sector in particular have been reduced much faster than was thought possible only a few years ago. Efforts should therefore be made to push ahead with the expansion of renewable energy. This will benefit the developing and newly industrialising countries as well.

In their own interests, developing and newly industrialising countries should place greater emphasis on renewable energy sources. This creates opportunities for more economic participation and prevents irreversible moves in the direction of carbon-intensive electricity generation.

Global warming can only be limited to a maximum of two degrees above pre-industrial levels if the developing and newly industrialising countries take part in the worldwide efforts to reduce greenhouse gases and remain well below the currently expected emission trend.

75 Cf. OECD (2012) and Stern (2006).
76 Cf. Stern (2006) and Edenhofer (2009).
77 Cf. relevant remarks in UBA (2009).
78 Lelieveld J. et al. (2012).

In remote rural areas, renewable energy sources provide an opportunity, by means of decentralised electricity supplies, to create access to electricity and economic participation. In many regions of Africa, India, Southeast Asia and parts of the Middle East the use of photovoltaic systems is already economic compared with electricity from diesel generators.

In countries like Brazil, India and China, photovoltaic systems will soon be competitive – in terms of electricity prices to household customers.[79] Moreover, the newly industrialising countries are playing an increasingly important role in competition on the fast expanding global markets for renewable energy technologies.

5.2 Effects on competitiveness, employment and economic development

The cost of renewable energy will continue to fall in the years ahead. Since conventional electricity generation will become more expensive as time goes on, renewable energy will increasingly become a paying proposition.

The massive reductions of recent years in the cost of wind and photovoltaic as key technologies open up new prospects for the transformation of the global energy system. At a local level, renewable energy technologies are in some cases already economic or only marginally more expensive than generation from fossil fuels, depending on regional circumstances.

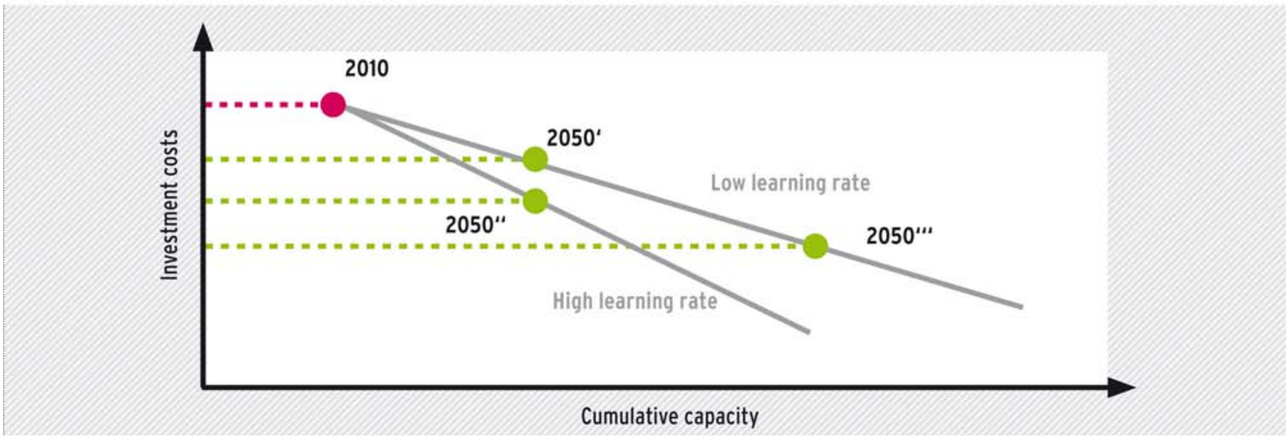
Reconstruction of the energy system with the aim of an energy mix of renewable energy sources is therefore advantageous from an economic standpoint as well, in view of the expected marked rise in fossil fuel costs and the ongoing advances in renewable energy technologies.

The cost of renewable energy is falling as a result of learning-curve effects. Because all countries profit from it, renewable energy expansion is a global task that needs to be tackled everywhere as a matter of urgency.

The international community of states should see the technological advances in renewable energy as an opportunity. The faster the global expansion of renewable energy goes ahead, the sooner it will be possible to reap the rewards of such a strategy in the form of diminishing costs. “Going through the learning curve” improves the competitive position of renewable energy sources.

Fig. 20 illustrates this connection. In the absence of all global efforts to increase capacity, the cost of renewable energy will remain at a relatively high level; depending on the learning rate the situation 2050' or 2050'' will apply in the middle of the century. Given ambitious expansion of renewable energy, by contrast, the subsequent generation could inherit a 2050''' world even with a comparatively low learning rate. This much improves the prospects for an affordable and climate-friendly electricity supply system.

Fig. 20: Schematic representation of going through various learning curves



Quelle: PIK (2012)

79 Bloomberg (2012), p. 12f.

Studies show that the transformation of the energy system is worthwhile from the standpoint of the national economy. Promoting renewable energy creates jobs and increases regional value added. It also improves the country's competitive position on the growing global markets for renewable energy technologies.

Around the world, some 5 million people are employed in the renewable energy sector – and the upward trend continues. Studies show that renewable energy expansion has a positive impact on net employment. The relevant estimates for Germany amount to between 143,000 and 182,000 additional jobs in 2030. In Europe the renewable energy expansion targeted by 2020 could lead on balance to 400,000 new jobs.

By 2025 the global market for green energy is set to grow to 747 billion EUR. Renewable energy sources play a central role here. They are key technologies for the energy supply of the future and are therefore of great economic relevance. Countries that push ahead with the expansion of renewable energy have competitive advantages on these markets.

5.3 Approaches to accelerated and affordable expansion of renewable energy

Electricity supply based entirely on renewable energy sources is an intergeneration task and a global innovation project. Local, regional, national and international actors should promote the expansion of renewable energy – with pioneers demonstrating feasibility, securing opportunities for the future and convincing the sceptical. Research and development, innovation assistance and instruments for promoting market diffusion are important to speed up the expansion of renewable energy.

Some technologies for generating electricity from renewable energy sources are still in their infancy. They are not very competitive yet, and the investment risks are high because of uncertainties about their technical performance. Research, development and innovation assistance and international cooperation help to facilitate investment funding and to ensure an earlier market launch of innovative technologies.

Other factors of central importance for renewable energy expansion include market-based assistance mechanisms such as the Renewable Energy Sources Act (EEG) in Germany. It creates planning certainty for investors, reduces financing costs by lowering the investment risk, and speeds up technical development and market diffusion through learning-by-doing and economies of scale.

Box 6: Successes and key points of the Renewable Energy Sources Act (EEG)

Since its entry into force in 2000, the Renewable Energy Sources Act in Germany has proved extremely successful: The renewables share of gross electricity consumption has risen from 6.4 percent in 2000 to 20.0 percent in 2011.[80] This pace of growth is unparalleled on an international comparison. The crucial elements for the success of the EEG are:

- **Priority connection to the electricity grid:** Grid operators are required to connect the renewable energy installations without delay and on a priority basis, and the connection point must be technically and economically appropriate.
- **Priority acceptance and distribution of electricity:** Grid operators take delivery of EEG electricity and distribute it nationwide.
- **Guaranteed feed-in payments:** The feed-in payment is fixed for 20 years to guarantee investment certainty. It is set separately for each technology and is based on the cost of generation. To take account of cost savings due to technological developments, the payment falls steadily for newly installed facilities.

In view of the great success of the EEG, other countries are following this example. Today as many as 65 countries and 27 provinces are using feed-in payments to finance the expansion of renewable energy sources. A total of 109 countries worldwide have introduced feed-in payments or other forms of assistance for renewable energy sources.[81] (REN21, 2012, S. 14).

80 BMU (2012a), p. 7.
81 REN21 (2012), p. 14.

Distortions of competition at the expense of renewable energy must be abolished. This calls for the discontinuation of climate-harmful subsidies and the internalisation of external costs in the electricity generation sector. This would considerably speed up the market penetration of renewable energy. At the same time it would substantially reduce the need for assistance for renewable energy.

Subsidies for fossil fuels and for nuclear power reduce the competitiveness of renewable energy sources. Abolishing such subsidies would therefore promote their faster diffusion. For this reason all states should gradually abolish subsidies for fossil fuels. Relevant approaches already exist and should be implemented without delay.[82]

The competitiveness of renewable energy is further impeded by the inadequate internalisation of the external environmental costs of electricity generation. Climate impacts and other harmful effects on health and the environment are several times greater for electricity generation from fossil fuels and nuclear power than they are for renewable energy sources. Emissions trading and other instruments for internalising external environmental costs must therefore be introduced and developed to push ahead with the worldwide use of renewable energy.

The expansion of renewable energy sources has to be paralleled by their integration in the electricity supply system. This requires the development of grids, load management and storage facilities.

For successful transformation of the electricity system towards a 100-percent renewable supply, there is a need for expansion of the electricity transmission and distribution grids to keep pace with the increasing demands arising from fluctuating energy sources.

As can be seen from the current energy turnaround in Germany, this calls for numerous actors to work hand in hand. Policy makers must create the right framework conditions, ensure early identification of grid bottlenecks, initiate the necessary planning processes and undertake timely refurbishment or expansion of the grids. The preparation of annual grid development plans could make an important contribution in this connection.

As well as grid expansion, there is also a need for improved load management to balance supply and demand. Existing flexibility potential must be mobilised and integrated in the electricity markets. Research and testing of storage technologies is another important precondition for the integration of supply-driven renewable energy sources in the power supply system.

5.4 Conclusions

At the World Climate Conference in 2010 the countries of the world agreed that average temperature should not increase by more than two degrees by the end of the century. One important step towards this is a transformation of the electricity supply system. In addition to a drastic improvement in energy efficiency, the expansion of renewable energy sources is the second pillar of climate-friendly electricity supply. The technical potential for such expansion exists. The trend of costs in recent years has shown that in some cases such expansion is already economic or involves only slight additional costs. Every state can play its part by using suitable instruments to advance the expansion of renewable energy sources in the electricity supply sector in the direction of 100-percent renewable supply. Internationally coordinated efforts aimed at a global transformation of the electricity supply system would further accelerate the already rapid decline in the cost of many renewable energy sources – to the benefit of all countries.

82 For example, the Kyoto Protocol explicitly calls for the abolition of subsidies that impede the reduction of greenhouse gases (UNFCCC (2007), Article 2, section 1, a) v)). Among the G20 decisions in Pittsburgh in September 2009, the heads of government undertook to phase out in the medium term subsidies for fossil fuels that encouraged wasteful consumption (G20 Leaders, 2009).

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