Ecologically Optimized Extension of Renewable Energy Utilization in Germany

Research Project commissioned by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

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Summary

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Background and purpose of the study

In the past, the growth of renewable energy sources has been largely determined by the conditions of the German national policy with regard to financial assistance. On the one hand this includes successes, such as the relatively continuous assistance for research and development over the last three decades and the market breakthrough for wind energy, and also the development of several other technologies to the threshold of energy relevance with the aid of the former Electricity Feed-In Act. In individual areas, however, there have also been various efforts that have been hesitant and not effective enough, sometimes resulting in setbacks on the way to a broader market introduction of renewable energy sources. It is only recently that there have been signs of a more purposeful and targeted extension strategy, not least as a result of the establishment of the Renewable Energy Sources Act and its ongoing development and because of the credible objective of doubling the contribution made by renewable energy sources by the year 2010. However, there is still a need to take further measures to ensure the successful achievement of this target. Against the background of continuing sustainability deficits in the energy supply sector, this doubling is regarded as no more than a first step in the process of further expanding the use of renewable energy sources. The targeted climate protection objectives require that in the long term, renewables should become the principal source of energy supply with a share of about 50 percent by around the middle of the century. The Federal Environment Ministry therefore considers it necessary that after 2010 the share of German energy supply due to renewables should increase by around 10 percent per decade.

These ambitious extension targets call for a sound analysis of the associated impacts on the environment, the energy industry, the economy in general, and society. The principal actors must be put in a position to assess as accurately as possible today the long-term process of the extension of renewable energy sources and its impacts. The favourable ecological effects that undoubtedly result from a marked extension of renewable energy sources with regard to the conservation of fossil energy resources and the reduction of greenhouse gas emissions have to be considered in the light of individual unfavourable impacts on the environment. Moreover, technology-specific conflicts may arise between climate and nature conservation interests and may lead to a rethinking of extension plans based entirely on technical or economic aspects. Examples of fields of conflict include water conservation (hydro power), encroachments on the landscape (wind power) and intensive use of biomass for energy purposes in the face of growing demands for "environmentalization of agriculture" and for greater consideration of nature conservation concerns.

In order to support the shaping of an "ecologically optimized" development path for renewable energy sources, the project pursues the following objectives:

- *Technical, economic and potential-related characterization of all relevant technologies for heat and power generation, and to a limited extent for fuel supply as well.*
- *Representation and assessment of all environmental impacts of these technologies by means of environmental balances and having regard to significant nature conservation aspects.*
- *An ecological and economic evaluation of various extension paths for renewables in the context of the further development of the overall energy system. On this basis, deduction of strategies for ecologically optimized extension of renewable energy sources having regard to economic and social aspects.*
- *Analysis of the framework conditions from the point of view of energy policy and energy economics, and of possible instruments for achieving the extension objectives. This will provide a basis for formulating appropriate packages of measures and recommendations for action in the field of energy policy.*

Here special importance has been attached to establishing the dynamic interactions within the long-term process of renewables development (period until 2050), not only with regard to the potentials that remain to be exploited and the advances still possible in the field of technology development and cost reduction, but also in view of the ecological impacts resulting from changing economic structures and the economic impacts resulting from increased extension. Although a large part of the work was devoted to the ecological component of extension, this was supported by a bundle of targets arising from the requirements for future sustainable energy supply.

The study was embedded in the Federal Environment Ministry's research focus area "Environment and Renewable Energy Sources". Funded by the Federal Government's "Future Investment Programme" ZIP and "Environmental Research Plan" UFOPLAN, a number of studies were commissioned in 2001 to investigate important aspects of environmentally sound application of individual technologies to the use of renewable energy sources. The present study was to have an umbrella function, taking account of the numerous individual findings and results of these studies in the design of extension strategies and integrating them in an overall picture. As a result of this pre-arranged approach, which lasted for the entire duration of the study and also resulted in a number of joint workshops, the present study was able to build on an unparalleled wealth of soundly based results for the individual technological areas and take advantage of them in designing and assessing extension paths for renewable energy sources. Moreover, a study of the potential of fuel cells made it possible to take a detailed look at the important field of the heat market and combined heat and power generation and to make use of the findings in the present study.

The studies undertaken within the BMU research focus area "Environment and Renewable Energy Sources" are:

- *"Nature conservation aspects in the use of renewable energy sources." Project manager: G. Reinhardt, IFEU Heidelberg.*
- *"Monitoring of the effects of the Biomass Ordinance on the basis of the Renewable Energy Sources Act from an environmental point of view." Project manager: J. Fischer, IE Leipzig.*
- *"Substance flow analysis for sustainable use of biomass for energy purposes." Project manager: U. Fritsche, Öko-Institut Darmstadt*
- *"Further extension of wind energy use with regard to climate protection." Project management: J-P. Molly, DEWI Wilhelmshaven.*
- *"Studies aimed at preventing and minimizing pollution of the marine environment by offshore wind energy parks in regions of the North Sea and Baltic Sea that are distant from the coast." Project manager: R. Knust, AWI Bremerhaven.*
- *"Geothermal power generation – networking and assessment of activities in the field of power generation from geothermal energy." Project manager: M. Kaltschmitt, IE Leipzig.*
- *"High-temperature solar thermal power generation" – "SOKRATES" study programme, project manager of study programme: F. Trieb, DLR Stuttgart.*
- *"Environmental impacts, framework conditions and market potential of distributed use of stationary fuel cells." Project manager: W. Krewitt, DLR Stuttgart.*
- *"Renewable energy sources and the environment in figures." Project manager: F. Staiß, ZSW Stuttgart.*

The study period lasted from 1 June 2001 to 31 December 2003. In addition to two interim reports in November 2001 and July 2002, two special working reports were produced in February 2003 on the "Renewable Energy Sources Act" and "Instruments in the Heat Market". The final report was submitted to the client at the end of February 2004.

Dr. Joachim Nitsch — Stuttgart, March 2004

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1 Sustainability requirements for energy supply, and possible solutions

“What matters is not predicting the future,
but being prepared for the future.”
Pericles, 500 AD

For more than two decades the term “sustainable development” has played a dominant role in discussions about the sparing use of our natural environment, fairer distribution of prosperity in the world, and a humane design of the basis for life of all people. These discussions have given rise to principles that can serve as a guide to the actors in the energy sector and for the development of energy policy action strategies. They are:

(1) Access and fair shares for all.

(2) Effective conservation of resources.

(3) Compatibility with environment, climate and health

(4) Social acceptability

(5) Low risks and fault tolerance

(6) Comprehensive cost-effectiveness

(7) Possibility of use in accordance with needs, and sustained reliability of supply

(8) Increased international cooperation

These principles call for a broader understanding of progress and development, especially in the highly industrialised states, if a change of course towards sustainability at global level is to be successful. In April 2002 the German Government adopted a national strategy for sustainable development. The strategy goes beyond the ecological challenges to serve as a guide for a comprehensive viable policy for the future that seeks to do justice to inter-generation responsibilities for economically, ecologically and socially sustainable development. Within the national sustainability strategy, environmentally sound extension of renewable energy sources is one of the main pillars of sustainable energy supply.

Measuring present-day energy supply in terms of these principles reveals four important sustainability deficits that have to be addressed with a view to prevention or minimization if we want to get closer to the principle of sustainability:

1. **The excessive use of finite energy resources**
2. **The incipient global climatic change**
3. **The risks of using nuclear energy**
4. **The extremely steep energy consumption gradient between industrialized and developing countries**

As things stand at present, there seems to be no possibility of any completely objective assessment and weighting of the relative importance of the generally acknowledged threat to the climate, the expected increases in the scarcity and prices of fossil fuels, the divergent attitudes to the risks associated with nuclear energy, and the social harm that results from the extremely ill-balanced access to energy.

An ideal development in global energy supply that simultaneously addresses all four of the sustainability deficits mentioned should proceed until the middle of the century as shown in **Fig. 1**. The starting point is to “freeze” the present average per capita consumption at 70 GJ/a (2000), which given increasing energy productivity still permits substantial further growth of goods and services. In this scenario the OECD states halve their energy input as a contribution to redressing the gross imbalance in worldwide energy consumption. This permits a doubling of per capita consumption in the developing countries and ensures them in 2050, in line with their growing populations, a 75% share of the primary energy consumption which will then stand at 635 EJ/a – or 1.5 times the present level. Eliminating or reducing the other three sustainability deficits calls for halving the use of fossil energy by 2050, discontinuing the use of nuclear energy, and changing from the mostly environmentally harmful "traditional" use of biomass (fuel wood) to an environmentally sound "modern" use of biomass. On this basis the use of modern technologies for exploiting renewable energy sources would have to grow 24-fold by 2050 to around 470 EJ/a; they would then cover 75% of total requirements.

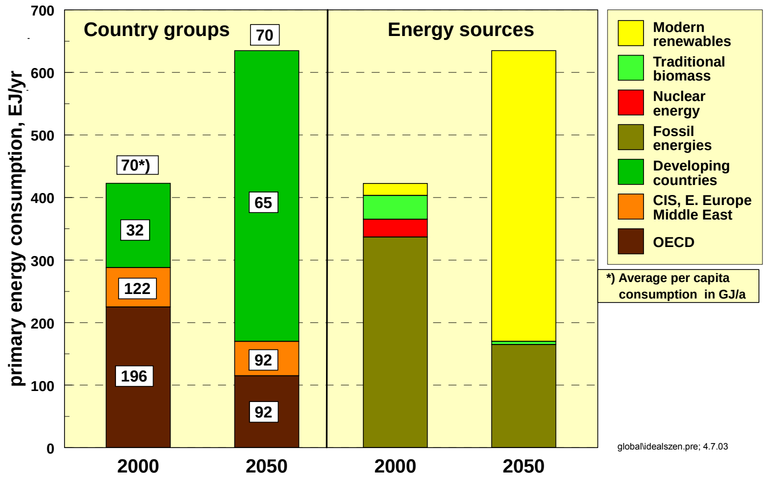


Fig. 1: Ideal scenario of sustainable global energy supply for the year 2050 in connection with the elimination or reduction of the four main sustainability deficits (population growth from 6 billion in 2000 to 9 billion in 2050).

Unlike the divergent ideas about possible efficiency improvements, the future use of nuclear energy and the possibilities of practicable large-scale CO_2 sequestration, virtually all current investigations of the global energy situation come to the unanimous conclusion that only a substantial increase in the contribution of renewable energy sources offers the prospect of turning onto a sustainable energy path. Figures for the contribution of renewables to world energy supply in 2050 range from just under 200 EJ/a to more than 600 EJ/a. Thus the figure of 470 EJ/a determined in the above "ideal scenario" is by no means the upper limit of what is considered possible for the use of renewable energy sources in 2050. Renewables thus **offer the only reliable guarantee of viable future energy supply.**

To date, the signs of appropriate political or social activities aimed at further development of the energy economy in the direction of greater sustainability at global level are no more than rudimentary. It is encouraging to note, however, that in a European context there has been a further intensification of moves in this direction. The European Parliament and the European Commission have breathed new life into the discussion process and taken important decisions on the extension of renewable energy sources. For example, a German initiative played a major part in the creation of the Johannesburg Declaration, "The Way Forward in Renewable Energy", in which about 100 countries undertake to set themselves ambitious targets for the extension of renewable energy. At the **International Conference on Renewable Energies ("Renewables 2004")**, to be held in Bonn in June 2004 at the invitation of the Federal Government, it is planned to reach specific bilateral and multilateral cooperation agreements.

Against the background of the four main sustainability deficits of energy supply, it is possible to conclude what objectives are necessary for the **redesign of the German energy supply sector** and to arrive at an approximate timetable for the necessary restructuring. Achieving substantial reductions in greenhouse gas emissions and phasing out the use of nuclear fission for energy production are the paramount objectives of German energy policy. It is however necessary to comply with the eight sustainability principles for energy systems. The solution strategies necessary for this purpose are objectives of energy policy as well, namely:

- a substantial increase in energy productivity (if possible, doubling by 2020) at all levels and in all areas of energy conversion and use;
- in particular, a marked expansion of combined heat and power generation (at least doubling, and in the long term exploitation of the structural potential with the aid of advanced, decentralised technologies);
- a marked and sustained increase in the contribution of renewable energy sources with the “doubling target 2010” (in relation to 2000) and a targeted share of around 50 percent of primary energy consumption by 2050.

If, on the basis of the principles, one investigates the resulting consequences for energy supply, there are a number of demands that can be satisfied immediately or are inherently linked with the above strategy. In particular, these are climate compatibility, low risks, international acceptability, creation of innovative thrusts and of viable jobs for the future, social equity, public acceptability and intergeneration equity. Other demands still present a challenge, since as things stand at present they are not yet sufficiently satisfied and require novel or generally more effective solutions which also have to be achieved within specific periods. These include:

- Guaranteeing supply that meet requirements at all times while ensuring continued compatibility with existing and developing infrastructures and supply facilities.
- Efficient use of fossil resources in the (suboptimal) transition period and of other scarce resources in the long term (land, in terms of both quantity and nature conservation aspects, consumption of biomass resources, demand for non-energy raw materials for creating facilities).
- Safeguarding macroeconomic and microeconomic acceptability in the transformation phase by creating cost-effective expansion paths, including expenditure on research, development and market launch of the new technologies and the necessary infrastructural and organizational changes.

Although there are few people today who doubt the necessity in principle of a restructuring of the energy system, in view of the open questions outlined above there are still widely varying opinions on the viability of a **development strategy that is based largely on “efficiency” and “renewable energy sources”**. For this reason the present study is designed to contribute to the further clarification and settlement of the questions still open in these fields and to indicate possible solutions.

2 Characterization of technologies for the use of renewable energy sources

An amazingly large number of technologies are available for using the many and various forms of renewable energy sources. They display marked differences in development progress, costs, performance, areas of application and development potential. Whereas hydro power has been used for decades to generate electricity, other technologies such as geothermal power generation are just taking their first steps in Germany with field trials. In the field of biomass utilization too, tried-and-tested “old” technologies exist alongside new methods such as gasification which have yet to find their way to final market maturity. Fluctuations in solar and wind energy will induce supply-dependent contributions into the grid, while hydro power and geothermal energy are able to provide energy to meet the basic load more or less independently of meteorological conditions. The performance of individual systems varies by several orders of magnitude (from 1 kW or less for photovoltaic systems to several 100 MW for hydro power stations). In most cases these are “distributed” technologies that are used directly at or close to the consumer, but the future will also see large-scale applications in the form of offshore wind parks or solar thermal power stations.

To be able to utilize the individual advantages of the different technologies and link them with each other, the entire spectrum of options available must be developed to market maturity and integrated step by step in the existing supply structures. For the future energy supply situation this will provide a complementary portfolio of environmentally friendly technologies for heat and power supply and for the provision of fuels.

The individual technologies:

- **Hydro power** is a mature technology that has long been used for economic generation of electricity. Additional potential can be exploited primarily by modernizing and expanding existing systems. The remaining limited cost reduction potential will probably be offset by the increasing site development problems and growing environmental requirements. It may be assumed that for small-scale systems, where power generation costs are in general higher in any case, the necessity to comply with minimum ecological requirements will tend to involve proportionately higher costs than for large systems.
- Within a short period of time, the dynamic development of **wind power** has resulted in the establishment of a market of relevance to the energy economy. In 2002 a prototype 4.5 MW turbine was installed in Germany. This is currently the largest wind turbine in the world. The cost of new systems has however stagnated in Germany in recent years. This is due in particular to the continuing high level of demand and the manufacturers' considerable advance investment in the development and introduction of a succession of new systems. Nevertheless, since technical developments have led to increases in specific yield, it has been possible to reduce electricity generation costs.

  Today a large proportion of the areas of Germany with good wind conditions are already being used for wind power generation. Particularly in the coastal regions, wind energy utilization is reaching its limits. One possibility for further expansion is repowering, in other words replacing older small turbines by modern large systems. Great potential of up to more than 100 TWh/a in the long term can be exploited in the offshore sector. The additional costs for foundations and grid connection are offset by higher yields, which means that electricity costs of less than 5 cents per kWh will be possible in the long term.
- Although the worldwide **photovoltaic** market has been growing at over 30 percent per annum in recent years, the contribution this technology makes to electricity generation is still very small. Development work is focused on improving existing modules and system components and on developing new types of cells in the thin-film sector and new materials for crystalline cells. It is expected that the efficiency of commercial crystalline cells will improve to between 15 and 20 percent in the next few years, and that thin-film cells using less raw material will become commercially available. The steady fall in production costs suggests that specific system costs can be reduced by nearly 50 percent by the year 2010. In addition there is considerable long-term cost reduction potential, which means that electricity costs of around 10 cents per kWh will be possible in Central Europe by 2050. Compared with other technologies for utilizing renewables, photovoltaic power must therefore be classified as a long-term option. Its importance derives from its great flexibility in use, its great technical and economic development prospects and its enormous technical potential.

- **Biomass**, which is used to supply heat, generate electricity and produce biogenic fuels, currently accounts for more than half of the final energy produced from renewable energy sources in Germany and can be utilized with an extremely broad portfolio of technologies. The crucial factor for the economics of biomass utilization is the cost of the input materials, which today range from “negative costs” for waste wood (credit for waste disposal costs avoided), through inexpensive residual materials to the more expensive energy crops. The resulting spectrum of energy generation costs is correspondingly broad. One of the most favourable options today in economic terms is the use of waste wood in steam turbine combined heat and power plants, which today is state of the art. Gasification of solid bio fuels makes it possible to develop a considerably wider range of applications. This option, however, is not yet fully developed and is still relatively expensive at present. In the long term it is expected that very favourable electricity production costs will be achieved by using wood gas both in micro CHP units (engines and fuel cells) and in gas-and-steam power plants. Great potential for the utilization of solid biomass also exists for heat generation in small systems and larger heating centres and plants with local heating networks. “Bio diesel” made from rapeseed methyl ester (RME) has become increasingly important in Germany in recent years. Processes for obtaining synthetic fuels from biogenic synthesis gases will also play an increasingly important role.
- **Geothermal energy** has long been used in Germany for supplying heat. Further intensive research and development work is still needed to speed up the progress of electricity generation from geothermal energy. In particular, the creation of large underground heat exchange surfaces (HDR technology) and the improvement of heat-and-power machines with organic rankine cycle (ORC) must be optimized in future projects. In suitable regions of Germany preparations are being made for the operation of pilot plants for geothermal power generation and combined heat and power generation. In November 2003 the first geothermal power plant, with a capacity of 210 kW, went into service at Neustadt-Glewe. Since geothermal power generation is still in its infancy, considerable cost reductions are expected to be achieved in future by using more efficient drilling and simulation methods and by improving the efficiency of the electricity generation system. Thus despite the present high level of costs (some 18 to 20 cents/kWh), electricity production costs – depending on payments for heat supply – are expected to come down to between 6 and 8 cents/kWh in the long term. With the great technical supply potential for power generation of 300 TWh/a it would be possible to supply the entire base load for Germany’s electricity supply sector. However, in view of the ecological and economic desirability of combined heat and power generation, the electricity generation potential is limited by the heat that can be used in the energy system. The exploitation of the great structural potential that still exists even then (66 TWh/a) presupposes a considerable expansion of heat distribution networks.
- Small **solar thermal collector systems** for water heating and auxiliary heating are well developed today and, thanks to targeted promotion, are used for a wide variety of applications. By contrast, large seasonal heat reservoirs that store heat from the summer until it is needed in the winter are only available as pilot plants at present. Only by means of solar local heating systems with seasonal storage would it be possible to supply large parts of the entire low-temperature heat market in Germany with solar energy. Crucial factors for the market launch will be low storage costs and an adequate usable heat yield (minimization of storage and transportation losses). In the case of systems with seasonal heat storage, the storage facility currently accounts for over 50 percent of the total cost. Even today, however, the solar thermal energy costs of a large solar thermal system with seasonal storage are, in spite of the high storage costs, no higher than for the small water heating systems in widespread use. One major obstacle to the introduction of large systems is the need to make the reservoir so large that it is necessary to connect a large number of consumers via a local heating network, which means that advance investment is required for a considerable period. Depending on the configuration of the system, it will

be possible in the long term to achieve solar thermal costs of between 4 and 7 cents/kWh.

- **Solar thermal power stations**, as concentrator systems, can only use direct sunlight and are thus dependent on high-irradiation locations. For example, North Africa has considerable technical extension potential which far exceeds local demand. In a well developed common European electricity grid it would be possible to exploit this great, inexpensive potential. The various solar thermal power station concepts (parabolic trough concentrators, power towers, parabolic dish concentrators, solar chimney power plants) offer good prospects for further technological development and cost reductions. One important technological development objective is the creation of large thermal energy reservoirs in order to extend the operating time of these systems beyond the sunlight period. Depending on incident solar radiation and mode of operation (e.g. power generation combined with seawater desalination), electricity production costs of below 5 cents/kWh are expected. In the long term the level of costs for imported solar electricity, including transport costs, could fall to 5.5 cents/kWh at the German border) The necessary decrease in costs presupposes rapid market introduction in the next few years.
- As renewable energies come to play a very large part in energy supply, the production of **hydrogen from renewables** gains importance as an energy carrier that is easy to store. It can be used to equalize fluctuations in electricity supply and to tap renewable energy sources for the transport sector beyond the possible contribution of biogenic automotive fuels. All primary energies that can be made available in the form of electricity can be converted into hydrogen relatively efficiently and inexpensively by means of electrolysis. In the long term, hydrogen costs of around 8 cents/kWh can be achieved both with wind power and with electricity from solar thermal power plants. In the medium term, however, the cost barrier compared with the usual present-day energy prices is difficult to overcome even for fully developed renewable systems. Since hydrogen from renewables, owing to its production from electricity, is some 80 to 100 percent more expensive than the electricity itself, direct use of renewable electricity is generally to be preferred in the field of stationary energy utilization, except where costs are pushed up by the limits of this use of electricity.
- A whole range of other forms of renewable energy forms can if necessary be utilized with the aid of appropriate technologies. They include tidal energy, wave energy and ocean thermal energy conversion, which are either adaptations of conventional power stations (tidal power plants) or are specially designed for the form in which the energy is available. The relevant systems are being tested in pilot plants (especially wave energy converters). They demonstrate the great variety of possibilities that exist for utilizing the natural energy flows that surround us.

Future development of technology costs

Most of the technologies employed today for the utilization of renewable energy sources are at an early stage of market development. Accordingly, the costs of electricity, heat and fuel production are as a rule higher today than the costs of competing conventional systems (see example of electricity generation in **(Fig. 2)**. It is however possible to achieve large reductions in these costs compared with established technologies by means of technical developments, manufacturing improvements and large-scale production. Especially when developing long-term scenarios spanning periods of several decades, the dynamic trend of cost developments over time plays a crucial role in identifying economically sensible extension strategies.

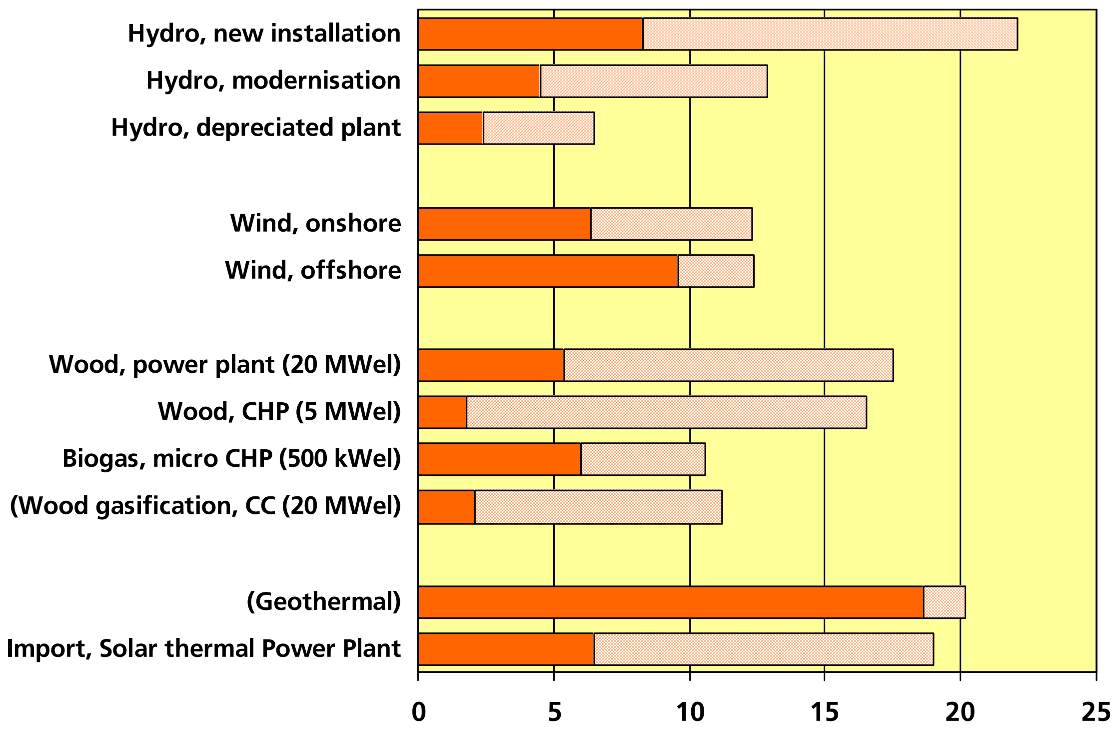


Fig. 2: Range of present-day costs for generation of electricity from renewable energy sources (excluding photovoltaic with costs of 50 to 80 cents/kWh).

The correlation between specific investment costs and cumulated production volume of a technology that is empirically observed for many products can be represented in the form of learning curves. The cost reduction that can be achieved by doubling cumulated production is known as the learning factor (a learning factor f = 0.9 means that costs fall by 10% if cumulative production doubles; this corresponds to a learning rate of 0.1). In order to estimate future cost trends with the aid of learning curves, technology-specific learning factors and the development of cumulative installed capacity have been determined using data obtained from the literature. The cost trends derived from the learning curves for the various technologies for utilization of renewable energies are shown in **Fig. 3**.

In the last 20 years the development of the wind energy markets has taken very different courses in different regions. Accordingly, various studies have observed relatively large regional differences in the individual learning factors. In Great Britain, for example, a country where expansion of wind energy has been very hesitant to date, the learning factor is still around 0.75, which points to a sharp downward trend in costs. In Germany, by contrast, a learning factor of 0.94 was determined for wind turbines built between 1990 and 2000. The low learning rate of 0.06 can be explained by the high level of advance investment by the manufacturers, who kept on putting new performance classes on the market at very short intervals. Although expectations are that the existing cost reduction potential is not yet exhausted, the low learning rate found for onshore systems in Germany is adopted here and taken as constant for the period under consideration. Owing to the relative lack of experience in the offshore sector, however, a greater cost reduction potential is expected here and it is assumed that the learning rate will be correspondingly higher.

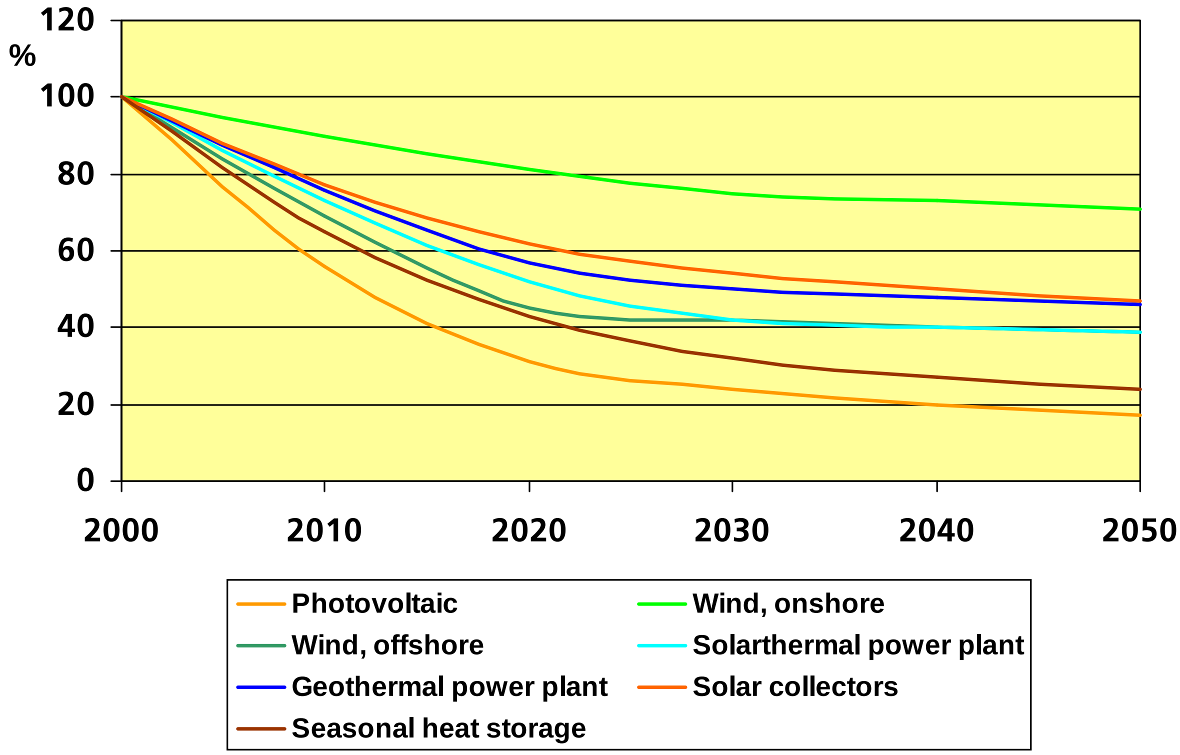


Fig. 3: Future development of costs (normalised to current cost levels) for technologies for the use of renewables, derived from learning curves.

No learning curves for technologies for the use of renewables have been so closely investigated as those for the photovoltaic sector, and there is scarcely another technology for which one can find such agreement in the literature on the findings: the learning factor for PV modules, taken as the mean of the figures for various module types, is fairly constant over a period of 30 years at around 0.80, which is relatively high. Cost data for photovoltaic systems installed in Germany during the last ten years also indicate a learning factor of 0.80, on the assumption of a global market and hence of global learning. This optimistic estimate is supported by the fact that it is still possible to achieve ongoing increases in the efficiency of PV modules both in the laboratory and under real conditions. In the long run, however, it must be assumed that the photovoltaic sector too will see a decline in the opportunities for cost reductions through technical learning, and that the learning rate will fall.

Owing to the small number of solar thermal power plants built to date, it is particularly difficult to arrive at reliable learning factors for this sector. Here it is assumed that the learning factor of 0.88 derived from the data for parabolic trough reflectors built in California will change to 0.95 in the course of market introduction up to 2030. For geothermal power generation systems, there are no learning curves in the literature despite a worldwide installed capacity of more than 8,000 MW_{el}. Since a large proportion of the costs in the geothermal field is due to deep drilling, figures for the oil production sector can be used for drawing analogies here. IPCC Scenarios work on the basis that geothermal power generation costs will fall by nearly 50 percent in the period from 2020 to 2050 alone. A learning factor of 0.986 was determined for hydroelectric power plants built in the OECD countries between 1975 and 1993. It may be assumed that as a result of compensating measures for nature conservation, which can amount to as much as 30 percent of the investment costs, the specific costs for hydro power plants will tend to rise in the course of time, especially as the limits of their potential come closer. Figures for the German collector market indicate a learning factor of nearly 0.90 for solar collectors, which indicates a relatively well developed system from a technological point of view. By contrast, the construction of seasonal heat reservoirs is expected to show a long-term cost reduction of over 70 percent, in view of the very small volume of the market at present, which is largely confined to demonstration systems.

It can be seen that most technologies, while continuing to grow rapidly, will be able to reduce their costs to a level between 30 and 60 percent of current costs by 2020, and to between 20 and less than 50 percent in a more or less fully developed state (after 2040).

By linking the available technical/structural potentials with the expected developments in costs it is possible to obtain supply curves for the relevant extension potential for each technology, as shown for example for wind energy in **Fig. 4** and for hydro power in **Fig. 5**. The potential for wind energy utilization at onshore windy sites is already largely exhausted. With around 60 TWh, by contrast, regions with a wind speed of less than 5 m/s (at a height of 10 m above ground level) still offer great potential, but its development involves higher costs. At 80 TWh, the offshore sector in particular offers great extension potential. If this potential is developed rapidly, a substantial reduction in costs can be achieved at the same time. Electricity production costs of between 3 and 5 cents/kWh, depending on location, are expected for new systems by as early as 2020, and this is lower than the costs for good onshore sites.

The electricity generation potential that can be tapped by means of modernization measures in the case of hydro power plants with a capacity of over 5 MW is put at some 1.3 TWh/a, the extension potential at 1 TWh/a, and the potential from new plants at sites already in use at 0.3 TWh/a. In theory a further 1.6 TWh/a could be exploited by new plants on the high Rhine, the upper Rhine and the Danube. From a present-day standpoint, however, new plants at these sites are not a realistic option, partly for nature conservation reasons. If one also takes into account the extension potential of small-scale hydro power plants, totalling nearly 1 TWh/a, the technically available potential for hydro power utilization as a result of modernization and extension of existing plants and extension of small-scale plants can be increased by around 3.6 TWh/a.

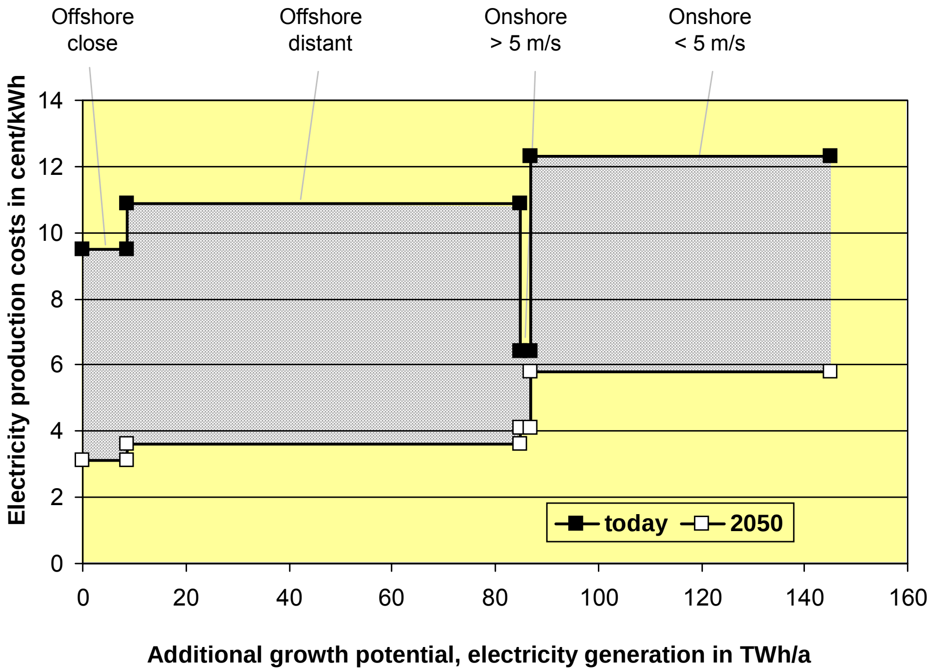


Fig. 4: Supply curve for the additional wind energy potential in Germany

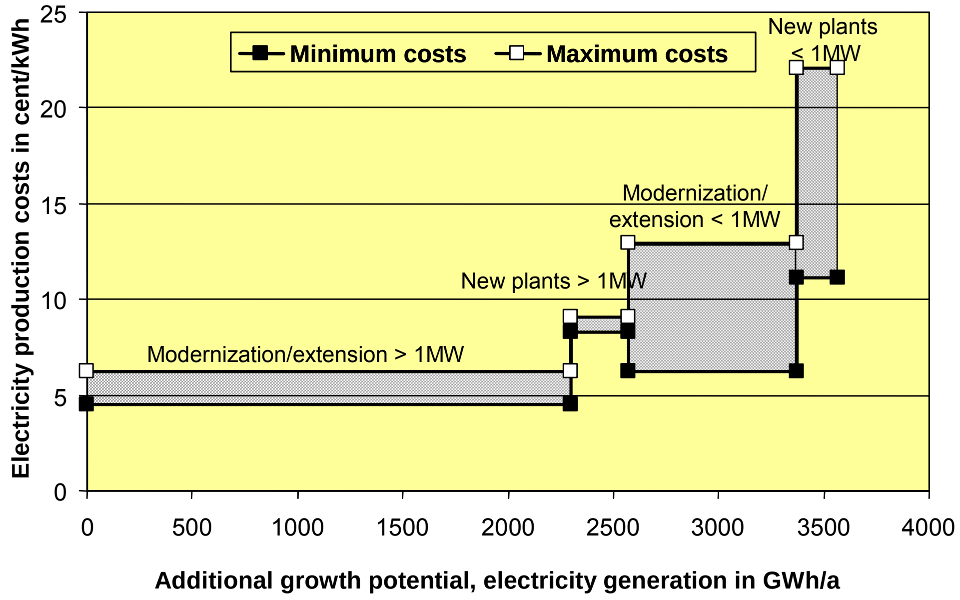
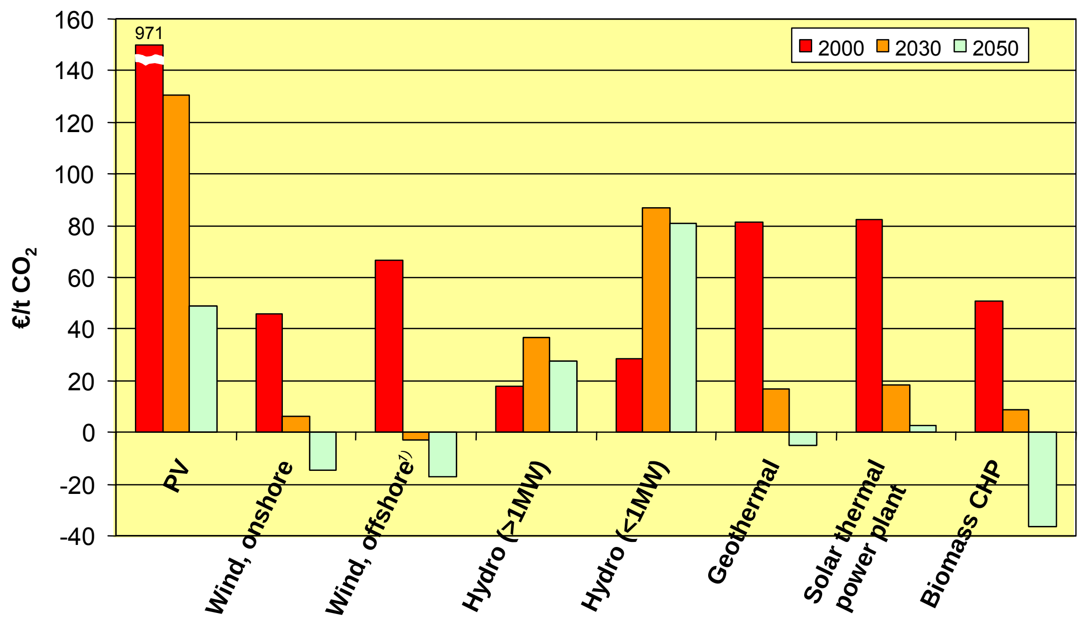


Fig. 5: Supply curves for additional hydro power potential in Germany.

CO_2 avoidance costs

In line with the spectrum of present-day electricity and heat supply costs, **CO_2 avoidance costs** also cover a wide span. Today the CO_2 avoidance costs for electricity generation (**Fig. 6**) from wind energy, geothermal energy, solar thermal power plants and biomass are between 40 and 80 €/t CO_2, whereas the avoidance costs for photovoltaic systems are still little short of 1000 €/t CO_2.



[1)] Initial figure stands for 2005

Fig. 6: CO_2 avoidance costs of electricity generation from renewable energy sources. Based on: mix of new condensing fossil-fuel power plants in line with the reference scenario; development of fossil fuel prices: "middle variant"

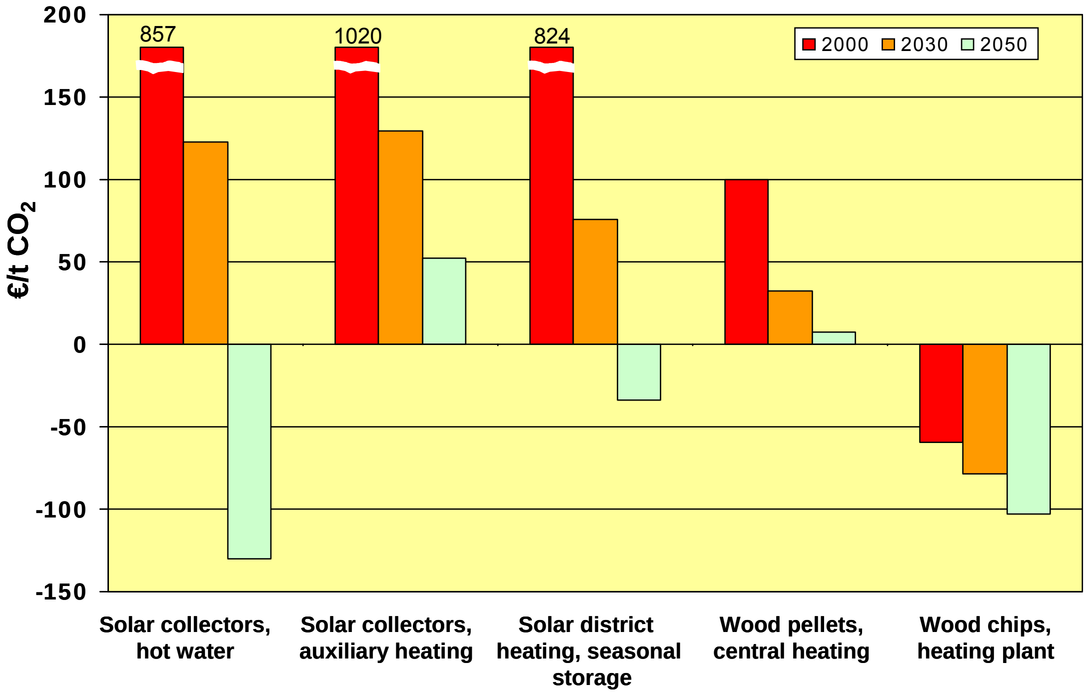


Fig. 7: CO_2 avoidance costs of heat production from renewable energy sources. Based on: heat supply for a singe-family house with a mix of gas-fired condensing boiler and oil-fired low-temperature burner in line with the reference scenario. Development of heating fuel prices: "middle variant"

However, in view of the decreasing cost of utilizing renewable energy sources and the simultaneous increase in the price of fossil heating fuels, most technologies will in the long term reach negative CO_2 avoidance costs. In other words, the use of renewable energy sources can not only reduce CO_2 emissions, but can at the same time reduce national expenditure on electricity generation. Thus in the long term, renewables possess considerable potential for low-cost reduction of greenhouse gas emissions if the remaining cost reduction potential is mobilized and the technologies not yet in use, such as offshore wind energy, geothermal power generation, biomass gasification or solar thermal power plants, are established on the market.

At present the CO_2 avoidance costs of heat production with solar collectors **(Fig. 7)** are still in the region of 800 to 1,000 €/t CO_2. Here too, however, there is great potential for reducing avoidance costs, which means that depending on the field of application and the system configuration it will in the long run be possible to achieve negative CO_2 avoidance costs with solar collectors as well. The CO_2 avoidance costs for biomass utilization are highly dependent on how heating fuel prices develop. At wood prices of around 1 cent/kWh, heat production in a wood chip heating plant already results in negative CO_2 avoidance costs.

3 Environmental impacts due to electricity, heat and fuel production from renewables

Every technological activity, including the utilization of renewable energy sources, involves environmental impacts. However, the crucial consideration for an overall assessment of renewable energy sources is how these technologies are to be rated now and in the future compared with the competing technologies, and whether the environmental impacts are caused by the properties of the renewable energy systems themselves or are "imported" into the renewable energy system “from outside” through the provision of energy, transport services and materials.

In a first step towards answering these questions, overall Life Cycle Assessments (LCA) were carried out for important energy chains on the basis of renewable energy sources (reference year 2010) and compared with conventional energy production. In a second step, these LCAs were made dynamic. To this end the technical properties of the renewable energy systems and the development of the “background systems” (systems that do not form a direct part of the system investigated, but are necessary for its creation, use or disposal, for example the power stations for the provision of production energy) were projected to 2030.

From the LCA results (see **Fig. 8** for a selection of examples) it follows that **for all renewable energy chains the inputs of finite energy resources and emissions of gases that are harmful to the climate are extremely low compared with the conventional system.** The relevant environmental impacts of the renewable energy systems amount to a maximum of 20% of an expected future reference mix for electricity, a maximum of 15% of the reference mix for heat, and a maximum of 55% of the future diesel car in the case of fuels. LCA results for the renewable energy systems reveals that the use made of the **material resources** investigated (iron ore, bauxite) is less than or similar to that made by conventional systems. Exceptions are photovoltaic (frame and assembly), solar collectors (collectors and supporting structure) and wind energy (steel tower). It should be noted that the other environmental impacts associated with the provision of the materials are of course taken into account, and that the input of materials in particular depends heavily on the local situation (e.g. use of concrete for hydro power stations, aluminium for photovoltaic, depending on the degree of integration).

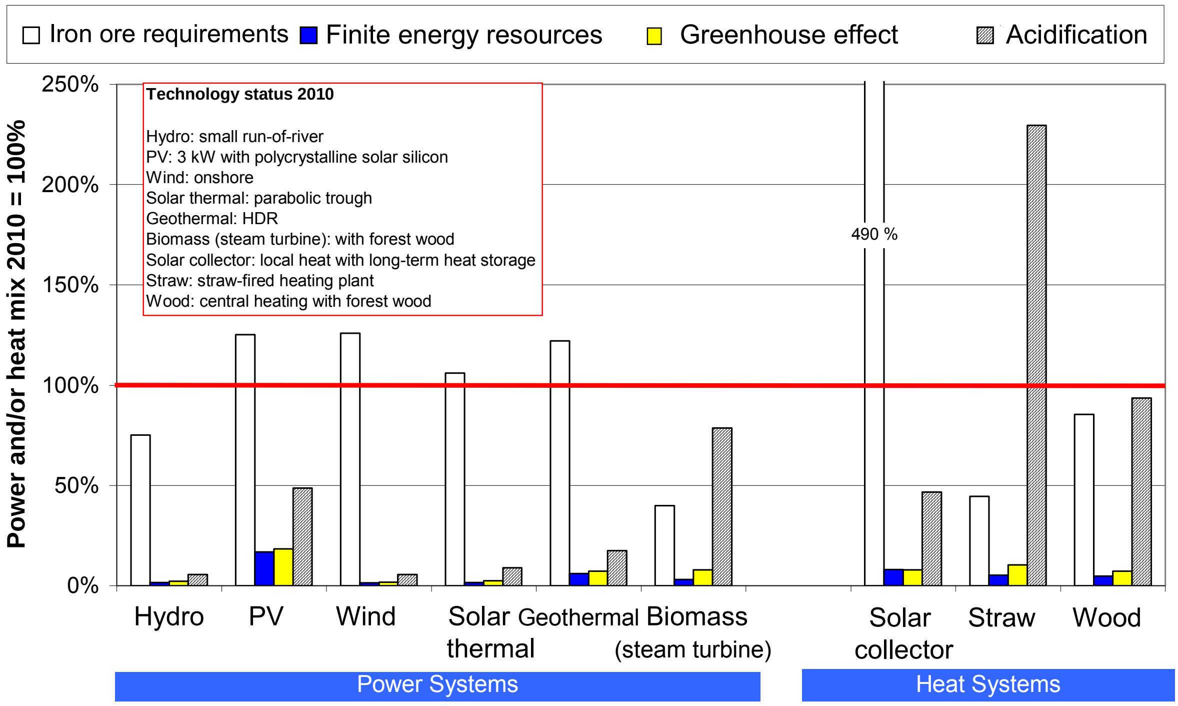


Fig. 8: Results from Life Cycle Assessment of various renewable energy systems (sample selection of systems and environmental impacts). The representation is based on a future electricity mix in accordance with the reference scenario or a small consumer heat mix.

Fig. 9 shows that the extension of renewable energy sources increases the demand for iron induced by electricity production by 1.5 percentage points to 5.5% of the total demand for iron in Germany. Thus the demand for iron caused by the electricity production sector remains small by comparison with the demand for iron due to the construction sector and the motor vehicle industry. Apart from the standard construction materials and mechanical engineering materials used, solar cells in particular make use of other materials. Depending on the type of solar cell, large-scale extension of PV could give rise to shortages of material especially in the case of thin-film cells, and these will have to be remedied by efficient resource and recycling management and diversification of materials.

For the other environmental impacts the findings do not reveal any clear verdict for or against renewable energies. The comparison depends more on a large number of context-dependent parameters, e.g.

- the technology configuration examined (e.g. polycrystalline, monocrystalline or amorphous silicon or thin-film solar cells, steam turbine or combustion engine CHP units, etc.);
- the type of energy source used, especially in the case of biomass, and its specific properties (fuel inventory, transport distances, etc.);
- the geographical location, topographical situation and local conditions of the plant (crucial for solar radiation, full-load hours, expenditure on barrages for hydro power, etc.) and
- integration in the local infrastructure (e.g. integration of photovoltaic in the building).

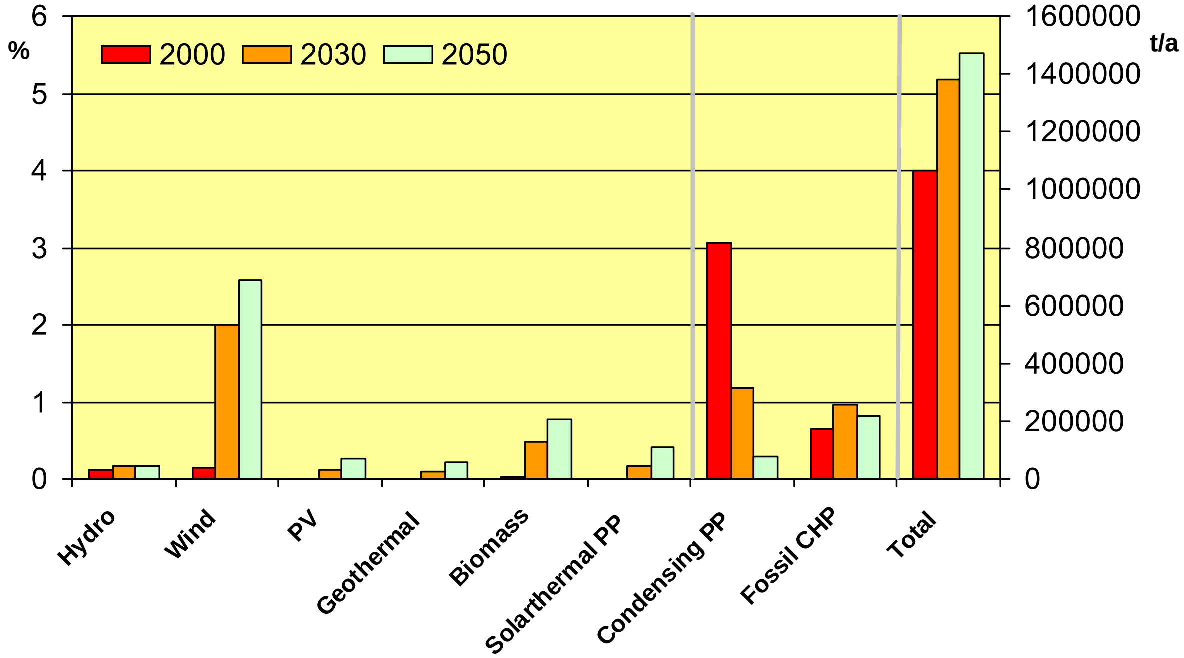


Fig. 9: Cumulative annual iron requirements for electricity generation in the "NatureConservationPlus" scenario, as a percentage of total iron demand in Germany in 2000 (without credits for CHP heat)

By its nature, environmental accounting for renewable energy systems can only provide information about typical systems. For example, the **acidification** figures for electricity generating systems are well below or similar to the future reference mix, with the exception of the biogas system, which is above the reference mix owing to the ammonia emissions of the agricultural system. Apart from straw as a fuel, the heat generating systems are also below or similar to the reference mix. Straw-fired heating plants emit more acidifying substances (chlorine and sulphur content, NO_x emissions) than short rotation wood, which in turn emits more than forest wood as a result of the fertilizer and cultivation input and the agricultural emissions.

The pattern for **eutrophication** is rather different: electricity generating systems excluding biomass are considerably better than the reference mix, but biomass systems are well above the reference mix (exception: systems with co-combustion of forest wood). This is due in particular to the fact that the NO_x emissions of small systems are higher, and that the advantages on the acidification side compared with the reference mix which result from avoiding the SO_2 emissions of coal-fired power stations do not make themselves felt when it comes to eutrophication.

Summer smog is lower than or similar to the reference mix for all electricity generating systems and transport systems (exception: waste wood); among the heat generating systems, straw-fired heating plants and central heating plants are higher than the reference mix by about a factor of 2.

On balance, there are thus clear advantages under the headings of greenhouse effect and consumption of finite energy resources. In the other impact categories the findings reveal no clear trends. Thus it is not possible to reach an objective decision. If one considers the great importance for energy resource consumption and greenhouse effect and the great specific contribution of the energy system to these environmental impacts, all renewable energy sources show clear advantages over the conventional variants where these environmental impacts are concerned.

In the case of biomass in particular it is not only the determination of environmental impacts per kilowatt-hour of final energy source that is relevant, but also the **environmental advantage that can be achieved per energy unit of biomass**, since biogenic fuels always offer the option of using them in different sectors, namely for electricity or heat generation or in the transport sector. If one compares the reduction effect in terms of CO_2 emissions in the various fields of application, **CHP systems and biomass co-incineration** in particular make a substantial contribution to climate protection. Owing to the high efficiency of the heating systems, such use for heat supply is also justifiable from a climate policy point of view, but the climate effect here is less favourable than use in efficient CHP systems. As far as the present situation is concerned, using solid biogenic fuels in the mobile sector, for example the production of BTL (biomass to liquid) fuels, saves less carbon dioxide per biomass unit than using them in efficient CHP or heat supply systems.

The increasing penetration of renewables into the power and heat sectors, the growing efficiency of the power plant portfolio, and the diminishing carbon intensity of the electricity and heat sector on the one hand, and increasingly complex nature of petroleum production and refining on the other hand, will however result in these differences in climate reduction effect growing smaller as time goes on. The same would be true if automotive fuel production at the same time made more efficient drive systems possible and thus not only avoided combustion of conventional fuels, but also achieved savings in fuel consumption (e.g. hydrogen).

In the case of biomass crops, it is also extremely important to take account of the **use of land**, particularly in view of the extensive areas required for agriculture and forestry compared with fossil fuels. Here short rotation crops achieve the biggest climate gas savings per unit area among the bio-energy sources, followed by ethanol from sugar beet and bio diesel from rape. Although the two “residual substances” straw and forest wood have a lower yield per unit area than biomass crops, they still offer appreciable overall savings potential.

There are further environmental impacts that result from bio energy sources, especially where the biomass is produced by agriculture in the form of biomass crops, as is the case with short rotation plantations for solid bio energy sources and with rape and sugar beet for the production of bio fuels. The best known environmental impacts due to agriculture are – apart from the factors already registered in quantitative terms in the LCA – nutrient input into groundwater and surface waters due to erosion and translocation, hazards due to pesticides, and reduction in biodiversity. Whereas the first group of environmental impacts display a much lower release or leaching potential than annual plants because of the ground cover throughout the year, the risk of hazards due to pesticides can be minimized by organic farming. In conventional farming approaches, the quantities of pesticides used for perennial crops are far lower than for the annual crops rape and sugar beet. From a biodiversity point of view, energy crops can be regarded as unproblematic if the production of bio energy sources takes place on a site-appropriate basis in compliance with the requirements of good professional practice, and if it does not impair the implementation of the supraregional biotope network pursuant to Section 3 of the Federal Nature Conservation Act or the hedges, marginal shrubs and stepping-stone biotopes called for in Section 5 of the Act as linking elements for the biotope network in the agricultural landscape.

Future developments will bring further appreciable reductions in the environmental impacts caused by renewable energy systems. There are various factors responsible for this:

- Advances in the technical parameters of the energy converters, especially improved efficiency, improved emission characteristics, increased life etc.
- Advances in the production processes of the energy converters and/or fuels, for example reduced sawing losses or wafer thicknesses in solar cells, reduced fertilizer inputs and increased yields for biomass crops, etc.
- Advances in the “external” services required from the conventional energy and transport system, for example improved supply of electricity or process heat for the manufacture of the systems, ecologically optimized transport systems for biomass transport, etc.
- Reductions in the credits that can be obtained for by-products of the renewable energy chains may in future result in reduced environmental relief effects (e.g. RME).

On the whole, a marked reduction in environmental impact can be achieved by exploiting optimization potential and by making improvements in the provision of materials and energy. As an example, **Fig. 10** shows results of a dynamic LCA for a polycrystalline photovoltaic system and the influence of various optimization parameters. In the examples investigated, it would be possible to reduce the environmental impacts of the systems in 2030 compared with the systems in 2010 by 20 to 30%, and in the case of photovoltaic systems by up to as much as 50 percent.

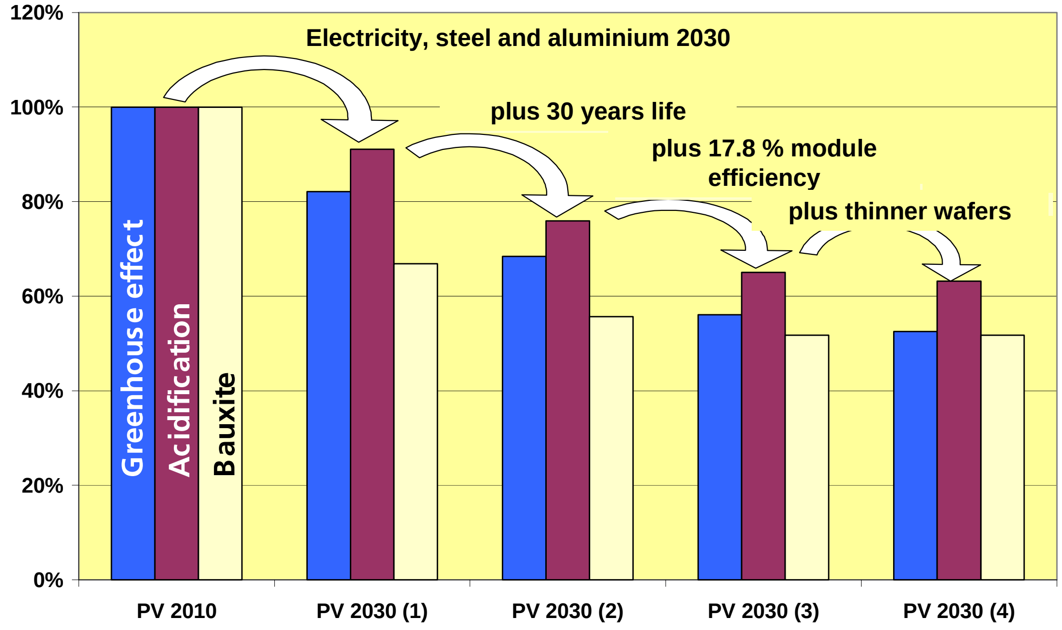


Fig. 10: Dynamic LCA of renewable energy systems, taking photovoltaic as an example. The representation is based on the environmental impacts of the non-dynamic system.

4 Renewables and nature conservation – potential for utilization of renewables, observing landscape and nature conservation interests

As well as the environmental impacts examined in the life cycle assessment, the utilization of renewable energy sources sometimes involves encroachments on local and regional ecosystems. Nature conservation considerations may therefore give rise to restrictions on the utilization of renewable energy sources. In order to draw attention to the possible effects of nature conservation specific restrictions on the use of renewable energies in the scenario analysis, two different potential variants are introduced:

- The **"Basic"** variant shows for renewable energy systems a potential capable of technical/structural exploitation that already takes account of major nature conservation interests (e.g. exclusion of wind parks in nature conservation areas etc.). From a landscape and nature conservation point of view, however, it is not always possible to make full use of even this potential, since local conditions may make it impossible to satisfy nature conservation requirements at individual sites, thereby ruling out their use for renewable energy purposes.
- When drawing up scenarios for the entire energy system there is a need to take account of the specific interests of nature conservation, which are usually investigated during the authorization phase for individual installations in the context of the environmental impact assessment, and thus to avoid overestimating the usable potential of renewable energy sources. For this reason the **"NatureConservationPlus"** variant arrives at a potential which is further reduced on nature conservation grounds and which is available in the long term even after allowing for stringent nature conservation requirements for the utilization of renewable energy systems. In the case of biomass utilization, however, there is also additional potential resulting from maintenance measures required on nature conservation grounds. At some points restrictions arising from acceptance considerations are recommended, because in many cases these cannot be strictly separated from nature conservation aspects.

The possible areas of conflict between renewable energies and nature conservation, and the conclusions to be drawn about restrictions on the utilization of renewable energy systems, are summarized below.

Hydropower: The effects on flowing waters that result from a hydroelectric power plant depend on the local conditions and the technology used. Problems that arise can be alleviated, but not entirely eliminated, by minimum environmental requirements and measures to minimize encroachment. Examples of minimum environmental requirements are ensuring the passage of fish and invertebrates, ensuring an ecological minimum water flow rate, and avoiding threshold operation and adverse effects on the water table in water meadow areas. From an ecological point of view it does not make sense to divide hydroelectric power plants into size categories, since neither “small-scale” nor “large-scale” water power leads in itself to a form of water power utilization that is entirely acceptable in ecological terms. It does however make sense to classify the severity of encroachment in terms of new plants on largely untouched watercourses, new plants and extensions at sites already in use, and modernization or recommissioning of existing power plants. Thus building new small-scale hydroelectric power plants may have greater adverse environmental effects than modernizing existing large-scale power plants.

The technical/structural extension potential still available today even after taking account of environmental reservations is put at **4 to 5 TWh/a**. The greatest contribution here can be achieved by modernizing large hydroelectric power plants. In principle, modernization should always go hand in hand with improvements in the ecological situation in the river. If one completely excludes the construction of new hydroelectric power plants on rivers which are currently largely in their natural state, this **reduces the extension potential by about 1 TWh/a.** Compared with the total potential for renewable energy systems in Germany, this reduction in the utilization potential is small. It must however be assumed that this restriction will in particular affect the construction of new small-scale hydroelectric power plants.

Wind energy: Simply because of their size and the need to make use of favourable wind conditions, wind energy installations result in changes in the appearance of the landscape. Depending on the individual landscape situation, they may interfere with landscape features “of great character and beauty” and thereby impair an asset that has to be protected under the Federal Nature Conservation Act. It is however difficult to characterize impairments of the landscape in general terms, as they depend on the specific situation of the landscape in question. The extension of wind energy further increases the growing utilization pressures on the open countryside.

Isolated cases of direct effects on birds in the form of direct impact are observed in the cases of wind energy systems; they are on the same sort of scale as for overhead electricity lines or transmitter masts. More important are adverse impacts in the form of uneasiness and scarecrow effects, as some species of birds keep their distance from wind energy systems up to a radius of several hundred metres. In coastal areas, areas extending up to several kilometres on the landward side of the dykes are regularly used by migratory birds, which means that the construction of wind energy systems in these areas may have a substantial impact on migratory birds in particular. Depending on the site conditions of the wind energy system, adverse effects on low-altitude bird migration have also been observed in upland areas well inland. Offshore wind parks may also result in the permanent destruction of areas that are used by birds as resting and feeding grounds.

To date there is only little reliable information on possible impacts of the construction and operation of offshore installations on organisms living on the seabed. We also know relatively little about the possible effects of magnetic fields emanating from the connecting cables between offshore wind park and onshore grid input sites. The Federal Environment Ministry is promoting various activities in the field of supplementary ecological research in order to improve the knowledge situation here.

A detailed analysis for two sample regions (Lower Saxony as a coastal region and Baden-Württemberg as an inland area) has shown that although the technical potential for wind energy utilization is substantially limited by nature and landscape conservation restrictions, considerable potential still exists for extension of wind energy in the two regions studied alone, despite strict nature conservation requirements **(Fig. 11**). In view of the present market situation and the **areas so far designated as suitable** for wind energy, current estimates indicate that onshore extension of wind energy could reach a level of **up to 30,000 MW**. The capacity to be installed on the available area in a repowering context is likely to depend to a large extent on the maximum permitted height of the installations as laid down in land use plans. Assuming careful site planning, nature conservation criteria do not constitute a limiting factor for such extension.

Onshore wind energy utilization is not limited by nature conservation interests alone, but possibly even more by landscape conservation aspects and hence ultimately by public acceptance of further extension of wind energy. The process of designating suitable areas for wind energy utilization which is under way in many regions indicates that the areas available for wind energy utilization are considerably smaller than the areas available under nature conservation restrictions. For example, an expert opinion on potential conflicts between wind energy and nature conservation in Mecklenburg/Western Pomerania comes to the conclusion that after taking account of areas excluded in the interests of safeguarding landscape appearance and habitat functions, approximately 5 percent of the land area is suitable for erecting wind energy installations from a nature conservation point of view. However, after weighing up competing land-use options and taking account of wind conditions, only 0.5 percent of the land area was ultimately designated as suitable in the regional policy programmes. In Schleswig-Holstein the suitable areas account for about 1 percent of the land area, while in inland regions away from the coast the figure is considerably smaller. In Baden-Württemberg the designation of priority areas is not yet complete in all regions, but in the Stuttgart region, which includes parts of the Swabian Alb hills with favourable wind conditions, the priority areas amount to barely 0.1 percent of the total area.

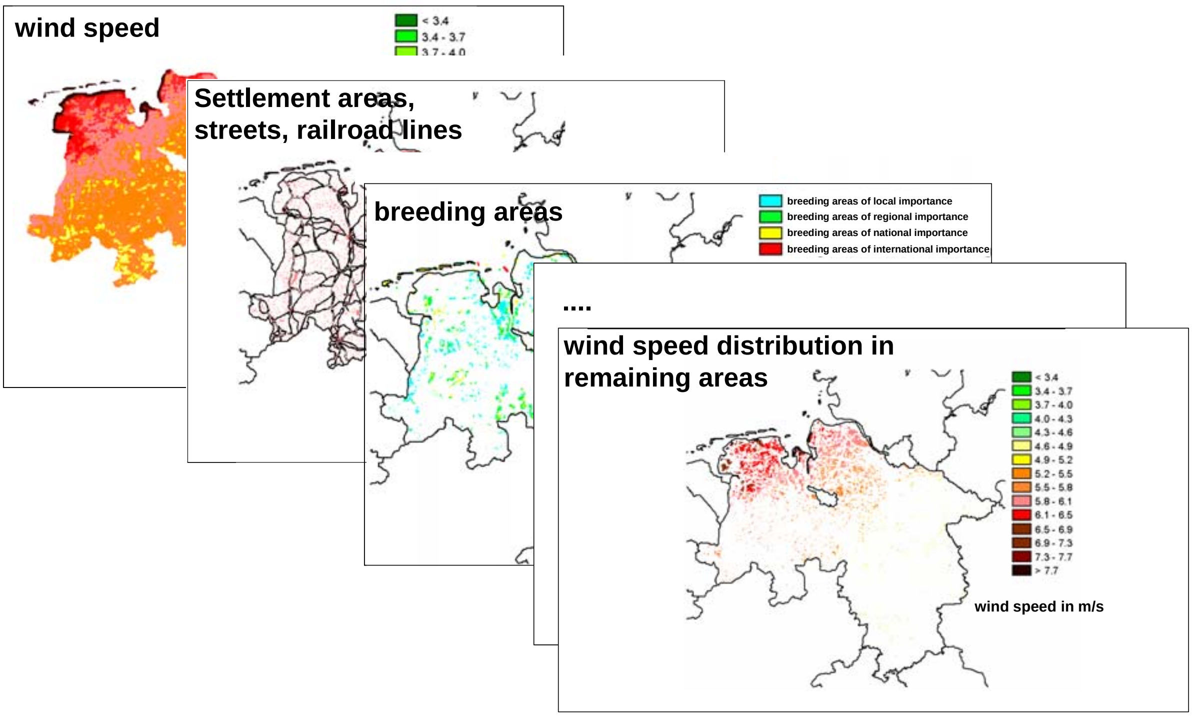


Fig. 11: GIS-based estimate of wind energy potential subject to nature conservation restrictions, taking Lower Saxony as an example

In order to provide a perspective that takes account of increased social awareness regarding further extension of onshore wind energy utilization, which is to a large extent due to the effects of wind energy systems on the landscape, the “NatureConservationPlus” variant works on the basis of a reduced potential for wind energy. Starting from the areas so far designated as suitable in various parts of Germany, it is assumed that in future a total of around **half a percent** of the area of Germany will be available for wind energy utilization, with a larger figure in the coastal regions and a distinctly smaller figure inland. Depending on installation size, this results in an **extension potential of around 20,000 to 25,000 MW**. This is explicitly a “soft” potential limit which is not primarily derived from nature conservation considerations, but is above all intended to ensure long-term public acceptance of wind energy utilization.

For wind energy utilization at sea, the Federal Government has identified first low-conflict areas that can be considered as areas specially suitable for offshore wind parks. Since offshore wind energy utilization constitutes a large-scale and long-term encroachment on the marine environment, and since the lack of practical experience makes it difficult to predict the installation-specific impacts of **offshore wind parks** with any certainty, the precautionary principle is to be catered for by adopting a step-by-step expansion approach. In this, the implementation of each successive stage presupposes that the results of the last stage are positive and reliable in terms of compatibility with the environment and nature. It is assumed that it will be possible to develop **a capacity of 20,000 to 25,000 MW by 2030**.

Biomass: bio fuels can be obtained from a wide variety of biogenic resources originating mainly from agriculture and forestry, but also from other areas such as landscape maintenance, industrial processes or households. Basically the fields in which nature conservation and biomass production are completely mutually exclusive are confined to a small number of core areas of nature conservation (e.g. process protection areas in core zones of national parks). Competition for areas in the strict sense therefore plays only a secondary role in determining the potential for energy from biomass. The focus in the task of determining such areas is rather on differences in the use of farmland, e.g. as arable or grassland. This includes in particular – with the greatest individual potential – the aspect of perennial plant cover on farmland, which may be desirable from a nature conservation point of view on sites with a high erosion risk. Compared with the production of biomass, the conversion of biomass into energy is of minor importance from a nature conservation point of view, having regard to the present legal framework conditions.

The starting point for determining area potential is the existing land use. The nature conservation specific area requirements or criteria, such as biotope network areas and erosion-risk areas, are applied to the present land use and used to determine future land use having special regard to nature conservation aspects. This results in not only deductions, but also additions, which have hitherto not been taken into account in potential assessments. This is the case, for example, where nature conservation requirements result in a reduction in the area under annual crops, but such areas are in future to be developed as grassland which in turn supply biomass that can be used for energy purposes. In connection with the production of biomass, Section 3 of the Federal Nature Conservation Act, which lays down area targets for the supraregional biotope network, is of special importance. On the **10 % of the total area of Germany** which is stated as a target here, priority will be given to nature conservation objectives, which does not necessarily mean that biomass utilization is ruled out here. Indeed, there is reason to expect changes of use (arable to grassland) or extensification of use on such land, unless the land is already designated for nature conservation and used accordingly.

Thus two biomass origin paths are important: growing of biomass crops and utilization of residual biomass. **Energy crops** are limited by the land potential. In this context **Fig. 12** shows the influence of the three objectives “Federal Government sustainability objectives such as extension of organic farming”, “provision of areas for the biotope network pursuant to Sections 3 and 5 of the Federal Nature Conservation Act” and “planting of all erosion-risk arable sites with perennial crops" compared with a policy that does not pursue or only partially pursues these objectives. If all the objectives mentioned are implemented, the area of **arable land** available for agricultural growing of non-food crops – and hence for energy crops – will be **some 2.3 million hectares less in 2010 and around 1.9 million hectares less in 2050** than for "total extension" in line with the "Basic" potential variant **(BASIC: 2.5 million hectares in 2010 and 6.1 million hectares in 2050).** Thus in 2010 only relatively marginal areas of around 0.2 million hectares can be considered for growing of energy crops. In the following decades, however, these show a marked increase in view of population growth and increased yields in agriculture, and in the long term they will provide appreciable biomass potential of 4.2 million hectares even under the strict criteria of the "NatureConservationPlus" potential variant.

On the other hand these restrictions give rise to additional potential on nature conservation areas, since biomass can be produced on the greater part of the land allocated to nature conservation. This includes biomass from the maintenance of forest margins, open country, compensation areas and the biotope network, and also coppice forest and composite forest. The removal of biomass from areas desirable from a nature conservation point of view, in conjunction with the biomass from the growing of perennial crops on erosion-risk sites, results in as much as an extra 150 PJ/a of biomass (Fig. 12, circle). In terms of magnitude this potential corresponds, for example, to the entire volume of biogas from residue biomass or the entire volume of energy from all residual wood fractions (industrial waste wood, old wood and wood in domestic refuse), and it thus represents an considerable bio energy potential that has hitherto been neglected.

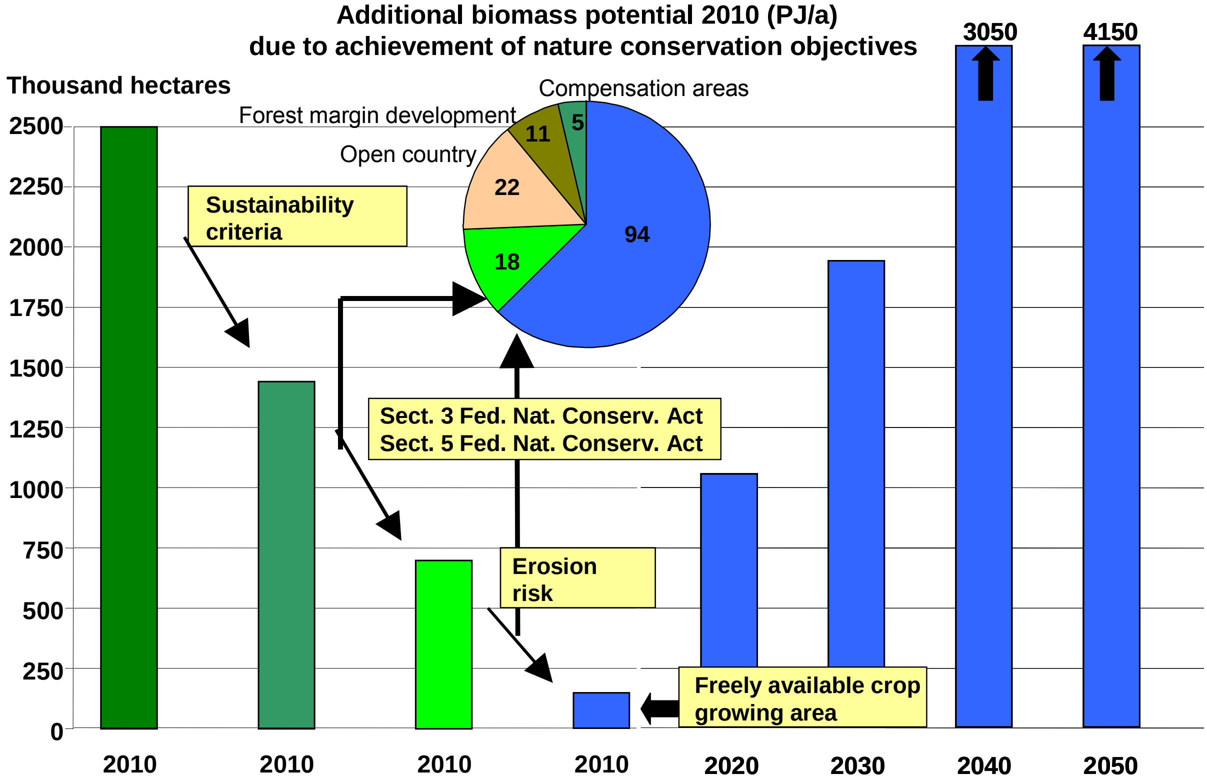


Fig. 12: Reduction in land potential in 2010 (based on the BASIC potential variant) as a result of the implementation of various sustainability measures (first four columns on left); resulting additional "biomass potential" (150 PJ/a, pie chart) and growth of these reduced areas (last four columns on right) up to 2050 in the potential variant "NatureConservationPlus".

If one adds to the available biomass outlined above the usual **solid residual substances** already registered in existing potential analyses (forest wood and smallwood, forest wood capable of additional exploitation, straw, material from landscape maintenance, residual wood from industry, used wood, wood from domestic refuse, sewage sludge, zoomass, extensive grassland), the BASIC potential variant results in an energy volume of around 740 PJ/a for the year 2010. This remains virtually constant over the period under consideration. The **biogas** obtained from fermentation of animal excrement and litter, from harvest residues, commercial and industrial waste and organic municipal waste, and the potential of sewage and landfill gas yields a further 160 PJ/a, which is also constant, so the **residual substances potential in the BASIC potential variant comes to 900 PJ/a**. Under the conditions of the **"NatureConservationPlus" potential variant** these figures are reduced to 530 PJ/a (2010) and 580 PJ/a (2050) for solid residual substances and to 145 PJ/a for biogas, in other words a total of **675 PJ/a (2010) or 725 PJ/a (2050)**.

All or part of the biomass available can be used either for stationary generation of heat and power or for production of automotive fuels. Thus in view of the different yields, the entire available biomass potential depends on the ratio of stationary to mobile use (**Fig.13**). The energy related potential of biomass crops is roughly twice as large for stationary heat and power generation as when they are used for the production of bio fuels. The residual substances potential does not change significantly over time, whereas the potential for biomass crops shows a marked increase by the year 2050. Especially in the potential variant "NatureConservationPlus", this also indicates a possible time path for the extension of the biomass market in the automotive fuels sector in particular. At least in the next 20 years, the potential for utilization of organic residues – regardless of whether or not nature conservation interests are taken into account – is considerably greater than the potential for biomass crops.

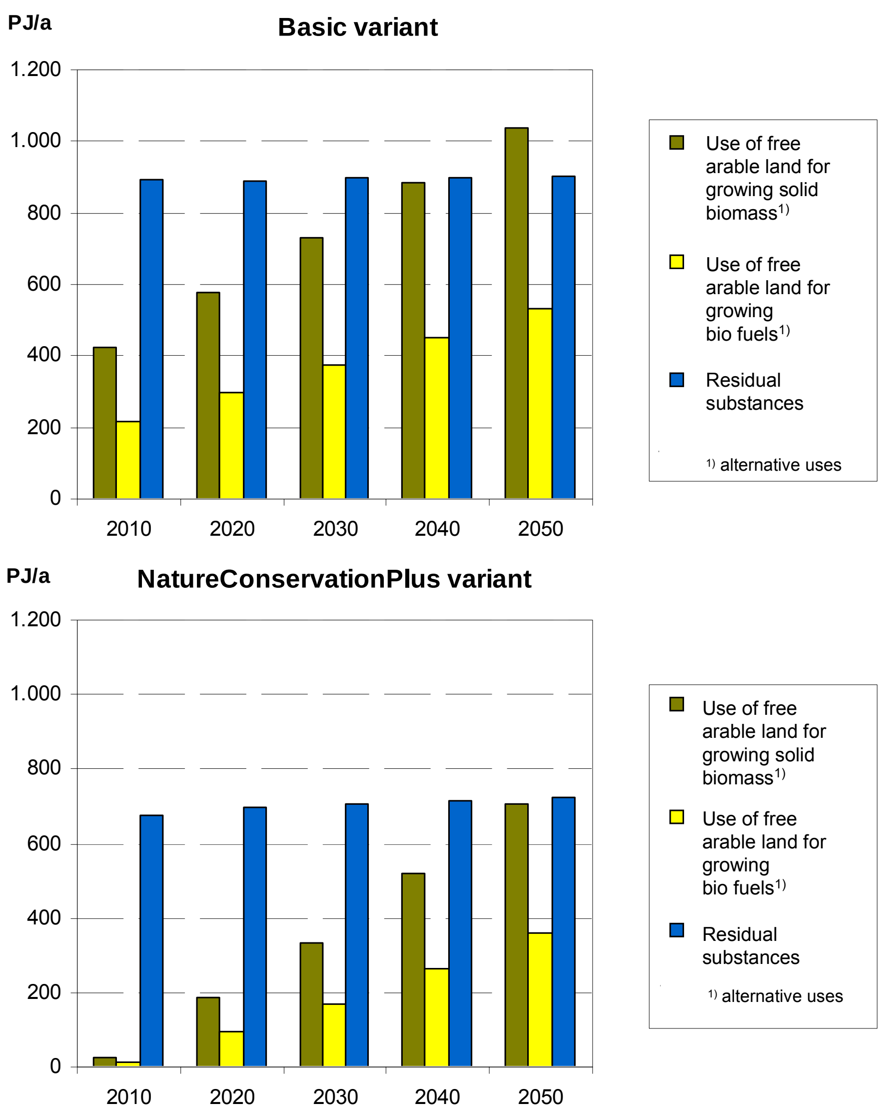


Fig. 13: Development over time of biomass potential of residual substances and of crop areas, taking account of various utilization options for energy crops.

In all cases the restrictions imposed by the variant “NatureConservationPlus” reduce the potential by about 25 percent. This makes it clear that although the demands of nature conservation in the biotope network context impose certain restrictions compared with total extension of energy crops, appreciable additional potential is created in the other areas, with the result that the combination of “nature conservation” and “utilization of biomass for energy” goes hand in hand here.

Photovoltaic and solar collectors: The construction and operation of building-integrated photovoltaic systems and solar collectors presents no problems from a nature conservation point of view. There is however controversial discussion when it comes to the construction of large free-standing “green fields” installations. Although free-standing installations are not the same as surface sealing of land areas, ultimately they always involve using up more land, something which should be avoided as far as possible in the interest of environmental protection. It is not difficult to foresee that large free-standing installations will increasingly raise the problem of effects on the landscape, and that this – as in the case of wind energy – will give rise to an acceptance debate in society. This can be avoided by confining expansion to building-integrated systems.

The various scenarios are far from making full use of the very great potential that exists within existing settlement structures (photovoltaic: 105 TWh_{el}/a; collectors: 360 TWh_{th}/a), so that from a capacity point of view there is no need to use unoccupied land. From the industry's point of view, the installation of free-standing systems may play an important role in rapid and inexpensive expansion of market volume. The conditions for promotion which are laid down in the draft of the Renewable Energy Sources Act are intended to ensure that there is no building on ecologically sensitive areas. Even so, unoccupied land should only be used for free-standing systems subject to stringent criteria and as an interim strategy during the market launch.

Heat and power generation from geothermal energy: To ensure sustainable use of geothermal power as a resource, the technical potential should only be developed gradually over a long period owing to the low level of the natural heat flow. Given a development period of 1,000 years, the technical supply potential works out at 300 TWh_{el}/a, and this is substantially reduced to around 65 TWh/a by restrictions on the demand side, especially the usable heat volume in the case of co-generation plants. Just like other forms of energy production, the utilization of geothermal energy represents an encroachment on the natural equilibrium of the environment (in this case the upper regions of the Earth's crust). Present knowledge indicates that the consequences of possible impacts, such as a hydraulic short-circuit between different strata in the substructure as a result of drilling, are slight. Cooling of the substructure will lead to changes in the chemistry of the reservoir and possibly to microseismic symptoms. Since this takes place at great depth and there is generally no connection with the biosphere, no repercussions on flora and fauna are known to date. In view of the lack of experience, however, such effects should be the subject of careful investigation in the future.

The **potential for utilization of renewable energy sources in Germany** that is available under the limiting conditions of the two variants "Basic" and "NatureConservationPlus" is summarized in **Fig. 14** and **Fig. 15**. For electricity the potential (without imports of energy produced from renewables) ranges from 370 to 775 TWh/a (BASIC) or 350 to 720 TWh/a (NatureConservationPlus); for heat it ranges from 2,215 to 3,345 PJ/a (BASIC) or 2,215 to 3,060 PJ/a (NatureConservationPlus). For fuels the figures range, depending on alternative uses, from 0 to 1,000 PJ/a (BASIC) or 0 to 740 PJ/a (NatureConservationPlus). It is clear that the stringent requirements from the point of view of nature and landscape protection reduce the available potential for individual renewables, and especially for onshore utilization of wind energy and for utilization of biomass, by some 20 to 30 percent. In overall terms, however, the additional nature conservation requirements do not result in any significant restriction of the potential available in Germany.

This finding provides further confirmation of the most environmentally sound possibilities of using renewable energy sources. Even allowing for nature conservation restrictions, all categories of renewable energy sources still possess considerable potential for expansion. Domestic potential alone could, if combined with an effective efficiency strategy, could meet a large proportion of Germany's future energy requirements. **The recommendation therefore goes clearly in favour of an extension strategy that applies stringent nature conservation criteria.** Such a strategy is capable of proving that only renewable energy sources are in a position to permit a genuinely "nature conserving" energy supply system. It will thus result in a further improvement in acceptance. From the point of view of potential and costs, the implications are no more than marginal, and in the long term there are adequate alternative options.

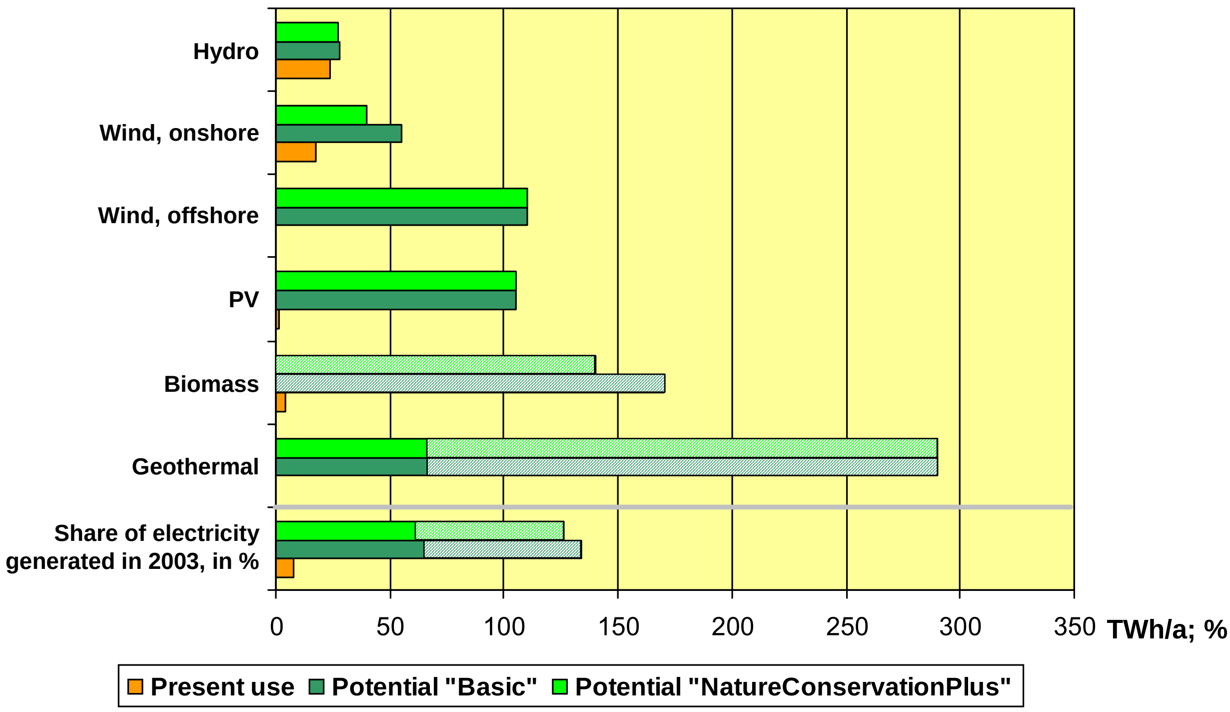


Fig. 14: Potential for electricity generation from renewable energy sources in Germany, excluding imports (hatched areas: potential subject to differences in biomass input options and other limitations)

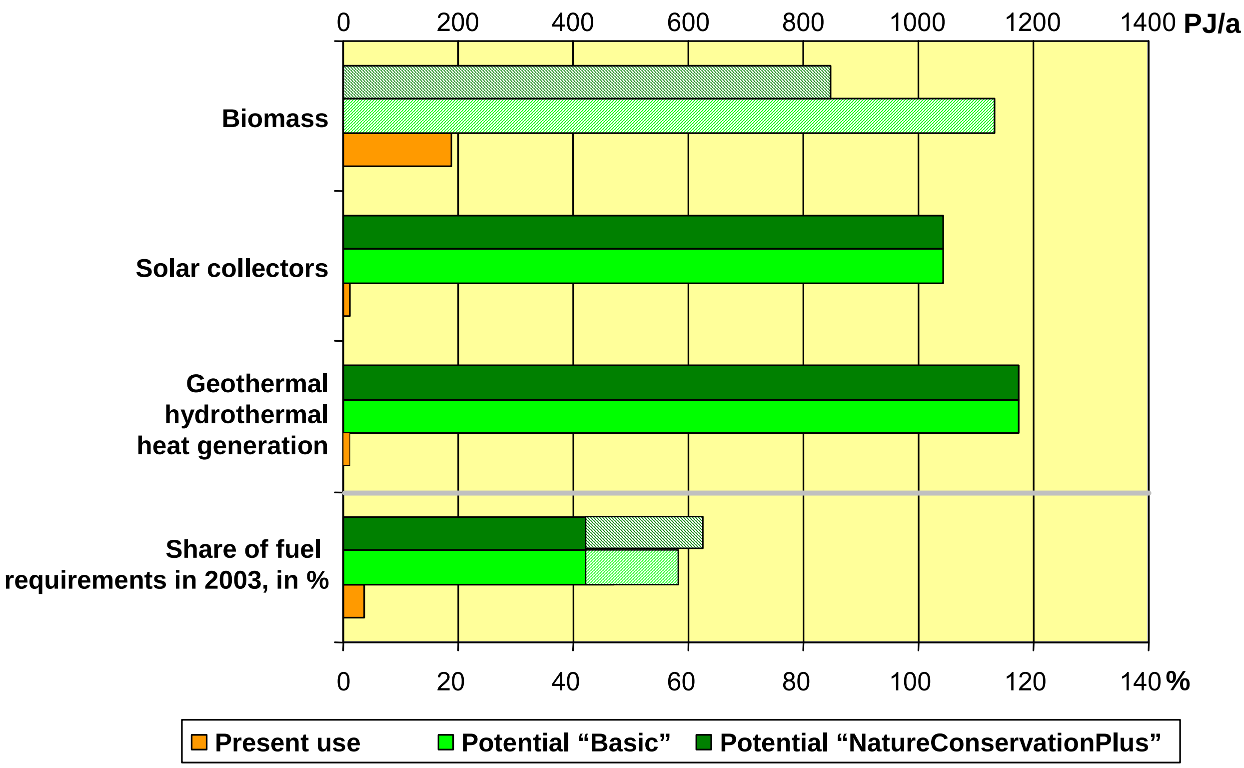


Fig. 15: Potential for heat generation from renewable energy sources in Germany, excluding imports (hatched areas: potential subject to differences in biomass input options and other limitations)

This study does not take account of the very large potential for utilization within Germany of power generated outside Germany that exists as a result of the interconnection of the European grids, neither does it include any imports of bio energy or fuels. In the long term the great “import potential” of electricity from renewables could be used to meet German energy demand in the context of a European overall strategy for mobilizing renewable energy sources. **Thus even with stringent restrictions from a potential point of view, there is nothing to prevent 100 percent of Germany’s energy requirements being met from renewable energy sources in the long term.**

5 Scenarios for ecologically optimized extension of renewables – Findings and conclusions

The purpose of the present analysis of the German energy supply system with the aid of five scenarios (four “extension scenarios” BASIC I and II, NatureConservationPlus I and II, reference scenario) is to combine the potential-oriented, structural, environmental and economic opportunities and limitations of various technological options in such a way as to reveal the principal interactions between these options in a far-reaching restructuring of energy supply over the next fifty years. This was done with the aid of three individual strategies: **the “efficiency strategy”, the “co-generation extension strategy” and the “renewables extension strategy”**. The complex interactions between the technology options and the individual strategies were determined separately for the areas **“electricity supply”, “heat and/or heating fuel supply” and “transport and/or automotive fuel supply”**, in order to take account of the great differences in the initial situation and the differences in the speed of change during the restructuring process.

The study period of 50 years covers a considerable period of time during which present-day energy supply structures, energy infrastructures and energy utilization structures may be totally altered or renewed. In the light of the past fifty years, this period can be expected to bring both huge technological developments and substantial structural changes. There may also be very far-reaching changes in social habits, value judgements and consumer preferences. Although the extension variants of the scenarios presented give rise to energy systems that are very different from an energy technology and economic point of view than we are used to today, they are merely a continuation of the ongoing change and restructuring of the energy system that has been taking place in recent decades. The scenarios can thus be described as “conservative” in the sense that they are merely based on the process of steady renewal and adaptation of the energy system to changing conditions, and that they make use of known technologies, processes and methods to achieve this. They do not call for any as yet unknown technological “breakthroughs”, structural upheavals or even political revolutions. Unlike the existing energy system, which has developed historically and has mostly been “shaped” on a reactive basis and with relatively short-term perspectives, these scenarios represent designs for a future energy sector that are **based on long-term macroeconomic and energy policy objectives**, and which are therefore (bound to be) based to some extent on different cost/benefit ratios and judgements than are used or have been used by the actors in present day-to-day business in the energy sector.

The scenarios, by contrast with the reference scenario, open up a corridor within which the future reorganization of the energy system is likely to take place. The more effectively the system of objectives derived from the principles of sustainable development is implemented in political, economic and social action, the more closely the structure is likely to resemble that of the extension scenarios. The less this system is reflected in energy policy, the less the energy system will differ from the reference trend that does not cater adequately for the objectives. Even the reference scenario, however, could be influenced in an even more unfavourable direction from a sustainability point of view by exceptional and unforeseeable – mostly crisis-like – developments (such as rocketing oil prices, disasters, armed conflicts).

Scenario calculation results and conclusions

(1) Sustainable energy supply are not possible without a substantial increase in the conversion and utilization efficiency of all energy sources.

Any reorganization of the energy system in the direction of sustainability must be based on a systematic improvement in the conversion and utilization efficiency of all energy sources. The existing mechanisms for improving energy efficiency, such as increasing the efficiency of power stations, stricter efficiency regulations for new installations (energy saving ordinance), improvements in vehicle engine efficiency, optimization of industrial processes, and the general autonomous efficiency improvements resulting from replacement of old equipment and installations by new systems, are not sufficient to produce a substantial reduction in energy consumption levels. If the past trend of a reduction in energy intensity (long-term primary energy trend 1.4%/a; electricity since 1984 approx. 0.9%/a) is stepped up only slightly (reference scenario until 2050 around 1.8%/a for primary energy, or 1.2%/a for electricity), electricity consumption continues to rise and primary energy consumption shows only a gradual reduction in parallel with the demographic trend **(Fig. 16**, upper lines).

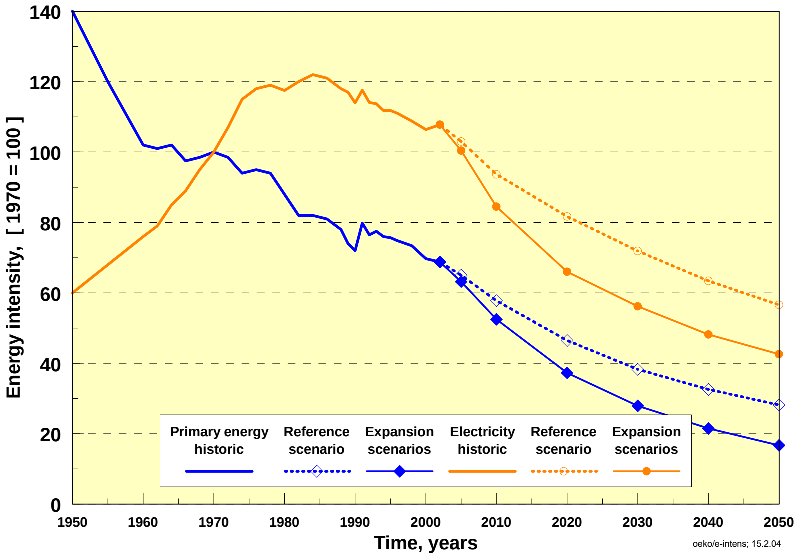


Fig. 16: Energy intensity curves (primary energy consumption/GDP; electricity/GDP) since 1950 and in the reference scenario and extension scenarios until 2050 (primary energy consumption/GDP (1970) = 9.93 GJ/1000 €$_{2000}$; electricity/GDP (1970) = 0.787 GJ/1000 €$_{2000}$; figures for 1970 = 100)

From a technological point of view, much more far-reaching efficiency improvements are possible. The annual efficiency improvements assumed in the extension scenarios, expressed as annual averages for the period 2000 – 2050, are therefore 2.6%/a for primary energy consumption (primary energy calculated by the substitution method), in other words almost double the long-term past trend, and 1.8%/a for electricity consumption, an increase of 50% on the past trend (Fig. 16, lower lines). On these assumptions, the implementation of the **efficiency strategy** means that about one third of present-day primary energy consumption will not be needed at all **(Fig. 17**). The resulting reduction in CO_2 emissions by 2050 is in the region of 280 million t/a. **Thus an effective efficiency strategy is indispensable** if the reduction target for 2050 is to be achieved on time and in an economically acceptable fashion.

(2) Substantial efficiency improvements make it easier to move into renewables

Speeding up improvements in efficiency is favourable from an economic point of view, since in many cases – calculated on a useful life basis – it is more cost-effective than producing additional energy. Some of the savings potential is still economic even with shorter amortization periods, which results in direct cost savings if it means that the construction of new energy production installations can be avoided. This has been shown for the electricity sector. Even given low and moderate energy price increases, the total annual cost of an extension strategy coupled with increased efficiency (20% reduction in electricity consumption compared with the reference scenario) is, at around 32 billion €/a, only slightly higher than for the reference case (30 billion €/a). In the case of the higher price variant they are in fact lower (35 billion €/a compared with 36 billion €/a, or 39 billion €/a in the case of CO_2 sequestration). Much the same is true of the building sector, where active solar measures do not usually make sense until measures have been taken to improve the energy efficiency of the building. **Thus a strategy of increased energy efficiency also has the effect of indirectly compensating for some of the additional cost differential of expanding renewable energy systems.** For this reason its successful implementation, especially in the period 2000 – 2020 when the absolute differential costs of expanding renewables is greatest, is of special importance for a macroeconomically acceptable reorganization of the energy system.

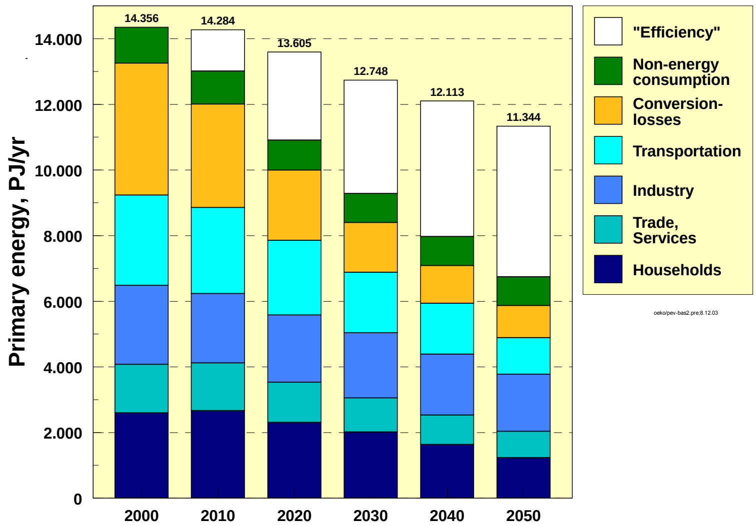


Fig. 17: Trends in final energy demand and the resulting primary energy (efficiency method) in the extension scenarios. "Efficiency" is taken to mean the additional reduction compared with the reference scenario that can be achieved by means of increased efficiency measures and the increased extension of combined heat and power generation.

(3) Combined heat and power (CHP) generation is an important mainstay of the extension of renewable energy systems.

One particularly effective way of improving efficiency in the conversion sector is combined heat and power generation (CHP). Although any increasing in the efficiency of condensing power plants is useful, even great successes here cannot approach the efficiency effect of CHP with overall efficiency levels of up to 95 percent. Its spectrum of applications and its potential can be considerably extended by introducing distributed CHP technologies (combustion engines, gas turbines) and their further developments (fuel cells, Stirling engines, micro gas turbines). Further extension of (distributed) CHP is even compatible with substantial reductions in heating requirements and also offers considerable scope for extension. Even with only a slight increase in usable heat energy (from the present 180 TWh/a to around 200 TWh/a), the electricity yield can **increase from the present 80 TWh/a to around 200 TWh/a** due to the expected increase of the electricity to heat ration**.** In connection with the extension of renewable energy systems, further extension of CHP is of special importance. The distributed nature of modern CHP technologies caters for the utilization of renewables, which in many fields is also distributed, and can help to prepare structures for the latter. A symbiosis of CHP and renewable energy systems is therefore advantageous, both in the power sector (virtual power plants) and in the heat sector (local heating systems, small stand-alone networks).

(4) BASIC and NatureConservationPlus scenarios – Structural framework conditions and nature conservation requirements influence extension strategies

Apart from the efficiency improvements assumed here, renewables must contribute a further reduction of approximately 220 million t/a CO_2 by 2050 compared with the reference case if the climate protection objectives are to be achieved on time. Four scenarios are developed to represent different extension strategies and their effects. To this end the **BASIC scenarios** exploit the **technical and structural potential.** The **restrictions on potential** resulting from further nature conservation requirements are represented in the **NatureConservationPlus** scenarios. Their effects are felt in the fields of biomass, onshore wind energy utilization and hydro power.

The various utilization options for biomass have a considerable influence on the shaping of the extension strategy for renewable energy systems (**Fig. 18**). In the **BASIC I scenario** preference is given to their stationary utilization insofar as the structural possibilities of the heat market permit, which results in about 1,200 PJ/a fuel supply for CHP plants and heating systems by the year 2050 and at the same time permits the production of 300 PJ/a of bio fuels. An extension path that meets not only the target of doubling power and heat from renewables by 2010 but also the target of maximum growth of the automotive fuel component **(BASIC II scenario)** would result in some 420 PJ/a of automotive fuels by 2050. Thus in the BASIC II scenario there would be about 1,000 PJ/a of biomass remaining for stationary use.

The scenarios NatureConservationPlus I and II are similarly defined. If stationary utilization is to be maintained on a similar scale to BASIC I, only about 100 PJ/a of fuels for transportation is left over **(NatureConservationPlus I scenario)**. If the scale of transportation fuel production is to be much the same as in BASIC I **(NatureConservationPlus II scenario)**, the biomass potential for heating is reduced to 800 PJ/a. Since at the same time large areas effectively do not become available until after 2010, transportation fuel production makes a very restrained start in these scenarios. In all scenarios the residual substances are used entirely in the stationary sector.

The key data for the scenarios for electricity production, heating fuel production and automotive fuel production show that in the scenarios BASIC I and II the directly usable contributions made by renewables (44% of total primary energy; approximately 8.5 times the present level) are sufficient to achieve the targeted reduction in CO_2 emissions to around 200 million t/a by 2050. Indirect utilization via hydrogen is not yet needed. This is partly due to the considerable potential of biomass in the BASIC variant. In the BASIC scenarios, biomass covers about 24% of final energy consumption in 2050 (in terms of current final energy consumption this is about 12%).

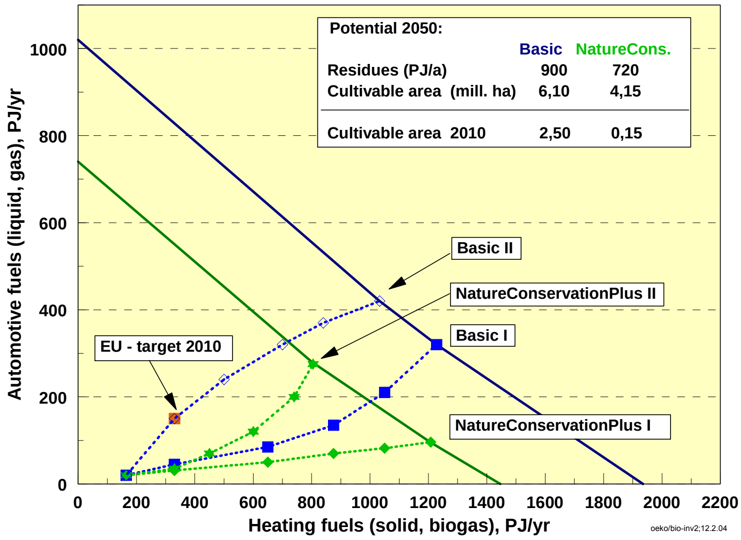


Fig. 18: Two paths each for possible utilization of the biomass potentials determined for stationary and mobile utilization in the scenarios BASIC and NatureConservationPlus. Each mark corresponds to an interval of 10 years, starting in 2000.

The reduction in biomass utilization specified for the NatureConservationPlus scenarios calls for compensation in other quarters if the targeted objective of an 80% reduction in greenhouse gases is to be achieved in the face of the calculated total demand for final energy. The next option that it makes sense to use is to take the additional potential for electricity generation from renewables that is available on a large scale and make use of it for **hydrogen production from about 2030 onwards**. In the NatureConservationPlus I scenario a further 70 TWh/a of electricity is used to produce 190 PJ/a hydrogen from electrolysis as fuel. In the NatureConservationPlus II scenario, 150 PJ/a hydrogen is used to supply distributed CHP plants, in which it is converted to power and usable heat with an efficiency of 90% and an electricity to heat ratio of 1.25.

(5) It is time to pave the way for investment in our future electricity supply

The extension scenarios (e.g. **Scenario NatureConservationPlus I)** provide for a total of 80 GW of new power plants **by 2020**, of which 45 GW comes from installations for utilization of renewable energy sources. Of the 35 GW plants fired by fossil fuels, 15 GW are coal-fired power stations (of which 10 GW as CHP plants), 13 GW are gas-fired power plants (of which 6 GW as CHP) and 7 GW are gas-fired small CHP plants. From 2030 onwards the gradual addition of plants for hydrogen production makes itself felt. This gives rise to a total new installed capacity **by 2050** of 144 GW, with a renewables contribution of 100 GW. This leaves a further requirement of 44 GW from fossil-fuel power plants, of which 32 GW comes from CHP plants in addition to the 12 GW from CHP plants fired by biomass. The resulting power plant structure will be utilized for an average of 3 400 h/a in 2050, and will generate 504 TWh/a of electricity. The proportion due to renewable energy systems is 68% (without biomass CHP = 56%; **Fig. 19**), and the CHP percentage is around 40%. In this scenario 65 TWh/a, or nearly 20%, of the total of 340 TWh/a from renewables in 2050 is provided via the European electricity network from high-yield European and North African sources. This is in line with the logic of such extension scenarios, since the renewables growth assumed here only makes sense in a pan-European network and it is only in this way that development and utilization of potential is possible on an economic basis. This offers benefits for both the supplier countries and the importing countries. In particular it is of great significance for affordable hydrogen supply.

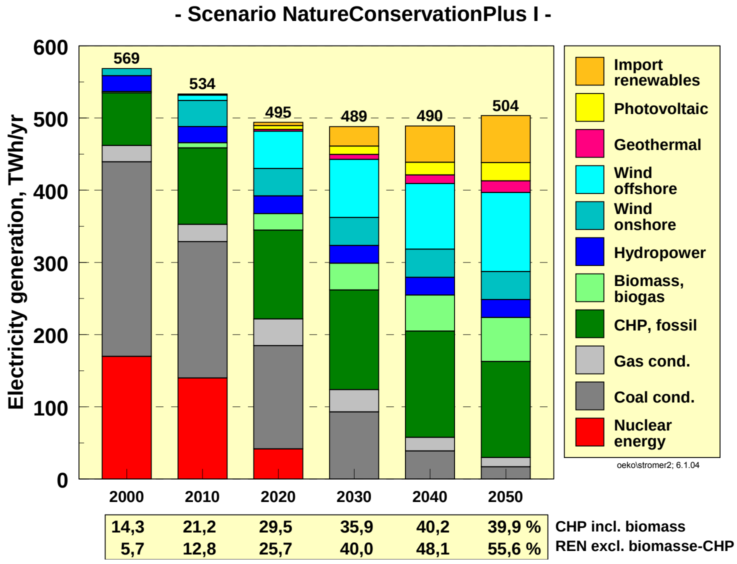


Fig. 19: Power generation by power plant types and energy sources in the NatureConservationPlus I scenario. The increase from 2030 onwards is due to the provision of electricity for hydrogen production (2030 = 10 TWh/a, 2040 = 33.5 TWh/a and 2050 = 70 TWh/a).

The extension strategy proposed here for the power sector can only be implemented on schedule if "timely" investment is made in the relevant systems and power plants. The investment requirements that result from the age structure of the existing power stations, the discontinuation of nuclear energy and the course of future demand for electricity must therefore be distributed in a balanced fashion among the options under discussion. Compared with the reference situation, in which 65% of the additional capacity required by 2020, or some 45 GW, is produced by condensing and CHP power plants, a very different approach must be taken to initiate the development described here. **On this basis the guiding principle for investment in power generation during the period up to 2020 should be that roughly a quarter each of electricity requirements should be (a) avoided by improving utilization efficiency, (b) produced by distributed co-generation, (c) produced by renewable energy systems and (d) produced in large-scale condensing and CHP power plants.** This corresponds to the construction of additional capacity of around 20 GW in major power plants and large-scale CHP on the one hand and small-scale and micro CHP on the other hand, and 40 GW in systems for the utilization of renewable energy sources.

(6) Power generation technologies for geothermal and solar thermal energy have yet to be established.

Two power generation technologies capable of making a significant contribution to reliable and inexpensive generation of power from renewable energy systems are not yet established today: power generation from geothermal energy and from solar thermal systems. Both are needed after 2020/2030 in order to supply inexpensive electricity in substantial quantities. If successful, geothermal energy offers substantial power generation potential. To date, however, not enough reliable data is available on its technical and economic performance. Further demonstration projects should therefore be set in motion as a matter of high priority, so that **a decision can be taken not later than 2010** about the conditions under which electricity generated from geothermal energy can be made available in the medium term. If it emerged that larger contributions to inexpensive power generation were possible, this would have a considerable influence on future power plant structure (smaller storage and compensation requirements, no need for hydrogen from the point of view of reliable power supply).

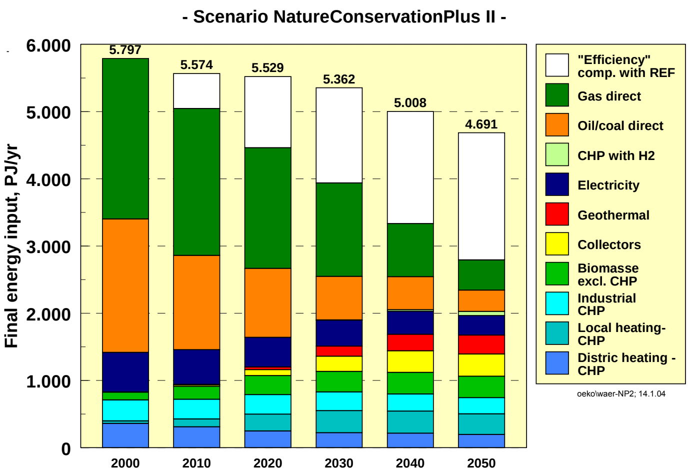
In view of the necessity in principle for a large-scale European electricity network for utilization of renewable energy sources, high priority should also be given to pushing ahead with the initiation of solar thermal power plant projects in Mediterranean countries and making a success of them. In this context, **Germany's present pioneering role should be exploited** to integrate the European Union and other Mediterranean countries in the necessary market introduction process. The first extension objective targeted should be the construction of at least 5,000 MW capacity within 10 years, in order to ensure rapid achievement of the potential cost reductions here as well.

(7) The heat market has a very urgent need for an efficient promotion instrument for large-scale plants and local heat supply systems.

There are three important starting points for the restructuring measures necessary in the heat supply sector: the great savings potential for space heating in existing buildings, the need to be able to utilize the heat produced by the targeted extension of combined heat and power generation, and the present situation with regard to renewable energy supply. The supply situation is characterized by less favourable initial conditions than is the case with power generation. Although some 12% of final energy demand for heat comes from CHP, the contribution made by small local networks is still very small at 0.7%. The contribution by renewable energy systems (excluding biomass for CHP plants) is still very small at 2.5% und and consists largely of individual heating systems for fuel wood. In the extension scenarios the contribution made by CHP heat (which includes the use of biomass in CHP plants) increases from the present 12% to 21% in 2030 and nearly 27% in 2050 (**Fig. 20**; scenario NatureConservationPlus II).

The potential competition between CHP and renewable energy systems in a shrinking heat market does not make itself felt until 2030, since adequate scope for substitution is offered by the very large heat supply segments totalling 85% which are currently covered by oil, natural gas and coal. After that there is a (slight) displacement of fossil-fuel CHP heat by other heat (solar thermal, geothermal) from renewable sources. In the NatureConservationPlus II scenario, renewable energy systems thus cover 35% of demand in 2050 (or 42% including the CHP biomass classified under CHP plants). Such contributions by renewables in the heat market call for a marked expansion of local heat supply systems, which currently account for less than 1% of heat supply. A desirable target would be in the region of 30-35% for local heat supply systems, which means that together with the existing large-scale district heating systems some 40% of heat supply in 2050 would be provided via large and small networks. For renewable energy sources the proportion due to local heat supply systems would then be as much as 75%.

It can be seen from the scenario analyses that **for the heat market** – starting from less favourable initial conditions – **it is necessary to set in motion a trend in the extension of renewable energy systems that displays similarly dynamic growth** to the present trend in the power sector. The present growth in the heat market is, in view of the existing promotion instruments, largely confined to small-scale systems where the potential, especially in the case of collectors and geothermal energy, is limited and the operating costs are relatively high. There is therefore an urgent need to **create a "Heat Act"** that is primarily tailored to the market introduction of larger systems and local heat supply systems. This act should be linked effectively with improved promotion of combined heat and power generation. This could be achieved by specifying as a core element the promotion of extension of (local) heating networks as a central infrastructural measure and demanding corresponding criteria for the heat to be input into them.



2000	2010	2020	2030	2040	2050	
12,3	14,3	16,7	21,0	24,0	26,7 %	CHP incl. biomass
2,6	4,5	9,4	17,5	27,3	35,0 %	REN excl. biomass CHP

Fig. 20: Structural changes in the heat market in the NatureConservationPlus II scenario as a result of building improvement and other efficiency measures and the extension of combined heat and power generation and of renewable energy systems by 2050.

(8) Transport – optimum use of renewables on the basis of improved efficiency

In the extension scenarios, the future development of the transport sector is initially characterized above all by marked efficiency improvements for all means of transport and by (limited) shifts of traffic volume from the roads to other means of transport. This makes it possible to halve fuel consumption by 2050 compared with the reference scenario. With a share of 0.9%, renewable energy sources are currently least well represented in the transport sector. Two strategies are reflected in the scenarios: the **scenario BASIC II represents the upper limit for the extension of renewable energy sources in the transport sector**. In line with the objective, the biomass crop potential is not subject to nature conservation reductions and is used for preference in the transport sector, which combined with the efficiency potential implemented and the rapid growth quickly results in large shares for renewable energy sources. At 37% or 420 PJ/a, more than one third of the fuel base in 2050 consists of renewables. **The lower limit for this strategy is the scenario NatureConservationPlus I (Fig. 21).** Here the reduced biomass potentials (residual substances and energy crops) are used primarily in the stationary sector, resulting in a relatively small bio fuel contribution of nearly 9% (100 PJ/a) in 2050. However, in order to achieve an appreciable renewables contribution in the transport sector, electrolytically produced hydrogen is also supplied from 2030 onwards, so that by the year 2050 roughly one quarter of automotive fuel requirements are met from renewable sources. In this scenario of delayed extension of renewables in the transport sector, it is not until after about 2030 that their share reaches a figure of more than 5% that is relevant for the energy economy.

The scenario makes it clear: **Only if substantial reductions in consumption and successful improvements in efficiency are achieved will renewable energy sources be able to meet an appreciable share of requirements in the transport sector in the foreseeable future and at reasonable cost.** Thus a strategy that attempts to replace fossil automotive fuels without making substantial changes in mobility structures and vehicle-specific energy expenditure will stand no chance of being successful.

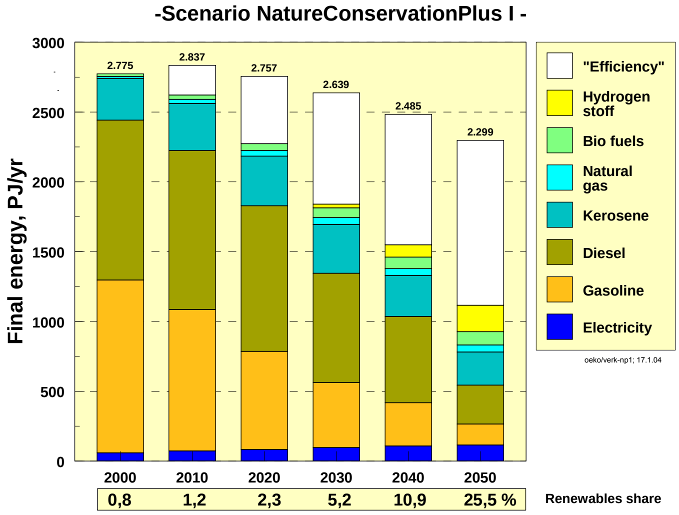


Fig. 21: Structural changes in automotive fuel supply in the NatureConservationPlus I scenario, showing the relevant shares due to renewable energy sources up to 2050.

(9) Biogenic residuals should be used for stationary generation of power and heat, and bio fuels should be introduced sparingly.

Biomass can make an important contribution to energy supply in the future. If one applies the nature conservation recommendations derived here with regard to guidelines for environmentally sound utilization of biomass, it is initially only possible to use residual substances, since it is only from about 2020 onwards that large areas will be available for growing energy crops. This has an influence on the time path for biomass utilization and on the most appropriate allocation to the utilization segments. It emerges that **preference should be given to utilization of biogenic residual substances in the stationary sector.** For one thing the usable energy yields are higher than in the transport sector, and for another, the transport sector has a much greater backlog to catch up in the restructuring field to achieve generally more efficient mobility.

Moreover, bio fuels give rise to relatively high differential costs in the medium term, since the straight supply costs of present-day fuels are low, at around 2.5 cents/kWh. These differential costs are reflected in lost petroleum excise duty revenue. Pushing ahead with supply in line with the present European objective gives rise to differential costs of around 2.5 billion €/a in 2010, increasing to around 3 billion €/a in the medium term (2020 /2030). What is more, under most marginal conditions the CO_2 prevention costs for bio fuels are distinctly higher than for bio energy sources for stationary use. For this reason the temptation to push the growth of bio fuels too hard should be resisted, despite the relative ease of gaining political acceptance for the promotion option of “exemption from petroleum excise duty”. It is recommended that **the timing of bio fuel introduction be guided by the availability of the crop growing areas having regard to nature conservation aspects.** The areas becoming available in the course of time for growing energy crops having regard to nature conservation aspects (0.15 million hectares (ha) in 2010; 1.1 million ha in 2020 and subsequently rising to 4.1 million ha in 2050) make it possible to supply between 80 and 130 PJ/a of bio fuels in 2010, increasing to around 300 PJ/a by 2050. This restrained introduction limits the differential costs to between one third and a half of the above figures.

On the assumption that residual substances are used entirely in the stationary sector, some 65 - 75% of the crop area is available for automotive fuel production in the long term. In terms of the total potential of the biomass, this corresponds after exploitation of the potentials to a **share of 20 - 25% for the transport sector**. If higher automotive fuel contributions are sought, especially in the period before 2020, this either takes place at the expense of the nature conservation requirements or makes it necessary to import bio fuels. Alternatively, biogenic residual substances could be used to produce automotive fuels at the expense of stationary use and with a lower yield of final energy.

(10) There is a need to harmonize and to a large extent speed up the growth processes of renewables

In the past, renewable energy sources have been mobilized to varying extents. To date, however, only onshore wind energy has profited from the existing energy policy measures to such an extent that it has become established as a relevant option in terms of energy economics. However, since all technologies are needed for extension at optimized cost and it is necessary to develop all sectors in the long term, it is important to ensure harmonization of the speed of growth of the individual technologies. **The growth process should be completed as quickly as possible, i.e. within a decade**, to ensure that the downward trend in costs makes itself felt as quickly as possible. To this end the following market volumes should be targeted on the domestic market in 2010 and 2020 **(Table 1)**:

Table 1: Annual turnover of renewables utilization technologies required at present and in future for effective exploitation of further cost reduction potentials

	Wind offshore MW/a	Photovoltaic MW/a	Collectors 1000 m²/a	Geothermal MWel/a; MWth/a	Biomass, biogas MWel/a; MWth/a
2003	Onshore: 2,600	120	850	0.3/10	120/600
2010	500	250	1,900	20/100	200/2500
2020	1,500	550	10,000	50/900	300/3500

Whereas in the wind energy sector the rapid growth of recent years will give way to a stabilization of the market, largely through repowering and offshore installations, all other technologies still have to undergo substantial market growth before they can be considered from an energy point of view. Power generation from biomass has reached this threshold. Until the year 2010 the necessary increases, with the exception of geothermal energy, are around a factor of 2. The real market growth phase will continue until 2020. **By then, however, annual market volumes will have to be increased by a factor of 5 to more than 10**. In 2010 the resulting annual investment volumes (for power and heat generation from renewable energy sources) are likely to be only slightly above the record year 2002 at nearly 6 billion €/a. Once all renewable energy systems are established in the market (from about 2020 onward) the **annual investment volume will be around 13 billion €/a.** Sluggish extension of the percentage due to renewable energy systems (reference scenario) leads to shrinking markets (in the case of wind energy to a virtual collapse of the market), and a corresponding lack of significant incentives to cost reductions and further technological development.

(11) Promotion instruments must be keyed to technology and cost reduction potential

In the power sector, renewable energy systems could in the long term, in an optimized mix, supply large quantities of electricity at an **average cost of around 5 to 5.5 cents/kWh** (ex installation). Even in the medium term (around 2020) these costs could fall to below 7 cents/kWh, (**Fig. 22**). In the space of only a decade these costs have already fallen from around 16 cents/kWh in 1990 to less than 10 cents/kWh in 2000. Promotion instruments that stimulate technology-specific cost reductions, such as the Renewable Energy Sources Act, should continue in existence as long as substantial cost reductions can be exploited. Once most technologies have reached a low and relatively similar cost level (around 2015 to 2020), it could be advisable to switch further market assistance to climate policy instruements.

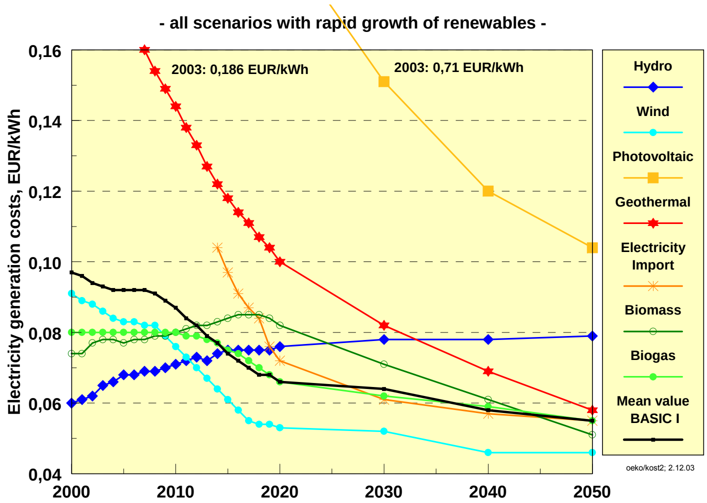


Fig. 22: Representative cost curves of the individual mixes of reference technologies (technology groups; new installations from 2000 onward) for individual renewable energy systems, and cost curve of the mean of the entire mix in the scenario BASIC I, (interest rate 6%/a).

Even if the present cost reduction curve continues, **photovoltaic** will need substantial financial support for a considerable time to come. The electricity supply costs of new systems in Germany are likely to reach around 20 cents/kWh (15 cents/kWh) in 2020 (2030), and in the long term (2050) a price of around 11 cents/kWh is expected. The differential costs in the extension scenarios reach a maximum of around 1.5 billion €/a (specifically 0.3 cents/kWh) in 2030. Thus from about 2020 onward, a Renewable Energy Sources Act – if it still existed – would become a straight photovoltaic promotion instrument. This could then have an adverse effect on the establishment of all other power-generating renewable technologies in the energy economy, at least as far as the political and social debate is concerned. It is therefore recommended, in view of the fact that by this time the foreign markets for photovoltaic are already likely to be very large, that further domestic promotion should then be provided from the point of view not of energy policy, but of **safeguarding export markets and industrial policy**.

(12) A reliable assessment of future costs calls for orientation to climate protection objectives.

The cost of electricity production, which currently stands at an average of 3.85 cents/kWh in terms of power supply at the medium voltage level, is bound to increase in future as a result of new power station construction and fuel price increases. If at the same time one assumes a steady reduction in CO_2 emissions due to power generation from the present 335 million t/a to 75 million t/a in 2050 as a result of an electricity mix of efficient power and CHP plants, distributed micro CHP plants and fuel cells in accordance with the extension scenarios, and a marked increase in the share due to renewable energy systems, this provides an appropriate basis for comparison of future electricity prices in line with the energy policy objective. In 2050 the extension scenarios, depending on the assumptions about fuel price increases, fulfil this objective with average electricity production costs of between 6.2 cents/kWh and 7.2 cents/kWh (**Fig. 23**; in terms of the medium voltage level because of input from distributed systems). In the reference case this requirement can only be met with CO_2 sequestration technologies (assumed from 2020 onward), which – assuming that this technology can be used at reasonable cost and on an environmentally sound basis and that the present cost estimates are reliable – results in average electricity production costs in 2050 of around 8.5 cents/kWh. **Thus an energy supply system that continues to rely on fossil fuels is considerably more expensive in the long term than steering a new course towards efficiency improvements and renewable energy sources**.

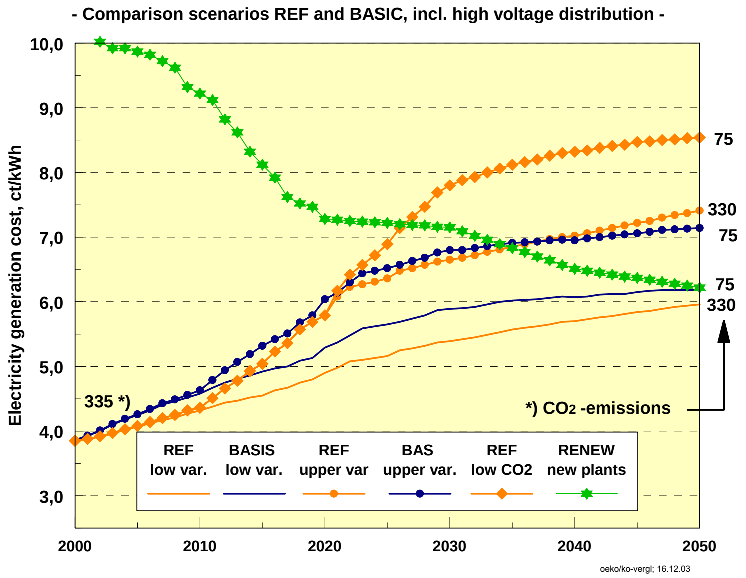


Fig. 23: Comparison of average electricity production costs in German power supply sector (including high-voltage distribution) for different variants of energy price trends, and with a typical cost curve for new installations for utilization of renewables (low CO_2 = sequestration of CO_2 from fossil-fuel power plants from 2020)

Only if one dispenses with the CO_2 reduction requirement and there is at the same time only a relatively slight increase in fuel prices, does the reference scenario offer marginally better electricity costs in the long term. If the increases in fuel prices are rather higher, the cost of electricity comes out the same in the long term. **For this reason a comparison of “fossil” and “renewable” systems that is meaningful from a climate protection point of view should make a start today on anticipating the CO_2 prevention costs.** Instruments that make these costs visible, such as trading in CO_2 certificates or an “eco-tax” designed on the basis of climate protection criteria, promote developments on the lines of the extension scenarios.

(13) Differential costs of renewable energy systems – a useful advance input by industry and society.

The additional uptake of renewable energy technologies in the energy system means that for the foreseeable future there will be additional expenditure over and above the estimated costs for conventional energy production. The level of the differential costs for a technology, and their development over time, depends not only on the individual price difference, but also on the relevant market volumes of the technologies in question. The **electricity sector** (**Fig. 24**, left) will continue to be dominated for the foreseeable future by wind energy. After 2015 there is a very rapid fall in its differential costs, because the cost differences approach zero despite large market volumes. Between 2015 and 2020, wind energy will be replaced by the differential costs of photovoltaic systems. Around 2025 (2020), wind energy utilization will become cheaper than conventional power production in the middle (upper) price variant. Only relatively small differential costs are on the whole caused by biomass, geothermal energy and imported electricity. With the exception of hydro power and photovoltaic, all renewable energy technologies will become cheaper than conventional power production during the period in view. In the middle price variant (without active climate protection measures), the total differential costs of electricity production briefly rise to 4 billion €/a, before falling steadily towards zero. Shortly before 2040 the total curve crosses the zero line. By 2050 the annual reduction in costs compared with conventional electricity production (fossil-fuel plants in reference scenario) is already in excess of 3 billion €/a.

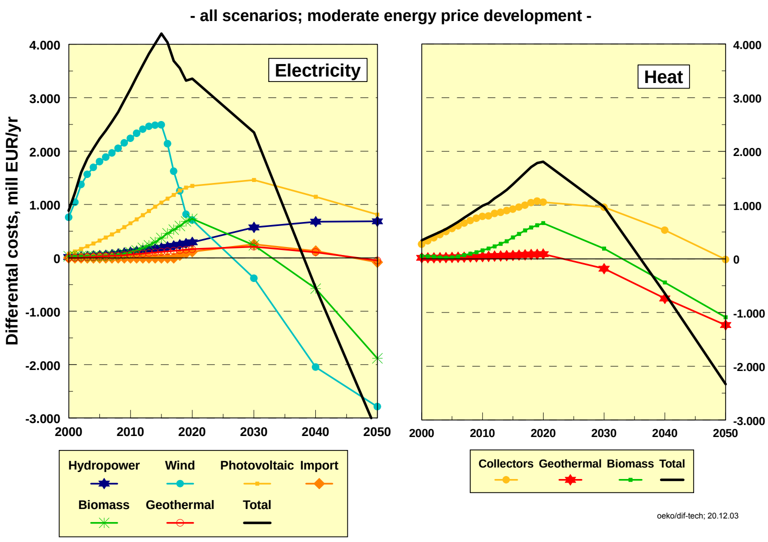


Fig. 24: Differential costs of the individual technologies given moderate price development (i.e. without active climate protection measures), using the BASIC I scenario.

In the **heat sector** (**Fig. 24**, right), it is the differential costs of collectors that predominate throughout the entire period. For geothermal energy and also for biomass (in view of the much greater energy volume), by contrast, they are relatively small and reach zero around 2030. The maximum differential costs of 1.8 billion €/a are reached around 2020; by 2050 heat supply from renewable energy sources are already nearly 2.5 billion €/a cheaper than supply based on fossil fuels.

The differential costs in specific form indicate what cost differences must be added to the energy sources traded in the various sectors if these advance inputs are to be paid for by a general charge. At present, for example, this figure in the Renewable Energy Sources Act is around 0.3 cents/kWh_{el} for electricity. In the electricity sector the specific differential costs show a temporary rise to 0.8 cents/kWh_{el}, (**Fig. 25**) which is increasingly contributed to by biomass and photovoltaic systems in addition to the continuing increase for wind energy.

Since the differential costs for photovoltaic systems continue to rise until 2030, this delays the fall in the differential costs in the power sector. In the middle price variant, no further differential costs occur in this scenario from 2040 onwards (in BASIC I from 2037); this reduces the overall cost of power supply compared with a scenario without the extension of renewable energies. This point in time moves forward to 2028 in the case of a comparison with CO_2-free fossil-fuel power plants. If price increases are small (lower variant), however, the curves may not intersect until around 2050.

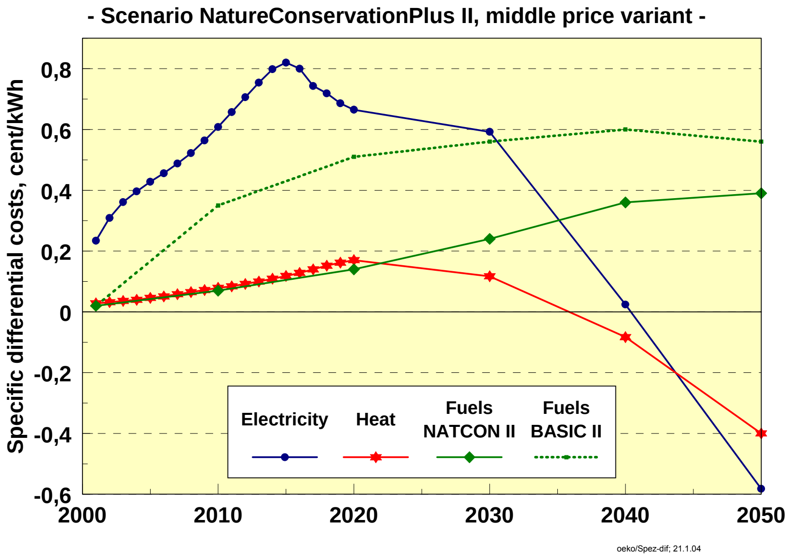


Fig. 25: Curves for the specific differential costs of renewable energies in the NatureConservationPlus scenario (for automotive fuels also BASIC II scenario) for the middle variant of applicable prices (i.e. without active climate protection measures) for the sectors power supply, heat supply and automotive fuel supply.

In the heat sector one encounters very low specific differential costs, with a maximum of 0.17 cents/kWh_{th} and an average between 2000 and 2020 of 0.10 cents/kWh_{th}. This makes it easier to create allocation-oriented promotion instruments, which have already demonstrated their effectiveness in the case of the power market. Specifically for the promotion suggested above for heat input into local heat networks from CHP and renewable energy systems, a construction of this kind might be very suitable. Initially the specific differential costs of automotive fuel supply from biomass with a gradual increase in fuel volumes are small at 0.10 to 0.20 cents/kWh. As a result of the marked increase in volume accompanied by falling differential cost, they increase to nearly 0.40 cents/kWh by 2050 (corresponding to 4 cents/l gasoline equivalent). In the BASIC II scenario with accelerated extension of bio fuels they reach this figure as early as 2010 and rise to a maximum of 0.6 cents/kWh by 2040.

(14) Use of effective climate protection instruments to speed up the benefits of a long-term precautionary strategy

On an overall balance, even with the assumed moderate price trend for fossil heating and automotive fuels, all extension scenarios show negative differential costs starting in 2030, or at the latest 2040; in other words they are then cheaper than an energy supply system that continues to be based on fossil energy sources. Active intervention in pricing in the interests of effective climate protection (e.g. through emissions trading, CO_2 taxes etc.) speeds up this process considerably, reduces the differential costs and brings forward the point when macroeconomic benefits are reached. Whereas for the middle price trend the cumulative differential costs of the extension of renewable energy systems for the period 2000 to 2050 compared with the reference scenario are between €36 billion (BASIC I) and about €50 billion (NatureConservationPlus I and II) **(around €32 billion on a discounted basis for all**

scenarios), in other words between 0.7 and 1.0 billion €/a, the cumulative differential costs in the case of a surcharge of 15 €/t CO_2 on fuel prices come to zero **(€19 billion on a discounted basis),** in other words their effect on costs for this period is practically neutral. If one makes the comparison on the – strictly appropriate – basis of equal CO_2 emissions (CO_2 sequestration), the macroeconomic benefits are clearly in favour of the extension scenarios. On a long-term precautionary view, the extension scenarios described here are thus not only advantageous from the point of view of climate protection aspects and the other criteria explained in the guidelines**, they are also to preferable on a macroeconomic view to a strategy that relies primarily on fossil energy sources**. It is therefore advisable to focus attention more closely than in the past on the political task of taking precautions as a central justification for energy policy objectives. Further studies of the "external" costs of present-day energy supply, and of the possibilities of taking account of them in macro- and microeconomic decision processes, could support this strategy.

(15) Optimum mobilization and use of advance inputs is necessary to enhance the macroeconomic benefits.

The greater part of the advance inputs for the extension of renewable energy systems has to be provided **by the year 2020**. Until that time, this expenditure is subject to relatively little influence from (subsequently effective) increases in the price of fossil energy sources and the impacts of climate protection instruments, being dominated instead by the necessary growth dynamic of the individual technologies. The real energy policy task is to safeguard these advance inputs – which on a day-to-day policy view will have to be made for a relatively long time. **However, these advance inputs are certainly not an "unreasonable" macroeconomic burden.** In the middle price variant (i.e. without active climate protection) they come to a maximum of 2.7% (around 2015) of the total annual cost of energy supply, and the average figure for the years 2000 to 2020 is around 2%. On a sectoral basis they are highest for electricity with a maximum of 9% (average 6.7%) and lowest in the heat sector with a maximum of 2% (average 0.9%). For all sectors together, the cumulative figure for this period is around **€85 billion** (€55 billion for power; €20 billion for heat and €10 billion for automotive fuels given restrained introduction), in other words an average annual figure of 4.25 billion €/a. In the same period the cumulative investment in systems for the utilization of renewable energy systems amounts to about **€170 billion.** In the long term, investment in maintenance and further extension of the systems in line with the extension scenarios settles down around 18 to 20 billion €/a depending on the intensity of the introduction strategy for automotive fuels from renewables, with differential costs which are then virtually negligible. In relation to the comprehensive benefits that this extension strategy can be expected to bring in the long term, the necessary advance inputs can be described as a very sensible investment in a sustainable energy future. **It is important from an energy policy point of view to provide effective support for this advance inputs phase by means of highly effective and acceptable instruments**, which in view of the scale of the funds to be mobilized can essentially only be shared-costs-based instruments compatible with market economy principles. Such instruments should be subject to constant adaptation and review, to ensure that the diverted funds are put to the best possible use for establishing the energy supply structure described here.

(16) Timely integration of distributed utilization of renewable energy systems in a supraregional and trans-European utilization system is essential.

It is obvious that in largely deregulated energy markets, an extension strategy for renewable energy systems that is as far-reaching as the one described here can only be implemented in the closest possible cooperation and consultation between neighbouring countries and in a spirit of partnership with all potential interested parties and beneficiaries. Early or "timely" integration of these **great possibilities of pan-European (with the Mediterranean**

countries even wider) joint use of renewable energy sources must form part of any extension strategy. To this end the usable energy must be supplied in a form that permits transport over long distances at reasonable cost (electricity, in the longer term hydrogen).

Such a strategy has **several obvious advantages**:

- The potentials of renewable energies (especially solar radiation) that can be tapped in this way can almost completely meet the energy supply requirements of all Europe and the Mediterranean countries, thereby more than offsetting regional limitations, whether due to nature conservation or economic considerations.
- From a macroeconomic point of view it is advantageous to develop and use the most freely available and least expensive potentials of renewable energy sources. These include in particular onshore and offshore wind energy potential along the Atlantic coasts and solar potentials in Southern Europe and North Africa. Including long-distance transport, the resulting electricity can be supplied on a long-term basis at lower cost than some of the domestic potential.
- Large-scale networking and the combination of various kinds of renewable energy systems facilitate load equalization and reserve capacity supply within the electricity network. Use could also be made here of the potential of geothermal energy (Iceland) and hydro power (Scandinavia). Regionally and locally optimized distributed supply structures could emerge below this network level.
- The political and economic effects of such cooperation could have extremely positive consequences for the enlarged European Union and the countries of North Africa and the Middle East. They enable the two groups of countries to create a viable energy supply system for the future and at the same time to ensure economic development for the countries bordering on the southern shores of the Mediterranean, thanks to the availability of large quantities of stable-cost energy both for their own use and for later export on similar lines to present-day exports of oil and natural gas.

Such a strategy can be successful if European countries, especially Germany, **continue to systematically pursue the adopted national course of utilizing renewable energy sources, thereby having a pioneering effect** and providing the necessary advance inputs of a technological and financial nature. On the other hand they should, in parallel, also support all opportunities for initiating as early as possible in the potential deployment countries the process of effective use of renewable energy sources for those countries' own needs, in order to ensure convergence and synchronization of not only technological and structural but also political and economic interests.

(17) When promoting "hydrogen strategies" it is important to observe the right order and priority.

In the foreseeable future the introduction of hydrogen as a source of energy is not necessary to achieve the principal energy policy objectives. **Hydrogen is not a requirement for speeding up the necessary "increase in conversion and utilization efficiency" and the "introduction of renewable energy systems"; it is rather a result of this strategy.** It becomes more important as these individual strategies begin to come up against their structural, economic or potential-oriented limits. In the weighting of the contributions of "efficiency" and "CHP" assumed in the scenarios, it is advisable to plan for utilization of hydrogen from the year 2030 onward, if the biomass potentials defined from a nature conservation point of view are not to be exceeded. In that case it will make about a 4% contribution to meeting final energy requirements in 2050. Among the configurations selected in the scenarios, the use of hydrogen is the most practical option for overcoming the limits of direct use of additional heat or power from renewable energy sources. If there is any substantial change in these conditions, this will influence the necessary hydrogen contribution. Greater restrictions on biomass or less “base load” from electricity from renewable energy sources (e.g. little electricity from geothermal power or solar thermal power plants) make it necessary to increase the hydrogen share. A generally less successful efficiency strategy – especially in the transport sector – also means increased hydrogen requirements. By contrast, opposite movements in these fields reduce the hydrogen requirement. The structural analyses also show that if there is a further increase in the share of renewable energies after 2050 the importance of hydrogen grows rapidly, and if fossil energy sources are replaced completely the share of final energy consumption due to hydrogen will probably have to be in the region of 25 - 30%. **Thus strategies for the further development of hydrogen production and utilization technologies should not be uncoupled from introduction strategies for renewable energies,** but must on the contrary be designed as an inherent, though not yet time-critical component of a changeover to a supply system based entirely on renewable energy systems.

(18) A “timetable” for the extension of renewable energy systems must be prepared and optimized separately for each supply sector.

The individual energy supply sectors are perceived by the public in different ways. The greatest interest is focused on the electricity sector, followed by the transport sector. There is usually relatively little interest in the heat sector, although it makes the biggest contribution to CO_2 emissions. The initial conditions for the extension of renewable energy systems are just as varied, owing to different starting levels (2003: power 7.9%; heat 4.1%, automotive fuels 0.9%), different structures and combinations of actors, widely differing obstacles and also very different kinds of promotion instruments. It follows from this that the future development of renewable energies will take different courses in the individual sectors. From the point of view of energy policy and energy economics, it is important to make sure that each sector makes an adequate contribution to climate protection and to macroeconomically efficient energy supply, and that the technologies which are most effective in climate protection terms and most cost-effective are mobilized at the right time and with the necessary intensity. Also, in the interests of maximum diversity of technological and structural options, no sector should have too dominant a position and no sector should be left too far behind. **Fig. 26** shows the **recommended “growth timetable” for renewables for each sector** on the basis of the above analyses and ideas. The reference value in each case is energy consumption in the individual sector. The figure also shows the share of primary energy consumption, separately for the efficiency method (continuous line) and the substitution method (dotted line).

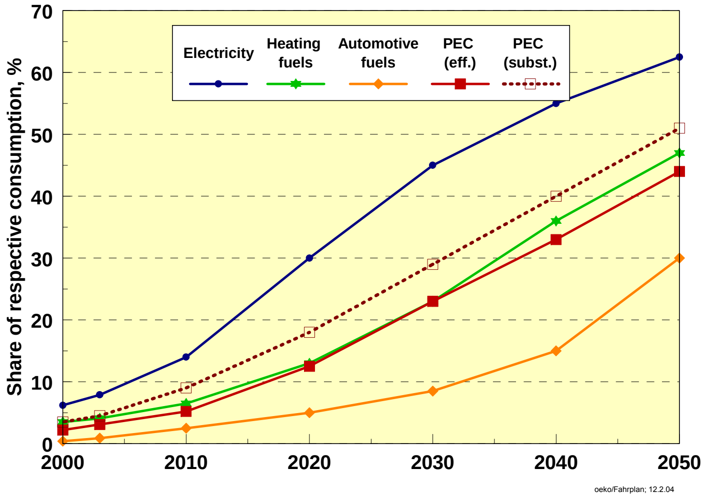


Fig. 26: Growth of renewable energy sources in the extension scenarios, shown separately for individual supply sectors (share of final energy), and growth of primary energy input between 2000 and 2050 (with distinction between efficiency method and substitution method).

In all sectors, renewable energy sources still have their real growth phase ahead of them. The pioneer here is the electricity supply sector. If the growth trend already under way is maintained, the 30% limit will be exceeded in 2020 (corresponding to 25% of present-day consumption) and the 50% limit in 2035. In 2050 the contribution of renewable energy systems to the electricity sector will be 65%. (Bandwidth of scenarios 63 - 68%.) It is of great importance to initiate a similar growth process in the heat market. As things stand at present, however, this will not set in until after 2010, because a potential “Heat Act” or similar measures will not begin to take effect before 2006. The share would reach 12% in 2020, and could continue increasing to over 45% in 2050. Following the initially restrained growth of renewable energy sources in the transport sector, appreciable growth should set in here too from about 2020 onwards, reaching the 10% limit around 2030. By the middle of the century some 30% of the relevant automotive fuel requirements could be met from renewables (in the BASIC II scenario, which assumes accelerated growth of renewables in the transport sector, the figure at this point is 38%).

The substitution method gives a more meaningful picture of the renewables share of primary energy consumption, since it assesses the substitution of fossil energy sources. Starting from 4.5% in 2003 (efficiency method = 3.1%), it reaches around 9% in 2010; thereafter it increases by roughly 10% percentage points per decade and thus exceeds the 50% mark in 2050. **The most important period for sufficiently powerful mobilization of renewable energy sources is the period up to about 2020.** If the efforts are successful, stable growth rates are achieved for all areas and technologies by that time. After that, further growth can be expected to become steadier and to continue until 2050 and beyond. In the second half of this century a continuation of the extension scenarios can then be expected to result in the complete replacement of fossil energy sources.

6 Successful policy framework for renewable energy sources

Today renewable energy sources have become a relevant economic factor. Investments in the energy supply sector must therefore face more than in the past the many and various requirements of the energy system (**Table 2**). Compared with many technologies available today, renewables have distinct advantages to offer on balance, if one takes the guideline for creating a sustainable energy supply system as a yardstick. On the other hand the requirements also give rise to development objectives that must be actively tackled and given political support in the years ahead, if renewable energy sources are to become one of the main pillars of energy supply in the future. The following list takes up the guiding principles and indicates those areas where there is still a need for action regarding the integration of renewables in the system.

Table 2: Requirements for the energy supply system of the future (in bold type: still to be ensured by an energy supply system largely based on renewable energy sources.)

- ***Utilization and supply in line with demand***
- Long-term reliability of supply
- Environmental and health compatibility (air, soil, water, nature and landscape)
- Climate compatibility
- Low risk, fault tolerant, low system vulnerability (resistance to terrorist attacks and sabotage)
- Efficient use of resources (conservation of fossil reserves, ***minimization of land use)***
- Social equity (economically compatible, inter-generation equity, and acceptance)
- Macroeconomic and ***microeconomic compatibility (cost-effectiveness)***
- ***Compatibility with existing infrastructures***
- Contribution to national added value and employment potential
- Technology and innovation potential (export stimulus)
- International acceptability (crisis resistance, equitable distribution)

Apart from specific policy measures (e.g. research and development projects for improving system integration or further development of power storage facilities), one aspect of crucial importance will be to shape the energy policy framework so that the impetus of the market growth that has gathered momentum in the last ten years is maintained or, where necessary, given an additional boost. In view of the high time constants in the energy sector, continuity in the creation of the framework conditions that provide planning security for investors is a particularly important aspect. This is not least a critical success factor for the establishment of domestic production structures.

In the years ahead, aspects that have to be considered in this context are in particular the systematic further development of the Renewable Energy Sources Act (EEG), the continuation of the tax concessions for bio fuels with parallel development of a biomass strategy which has to be seen in the light of maximum efficiency in the use of finite primary resources and which channels the wide-ranging demand for and competing uses of biomass, and the earliest possible establishment of an instrument as successful as the Renewable Energy Sources Act for the heat market.

In the **power sector** the Renewable Energy Sources Act should be supported by other measures:

- Establishing a viable grid connection and extension concept for nationwide extension of renewables (especially wind energy in the offshore sector), e.g. setting up a permanent working group with the aim of promoting integrated optimization of power plant locations (wind energy, fossil-fuel plants), consumer demand structures and appropriate grid extension.
- Analysing ways and means of supporting other interesting options whose implementation is not promoted by the Renewable Energy Sources Act (especially use of biomass for co-firing in coal fired power plants).
- Improving the system of incentives for customers to switch to eco power producers (e.g. tax concessions or collection of “bonus points” that consumers can trade in or be credited with for compliance with statutory requirements, e.g. in the field of building improvement)

- Creating a uniform nationwide basis for authorization and planning (in the wind energy sector in particular there are frequently substantial differences between federal, state and regional decisions, but in the town planning sector this is also of great importance for the establishment of local heating networks)

- Ensuring greater local participation by the parties concerned in the authorization, planning and possibly operation of installations by introducing an "environmental clearing house" with regard to wind energy in particular.

In the field of **heat supply** there is currently a lack of a key instrument comparable to the Renewable Energy Sources Act for bringing about an equally dynamic and ongoing expansion of the market. In Germany today it is mainly the market incentive programme for promoting the use of renewable energy sources that is encouraging supply of heat from renewable energy systems. Various options for improved promotion of renewables, especially the large-scale installations that are important from an economic and potential point of view, are under discussion. The appendix to the full version of this study provides a detailed explanation of these options on the basis of a working report dating from February 2004. At least one effective instrument should be established before the end of this term of parliament, to permit timely achievement of the target of doubling by 2010 in the heat market as well.

For **automotive fuels** produced on the basis of renewable energy sources, 2003 saw a number of crucial decisions. Following the Bundestag resolution of 07.06.03, this applies in particular to the exemption of bio fuels, biogas and synthetic fuels from solid biomass from petroleum excise duty until the end of 2008. Starting on 01.01.04, bio fuels for admixture ($\leq$ 5%) are also exempt from petroleum excise duty. This is expected to give the market a substantial boost, because the petroleum industry says it intends to devote greater attention to this fuel market. In order to use the limited resources as efficiently as possible and permit efficient control by the legislature in the face of growing demand from other consumption sectors as well, there is a need for a holistic approach to biomass utilization that takes account of the competing use options and their future prospects. Input efficiency is an important parameter here, and attention must be paid to the indicators environmental reduction, CO_2 reduction costs, technological boosts, innovation potential, employment effects etc.

Regardless of the application sector, great importance must be attached to nature conservation when continuing or introducing promotion implements in the future. In many cases the utilization of renewable energy sources can be combined with advantages for nature conservation and with great potential at only slight extra cost. One example of this is growing perennial energy crops on erosion-risk sites.

Looking ahead, it is virtually impossible to see any alternative to the Renewable Energy Sources Act in the foreseeable future as far as the electricity market is concerned. **The emissions trading system due to come into force throughout the EU in 2005 will initially not create sufficient incentives to replace the Renewable Energy Sources Act**. Its effect (for private investors) is in any case more of an indirect character, in that at first it will probably result in an increase in conventional electricity prices. Nevertheless, in the light of existing ideas about the national allocation plan (awarding emission rights on the basis of existing emissions during a basic period at least until 2012), it is theoretically possible that incentives might emerge for the larger power generation companies to cut back loads at their fossil-fuel power stations and make good the difference from renewable energy sources.

Even assuming that the specific supply costs of electricity generation from renewable energy sources will gradually be reduced in the course of the ongoing market introduction and technological advances, the certificate price per tonne of CO_2 in 2010 would have to be more than 60 €/t CO_2 to be able to create a similar incentive effect to the Renewable Energy Sources Act across the range of the utilization technologies at this early stage. This is a figure that is far in excess of the present expectations of 5 to a maximum of 10 €/t CO_2 for this period. If costs in the renewables field continue to fall, however, it is possible that in the medium term **certificate prices of 30 €/t CO_2** might be sufficient to close the cost-effectiveness gap between renewable and conventional power generation, a figure which is quite conceivable for the **year 2020** (**Fig. 27).** This is all the more true as the certificate price approaches the expected range of costs for CO_2 disposal (30 to 50 €/t CO_2). At least for the cost-effective individual technologies in the field of renewable energy sources, this could under certain conditions make a medium-term transition to a free competitive market conceivable, whereas for the other technologies (e.g. photovoltaic) it would still be necessary to use other instruments to maintain the necessary growth trend.

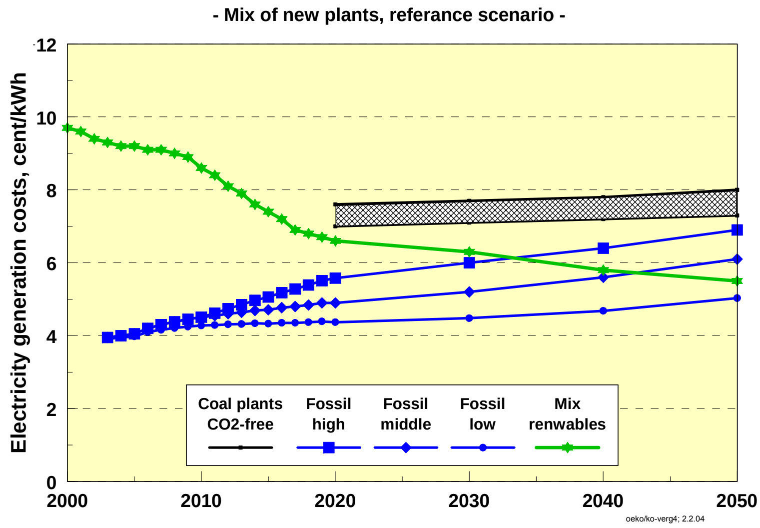


Fig. 27: Electricity production costs of new fossil-fuel plants in the reference scenario for three price variants, and for coal-fired power stations with CO_2 retention (from 2020) and a representative mix of renewable energy systems (upper = middle + 15 €/t CO_2 mark-up)

As a perspective for the future, the EU trading system planned for 2005 could also develop into a **general CO_2 trading system** that not only included large emitters such as power plants and industrial installations, but also considered all sources of CO_2. From an economic point of view it can be expected that in this case the keen competitive situation would lead to lower CO_2 certificate prices, thereby resulting in even lower incentives for renewable energy sources.

Whenever alternative instruments are discussed, the question of **quota systems** is regularly raised. However, such systems have yet to prove their efficiency and have in particular shown themselves to be not very efficient for entry markets of heterogeneous structure. What is more, they do little to create planning certainty (especially for private investors). On the costs side too, however, experience indicates that this instrument does not result in significant advantages, as shown by recent figures from the quota systems in the United Kingdom and Italy, which despite much better wind conditions in some cases lead to higher payment rates than the German Renewable Energies Act. One perspective that does seem worth pursuing, however, is the idea of levying a **quota for renewable energies on the construction of additional conventional capacity**, in order to oblige those who want to build conventional power plants to produce a certain amount of the output on the basis of renewable energy sources. In this way the dynamic trend of power plant replacement requirements that will emerge on a massive scale not later than 2010 onwards could be used to integrate the energy industry itself more closely in the extension of renewable energies, disproving the argument that the addition of renewable energies in the power sector is not taking place on a needs-oriented basis.

Following a marked expansion of market share, especially in relation to individual forms of energy (e.g. wind energy), one could basically also consider a transition to a **combined fixed price/market price system** that contained more competitive elements, such as granting a fixed bonus, decreasing over time, in addition to the market price and possibly other concessions. A comparable mechanism is currently implemented in the Co-generation Act. In terms of perspectives, such a system could pave the way for a transition to a straight CO_2 certificate market (in which the credits would however be determined by the market). In such a system, as with quota models, it would primarily be professional operators who became established, as their experience would enable them to bear the greater price risk and cover the greater transaction input. However, since a large proportion of the private operator market is likely to be exploited by the year 2010, this need no longer be a fundamental problem, assuming safeguards for the continued existence of the existing (private) installations.

From the present study and previous studies it has become apparent that the challenges of future energy supply make it necessary – building on the present market entry phase of renewable energy sources – to develop a step-by-step but continuous market introduction strategy, if renewable energy systems are to play a central role in energy supply by the middle of this century. It is possible to distinguish five phases. In the first two phases (up to 2010 and 2010-2020) the crucial requirement will be to use effective and constantly adapting instruments, the most important of which have been mentioned above, to establish an irreversible growth trend for renewable energy systems. During this period the individual markets, driven by a small number of pioneer countries, must be further developed into a general global market for renewable energy sources. Bearing in mind the goal that half our energy supply should be based on renewable energy systems by 2050, we can characterize these five phases as follows **(Table 3).**

Table 3: Extension strategy for renewable energy systems with the aim of contributing about 50% of energy supply by the middle of the century, followed by the gradual replacement of fossil energy sources.

- **Up to 2010**: **"Entry"** supported by energy policy measures, based on target specifications and effective packages of instruments keyed to renewable energy systems;
- **2010 – 2020**: **"Stabilization"** of growth with gradual incorporation of support for renewable energy systems in general climate protection instruments;
- **2020 – 2030**: Complete **"Establishment"** of all new technologies for utilization of renewable energy sources with optimized contributions in the individual consumption sectors and incipient use of low-cost potentials throughout Europe and the Mediterranean region by means of an electricity supply network system;
- **2030 – 2050**: Incipient **"Dominance"** of renewable energy systems in all energy supply sectors and incipient use of hydrogen from renewables;
- **After 2050**: Progressive **"Replacement"** of fossil energy sources and establishment of an energy economy based entirely on renewable energy systems, partly through progressive entry into the hydrogen supply business.