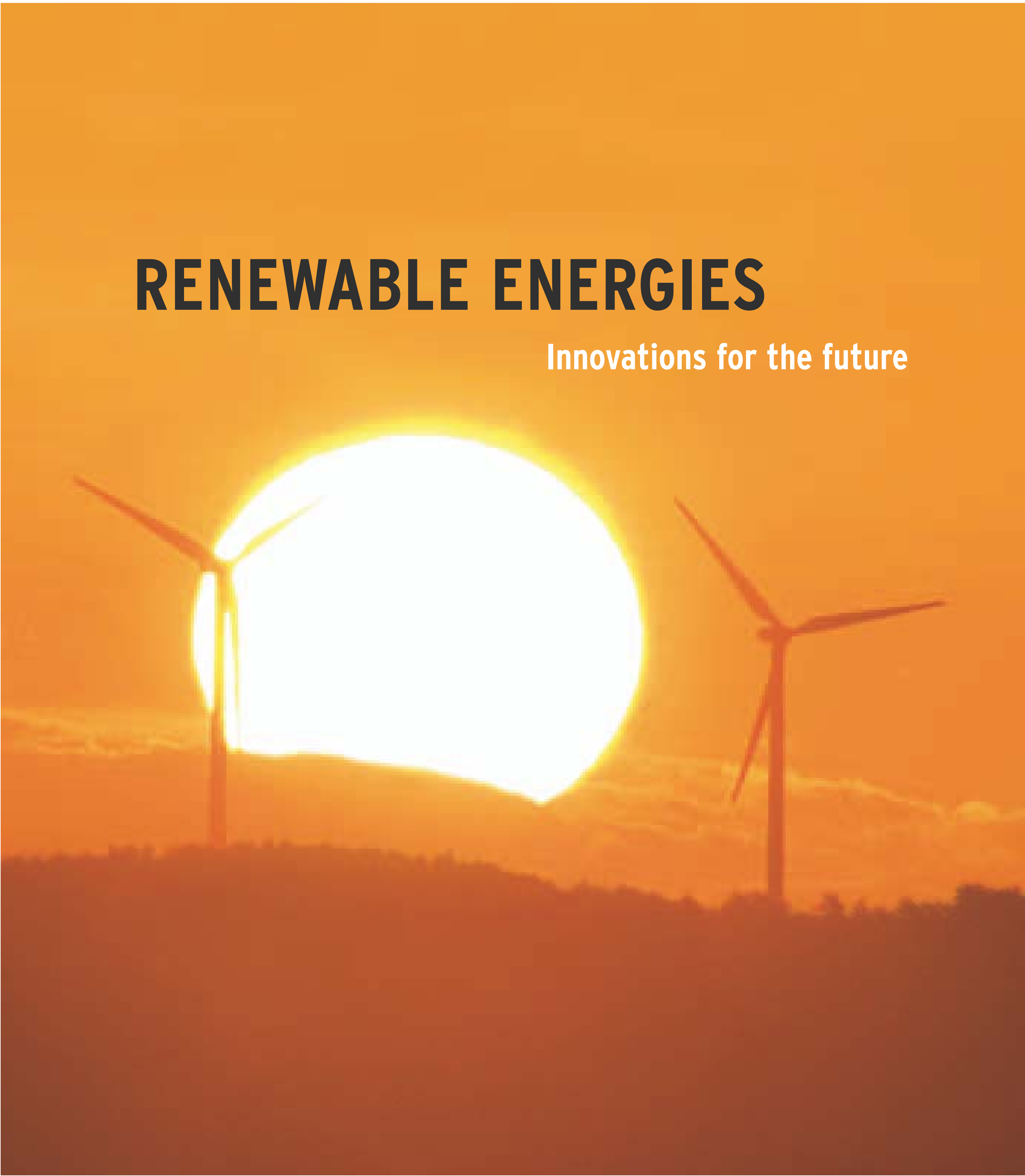
Federal Ministry for the
Environment, Nature Conservation
and Nuclear Safety

RENEWABLE ENERGIES

Innovations for the future



Imprint

Publisher:	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) Public Relations Division • D-11055 Berlin E-mail: service@bmu.bund.de • Internet: www.bmu.de
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Design:	Block Design, Berlin
Print:	Bonifatius, Paderborn
Photos:	© agenda/Joerg Boethling: 56, 57 © AG Solar NRW/Universität Essen: 71 (2) © Aral: 126 (1) © Arsenal Research/Christian Halter: 71 (1) © Bestec GmbH: 111 (3) © Bundesverband Windenergie: 63 © C.A.R.M.E.N.: 94 (1) © Choren Industries: 106 (1) © CoverSpot: Titel © Das grüne Emissionshaus: 59 © DLR: 78 (2); 86 (1) © DUH: 70 (2) © EnBW: 66 (2) © Enercon: 61, 64 © ExpoStadt: 83 (1); 90 (1, 2) © Flagsol/Solarmillenium: 77 (1) © Geoforschungszentrum Potsdam (GFZ)/A. Sadaat: 115 © Gesellschaft für Handel und Finanz mbH: 66 (3) © Haase: 94 (2), 124 (1) © Institut für Geowissenschaftliche Gemeinschaftsaufgaben (GGA): 114 © Iogen: 106 (2) © Thomas Kläber: 65/Montage: © Block Design © Kramer Junction Company: 76 (3) © MVV Energie AG: 122 © Michael Nast (DLR): 83 (2); 86 (2); 89 © Nordzucker: 103 (3) © Norsk Hydro Electrolyseurs: 126(2) © Picture Alliance: 67; 69; 70 (1); 71 (1); 73; 96; 97; 101; 107; 108; 111 (1, 2); 117; 119 © Sandia: 78 (1) © Schlaich Bergermann und Partner: 76 (1); 80 (1, 2) © Senertec: 124 (2) © Solarmundo: 77 (2) © Stadtwerke Bielefeld: 128 © STEAG Saar Energie: 120 © Uwe Strobel: 90 (3) © ThermoLux: 83 (3) © ufop: 103 (2); 105 (1) © Vestas Central Europe: 59 (2, 3); 62 © Vorarlberger Illwerke Kopsee: 66 (1) © Wodtke: 94 (3) © Wolfgang Steche/Visum: 105 (2) © www.BilderBox.com: 99
Date:	April 2006
Second edition:	10,000 copies

Dear Reader,

A sustainable energy economy is distinguished by several attributes: environmental compatibility, profitability, competitiveness, resource conservation, security, social equity, and public acceptance.

It will still take some effort, however, to achieve an energy economy which can satisfy these demands. Only then will we be able to create new employment opportunities while preserving the existing ones.

Moreover, Germany has the opportunity to become established in a seminal global market: with both renewable energy and energy efficiency. For a sustainable energy economy is only achievable with further innovations in these areas. Only those national economies which understand how to deal with energy in an intelligent way will be able to take on a leading role in the global economy of the medium- and long-term future. We choose to forgo the use of nuclear power. Nuclear power does not meet the sustainability criteria and is not required to meet our goals.

The share of renewable energy in Germany's energy supply has been increasing for years. In 2005, already 10.2 % of the electricity consumed was renewable, 5.4 % of the heat, and 3.4 % of the fuel for road traffic. In total, 6.4 % of the final energy consumption in Germany was supplied from renewable sources. Renewable energy has already clearly reduced Germany's dependency on imports of fossil and nuclear fuels, it prevented the emission of 83 million tonnes of CO_2 in 2005, and it employed about 170,000 people.

The German government has set itself ambitious goals:

The share of renewable energy should increase

— to at least 4.2 % of the total energy consumption by 2010, to at least 10 % by 2020, and to about 50 % by mid-century,

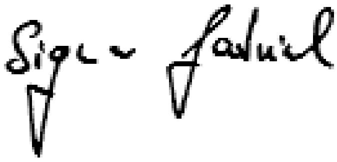
— to at least 12.5 % of the electricity consumption by 2010 and to at least 20 % by 2020,

— and to 5.75 % of the fuel consumption by 2010.

The fast-paced development of the past few years and current studies show that these goals can be achieved and even surpassed. I therefore consider it even probable that already a fourth of our electricity will be generated by renewable energy sources in 2020.

The present overview about the state of the art, application possibilities, potentials, and development prospects of renewable energy provides in-depth and current information for everyone who wants to make their own contribution to environmental protection and sustainable development in the energy sector, or who wants to form their own opinion on renewable energy.

The balance of the development so far and the future prospects – derived from several studies performed on behalf of the Federal Environment Ministry – indicate the exemplary capabilities of the combined innovation in science, economy, and politics.



Sigmar Gabriel
Federal Minister for the Environment, Nature Conservation and Nuclear Safety

CONTENT

SUSTAINABILITY AND ENERGY SUPPLY

Sustainability in the energy context

For about two decades now, the term “sustainable development” has characterised the discussions about conserving our natural environment, distributing prosperity more fairly throughout the world, and enabling more humane living conditions for all people. Sustainability encompasses not only ecological but also economical and social aspects, which must always be considered collectively and in their interactions. A comprehensive definition for sustainability was first formulated by the Brundtland Commission, adopted by the Rio Conference 1992, and has since been interpreted in numerous documents:

“Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

Energy plays a crucial role in sustainable development. The nature of its availability influences practically all fields of social, economical, and political activities; the state of the environment and the climate are influenced by it, and often it determines whether nations will live in peace or conflict with each other. Accordingly, *“the use of energy is only sustainable if the sufficient and permanent availability of suitable energy resources is assured, while at the same time limiting the detrimental effects of supplying, transporting, and using the energy.”*

An energy usage is sustainable if the sufficient and permanent availability of suitable energy resources is assured, while at the same time limiting the detrimental effects of supplying, transporting, and using the energy.

Concrete guidelines derived from this definition help orient the decision-makers active in the energy sector and guide the development of political energy strategies. According to this understanding of sustainability, these guidelines should be considered as the minimum requirements for a sustainable development. Other major activities for the further development of societies and states, like assuring economic growth and propagating prosperity and freedom, should therefore only progress to an extent that the minimum requirements for sustainability are not endangered (see boxed text). In April 2002 the German Government passed a resolution on a national strategy for sustainable development titled “Perspektiven für Deutschland” (Prospects for Germany). It clarified in which direction Germany must develop and which signals must be set to achieve sustainability goals. Above and beyond the ecological challenges, the strategy serves as a guide for comprehensive future policies which do justice to the responsibility spanning over several generations for an economically, ecologically, and socially acceptable development. Both the implementation and the updating of this “National Sustainability Strategy” are repeatedly documented in progress reports. In their coalition contract from November 2005, the newly configured German Government also stipulated that the National Sustainability Strategy should be acted on and further developed. Accordingly, the ecologically compatible expansion of renewable energies is among the fundamental pillars of a sustainable energy supply.

The principles of action for sustainable development call for a deeper understanding of progress and development, particularly in the highly industrialised countries, if the course towards sustainability is to be successful at a global level. Despite Germany’s certainly progressive status in environmental policies for certain areas like water protection or low-pollution electricity generation, today it is still far from a sustainable development. If today’s energy supply is measured on the basis of these guidelines, then the following major deficits are identified:

- Excessive consumption of finite energy resources
- Looming changes in the global climate
- Extremely large differences in energy consumption between industrialised and developing countries
- Risks associated with nuclear power

Fossil fuels – the motor of today’s global economy

Since the beginning of industrialisation, energy consumption has increased considerably more rapidly than the number of people on the planet. Whereas the world population has quadrupled since 1870, to 6.3 billion at present, the global energy consumption, and therefore the consumption of fossil resources in the form of coal, oil, and natural gas, has increased by a factor of sixty to 450 EJ/a in 2004 (EJ = Exajoule=1018 Joule). The average person today consumes fifteen times more energy than a person 130 years ago, and those living in the industrialised countries consume significantly more than the average (see Figure: Development of primary energy consumption). Temporary drops in the past, caused e.g. by the two world wars, the oil-price crises, or the serious decline of industrial production in the states of the

Guidelines for a globally sustainable energy supply

Source: HGF 2001

→ **1. Equality of access and distribution for all:**

All people shall be assured equal opportunities in accessing energy resources and energy services.

→ **2. Conservation of resources:**

The various energy resources shall be maintained for the coming generations, or comparable options must be created to provide sufficient energy services for future generations.

→ **3. Compatibility with environment, climate and health:**

The adaptability and the regeneration capability of natural systems (the "environment") may not be exceeded by energy-related emissions and waste. Risks for human health –e.g. by an accumulation of problematic pollutants and harmful substances – shall be avoided.

→ **4. Social compatibility:**

The design of energy supply systems shall assure that all people affected by the system are able to participate in the decision-making processes. The system should not restrict the ability of economic players and communities to act and influence, but should rather broaden these abilities wherever possible.

→ **5. Low risk and error tolerance:**

Unavoidable risks and hazards arising from the generation and use of energy shall be minimised and limited in their propagation in space and time. Human errors, improper handling, wilful damage, and incorrect use shall also be taken into consideration in the assessment.

→ **6. Comprehensive economic efficiency:**

Energy services shall – in relation to other economical and consumer costs – be provided at acceptable costs. The criterion of "acceptability" refers, on the one hand, to specific costs arising in conjunction with the generation and use of the energy and, on the other hand, to the overall economic costs while also taking the external ecological and social costs into consideration.

→ **7. Availability and security of supply:**

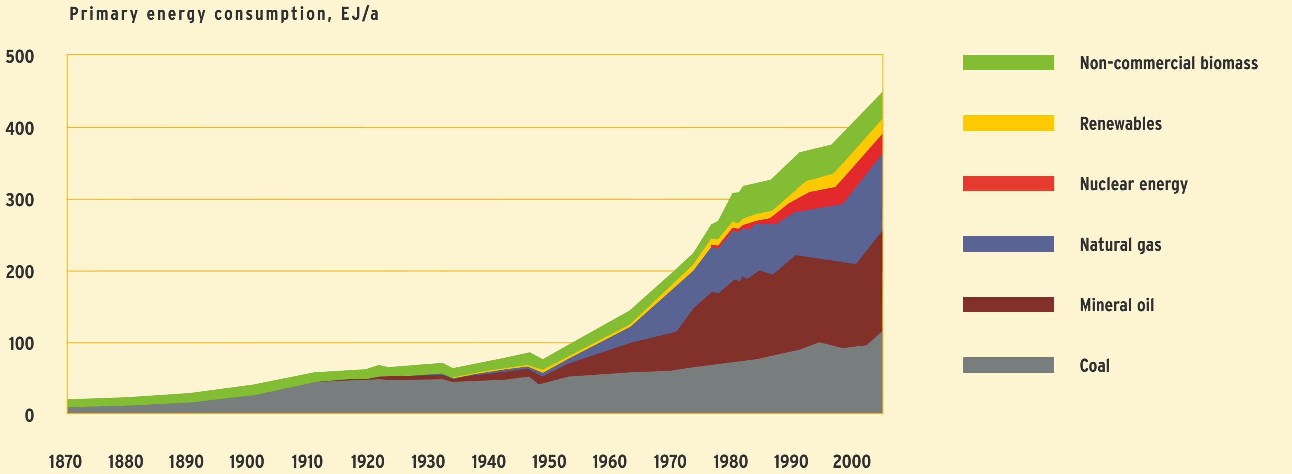
A steady and sufficient supply of energy must be available to satisfy human needs when and where they arise. The energy supply must be adequately diversified so as to be able to react to crises and to have sufficient margins for the future and room to expand as required. Efficient and flexible supply systems harmonising efficiently with existing population structures shall be created and maintained.

→ **8. International co-operation:**

The further development of energy systems shall reduce or eliminate potential conflicts between states that are caused by a shortage of resources and also promote their peaceful co-operation by a joint use of capabilities and potentials.

→ Development of primary energy consumption

Sources: IEA statistics and others



Development of the global primary energy consumption and the distribution of energy sources between the years 1870 and 2004, including the non-commercial use of biomass (firewood)

former Soviet Union, interrupted this upwards growth trend only for short periods of time. The rapid increase in energy consumption started about 1950. The global energy consumption doubled just between 1970 and 2000. Moreover, no fundamental change of this growth trend is expected in the foreseeable future.

At the present time, the traditional use of biomass, i.e. the non-commercial use of firewood, in numerous less-developed countries constitutes nearly 9 % of the global consumption of primary energy. However, this use is not always sustainable. The other types of renewable energy, first and foremost hydropower, add up together to a share of 4.8 % (in energy statistics, electricity from water, wind, and solar irradiation are assessed as primary energy with a ratio of 1:1; a ratio of 3:1 is used for electricity from nuclear power; and the fossil primary energy sources and biomass are characterised by their calorific value). Nuclear power meets 6.4 % of the demand. Thus 80 % of the world's energy supply is based on finite fossil energy carriers. In commercial applications this figure is as high as 90 %. Several hundred million years of photosynthesis were necessary to synthesise the energy-rich carbon compounds. Within just a few centuries, the human race has consumed these valuable resources and polluted the environment with their residues.

Within just a few centuries, the human race has consumed valuable resources which took millions of years to produce, and moreover polluted the environment with their residues.

The energy supply, both globally and in Germany, is based primarily on the finite fossil energy carriers of coal, mineral oil, and natural gas. Thus it is clear that, even with very rapid changes in the energy supply, fossil-based energy will still be needed for decades to come, and possibly to an even greater extent than today. Therefore, the question of which resources are still available, and for how long, is of central importance. The term "reserves" concerns those quantities of energy which are proven to exist and which are economically feasible applying today's engineering techniques. The term "resources", on the other hand, describes either those quantities which have been proven to exist geologically, but cannot yet be tapped economically, or those that are not proven, yet are presumed to exist in the area in question for geological reasons. The reserves of fossil sources of energy still remaining amount to just under 34,000 EJ (status 2004), corresponding to approximately 75 times the yearly energy consumption in the world today (see Figure: Fossil energy reserves), but only 2.2 times the total amount of fossil energy already consumed. Coal constitutes 60 % of these reserves. Conventional mineral oil, representing 20 % of the remaining reserves, is already the most-exploited energy carrier of all the fossil energy sources. Comparing this fact with the major significance assigned to mineral oil, with a 38 % share of the global energy supply, it becomes clear that we will also have to resort to exploiting non-conventional oil reserves (heavy oil, oil shale, oil sands) and costly resources in the foreseeable future if we are to continue meeting the – still increasing – demand in the future. Large resources up to 105,000 EJ are still assumed for coal.

The indicated scarcity trends in the reserves of oil and natural gas are also reflected in the static ranges of these sources, representing the time remaining until these reserves are completely exhausted should the present-day rate of consumption continue. The shortest static range is for conventional mineral oil at 43 years. If unconventional mineral oil – i.e. heavy oils, oil sands, and oil shale – is included as well, then the static range increases to 62 years. At the current rate of consumption, natural gas will last for approximately another 64 years, whereas the coal reserves will be available for about another 200 years. Uranium, another finite source of energy, will only last for about another 40 years when using light-water reactors and without re-processing nuclear fuels. At first, these time periods might not seem to be alarming. However, such considerations do not include the following two aspects:

— **Increasing prices and the resulting economic disturbances are anticipated long before the fossil energy supplies run out.** That is, once the supply cannot continuously meet the demand. Experts estimate that this point in time will occur shortly after passing the global production maximum. For technical-physical reasons, this will happen near the so-called "mid-depletion point" for mineral oil, a point in time when half of the total assumed mineral oil reservoirs have been consumed. The mid-depletion point for mineral oil will be reached in the next 5 to 20 years if consumption continues at the current or even higher rates. By that time, at the latest, considerable price increases for crude oil are expected. Natural gas alone cannot meet the supply deficit, and the reserves of unconventional oil are always more expensive. Furthermore, the reserves of mineral oil and natural gas are distributed very unequally over the globe. More than 70 % of the mineral-oil reserves, and more than 65 % of natural-gas reserves, are located within the "strategic ellipse" of countries extending from Saudi Arabia in the south, over Iraq and Iran, up to Russia (see Figure: Distribution of resources). Considering these two facts together, it becomes very apparent how explosive the supply situation for the "energy-hungry West" may become in the foreseeable future. Already today, the assured access to cheap energy resources is of such major significance for the industrial countries that it is contributing to the development and propagation of political and even military conflicts.

— The **intergenerational equity**, i.e. the just distribution of resources between present-day and future generations – a major principle of sustainability – is also being ignored. Even if today's generations were to conclude that appropriate room for action should be left for future generations, despite the exploitation of the reserves of fossil and nuclear energy carriers, then the minimum requirement must be to introduce new energy technologies which do not depend on fossil or nuclear fuels already today, since a long time is needed to develop and introduce these new technologies. Structures which would make changes in this context either impossible or impede change in any significant way may not be prescribed. For example, a power plant has a useful service life of between 30 and 40 years, new brown coal pits last for about 60 years, and even the development and any appreciable market launch of a new generation of energy converters, like fuel cells, can take between 20 and 30 years.

The limitations and the geographical distribution of energy reserves thus emphasise how important it is to begin as early as possible with setting up a sustainable energy supply system. This statement still applies even when fossil energy resources are taken into account, considering those deposits still not worth developing

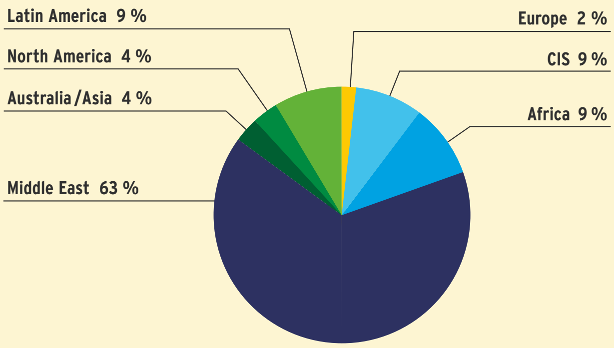
→ Fossil energy reserves

Source: BGR 2005

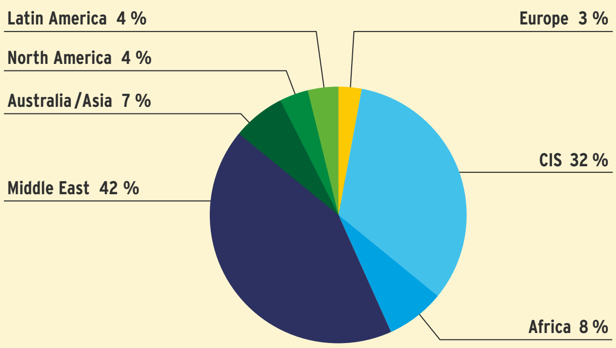
Fossil energy reserves compared to the quantities already consumed, data from 2004

Source: BGR 2005

➔ Distribution of resources



Oil reserves 2004: 6,670 EJ



Natural gas reserves 2004: 5,600 EJ

Distribution of the reserves (2004) of crude oil and natural gas by country groups

under present-day conditions. Assuming that the global energy consumption continuously increases at the rate of about 2 % per year, including these resources will extend the availability of mineral oil and natural gas by only a few decades longer than for reserves alone. The exploitation of these resources, however, involves a disproportionately higher effort than is required today to access the reserves. Furthermore, the environmental effects associated with their exploitation are not known with any certainty. For example, the risks from emitting large quantities of the climate-relevant trace gas methane during the production of gas hydrates are still unknown. If, on the other hand, we start to reduce the consumption of finite energy carriers now, we can protect ourselves from the dangers of future and possibly similarly drastic price increases like those experienced for mineral oil in the seventies. At the same time, we will be following the guidelines given for environmental and climate protection.

The global climate is becoming unbalanced

Presumably, we will not be forced to change our energy usage habits primarily because of the depletion of fossil energy resources. It is more likely the limited capacity of the environment to absorb the waste products of our energy consumption which will demand resolute actions towards a more sustainable energy economy. This condition applies particularly to the products released into the atmosphere. During the combustion of fossil energy carriers, pollutants like sulphur dioxide and nitrogen oxide are formed which contribute to the formation of acid rain. An incomplete combustion process causes emissions of carbon monoxide, unburned hydrocarbons, and soot particles; the combustion of solid fuels also produces considerable amounts of dust. These emissions, along with a number of others, not only have a detrimental affect on the environment; they are also directly injurious to human health. They are therefore known as air pollutants.

Improved combustion and the use of catalysts and filters can however considerably reduce those emissions. Significant progress in this respect has been made over the last three decades in many industrialised countries, particularly in Germany. The driving force behind these efforts has been an effective environmental policy supported by substantial financial resources. As a result, the air has become cleaner, particularly in the more congested urban areas. In contrast, the burdens from these pollutants are still increasing in the fast-growing urban centres of less-developed countries, resulting in all of the negative impacts, like croup, known from the industrialised countries of the past.

Besides these emissions, often referred to as the “classic” air pollutants, **carbon dioxide** is always emitted during the combustion of fossil fuels. Although this gas is not toxic for organisms, it has the detrimental effect of boosting the greenhouse effect and thereby increasing the global temperatures. The concentration of carbon dioxide in the atmosphere has already risen by a fourth since the beginning of industrialisation, thereby causing the mean temperature near the ground to increase by 0.6 ± 0.2 °C. If no countermeasures are undertaken to reduce the emissions of this and other greenhouse gases, scenarios calculated by the Intergovernmental Panel on Climate Change (IPCC) indicate a further increase of the mean temperature in the range of 1.4 °C to 5.8 °C by the year 2100, whereby locally observed changes may differ strongly. Along with the temperature increase, changes in the distribution of precipitation, an increase in the frequency of extreme weather conditions, a shift in climate and vegetation zones, and a degradation of soil quality with fatal results for the already strained global nutritional situation and human health are to be expected. Climate changes have often occurred in the history of the Earth. The menacing aspect of the present changes is that they are too fast and too abrupt. Neither human civilisation nor the environment have enough time to adapt to such rapidly changing conditions.

In order to limit the global rise in temperature, the industrialised countries must reduce their CO_2 emissions by up to 80 %.

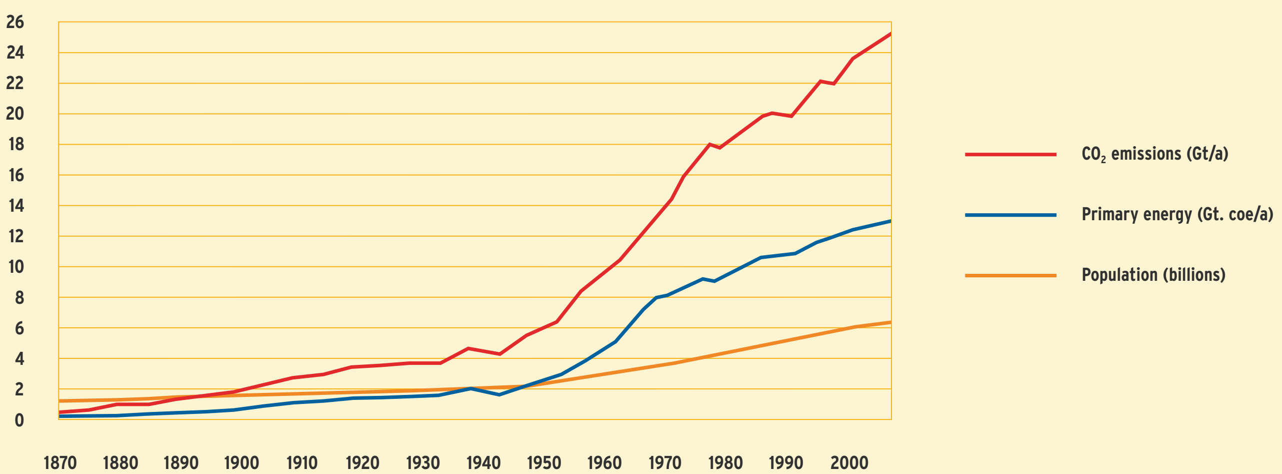
Energy-related CO_2 emissions contribute to about half of the man-made greenhouse effect. The efforts of climate protection activities are therefore focussing on reducing these emissions. The increase of these energy-related global carbon dioxide emissions resulting from the growing world-wide energy consumption, amounting to 25.2 billion tonnes of CO_2 in 2003, has led to the emission of a total of 1,000 billion tonnes of additional CO_2 into the atmosphere since the beginning of industrialisation, 80 % of which was emitted in the last 50 years. Since the growth has mainly taken place in the industrialised countries, these nations are responsible for about 90 % of the CO_2 emissions generated from energy consumption. At the present, these countries account for two thirds of the global CO_2 emissions. Germany emitted 866 million tonnes of CO_2 in 2005, corresponding to 3.4 % of the world-wide emissions. Each inhabitant of Germany is thus responsible for emitting more than 10 tonnes CO_2 of carbon dioxide every year. An American produces 20 tonnes, about twice as much. In contrast, a Chinese produces just 2.7 tonnes and a person in India only 1 tonne.

Global warming due to the combustion of fossil energy carriers, the overexploitation of forests, and industrialised agriculture (emission of the greenhouse gas N_2O) is considered proven nowadays. In order to keep temperature rise within a lower limit of 2 °C, the current CO_2 concentration in the atmosphere of around 360 ppm must not be allowed to rise above 450 ppm before the end of this century (see Figure: Scenarios of global CO_2 emissions). To comply with this target, it is essential that the world-wide energy-related CO_2 emissions are reduced by more than half by the year 2100. Bearing in mind the world population growth, each of the prospective 10 billion humans may then only emit slightly more than one ton of CO_2 per year. To meet this long-term goal, Germany would have to reduce its national CO_2 emissions by 80 % by the year 2050. If instead we assume a continued unlimited coverage of our growing energy consumption by predominantly fossil-based energy, then the CO_2 emissions will rise considerably and the resulting temperature changes will reach uncontrollable values, according to the scenario A1FI from the IPCC which presupposes extensive consumption of all fossil resources. Therefore, an effective combination of technologies for more efficient energy use in all sectors, as well as CO_2-free or low-CO_2 energy conversion technologies are needed quickly, within just a few decades, to keep the climate changes already taking place within tolerable limits.

In contrast to the classic air pollutants, the negative impacts of the CO_2 emissions are of global nature – and they are not immediately apparent, but develop rather gradually and vary regionally. A reduction of these emissions does not lead directly to any immediate

→ Scenarios of global CO_2 emissions

Source: DLR



Development of global energy-related CO_2 emissions since 1870 and the main causes: population growth and the combustion of coal, mineral oil, and natural gas (1 Gt. coe: 1 billion tonnes of coal equivalent corresponds to 29.3 EJ)

advantages for the local energy consumer. Only world-wide measures can reduce the CO_2 emissions to the necessary extent. Individual states or groups of states can play an important guiding role here.

In view of the far-reaching dangers associated with the greenhouse effect, climate protection is one of the prime reasons for introducing a sustainable energy economy. Of course, the ongoing reduction of other pollutants remains a major concern. Also, the far-reaching impacts of present energy uses, e.g. the extensive destruction of landscapes by mining lignite, coal, and uranium, and the pollution of the seas by oil production and oil-tanker accidents, increasing environmental pollution by the exploitation of unconventional hydrocarbons, and the severe consequences of large hydropower plants, especially when large areas of land are flooded, should not be forgotten.

Nuclear power – the risks exceed the benefits

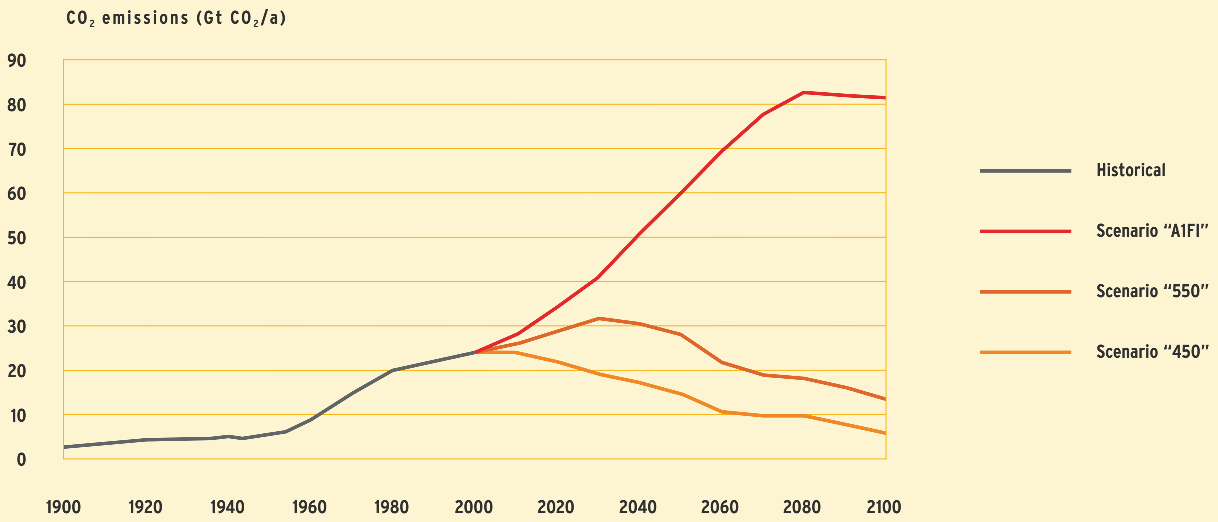
As electricity generation from nuclear fission is almost completely CO_2-free, nuclear power – and sometimes the associated nuclear fusion – is often considered indispensable for achieving our CO_2 reduction targets. This assumption, however, is not tenable under closer inspection: Only the long-term continuous avoidance of large amounts of carbon dioxide is meaningful from the climate protection point of view. For that purpose, the contribution of nuclear energy to the global energy supply would have to increase severalfold and be maintained over centuries. Irrespective of the risk increase with each new nuclear power plant (also in countries with lower safety standards and less political stability than in Europe), nuclear power does not have the resources to meet these demands. Even at today's level of nuclear energy use, the availability of cheap uranium for light-water reactors is expected to last for only another 40 years. The long-term supply of a large amount of electricity would require the use of reprocessing and breeding technologies which are not only more costly, but also involve greater risks than those associated with today's reactors. Already today, nuclear energy conflicts with the basic guidelines of a sustainable energy supply (see page 9):

– Core meltdown accidents in nuclear reactors with unacceptably high human health risks and extreme consequential losses cannot be ruled out (refer to Guideline 3).

– All processes of the nuclear fuel cycle, including fuel preparation, processing, and waste disposal generate radioactive material, some of which is emitted. The large remainder must be shielded from the ecosphere and monitored, at a high technical and logistic expense (refer to Guidelines 3 and 4). The question of how to achieve this storage is still unsolved.

→ Development of energy-related CO_2 emissions

Source: IPCC 2002



Szenario:	Historical	"A1FI"	"550"	"450"
Cumulative CO_2 (Gt C):	300	2200	1000	700
CO_2 concentration in 2100 (ppm):	(360)	950	550	450
Mean temperature rise (°C):	0.4 – 0.8	4.5 – 5.0	2.5 – 3.0	1.5 – 2.0

Development of energy-related CO_2 emissions in different IPCC scenarios and their impacts on the atmospheric CO_2 concentration and temperature (A1FI = Growth scenario in which the energy demand is mainly met by fossil energies; "450" and "550" = average values of scenarios which result in a stable concentration of CO_2 in the atmosphere)

- Complete protection against the misuse of the plutonium by-product from nuclear fission seems to be impossible. Any misuse of weapon-grade plutonium by individual states or supranational groups is a continuous threat for humanity (refer to Guidelines 5 and 8).

- Full protection of nuclear facilities against external forces and sabotage is impossible, or would lead to extremely high costs and a limitation of civil liberties (refer to Guidelines 4 and 6).

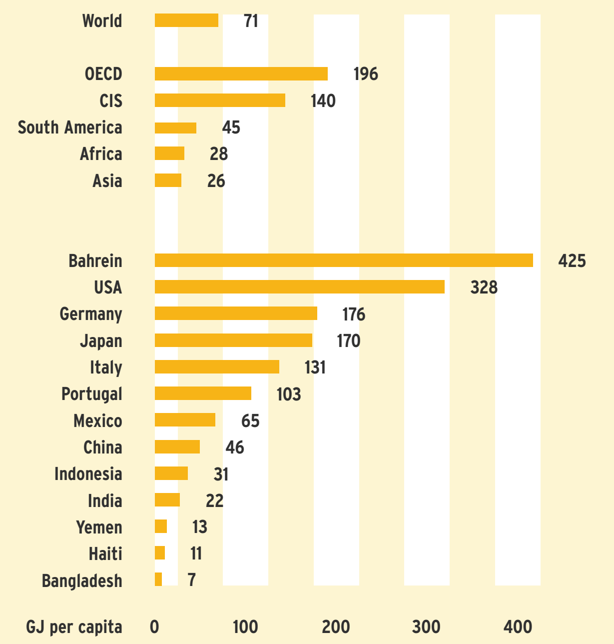
- Limiting the use of nuclear power to only the "highly developed" countries in order to reduce the risks described above would hinder peaceful world-wide co-operation and is thus not politically viable (refer to Guideline 8). The current Iran crisis clearly demonstrates how fast a disagreement about atomic energy can lead the world community to the threshold of a military conflict.

As a result of a comprehensive and thorough consideration of these issues, the benefits of a carbon-free electricity supply from nuclear power appear small compared to the risks inherent to the continued use or even further expansion of nuclear power. Fortunately, there are more than adequate non-fossil energy sources available. The huge technical potential of renewable energy is sufficient to meet the global energy demand several times. The decision in 2000 to phase out nuclear energy, reached by the German Government and the electricity utilities in Germany, recognises this conclusion and the necessary policy shifts have already been initiated.

Energy-squanderers and energy have-nots – an explosive situation

A further severe sustainability problem is the huge disparity in energy consumption between industrialised and developing countries, which has increased rather than decreased in recent years. Today, 18 % of the world population in the OECD countries has over 81 % of the gross world product at its disposal and is "responsible" for more than half of the world-wide primary energy consumption and global CO_2 emissions (see Figure: Prosperity and world-wide energy consumption). While the mean values across groups of countries conceal some of the differences between country-specific indicators, the discrepancies are even more extreme when looking at individual countries (see Figure: Per-capita energy consumption). Thus an average citizen of the USA consumes nearly 12 times more energy than an average African, and almost 5 times more than the world average. The inhabitants of the poorest countries (Yemen, Haiti, and Bangladesh, among others) have to get by with a thirtieth of the energy consumption of a North American. The per-capita energy consumption in Europe and Japan is about 50 % lower than in North America, indicating that prosperity is only loosely linked

→ Per-capita energy consumption



Source: IEA 2005

International comparison of per-capita energy consumption

to a high level of energy consumption. Nevertheless, at ca 175 GJ per capita and year they still consume 2.5 times more than the world average.

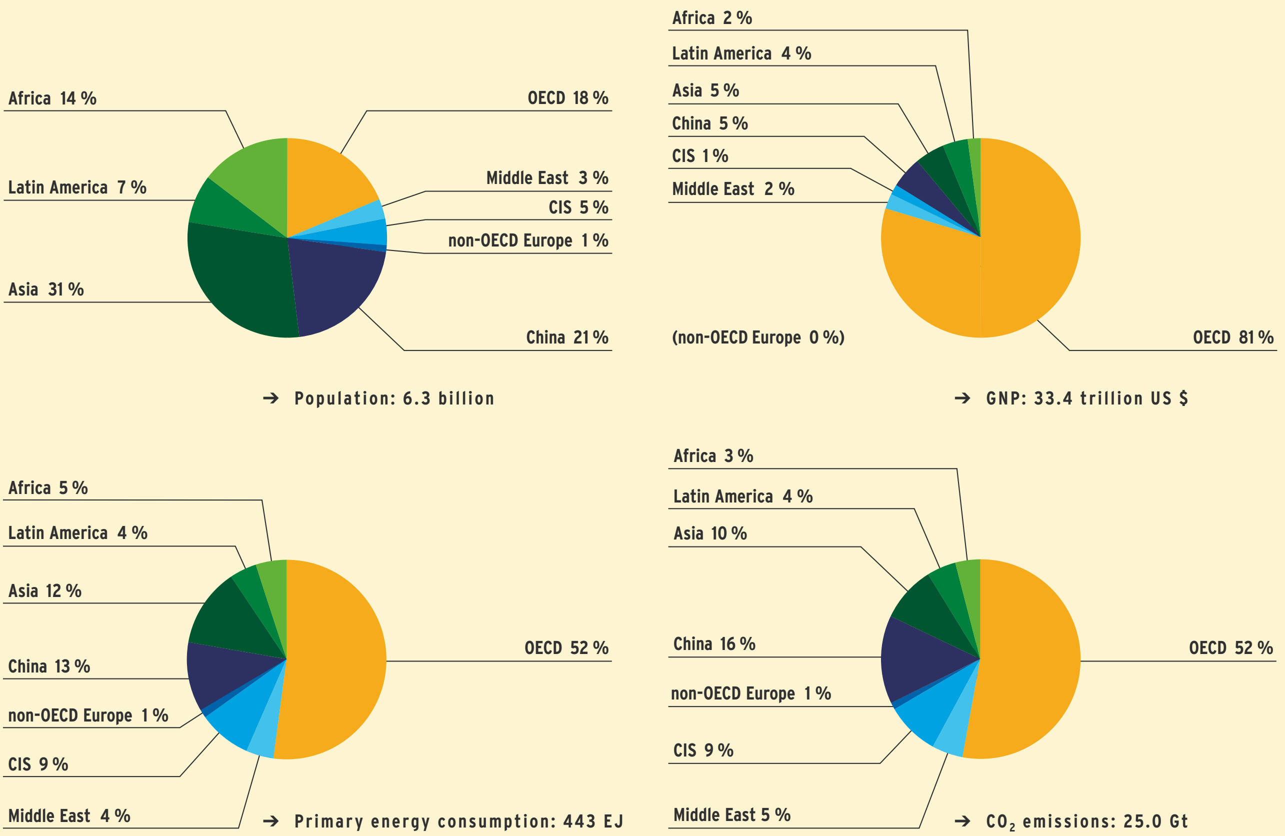
The task of a more fair distribution of energy world-wide is very important, also when considering the long-term economic and environmental consequences. Scenario calculations suggest that the regions which are most likely to be affected by global climate change impacts are those which contribute least to global greenhouse gas emissions and have the least technical and economic resources for implementing mitigation measures – a fact which might lead to serious social and economic conflicts in the future.

Even just a slight compensation of the grave differences in energy usage, which is absolutely necessary to address social sustainability, unavoidably leads to a further growth in the world energy demand since the world population is expected to increase to 9 or 10 billion people by the year 2050. Since the type and extent of

18 % of the world population in the OECD countries possesses over 81 % of the gross world product and is responsible for more than half of the world-wide primary energy consumption and global CO_2 emissions.

→ Prosperity and world-wide energy consumption

Source: IEA 2005



Statistics of a divided world (2003): the poorer you are, the less there is – the industrialised countries claim the greatest shares of prosperity and energy.

energy supply in the industrialised countries serves as a model for the poorer countries, because of the considerable prosperity attained here, they are developing in the same resources-consuming direction which we set a long time ago, thereby further increasing the deficits in sustainability. Therefore, it is only when we fundamentally change our energy supply that there will be any chance at all to limit the pre-programmed increase in the global energy consumption and, at the same time, reduce the use of fossil-based fuel for climate protection reasons.

Ways towards a sustainable energy economy

Looking at it today, it seems impossible to completely and objectively consider and weigh between the dangers of global climate change, the expected tendency for fossil fuels to become scarce and costly, the diverging attitudes towards the risks associated with nuclear power, and the economic and social damage given by the extreme inequality in access to energy. The previous discussion does however allow certain basic conclusions to be drawn: a future energy supply can not be based exclusively on fossil and nuclear energy carriers. Instead, a system needs to be established which follows the eight guidelines for a sustainable energy supply as closely as possible, or which at least enables them to be continuously approached. There are three key strategy elements which support the re-structuring of the energy supply system, referred to as “efficiency”, “consistency”, and “sufficiency” (see boxed text).

None of these elements alone can ensure success – they are complementary and only through their close interaction can sustainability goals be met. A significant reduction of energy consumption is a prerequisite in order for renewable energy to be able to cost-effectively meet a reasonable share of the energy demand. Only an energy-conscious way of life will pave the way for the success of energy-efficient technologies. On the other hand, each unit of energy saved makes saving any additional unit of energy more difficult. As we do not envisage a “zero-energy society”, sustainable energy flows, using renewable energies, are necessary. At the same time, a change of public opinion and values must shift away from the constantly growing consumption of goods to an improved quality in consumer satisfaction, together with a strengthened sensitivity towards the

Key strategy elements

➔ **Efficiency:**

Desired energy services include a comfortable room climate, hot water, illumination, functional machines, and mobility. During the conversion of primary energy to such energy services, energy carriers run through several processes, all of which are associated with efficiency losses. These losses can be reduced considerably by modern conversion technologies and energy management techniques. Besides even greater efficiency in the energy conversion and a more rational use of energy in all equipment, avoidance of energy use (e.g. strong reduction of energy for heating purposes by using improved thermal insulation) and the substitution of high-grade energy by less “valuable” energy are also part of this strategy. For example, using the “noble” energy carrier electricity in electric heaters becomes unnecessary when heat from combined heat and power plants is used instead.

➔ **Consistency:**

The present energy system is “open” since fossil and nuclear energy resources are consumed and their waste products are disposed of in the environment. However, only “closed” systems, which provide energy without consuming raw materials or which return the materials in a closed cycle, are sustainable in the long run. Energy systems that “tap into” the natural energy cycles driven by the sun, gravity, or geothermal heat and only occasionally remove small fractions of the energy are very close to this ideal. These systems are also open in terms of energy flow, since solar irradiation enters from outer space. The materials employed within these processes can be recycled to a great extent as they are not contaminated; energy carriers are not “consumed”.

➔ **Sufficiency:**

The energy demand depends on the lifestyle and consumer habits. Changes in the human activities and needs, e.g. in recreational behaviour, can have a strong impact on the resulting energy consumption. The scope of self-dependent responsibility is rather large, ranging from a deliberate renunciation of energy-intensive products or exaggerated mobility to an intelligent assortment of foods and transportation means. From an awareness that old habits calling for “further, faster, and more” will not be sustainable in the long run, a change of values in the industrial countries calling for “living better instead of having more” would have a considerable influence on future energy demands.

environment. Such a change, however, will take time to reach a majority of the population. In particular, the ongoing globalisation of all kinds of activities – including consumer behaviour – and the strong focus on short-term economic successes instead of future-oriented, long-term reform measures hinders these necessary changes. A large variety of “social innovations” is therefore required before a conscious use of natural resources becomes a matter of course.

Renewable energy – guarantor of a sustainable energy supply

Although there are different opinions about the potential for increased efficiency in the energy sector and about the feasibility of widespread CO_2 sequestration, many scientific studies agree that only a significant expansion of renewable energies offers the chance to join a sustainable energy path. Renewable energy is thus the only dependable guarantor for a future energy supply. A distinguishing characteristic of renewable energy use is that minor components of the natural energy fluxes are temporarily withdrawn from the ecosphere and returned in form of “depreciated” heat after providing certain energy services. The inexhaustible vigour of the sun is the ultimate source of this energy. The sun is a gigantic fusion reactor which has been supplying abundant energy from a safe distance to the earth for billions of years and will continue to do so in future. All life on earth obtains its energy from the sun. Plants grow and synthesise biomass by using solar energy. The sun drives the weather, wind, and precipitation, thus creating the preconditions for wind power and hydropower.

Solar thermal collectors, photovoltaic systems, and concentrating solar power systems directly use solar

External costs – how to correctly determine the costs of energy

The damage caused by energy conversion and use can, under certain circumstances, lead to considerable costs. Since these costs are not borne by the cause itself and are also not reflected in the market prices for electricity or heat, they are termed **external costs**. Such external effects lead to – in the language used by the economists – a non-optimal allocation of scarce resources, i.e. the environment is being overexploited.

The solution to the problem is simple in theory: the external effects have to be "internalised", i.e. the costs attributable to the burdens on the environment must be allocated to the cause so that the market prices include all the relevant costs associated with the product or services. This internalisation can be realised by means of environment-related taxation, levied charges, trading with emission rights, price regulations, and similar instruments. Unfortunately, putting theory into practice is not that simple. It presupposes the exact assessment of the damage to the environment and the quantification of the economic damage. In order to establish a causal relationship between the environmental burden and the resulting damage, the attempt is being made to describe the entire chain of effects attributable to a pollutant from its emission, via transportation and conversion processes, and finally its effects on human beings or ecological systems.

Despite considerable uncertainties, scientific models have been developed which allow quantified estimates of air-pollutant effects on materials (e.g. higher corrosion), on human health (from slight respiratory symptoms through to higher mortality risks), or through the acidification and eutrophication of ecological systems.

In recent years, large attempts to estimate the damage caused by global climate changes and the resulting costs have been undertaken. The uncertainties in estimating the costs of the damage from the greenhouse effect are however very high, so that it is not yet possible to define a dependable monetary assessment of the resulting damage. The values published in the literature range over several orders of magnitude.

Today's best estimates indicate that values of about 70 Euros/t CO_2 are reasonable for the costs of damage caused by the global climate change. Since the consequences of climate change are not yet fully understood, these costs could also be significantly higher. The external costs are essentially determined by the costs of climate change and by health hazards, in particular due to increased concentrations of fine dust. The currently available values for quantifiable external costs are "best estimates" and should not be interpreted without considering the above-mentioned uncertainties and limitations of the methods used.

For new lignite-fired power plants, the external costs are 4.5 Cents per kWh electricity – an internalisation of the external costs would therefore more than double the costs for electricity generation. The external costs of ca 4 Cents per kWh for a hard-coal-fired power plant are also similar to costs of the electricity generation itself. Although significantly lower for gas-fired power plants, at ca 2 Cents per kWh they are not negligible. Comparing these costs with estimates for removing the CO_2 from fossil-type fuels or from the exhaust gases from power plants yields a cost increase in the same order of magnitude. CO_2-free electricity from conventional power plants will therefore be more expensive than today's electricity.

The quantification of external costs from nuclear power plants is difficult, in particular due to controversies on how to evaluate large accidents and the extremely long time periods involved in radioactive waste storage. The external costs determined for nuclear energy therefore depend strongly on the assumptions taken.

Electricity generation from photovoltaic systems, wind, and hydropower is free of emissions. Environmental damage is practically only caused by the emissions from upstream process steps like material production or the manufacture of system components. The generation of electricity from wind and hydropower therefore leads to very low external costs of ca 0.1 Cents per kWh. Photovoltaic systems incur relatively high external costs of 0.8 Cents per kWh, mostly due to their still-expensive manufacturing process which requires large amounts of fossil energy carriers. The type and magnitude of the emissions, and therefore the damages attributed to the production of the installation, are determined primarily by the fossil energy carriers used in the upstream processing stages.

In contrast to fossil-fired power plants, the CO_2 emissions for renewable energy installations will decrease to the same degree that low-CO_2 or CO_2-free energy carriers are implemented in the future energy supply system. The technical possibilities for improving these very young technologies will lead to significant reductions in their external costs.

These comparisons make clear that the evaluation of the most "cost-effective" energy supply today is based on inadequate assumptions. Fossil and nuclear energies are more expensive than indicated by the economical calculations. And they will become even more expensive in the future. In contrast, the costs of renewable energy are already telling the ecological truth today and can become significantly lower in the future because of growing markets and further technical advances.

It is therefore only a question of time before energy from renewable energy sources will be more cost-favourable than energy from conventional, limited sources. Therefore, those wanting to use cost-effective energy in the future should invest in renewable energy today. And the more effectively the external costs are internalised, the sooner the fundamental changes necessary in the present energy supply system will become more attractive from the economical point of view (see Figure: Development of costs for renewable and conventional energy sources). For this purpose, energy policy must provide appropriate guidelines.

Appropriate "guiding barriers" should therefore ensure that the longer-term perspectives of a sustained economy are established to complement the short-sighted market perception. One example for a good approach in this direction is the **ecological tax**. The **Renewable Energy Sources Act** can also be seen as "anticipating" the corrections already overdue in the price of energy. The feed-in tariffs guaranteed by this legislation can be considered as a compensation for non-internalised external costs of other energy carriers.

irradiation without needing other media. Heat pumps employ conventional energy to use ambient heat. Finally, we can tap geothermal energy, a renewable source based on the radioactive decay occurring at great depths in the earth, and gravity which is responsible for the tides. For thousands of years, man relied exclusively on renewable sources of energy, however only at a very low level and with low efficiency. Compared with our ancestors, we now have considerable advantages.

Technologies are available today which make renewable energy services possible at the same high level as fossil

→ Renewable energy sources

Primary energy source	Manifestation	Natural energy conversion	Technical energy conversion	Secondary energy
SUN	Biomass	Biomass production	Co-generation plant / Conversion plant	Heat, electricity, fuel
	Hydropower	Evaporation, Precipitation, Melting	Hydropower plant	Electricity
	Wind power	Atmospheric motion	Wind turbine	Electricity
		Wave motion	Wave power station	Electricity
	Solar radiation	Ocean currents	Ocean current power station	Electricity
		Heating of Earth's surface and atmosphere	Heat pumps	Heat
			Ocean thermal energy conversion	Electricity
		Solar radiation	Photolysis	Fuel
			Solar cell, Photovoltaic power station	Electricity
			Solar coll., Solar-thermal power station	Heat
MOON	Gravity	Tides	Tidal power station	Electricity
EARTH	Mainly Isotope decay	Geothermal	Geothermal cogeneration plant	Heat, electricity

Renewable energies are derived from solar radiation, isotope decay in the earth's interior, and the gravitational pull of the moon.

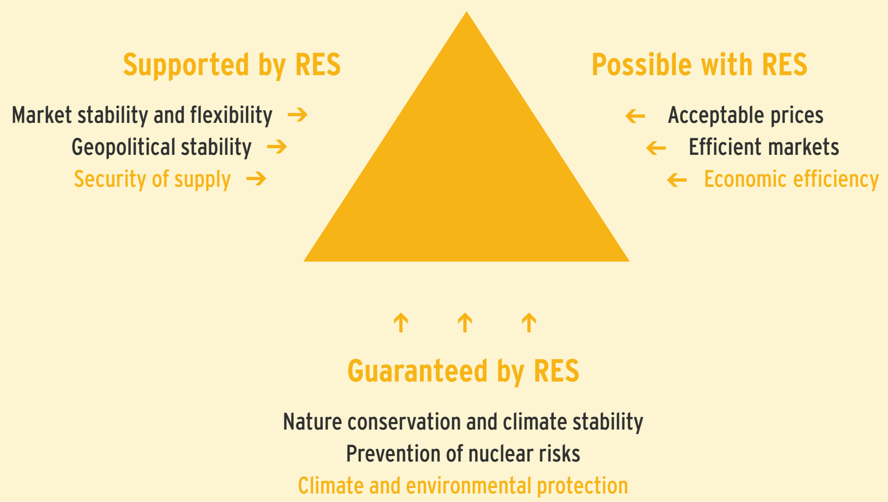
and nuclear sources. The associated costs are affordable as well if such techniques are applied on a large scale and if the existing possibilities for cost reduction are exploited. Moreover, "costs" must always be judged in relation to the environmental and social "qualities" of the services provided, i.e. considering the external costs and damages that would result from a possible adherence to fossil and nuclear energy systems (see boxed text: "External costs – how to correctly determine the costs of energy"). After assessing all these considerations, we find that renewable energies can meet all essential requirements of a future sustainable energy supply system (see Figure: Energy triangle).

A particular characteristic of renewable energy is the diversity of resources and technologies and the enormous range of power ratings from a few watts to hundreds of megawatts. Renewable energy can be adapted to any kind of energy service and be closely inter-linked with conventional modern energy technologies to ensure security of supply at all times and at any location. Characteristic for this kind of energy supply is, on the one hand, the increasing integration on a decentralised level (see Chapter: "Supply structures of the future"). On the other hand, intercontinental grids are in a position to effectively combine the different regional. Beyond the country-specific decentralised use of renewable energies, large supply centres will evolve in the future at sites with a very abundant (and thus also cost-efficient) supply of renewable energy, which then supply regions of high energy demand by means of high-voltage transmission lines or (hydrogen) pipelines. Thus all "reservoirs" of renewable energy can be "tapped" and used in a cost-efficient manner.

How renewable energies contribute to sustainability

- Renewable energies **contribute considerably to climate protection** – they prevented the emission of ca 83 million tonnes of the greenhouse gas CO_2 in 2005.
- Renewable energies diversify resources, ease the dependence on fossil resources, and thus contribute to the **security of supply** and help **prevent resource conflicts**.
- On the medium term, renewable energies also **protect us from the inevitable cost increases** due to scare fossil and nuclear resources.
- Renewable energy systems can be **simply dismantled** and **recycled** at the end of their service life. They are not radioactive, like nuclear waste, and do not leave any collieries behind.
- Renewable energies are often **domestic energy carriers** which contribute **regional added value** and secure employment.
- Renewable energies simplify **the access to energy for large population groups**, e.g. through rural electrification, and can help lead poor countries out of poverty.

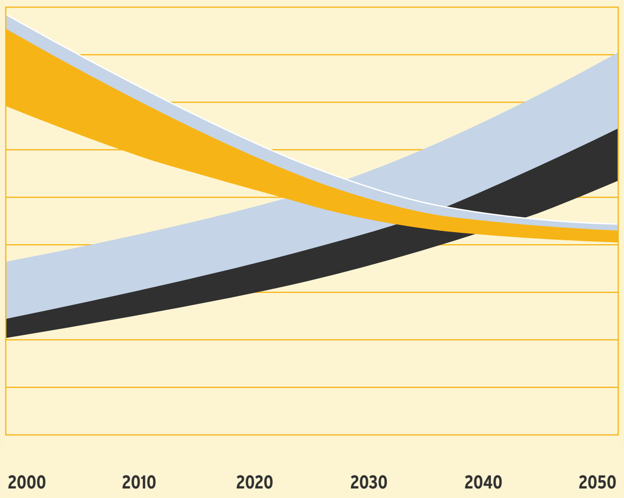
→ The energy triangle



The energy triangle – all essential requirements of a sustainable energy supply can be fulfilled by renewables, already today and in the future.

Source: DLR

→ Development of costs for renewable and conventional energy sources



Renewable energies
- Young technologies; large potential for technological progress and cost reduction
- Unlimited, global availability
- Globally applicable, can not be misused, practically no hazards
- Low external costs (system manufacture)

Fossil and nuclear energies
- Limited resources, unequal regional distribution
- Prices increase in the long term
- Expensive and high-risk nuclear technologies (breeders) required to substitute fossil resources
- Nuclear energy is not globally available; high potential for misuse and high-risk
- External costs: prohibitive in the long term for fossil fuels (climate change), probably prohibitive for nuclear

Renewable energies
Fossil and nuclear energies
External costs

Renewable energy sources provide the cheapest energy in the long run.

At the same time, such centres can become regional nuclei of economic development and increasing prosperity, thereby helping to stabilise socio-economic structures. Since most of these centres will likely be established in developing countries (e.g. in North Africa), a relevant mobilisation of renewable energies will inherently involve a positive development of these countries.

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POTENTIAL FOR RENEWABLE ENERGIES

Global availability of energy

Extraordinarily large and inexhaustible flows of energy on our planet Earth can provide enough energy to meet our demand many times, without having to use any of the finite energy resources. The available energy sources are the continental solar irradiation, the kinetic energy from the wind, waves, and ocean currents, the biomass which grows again each year, the potential energy of water, the geothermal energy, and the thermal energy from the seas. These flows of energy are equivalent to about 3,000 times the annual global energy consumption at the present time.

The **technical potential for use** can be derived from the physical potential of the renewable energy (see Figure: Natural availability of renewable energy), providing energy in a form usable by the end consumer – i.e. as useful heat of various temperatures, electricity, or fuel for heating or mobility purposes.

There are various criteria to be considered when determining the potential:

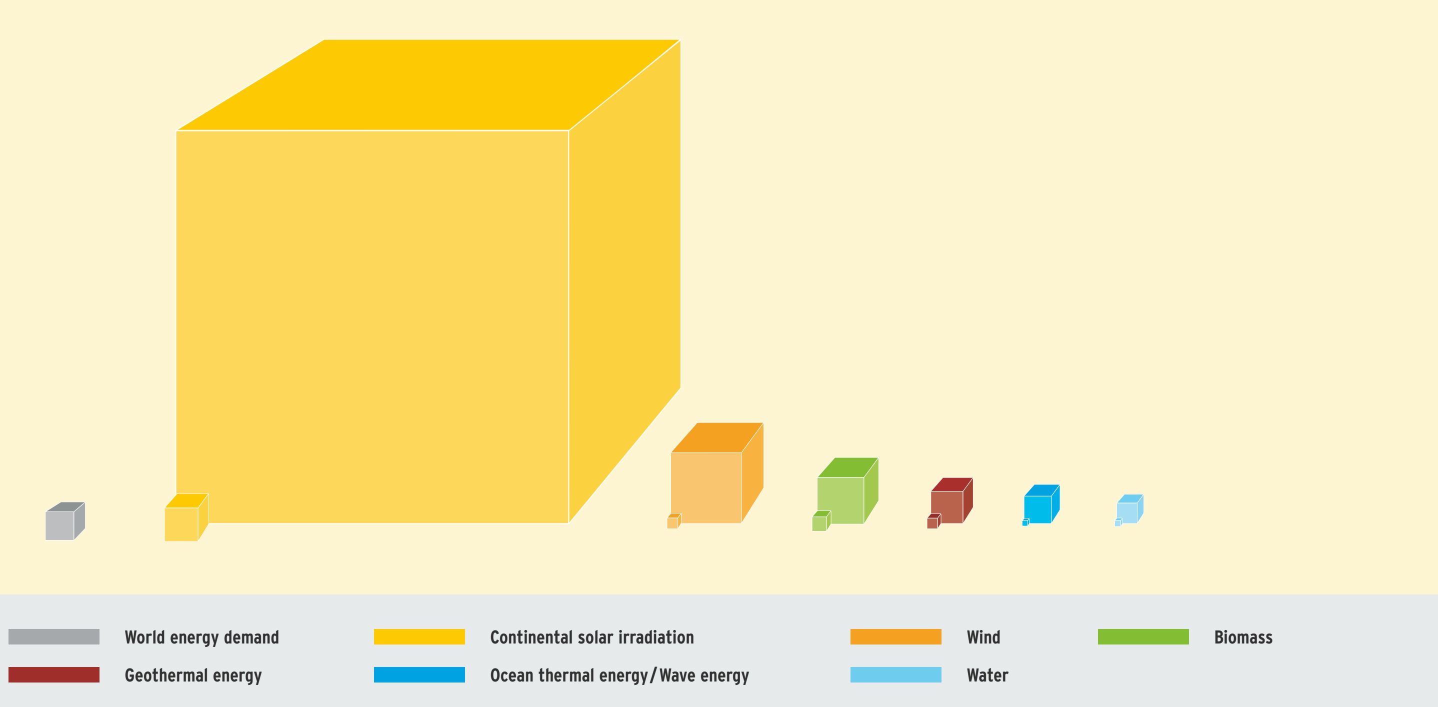
- **Limits in the efficiency, plant size, and technical development potential** of the technologies which are either currently available or will be in the near future.

- **Structural restrictions** limiting usage due to location dependency (e.g. geothermal energy), a limited radius of transportation (e.g. biomass), availability of appropriate areas or competitive uses (e.g. collectors, solar cells, energy crop cultivation), nonexistent infrastructure (e.g. lack of heat distribution networks), and/or limited availability and reliability of the energy supply (e.g. electricity from fluctuating sources, like wind or solar irradiation).

- **Ecological restrictions** regarding the space requirements (e.g. wind power), disturbances in flowing water (e.g. hydropower) or the landscape (e.g. wind power), as well as restrictions in the possible uses for biomass (e.g. waste materials from forestry and agriculture, energy crop cultivation).

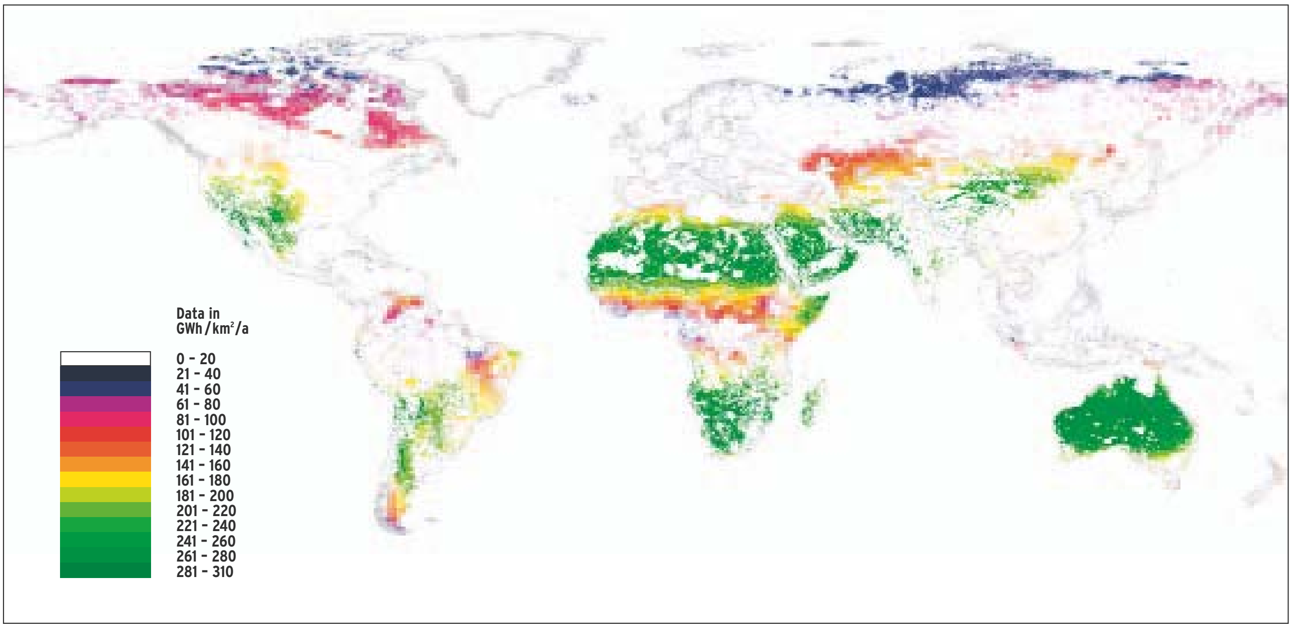
→ Natural availability of renewable energy

Source: DLR



Rear cubes: The natural availability of renewable energy is extraordinarily large. Front cubes: The technically available energy in the form of electricity, heat, and chemical energy carriers exceeds the present-day energy demand (grey cube, left) by a factor of six.

Source: DLR



Global technical potential for electricity generation by solar thermal power plants. The electrical energy yield in one year per square kilometre available land is indicated.

The technical potential of renewable energy is thus not constant over time. It represents a cautious indication with regard to the technically feasibility within a longer-term period, and shows which importance each of the energy sources and the respective technologies could have for different countries and regions.

Considering these restricting criteria, only a few parts per thousand (solar radiation, wind) to a few percent (biomass, geothermal energy) of the natural energy flows are suited for exploitation (see Figure: Natural availability of renewable energy; front cubes). Only hydropower demonstrates technical exploitation in the order of 10 %. Even for very stringent restrictions, the total global potential of technically usable renewable energy is approximately six times the current world-wide consumption of final energy. About two thirds is provided by the radiant energy from the sun.

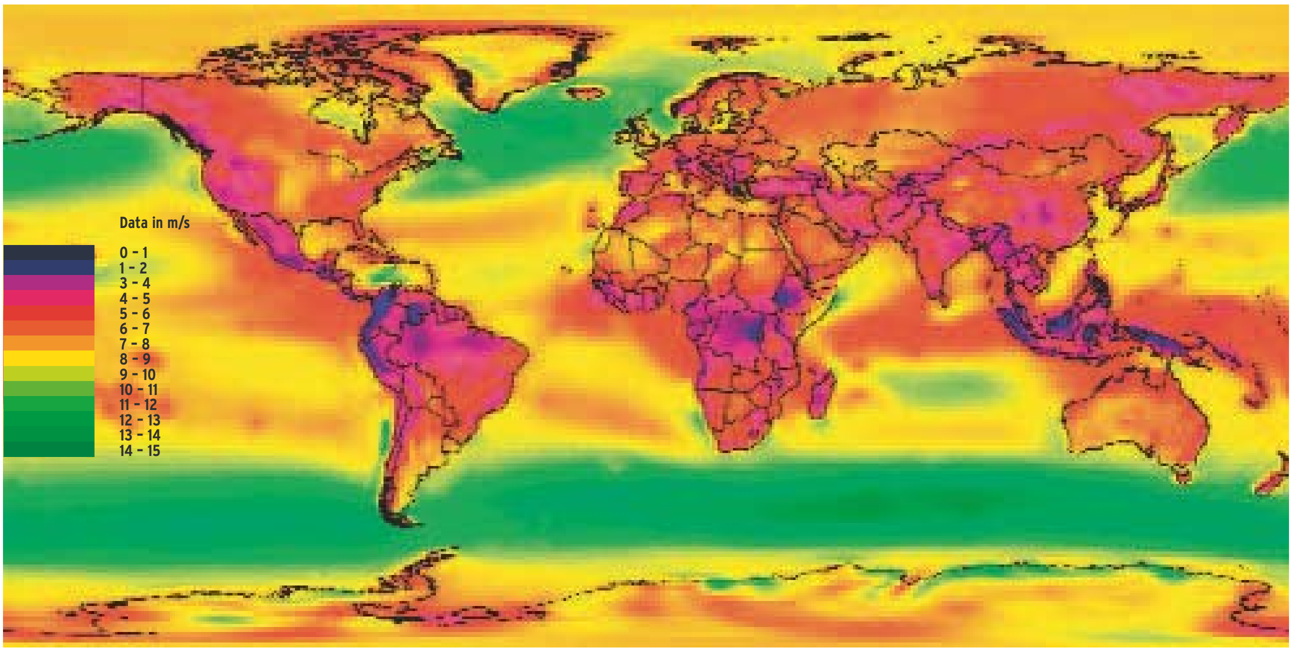
Renewable energy can thus, in principle, still meet an increasing demand for energy, completely and permanently. Accordingly, contributions from renewable energy sources in the range of 50 % and more to the world energy consumption are already considered feasible in the various scenarios for the future up to the middle of the next century (see Chapter "Perspectives of renewable energies").

The availability of renewable energy differs considerably throughout the various regions of the world, as demonstrated exemplarily for solar-thermal power plants (see Chapter: "Solar thermal power plants"). The largest potential for this technology, which uses solar radiation in concentrated form, lies in the regions belonging to the so-called "global sun belt" of the Earth, i.e. between the 20th and the 40th latitudes of the southern and northern hemispheres (see Figure: Global technical potential). In particular, the tropical cloud cover around the equator and the low-pressure regions in the west-wind zones are responsible for the global sun belt.
A similar pattern is apparent for photovoltaic systems as well. The influence of an overcast sky is however less dramatic, since photovoltaic systems can also utilise diffuse irradiation. The regional differences in potential are even more pronounced if the technical restrictions and reductions for non-suitable or otherwise used areas are taken into account, e.g. settled areas, forests, agricultural areas, bodies of water and swamps, dunes, protected areas, or steep topography.

The technically useful potential for renewable energies is about six times the current world energy demand.

As shown in the world map, North Africa, the Arabian Peninsula, and Australia all have an enormously high potential for the solar-thermal generation of electricity. In North Africa alone more than a hundred times the world's electricity requirement could be provided by means of solar power plants. Each square kilometre of land in North African locations could supply 200 to 300 $GWh/km^2/a$, as much energy as a conventional coal or natural-gas power plant with an output of 50 MW

Source: DLR



Long-term average values of the wind speed at 80 m altitude, in m/s.

and 6,000 full-load hours per year. The Mediterranean region is also suited for supplying solar electricity. The area and irradiation potential principally available in Spain alone would theoretically even suffice to generate enough electricity to meet present-day demand in Europe.

The corresponding potential for wind power depends on other factors: The average wind speed is considerably lower over the land masses of the continents, due to the harsh topography of the countryside which slows down the winds, than out at sea, where the wind can blow unhindered. The North Sea is one of the stormiest regions of the world. However, exposed areas also exist on land where the particular topography provides excellent wind conditions.

Thus the following can be concluded: The technical potential of the individual sources of renewable energy varies considerably from region to region. Not every energy source is available in every country. Certain regions have sources which are particularly favourable to develop. The greater the variety of energy sources and technologies used – solar energy, wind, geothermal energy, biomass, hydroelectric power – the easier it is to compensate for any regional deficits in a particular source of energy by tapping other potential sources of energy. A diversification of energy sources and technologies is thus very sensible when considering regional potential. There are attractive renewable energy potentials in practically every country, just waiting to be exploited. In the foreseeable future, these domestic potentials will guide national developments in renewable energies. In the long term, certain regions with substantial potential for renewable energy can furthermore become suppliers of cost-effective secondary energy. Thus today's world trading with fossil energy carriers could at some time in the future be replaced by trading with electricity and hydrogen produced from renewable energy sources.

Potentials in Europe

Europe possesses a wide variety of renewable energy resources, which have been utilised to various degrees so far. At 80%, the potential for hydropower has already been extensively developed, excluding new power plants on natural rivers. Biomass is also already used to a large extent. However, large capacities for biomass are still unused. Just a fraction of the other possibilities for renewable energy production are being exploited so far. A total assured potential of at least 40,000 PJ per year of renewable energy is available in Western Europe, corresponding to approximately 60 % of the current primary energy consumption in the 25 EU countries. So far, only ca 12 % of this enormous potential is being used. In the long term, further potentials can be developed once all renewable energies are established in the future energy supply. A few examples:

- 2,000 TWh/a additional electricity generation from more extensive use of offshore wind energy along the European coasts;
- 3,500 PJ/a additional primary energy from energy plant cultivation on 30 million ha of currently unused agricultural land;

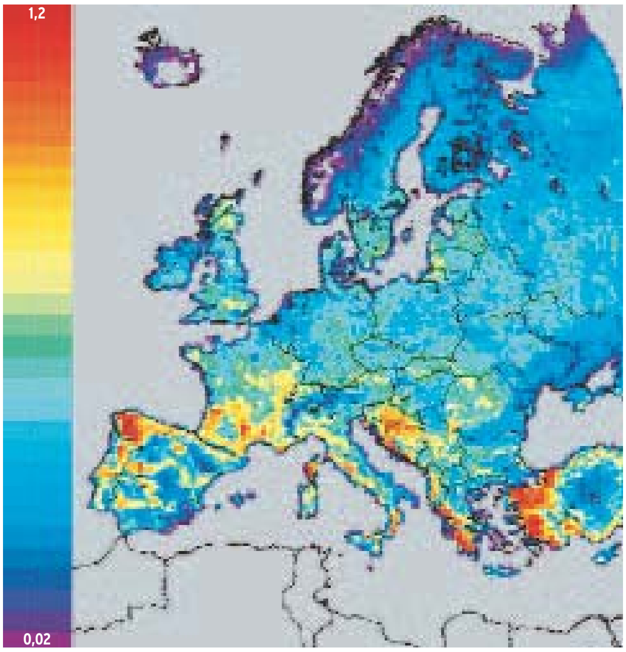
– up to 1,700 TWh/a through the use of further geothermal resources in West Europe with the potential for electricity generation;

– several 10,000 TWh/a electricity from solar thermal power plants located in North Africa as a part of a Mediterranean electricity network

These possibilities add up to an additional technical potential for primary energy of more than 80,000 PJ per year – principally enough renewable energy to meet the West European energy demand, even at the higher levels expected in the long term.

The varying availability of the resources sun, wind, hydropower, geothermal heat, and biomass in the individual European countries manifest that the potentials in Europe, and also especially in North Africa, should be used collectively for a sustainable energy supply, involving close networking and cooperation between the regions. In this manner, renewable energies can become a component of international cooperation for global climate protection and sustainable development.

Source: DLR



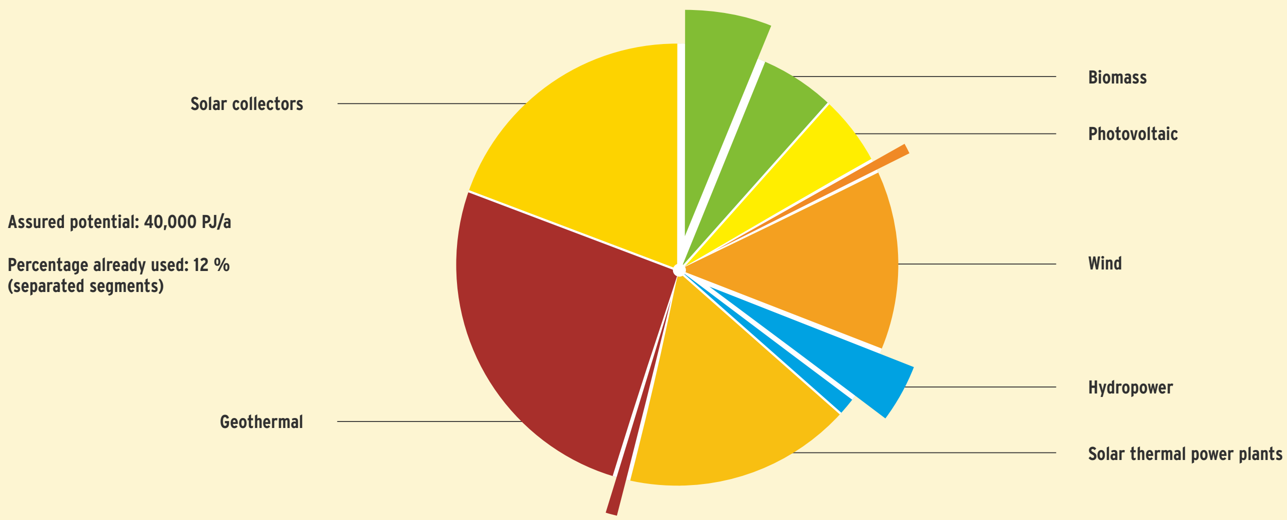
Net primary production of photosynthesised biomass in mega-tonnes of carbon per year over a land area of ca 27.5 x 27.5 km (each pixel) in 1998.

Potentials for Germany and their costs

Germany is a good example of how a country with a moderate climate can develop a variety of renewable energy sources and, by doing so, can meet a considerable proportion of its own energy demand. The potential for the use of renewable energy sources within Germany amounts to 5,200 PJ/a, which corresponds to 37 % of the present-day primary energy consumption. If we can succeed in lowering the energy demand in Germany, then the proportion of these domestic sources of renewable energy will correspondingly increase to levels considerably higher than 60 %. The renewable energy potential is assessed considering restrictions on the areas which could be used for collectors and solar cells, for wind power sites, or for energy crop cultivation. According to statistics, electricity from hydropower,

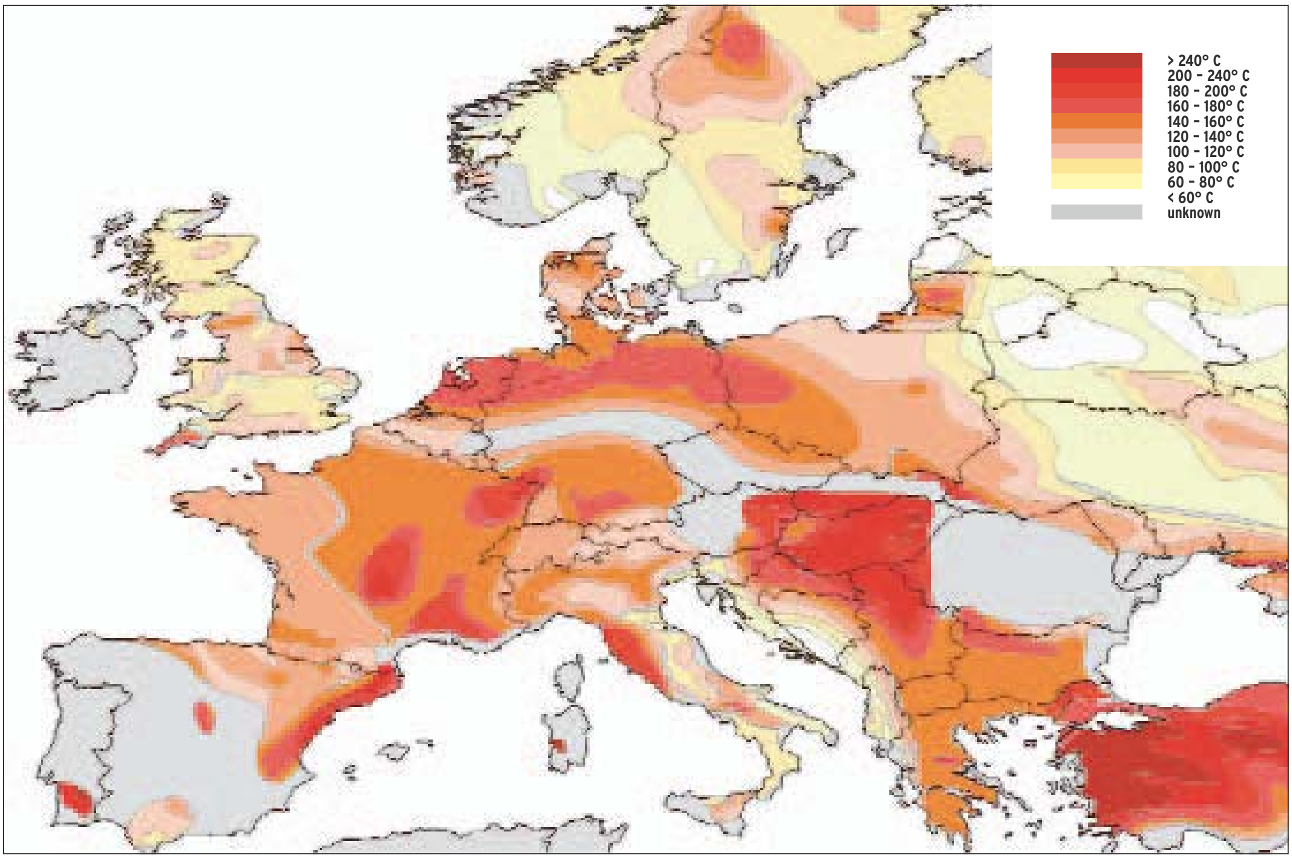
→ European potentials

Source: DLR



Assured potential of renewable energy in West Europe. So far, only hydropower and biomass are exploited to a large extent.

Source: Bestec 2004



Rock temperatures at 5,000 m depth as an indicator of the potential for geothermal electricity generation in Europe.

Currently, only 6.5 % of the German renewable energy potential is being exploited.

wind, and solar power plants is defined 1:1 as primary energy (i.e. energy resource). Nevertheless, renewable energy sources are the most important domestic source of primary energy. And just like the fossil energy of today, energy carriers produced from renewable energy sources can also be imported in practically unlimited quantities at a later point in time. Beginning with a low proportion of this potential as "indicators" in the **baseline potential** for Germany, the corresponding value for the potentially available primary energy from renewable energy sources amounts to at least 9,000 PJ/a for Germany. With ca. 590 PJ/a, only 6.5 % of this potential is being exploited at the present time.

More important than just information concerning the potential are those segments of the potential which are usable at a given point in time, since the entire above-mentioned baseline potential is not immediately available. It is important to classify potentials into cost categories and consider possible future cost reductions, enabling the economic potential to be derived for a given point in time. Except for hydroelectric power and biomass, the **possibility for considerable cost reductions** is inherent in every technology. These possible reductions depend essentially on the further technical progress and market development. Calculations based on the analysis of past cost developments, comparisons with other plants which are similar to the plants for using renewable energy, and assumptions regarding the expected market development describe the cost reductions achievable in the future for a given energy technology. The cost reductions can be approximately derived from learning curves, which indicate the percentage by which the costs of a particular technology decline when the corresponding cumulated installed capacity is doubled. Typical values lie between 10 and 30 %. The cost developments for wind power and photovoltaics show that such learning-curve values can actually be achieved. By 2004, the cost of electricity generation from photovoltaic modules sank to less than half of the cost in 1992 (not adjusted for inflation). The cost of electricity generation from wind also dropped significantly within the same time period (1990: ca 14 Cents/ kWh, 2004: ca 9 Cents/kWh).

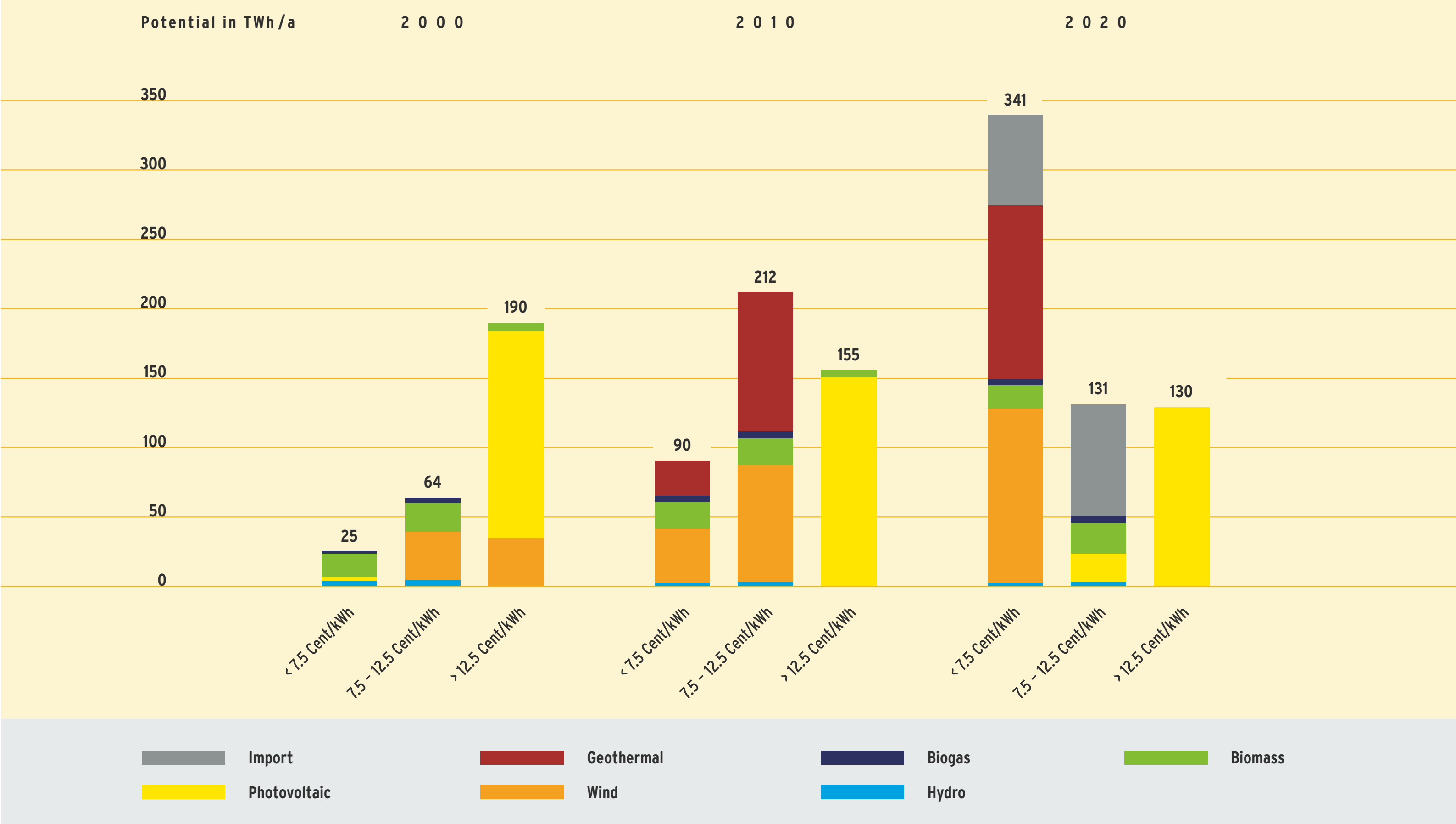
This **relationship between market growth and cost reduction** is also of considerable significance when designing the supporting measures aiming to effectively mobilise renewable energy on the long term. In any case, these measures must be effective enough to sufficiently mobilise a large volume of the market while, at the same time, exerting continuous pressure on the production costs so that the technologies can eventually assert themselves on the energy market within a reasonably short time period.

With costs of up to 7.5 Cents/kWh, the most cost-effective segment in the field of electricity at the present time is 25 TWh/a from hydroelectric power, from biomass, and from wind at favourable locations. Some 65 TWh/a are provided at costs between 7.5 and 12.5 Cents/kWh. A further 190 TWh/a, especially from photovoltaics, costs more than 12.5 Cents/kWh. If the market developments of all technologies are sufficiently stimulated, then the most cost-effective segment can grow to some 90 TWh/a by 2010, resulting from a decline of costs and the market introduction of new technologies (offshore wind, geothermal energy). For the same reasons, the overall potential can increase to around 450 TWh/a. In the longer-term, i.e. after 2020, the cost-effective potential segment can grow to some 350 TWh/a by further mobilising of all these technologies. The total potential can thus exceed 600 TWh/a, thereby surpassing the quantities of electricity being generated today. This capacity is enabled by the import of electricity from renewable energy sources which will then be possible, the widespread utilisation of wind potential (offshore), and by exploiting the potential for electricity generation from geothermal sources. The available amount of electricity according to the baseline potential is to about two thirds from the fluctuating sources of wind and solar radiation. An extensive exploitation of this potential therefore calls for redesigning the supply structure, to modify present-day distribution networks, and to make appropriate modifications in load management, reserves, and control systems for power plants. Since such a process requires decades to complete, it can be carried out along with pending new investments while continuously integrating technical advances.

The potential for providing useful heat can be structured in a similar manner as for generating electricity (see Figure: “Heat generation potential”). A total potential of 3,000 PJ per year (of final energy) is available, equivalent to approximately 55 % of the quantities of fuel currently being used for generating heat. Heat from renewable

→ Electricity generation potential

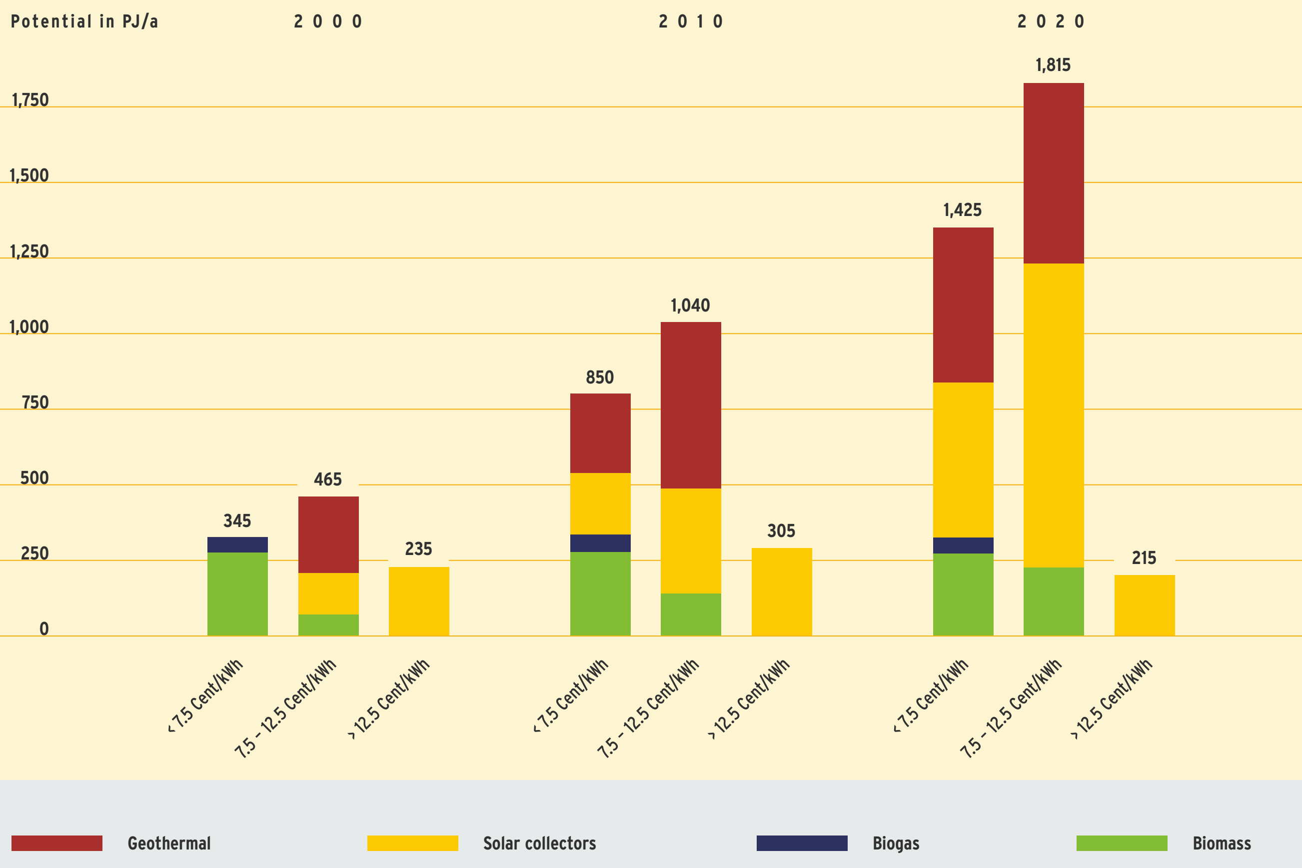
Source: HGF 2001



The renewable energy potentials will increase in the future and become more cost-effective. Electricity generation potential for three points in time, divided into three cost categories each.

➔ Heat generation potential

Source: HGF 2001



Heat generation potential for three points in time, divided into three cost categories each.

energy sources can be provided by stand-alone systems (e.g. wood-fired boilers, hot-water collectors) as well as by means of smaller and larger heat distribution networks. The latter play a very significant role in the further-reaching developments on the heat market. In many cases, any utilisation at all is only possible by this means (geothermal energy, large-scale collectors for heating purposes, biomass systems for combined heat and power generation; see Chapter "Future supply structures"). The heat is made more expensive by its distribution; typical heat distribution costs for district heat networks lie between 2 and 3 Cents/kWh. However, since the larger centralised heating systems have lower specific costs than the small-scale systems for individual buildings, the overall costs for heat in district heat systems are, for a careful design and full use of the network, often lower than those for stand-alone heating systems. It must be noted that heat distribution networks must also be constructed in already existing residential areas if the potential for renewable energy use is to be effectively developed.

At the moment, approximately two thirds of the heat potential from renewable energy sources are not yet directly available for structural and technical reasons. Examples include solar district heating systems with seasonal storage, using the heat from deep underground layers, and biomass from plantations of energy crops. The cost-favourable potential under 7.5 Cents/kWh, which is economical when heating oil costs care at 0.5 Euro/litre or more, currently amounts to almost 350 PJ/a and consists entirely of biomass residuals. Cost reductions, in particular for collector systems, will increase this potential to around 850 PJ/a by the year 2010.

The today still low utilisation of the renewable energy potentials should not lead to the conclusion economic considerations alone hinder the otherwise rapid expansion of renewable energy usage. Equally significant for a continuous development is to consider the investment cycles of buildings and power plants. An accelerated expansion of renewable energy use therefore calls for their timely and high-priority inclusion in all plans and investment decisions pertaining to the energy supply, and particularly in the area of residential buildings.

THE ECOLOGICAL QUALITIES OF RENEWABLE ENERGIES

The chapter entitled “Sustainability and energy supply” described how our energy system still exhibits numerous sustainability deficits, in particular with respect to its impacts on ecosystems. It is based on energy carriers with a limited availability. It burdens our atmosphere, our soil, and our water with pollutants and greenhouse gases. And that is not all: Leaks in oil pipelines, oil tanker accidents, and area-devastating coal mining, as well as the still unsolved problem of nuclear waste disposal and the possibility of reactor accidents: the list of environmental problems related to energy is long.

The intensive use of renewable energy promises relief in many areas. The “fuels” of the corresponding energy conversion technologies are the natural energy fluxes in our environment – solar radiation, wind, flowing water and waves, biomass, and geothermal heat. By using these natural energy fluxes, we can avoid the further consumption of the fossil and nuclear resources.

Compatibility of renewable energy with climate and resources

Furthermore, renewable “fuels” do not contain any fossil carbon atoms which would form climate-damaging CO_2 during combustion. Renewable energy is thus not only resource compatible, but also climate compatible. In 2005 alone, the emission of CO_2 was reduced by ca

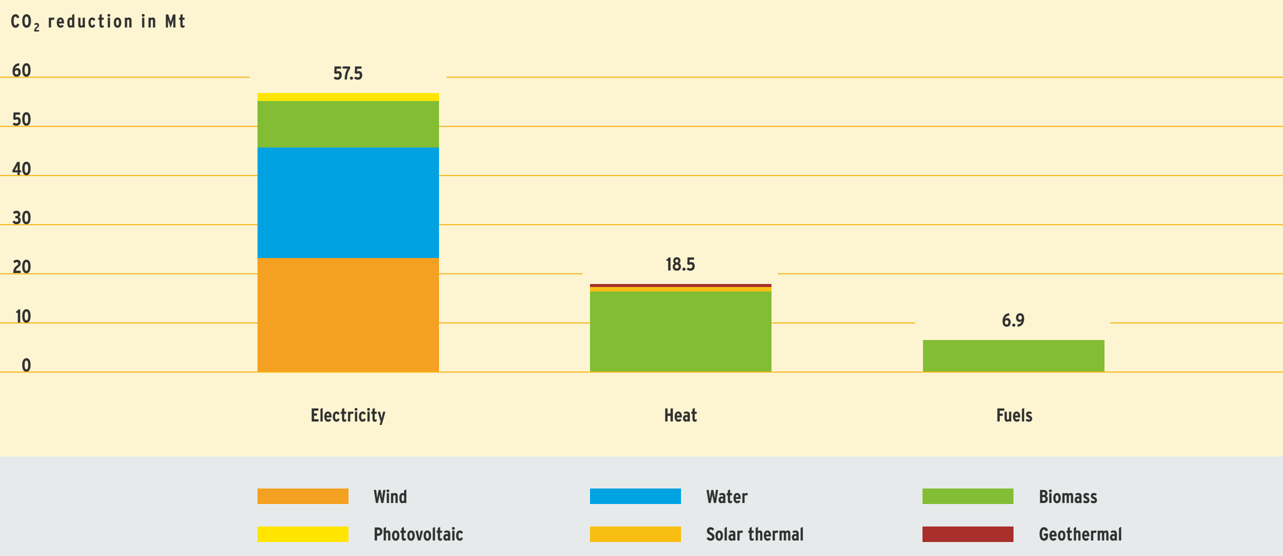
In 2005, renewable energy installations prevented the emission of 83 million tonnes of climate-damaging carbon dioxide. The energy-related CO_2 emissions in Germany would be about 10 % higher if we did not use renewable energy.

83 million tonnes through the use of renewable energy – 8 million tonnes more than in the year before. In other words: if we did not use renewable energy, the energy-related emissions of CO_2 in Germany would be about 10 % higher. The German Federal Government could scarcely fulfil its climate protection commitments without renewables.

The contribution of renewable energy to climate protection is therefore significantly larger than their share of energy consumption. This fact is related to the different fossil energy carriers which are substituted in each sector: especially coal in the electricity sector, which has a higher combustion-related CO_2 factor than mineral oil products or natural gas. The effect in the electricity sector is also particularly high because the conversion efficiency for power plants is much lower than those

→ Avoiding CO_2 emissions through the use of renewable energy

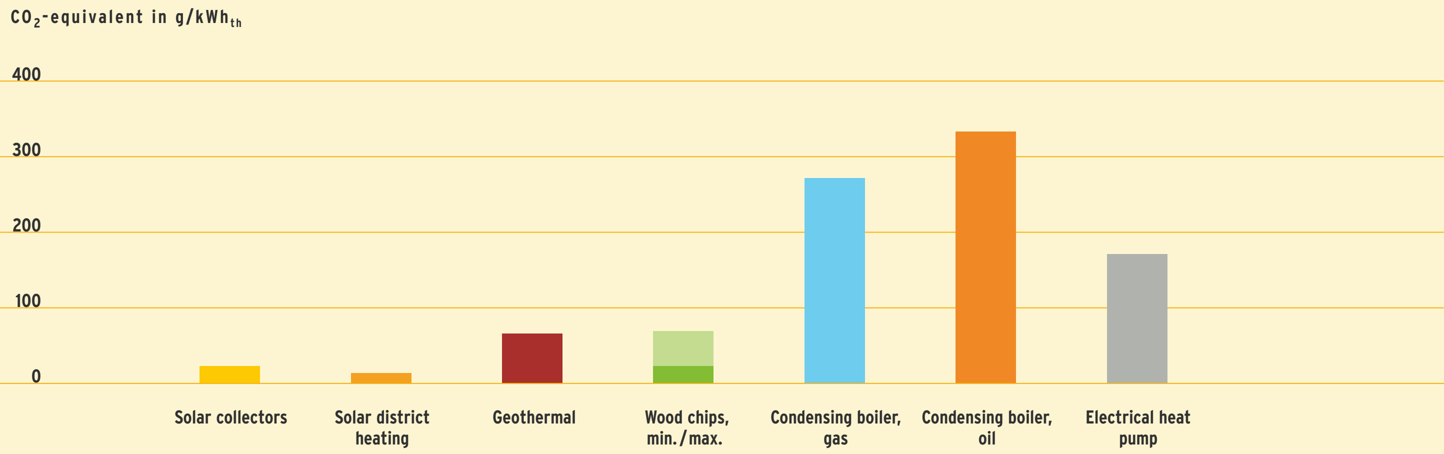
Source: AGEE-Stat, preliminary data



A total of ca 83 million tonnes CO_2 could be avoided in 2005 through the use of renewable energy

→ Greenhouse gas emissions from heat generation

Source: Ifeu / DLR



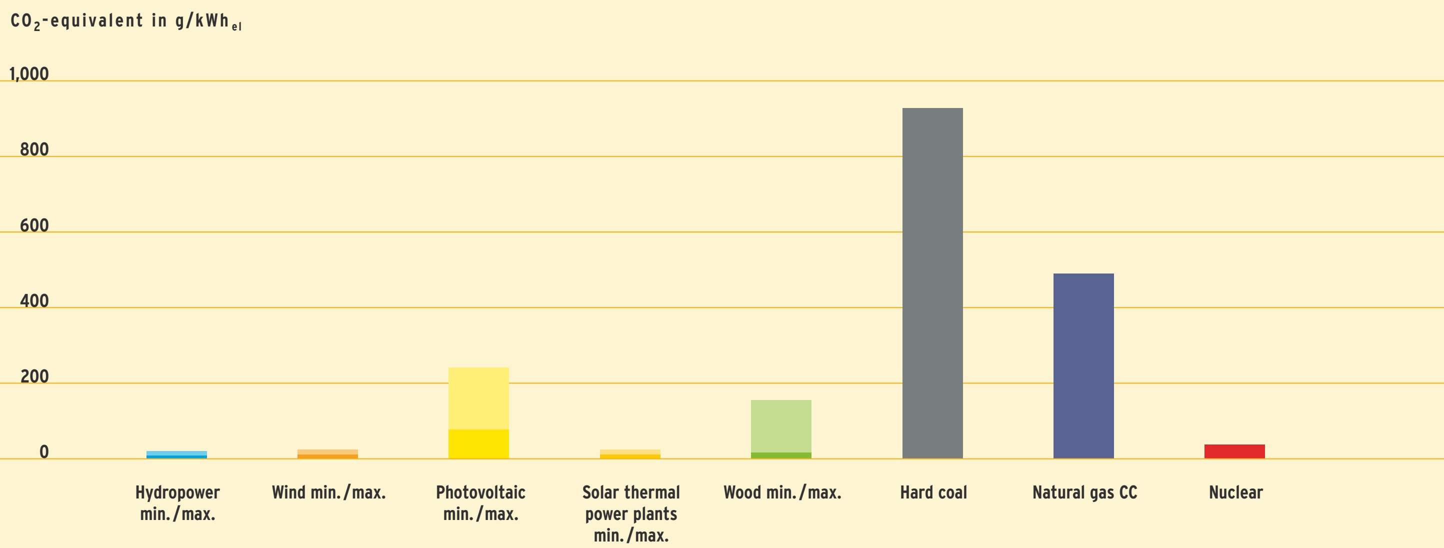
Greenhouse-gas emissions from different heat production technologies, in CO_2-equivalent per kWh useful energy. Emissions from renewable energy sources are very low compared those from fossil fuels.

for heat-generating systems. It accounts for about 58 million tonnes CO_2 avoidance in the electricity sector, and "only" ca 19 million tonnes in the heat sector (see Figure: Avoiding CO_2 emissions through the use of renewable energy). Nearly 7 Mt CO_2 are avoided in the fuel sector.

These calculations already take into account that the systems required to convert these energy fluxes must be constructed, operated, and dismantled at the end of their useful lifetime – known as the life cycle of the installation. Raw materials and energy are required for this purpose. The greenhouse gas emissions which are associated with the life cycle of renewable energy technologies – with the exception of photovoltaic – lie between 10 and 25 g/kWh of useful energy. For the use of biomass in boilers, steam turbines, or cogeneration plants, the values range between 20 and 85 g/kWh of useful energy, depending on the cultivation and harvesting of the wood. In contrast, the greenhouse gas emissions for fossil technologies are significantly higher – boilers burning gas and oil emit three times more

→ Greenhouse gas emissions from electricity generation

Source: Ifeu / DLR



Greenhouse gas emissions from different electricity generation technologies: emissions from renewable and nuclear technologies are much lower than from those based on fossil fuels

greenhouse gases, coal power plants even emit up to two orders of magnitude more than their renewable competitors. A hard coal power plant emits more than 900 g/kWh.

Photovoltaics is a good example to show how important it is to also analyse the development potential, and not just the current status. Whereas the present-day production of photovoltaic systems, depending on the type and the location, accounts for 100 to 250 g greenhouse gas emissions per kWh electricity, new solar cell types, higher conversion efficiencies, improved manufacturing processes, and new materials which are tailored to the needs of the solar industry can all radically reduce these emissions. Considering the fact that the future energy supply will contain a higher proportion of renewable energy, then the greenhouse gas emissions attributed to the installation manufacture will drop even further, since low-emission energy will also be used in the manufacturing process.

Another key figure is helpful when comparing fossil-fuelled and renewable energy systems: the **energy payback time**, i.e. the time needed by an energy system to generate the same amount of energy required for its construction, operation and disposal.

The energy payback times for renewable energy installations are very short. Fossil-fuelled power plants never amortise.

For fossil-fuelled or nuclear plants, the energy payback time for the construction of the plant is around 2 to 3 months. Yet in terms of their overall operation, these plants never amortise because more energy is always consumed in the form of fuel than is produced in the form of useful energy! For example, a typical lignite power plant must burn coal with an energy content of about 2.5 kWh in order to generate 1 kWh of electricity.

Water, wind, and solar thermal power plants need between 3 and 13 months to amortise the energy consumed to produce them. Once this amortisation time has elapsed, each hour of operation then provides valuable energy which is "ecologically gratis". The production of solar cells is more energy intensive. Today's systems based on crystalline silicon have energy payback times of two to five years at our latitudes. Their product lifetime is, however, many times longer. Further advances in solar cell technology and in their manufacture are

Source: Ifeu / DLR

➔ Energy payback time for construction, operation, and disposal

Electricity generation compared to today's energy mix	
Wind power	3 to 7 months
Hydroelectric power	9 to 13 months
Solar thermal power plant in Morocco	3 to 7 months
Photovoltaic system in Central Europe • Polycrystalline silicon, modern production technology • Thin-film cells	 3 to 5 years 2 to 3 years
Gas power plant	Never *
Coal-fired power plant	Never *
Nuclear power station	Never *
Generation of heat compared to a natural gas boiler	
Solar collectors	1.5 to 2.5 years
Geothermal energy (hydrothermal)	7 to 10 months
Gas-fired boilers	Never *
Oil-fired boilers	Never *

The energy payback time describes the time which is needed by the installations to produce the same amount of energy as was required for its construction, operation, and subsequent disposal. * Power plants and boilers based on finite energy carriers can never amortise in terms of energy, since they always consume more fuel than the useful energy they generate.

Economy of scale, technical advances, and increasing prices for fossil energy carriers will considerably reduce the CO_2 avoidance costs for renewable energy in the future. The trend for fossil-fuelled power plants is in the exact opposite direction.

expected to reduce the energy payback time to one or two years within the next decade.

Similar conditions prevail for heat generation. The energy payback time is between 18 and 30 months for **solar collector systems**, and just 7 to 10 months for hydrothermal geothermal energy installations. Renewable energy systems therefore generate the energy required for their manufacture many times over – in direct contrast to fossil-fuelled plants.

The price of avoiding CO_2 emission

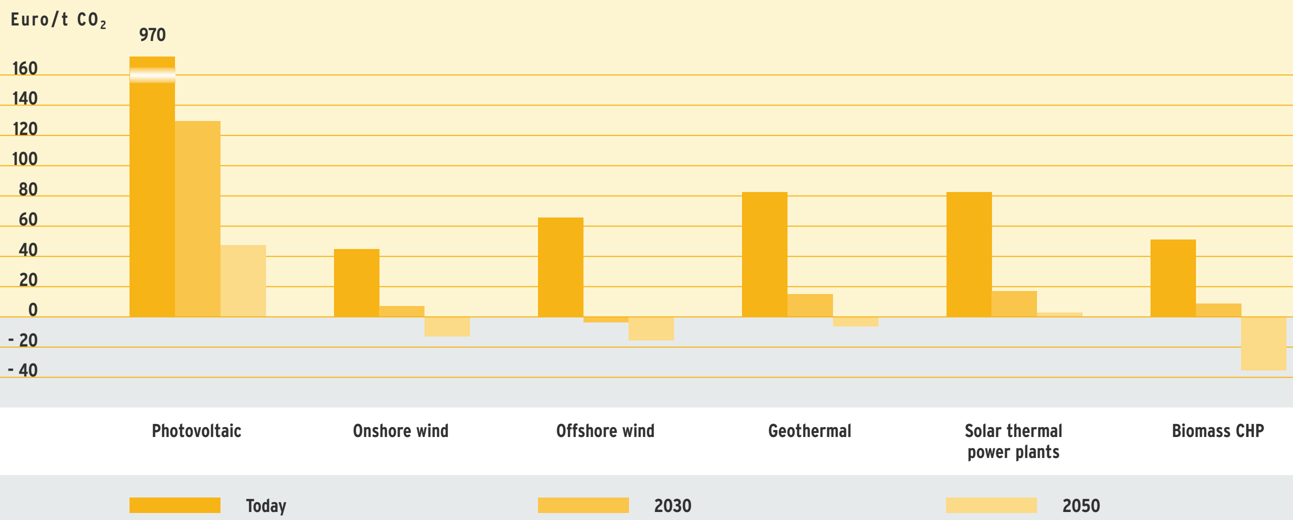
The goal of an efficient climate-protection policy is to achieve the necessary reduction of greenhouse gas emissions with the least possible expenditures. The CO_2 avoidance costs are often consulted to gauge the efficiency of reduction measures. They represent the reduction of CO_2 emissions resulting from the use of a particular technology. An important convention for calculating the CO_2 avoidance costs is to determine a reference with which the respective costs for the reduced emissions is to be compared. The reference value used here to represent the CO_2 avoidance costs resulting from electricity generated from renewable sources is based on the electricity generation costs and the CO_2 emissions from a mix of new fossil-fuelled condensation power stations, according to the reference development described by the Enquête Commission on "Sustainable Energy Supply". Furthermore, a moderate increase in fuel prices is assumed. A mix of oil and gas boilers used to heat single-family houses serves as a basis to determine the CO_2 reduction costs resulting from heat generated from renewable sources.

In accordance with the wide range of electricity and heat generation costs, the CO_2 avoidance costs also span a wide range, including some quite sizeable values effective today. For foresighted politics it is particularly important to take the time-related dynamics into consideration: Whereas the CO_2 avoidance costs for electricity generation from wind, geothermal and solar thermal power plants, and biomass currently lie between 40 and 100 Euro/t CO_2, they will drop to below 20 Euro/t CO_2 by 2030 as a result of increasing fossil fuel prices and decreasing costs for renewable energy technologies. In the long term, even negative CO_2 avoidance costs will be achieved in some cases, i.e. not only CO_2 emissions are reduced, but also the socio-economic expenses at the same time.

The price of avoiding CO_2 for electricity from a biomass cogeneration plant depends on the fuel prices and the reimbursement for the heat supplied. The use of biomass is already a cost-neutral means of CO_2 reduction for low fuel prices. Due to the still high electricity generation costs, the CO_2 avoidance costs for photovoltaics are currently just under 1,000 Euro/t CO_2. However, they will drop to under 50 Euro/t CO_2 in the long term.

→ CO_2-avoidance costs (electricity)

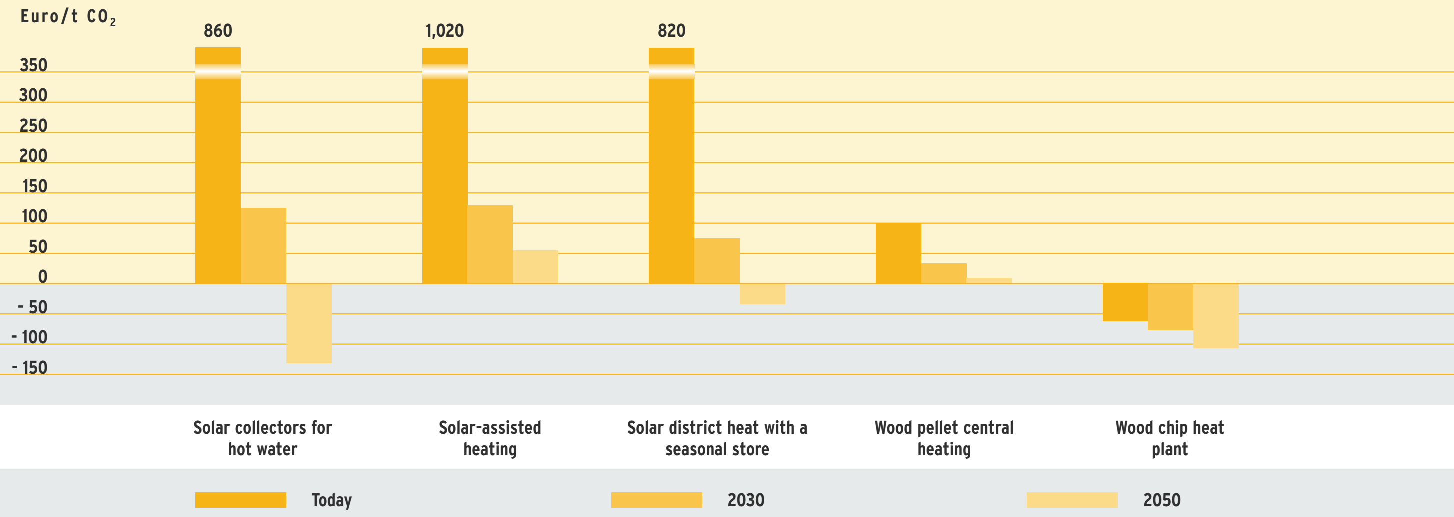
Source: DLR



Costs per tonne of CO_2 not emitted through the use of renewable energy to generate electricity. Baseline: Mix of new fossil-fuelled condensation power stations.

Source: DLR

→ CO_2-avoidance costs (heat)

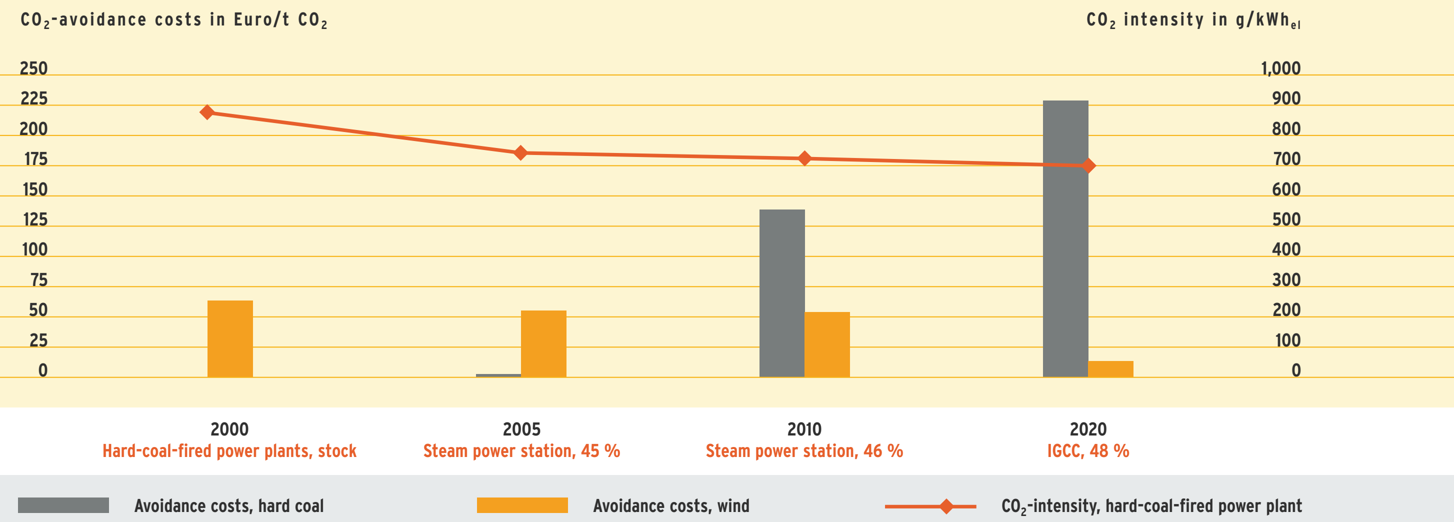


Costs per tonne of CO_2 not emitted due to heat generation with renewable sources. Baseline: Heat supply of single-family houses with a mix out of gas-fuelled condensing boilers and oil-fuelled low-temperature boilers.

The current CO_2 avoidance costs for supplying heat with solar collectors also still lie in the range of 800 to 1,000 Euro/t CO_2. However, a large potential to reduce the avoidance costs is also present here, so that in the long term, solar collectors should also achieve negative avoidance costs, depending on the application and the system configuration. The CO_2 avoidance costs for heat from biomass depend on the fuel price development. They are currently about 100 Euro/t CO_2 for a wood pellet central heating system. Assuming a constant price for pellets, the CO_2 avoidance costs will drop under 10 Euro/t CO_2 in the long term. Present-day heat production in a wood chip heating plant already leads to negative CO_2 avoidance costs.

It is important to keep the future development potential in view. Whereas the CO_2 emissions from existing hard-coal-fired power plants can initially be reduced at low costs by building new plants, any further reduction of the CO_2 intensity is associated with strongly increasing CO_2 avoidance costs. Thus, using technical improvement to raise the efficiency of a steam power station from 45 % to 46 %, together with a slight increase in the price of coal, leads to CO_2 avoidance costs of 140 Euro/t CO_2.

→ CO_2-avoidance costs (wind and hard coal)



Development of the CO_2 avoidance costs for wind and hard coal

In contrast, the CO_2 avoidance costs for wind power decline continuously due to the expected economy of scale. Already in the medium term they will be significantly lower than the reduction costs for the hard-coal technology (each compared to the hard coal forerunner technology).

Further environmental impacts due to renewable energies

Besides the greenhouse gas emissions which are particularly important for the power industry and the consumption of energy resources, there are further environmental impacts that can be reduced through the use of renewable energy, e.g. soil acidification, eutrophication (nutrient accumulation) of soil and bodies of water, summer smog, and the discharge of toxic materials. The ecological evaluation depends strongly on the specific technology, the employed energy carrier, and the application context such as the geographic location of the system.

The **acidifying emissions** of nearly all renewable electricity systems are significantly lower than the average emissions of the German power plants. This trend is also true for renewable heat systems – except for straw, which has higher emissions than a typical oil or gas boiler due to its chlorine and sulphur content and the nitrogen oxides.

Most renewable energy systems contribute less to **eutrophication** and summer smog than their fossil competitors – with the exception of some biomass systems. Biomass power plants are generally smaller than gas- or coal-fired power plants and are therefore less able to reduce nitrogen oxide emissions. Cultivated biomass additionally incurs contributions from the agricultural machines, fertiliser production, and emissions from the farmland.

Furthermore, the **particulate** emissions from small biomass furnaces, which have enjoyed considerable propagation over the last few years, are higher than for gas- and oil-fired heating systems. Pellet heating systems produce significantly fewer particulate emissions than wood chip or split log systems. The manufacturers of biomass furnaces are in the process of developing cost-effective dust filters and an improved furnace technology so that these dust emissions can be appreciably reduced in the future.

Further environmental impacts can result from energy plantations producing bio-energy carriers. Other factors beyond those already quantified in the ecological evaluation include the introduction of nutrients into the ground and surface water, pollution with pesticides, and a decline in biodiversity. Regarding soil erosion: since perennial plants cover the ground throughout the year they contribute less to the removal or washing away of soil than annual plants. The risk of pollution with pesticides can be minimised by using organic farming methods. In conventional agriculture, fewer pesticides are required for perennial crops than for annual crops like rapeseed and sugar beets.

The cultivation of energy plants is not problematic in terms of biodiversity if the production of the bio-energy carriers occurs with location adjustments known through expert experience and if the supra-regional habitat is not disturbed.

Renewable energy and nature conservation

The ecologically optimised expansion of renewable energies must furthermore secure the **biodiversity**, the **ecosystem**, the **natural scenery**, and **environmentally sound flood control measures.** Considering nature conservation concerns guarantees a wide acceptance for the expansion of renewable energies. In order to exclude or minimise possible negative effects, the impacts from the generation and use of renewable energies on the ecosystem and the landscape must be investigated in the context of supporting research by expert nature conservationists. Such research includes the development and testing of long-term precautions to prevent and reduce negative impacts as well as suitable compensation measures.

The construction of **wind power stations** must integrate both nature protection and landscape conservation concerns. Wind turbines, by nature, are installed at particularly windy and therefore exposed locations. At the same time, such locations often coincide with bird flight routes. Installation planning must take these and other nature conservation concerns into consideration. The impacts of wind power stations on fauna and avifauna (birds) concern interference with natural habitats, including the loss of resting, breeding, and food habitats, disturbances and scaring, and finally also the direct loss of life, e.g. through bird strike. These concerns hold for both onshore and offshore wind power stations. The potential disturbance of the natural scenery, especially in the strongly structured low mountain ranges, can be illustrated with appropriate techniques in order to evaluate the visual sensitivity of the affected areas. The number of turbines, the location, the arrangement of the installation to the geomorphological features of the location, the long-range effects, and the relationship to lines of sight all play an important role in the evaluation.

All in all, it is important that the control instruments available at the communal level are used. Thus, location-specific nature conservation concerns are examined and evaluated during the actual authorisation process. Restrictions are thereby formulated in order to avoid or exclude disturbances for birds in migratory and roosting areas. Similar conditions are formulated to address landscape conservation.

Impacts on nature and landscapes can be minimised and synergies utilised through the selection of suitable locations and an expedient mix of renewable energies.

Hydropower plants generate practically emission-free energy as compared to fossil energy carriers. However, they produce local and supra-regional effects which can negatively influence the ecological balance of the water courses as well as the land-based ecological systems and wetlands dependent on them. Since only 21 % of the water structure quality of surveyed water courses in Germany can be classified as moderately changed or unaltered, there are conflicting interests between hydropower exploitation, nature conservation, and water conservation. For example, run-of-river power stations can impede fish migrations by interrupting the water flow. The construction of weirs, guiding channels, and dams, and the reduction of flow speed, turbulence, and drag power of the water change the water structure, the transport of sediments, and the ecosystem of the water and its surroundings.

The conflicts between climate, nature, and water conservation can be eased through suitable design measures for water constructions. For example, fish ladders, bypass channels, and attraction currents improve the passibility of the rivers. The goal for further expansion of hydropower is to improve their performance while improving the water ecology at the same time. Under these conditions, the potential for hydropower can be best accessed through the replacement and modernisation of existing plants.

Nature conservation concerns must also be considered for the construction and operation of **solar energy installations** when built on open land. One of the most important factors to avoid conflicts is the choice of the "correct" location. The majority of **photovoltaic systems** are installed on buildings. Correspondingly, they do not cause any additional environmental impacts. It is precisely this aspect which leads to the fascination and high acceptance of photovoltaics. In contrast, systems installed on open land can by all means interfere with the environment – by compression and sealing soil, cutting off habitats, and the loss of vegetation and habitat systems. Currently, less than 10 % of the photovoltaic systems are installed on open land. In these cases, the intrusion is low (e.g. only max. 4 % of the area is sealed by the foundation) or minimised by technical measures (e.g. by doing without fences or at least constructing them so that small animals can pass). Furthermore, areas can be selected which are already ecologically spoiled by a previous use (e.g. landfills, waste land, farm land). Accordingly, the Renewable Energy Act only allows compensation for open land installations when the land was previously used.

Biomass has so far mainly been cultivated for the production of food and fodder. However, it is increasingly used for energy or substance (renewable resources for the chemical, pharmaceutical, or construction industries). Today, mostly organic residuals and waste materials are used for electricity and heat generation. To an increasing degree, energy plants are also being cultivated for the production of biofuels. At first, they can be cultivated on land which has been set aside to reduce the surplus food production. A significant increase in biofuel production, as demanded by the European guidelines from 2003, will however also require an expansion of cultivation areas in the medium term (see "Biofuels" chapter). The guidelines plan to increase the share of biofuels in the transportation sector up to 5.75 % by 2010, for which Germany would require ca 2 million ha land area.

From the environmental and natural conservation point of view, innovative technologies like gaseous and synthetic **biofuels**, the so-called "second generation biofuels", are more promising than biodiesel and bioethanol (see "Biofuels" chapter). In contrast to biodiesel (mostly from rapeseed oil) and bioethanol (mostly from carbohydrate-containing plants like wheat or sugar beets), the input-biomass for both biogas production and the "biomass-to-liquid" (BTL) technique is not limited to a few plant sources, whose cultivation often involves environmental damage. Furthermore, these techniques utilise the energy content of the entire plant. The higher energy yield reduces the area required for cultivation. An increased demand for bio-energy carriers is expected for electricity and heat generation purposes. The organic residual and waste materials from agriculture (straw, beet leaves, liquid manure, sewage, and dung), grassland, landscape, and forest maintenance (grass and hedge clippings, and forest wood residuals), and old timber mainly utilised so far will probably not be able to meet the demand. Therefore these methods will also require the increased cultivation of energy plants (whole-plant utilisation of shrubs or perennial groves).

Natural conservation aspects thus broach two questions: how is this booming non-food biomass cultivation to be assessed, when environmental problems are already known from conventional agriculture, and how is the competition between the land area required for biomass and other national sustainability strategy goals, which also require area, to be evaluated? The following sustainability topics are important in this regard:

- **Organic farming**: The German Federal Government's sustainability strategy plans to increase the share of the agricultural land used for organic farming to 20 % by 2010.

– **Land coverage**: A further goal of the sustainability strategy is to reduce the area required for urban and transportation purposes to 30 ha/day by 2020.

– **Compensation areas**: When, e.g. industrial areas are constructed on green meadows, nature conservation measures are taken as compensation. These measures from the so-called impact regulation under nature conservation law claim large amounts of farm land.

– **Habitat systems**: §3 of the federal nature conservation law requires the creation of cross-national habitat systems, encompassing 10 % of the land area, with the purpose of conserving biodiversity and habitats.

– **Soil and water conservation**: For reasons of soil and water conservation, the cultivation of perennial crops is preferred over that of annual crops on areas with a high risk for soil erosion. Although this stipulation reduces the amount of "freely available area", the perennial plants can also be utilised, e.g. as energy plants.

The additional area required by the full implementation of these sustainability goals exceeds 2 million ha. This amount is approximately the amount of agricultural area which remains if a 100 % degree of self-sufficiency is strived for as a further sustainability goal, i.e. that 100 % of the food and fodder consumed in Germany is also domestically produced. These figures clearly show that German land area is not only a very scarce commodity, but also that several interests threaten to compete for the remaining areas. Such competition is already known from identifying areas for habitat systems, for bird protection guidelines, or for the NATURA 2000 areas. On the other hand, the developments in agriculture will free up land area due to EU guidelines, yield increases, or a considerably reduced degree of self-sufficiency, as well as due to a long-term decline in population.

The various nature conservation measures do not just lead to restrictions for biomass utilisation – a series of **synergy effects** can also result. For example, additional biomass potentials develop in habitat systems and through compensation measures, as well as through maintenance of open land and forest fringes. These potentials add up to ca 150 PJ per year – as much as the total biogas potential.

The potential conflicts identified between nature and climate conservation interests are not unsolvable – on the contrary: suitable location selection and an expedient mix of renewable energies can minimise impacts on nature and landscapes, and also exploit synergies. In this way, both goals of the sustainable expansion of renewable energies and the conservation of biodiversity can be pursued.

The self-evident criteria for the environmentally compatible utilisation of renewable energies must also apply to the fossil and nuclear energy types. Otherwise the danger exists of a one-sided and therefore biased assessment, which can lead to a situation in which small local impacts from using renewable energy are classified as alarming, while considerably more serious effects on our entire habitat from using fossil and nuclear energy are overlooked.

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Internet link

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www.bfn.de

STATUS AND PERSPECTIVES OF RENEWABLE ENERGIES

Today's use of energy in Germany

> The contribution of renewable energy to Germany's supply increased from 2.6 to 4.6 % over the past five years.

About 14,238 petajoule (PJ) of primary energy were consumed in Germany in 2005. This amount corresponds to an equivalent of 6 tons of coal or 48,000 kWh per inhabitant. We use about one third personally as final energy – to heat our homes, to cook, for lighting and other electrical applications, and for our mobility. The rest is needed to supply goods and services, but a portion is also lost during the conversion of energy carriers – through electricity generation or fuel production.

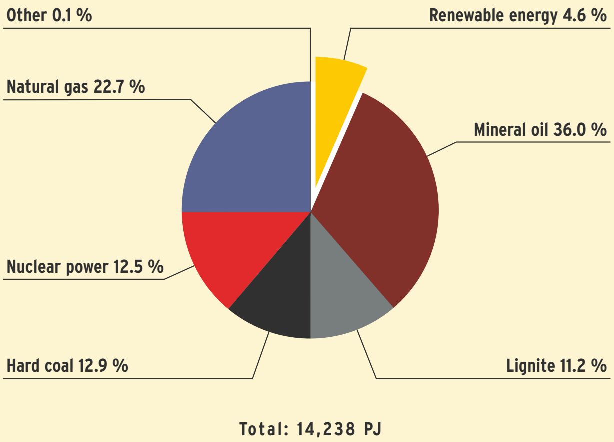
Whereas the energy consumption for road traffic in particular has increased strongly over the past years, the industrial energy demand is declining. Reasons include increasingly efficient production technologies, but also structural changes in industry and the tendency for commercial services. In total, the primary energy consumption in Germany has practically remained constant although the economic performance grew. The so-called energy intensity – the energy input per unit GNP – is thus declining. Observed over a longer period of time, this means e.g. that we consume about half of the energy needed 50 years ago for a comparable economic performance.

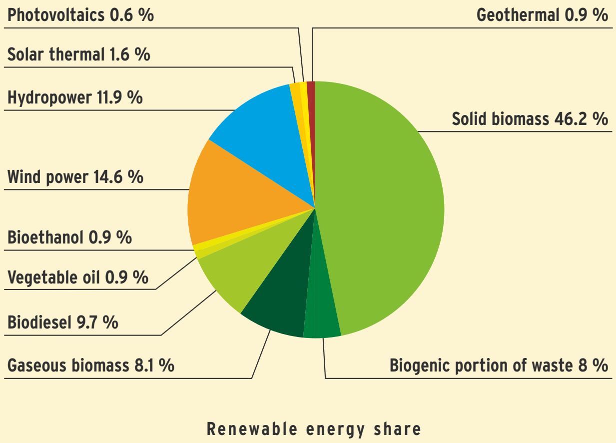
The decoupling of economic performance and energy consumption is a central prerequisite for sustainable development. However, the energy mix must also change, because our energy supply is still based mainly on fossil energy carriers. The heat market is dominated by natural gas and heating oil, and the transportation sector almost exclusively uses mineral oil products. Electricity is predominantly generated from brown and hard coal, with an increasing tendency towards natural gas. The share of nuclear power generation is currently ca 26 %, whereby the importance of nuclear energy is fading as a result of the nuclear power phase-out resolution.

Renewable energies offer the alternatives. The various forms of biomass, hydropower, wind power, geothermal heat, and the thermal and electrical utilisation of solar energy met ca 4.6 % of the primary energy demand in 2005 (calculated according to the efficiency method). At first, this amount appears to be small, the high growth rates are however remarkable: the share was 2.6 % just five years ago. The impression shifts once the contributions to final energy consumption are considered. Unlike fossil-fired power plants, hydropower, wind power, and photovoltaics do not convert fuel into electricity. There are no conversion losses and electricity from these installations is therefore designated as primary electricity. For this reason, renewable energy has already crossed the 10 % threshold in the electricity sector and become

→ Consumption of primary energy

AGEE-Stat; AG Energiebilanzen (preliminary data)





Consumption of primary energy and renewable energy in Germany, 2005 (efficiency method)

Around 170,000 jobs in Germany were already secured by renewable energy – and growing.

an important factor. This value was only 6.7 % in 2000. Renewable energy is also gaining in the heat market: the strong price increases for heating oil and natural gas contribute to a renaissance in wood use, which has simultaneously transformed into a modern, domestic energy carrier. Efficient and environmentally friendly wood-based central heating systems have been on the market for some time now, which use "pellets" of compressed wood chips and sawdust (see "Biomass combustion" chapter). Since they can be easily regulated and the fuel is loaded automatically, they offer the comfort that today's consumers expect. Tapping into geothermal and solar energy is becoming more and more popular. So far, over 7 million square meters of solar collector surface area have already been installed in Germany. They supply energy for hot water and heating for approximately one million households.

The wide-spread use of renewable energy for transportation purposes first began a few years ago. Initially restricted to vehicle fleets and the occasional biodiesel filling station, it is nowadays mixed in with diesel and petrol. Sales have increased from 0.25 million tonnes in 2000 to over 2 million tonnes in 2005. The share of fuel consumption for road traffic increased thereby from 0.3 % to 3.4 %. About 2 million automobiles could run on this amount of biofuel. Biodiesel and rapeseed methyl ester (RME) represent the largest share of biofuels, but the production of vegetable oils and bioethanol is also increasing.

Renewable energy as an economic factor

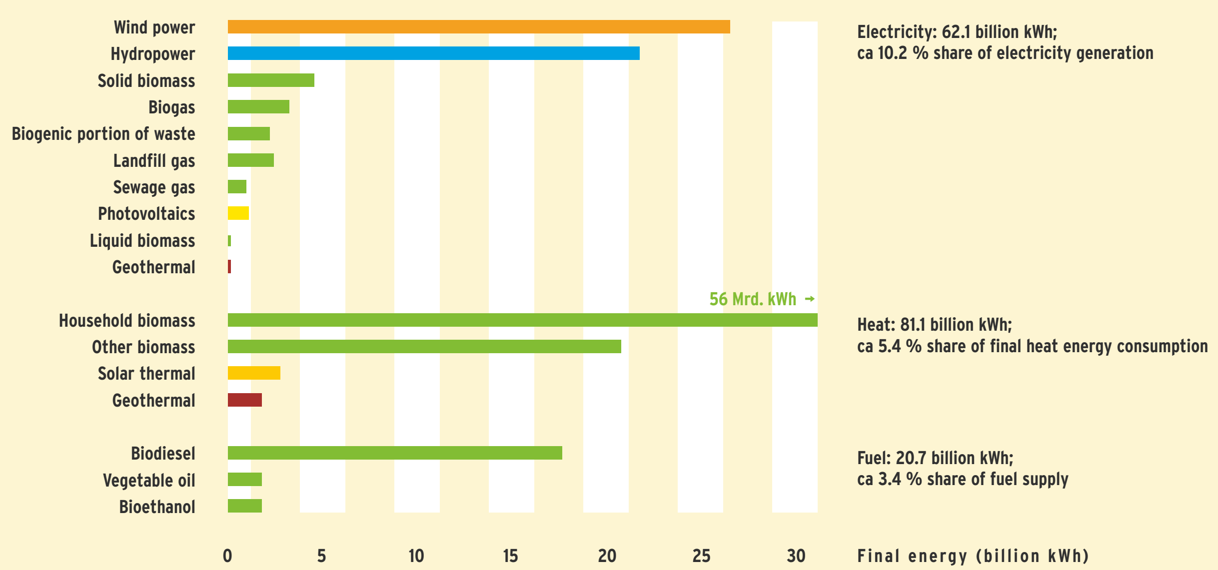
Renewable energy has developed into an important economic factor with attractive growth rates. In 2005 the renewable energy market achieved turnovers in the range of 16 billion Euros in Germany alone – twice as much as in 2001. Nearly 9 billion Euros were invested in new installations in 2005.

Due to the high construction dynamics, the largest shares of new investments were for photovoltaic systems for solar electricity generation and for solar collector systems for hot water and to support the heating systems. The second largest area is the energetic use of biomass. The dramatically increasing prices for fossil energy carriers have given a huge boost to the market for thermal systems: over half a million households decided to use renewable energy in 2005 – more than ever before. As expected, slightly less was invested in wind power than in the previous year. Instead, the companies are profiting from the increasing export of wind turbines.

The energy produced by renewable systems also generates revenue. For electricity-producing systems, the amount fed into the grid is compensated, adding up to over 5 billion Euros. Biofuels generated an estimated 1.7 billion Euros in 2005. These figures are significantly lower in the heat market because basically only the

→ Shares of the energy supply

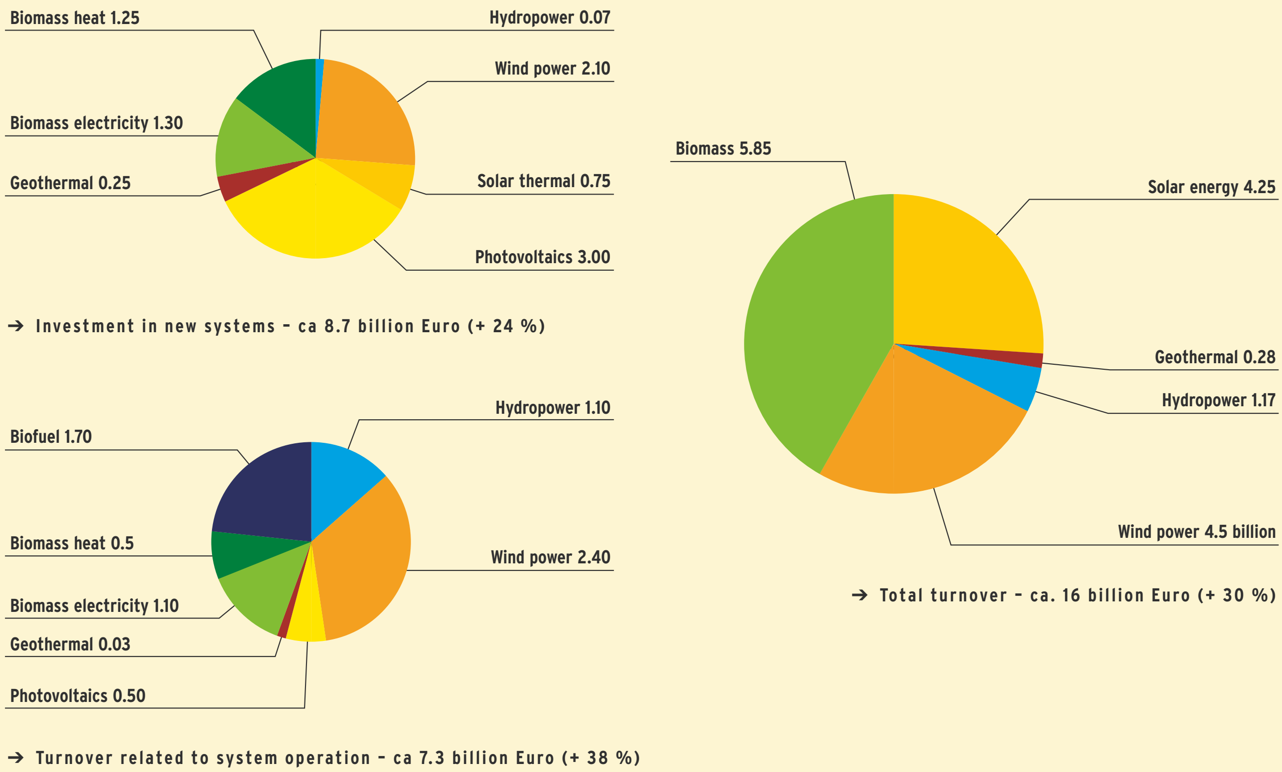
Source: AGEE-Stat (preliminary data)



Contributions of renewable energy to the electricity, heat, and fuel supply in 2005. Share of total final energy consumption: 6.5 %.

→ Turnover in the renewable energy sector, in billions of Euros

Source: Jahrbuch Erneuerbare Energien



Turnover in the renewable energy industry in Germany in 2005, and increase from 2004

revenues from the sale of fuel are calculated. However, from the consumer point of view, i.e. especially for private households, heating with renewable energy has a large economical impact, for they saved on fossil fuels to the order of 3.5 billion Euros a year.

Utilising renewable energy creates jobs – already ca 170,000 positions in Germany in 2005, and growing. The industry estimates that this number will increase by more than 50 % by 2010. Renewable energy also fulfils an important function in structural policy, for the jobs are created in those regions where they are particularly needed. For example, in the coastal regions where the construction of wind turbines creates work for the dockyards or in Eastern Germany and the former coal regions of North Rhine-Westphalia where many companies in the renewable energy industry have settled.

Since renewable energy sources are domestic energy carriers, a large portion of their added value stays in the region. Especially through the utilisation of biomass we create new local economic cycles and thereby local employment. This tendency also holds for the construction industry and handicrafts. Step by step, the funds which so far have been flowing to the countries which export oil, natural gas, and coal will transform into regional added value.

On the other hand, we should not forget that these changes will suppress some areas of domestic employment in the conventional energy industry. Furthermore, today it is generally still more expensive to produce electricity, heat, and fuel from renewable energy. While they are still not competitive, the cost difference must be paid by the energy consumers and, as a result, is not available for the household to consume other goods. This so-called budget effect can lead to negative employment impacts in other industries. Given the persistent high unemployment rates in Germany, environmental measures must therefore also keep the net employment impacts in view. Foreign trade plays an important role in this sense, because it positively influences the employment balance.

Many companies export significantly more than they purchase abroad. We can therefore assume for 2005 that half of the world-wide turnover with wind turbines stems from German production – a portion as complete systems, but also components like generators or gearing which foreign manufacturers install in their systems. It is important that the German market functions for foreign investors to value German products. In the past, various examples have shown that a true chance for a good position in the international market is only possible when a national market exists. A well-known

Germany is generally the "world champion" in exports. Renewable energy is no exception – we possess top-level technology available for export.

example is the mobile telephone technology, for which Japan and South Korea developed a strong market early on. Now, companies from these countries dominate today's world market.

In the final calculation, not only is the gross employment impact positive for renewable energy, but also the net employment impact. The importance of the international market will increase further in the future.

Measures to promote renewable energy

The expansion of renewable energy does not materialise on its own. For them to become a supporting pillar of the energy supply, favourable economic conditions must exist along with the technical, legal, and organisational prerequisites. The market introduction phase must therefore be financially supported in such a way that the potential for cost reduction is tapped as soon as possible by means of so-called "market learning". The subsidies can then be trimmed down successively until renewable energy has achieved widespread competitiveness.

The German Federal Government supports the market development in renewable energy with several different measures. The most important instruments are

- for the electricity market: the Renewable Energy Sources Act
- for the heat market: the federal market stimulation programme and a planned Renewable Heat Sources Act
- in the fuel market: reduction of the mineral oil tax for biofuels as a part of the ecological tax reform and a planned admixture requirement

A particularly effective example is the Renewable Energy Sources Act (EEG; see boxed text "Activities already being undertaken by the German government"), which came into effect in 2000. As a result of the EEG, the generation of electricity from renewable sources has more than doubled from 30 billion kWh in 1999 to ca 62 billion kWh in 2005. If we subtract the electricity generated by large existing hydropower plants and from biogenic waste, which is not included in the EEG, then the act's impact is even larger: the amount of electricity receiving reimbursement by the EEG nearly quadrupled to ca 43 billion kWh during this time period. The largest share results from electricity generation by wind power (62 %), followed by biomass (24 %), the hydropower sources included in the EEG (11 %), solar electricity generation (2.3 %), and geothermal sources (0.5 %). Already today, the emission of 38 million tonnes of carbon dioxide was avoided because of the EEG. It is therefore one of the most important policy instruments for climate protection in Germany, and in the mean time similar instruments are being employed in other countries.

The Renewable Energy Sources Act triggered a boom in the production of renewable electricity.

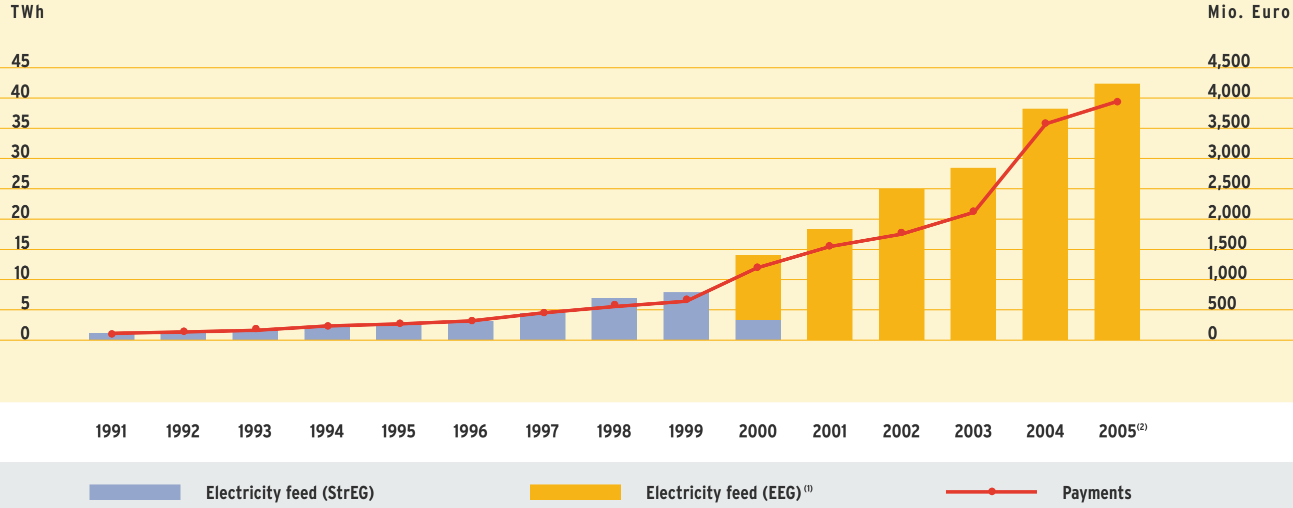
The new EEG came into effect in 2004. Among the most important modifications are the inclusion of expansions of large (over 5 MW) hydropower plants, a reorganisation of the reimbursement rates for solar electricity generation, and various bonus regulations for the use of renewable resources and new technologies for converting biomass to electricity. Thus especially solar electricity generation and the conversion of biogas to electricity are given additional incentives. However, a whole series of projects are in the pipeline, addressing the areas of hydropower and geothermal energy.

The market stimulation programme for the promotion of renewable energy usage is particularly important for the heat-generating technologies. So far, over 400,000 solar collector systems and 60,000 small biomass boilers have been subsidised. The Reconstruction Loan Corporation (Kreditanstalt für Wiederaufbau, KfW) provides a supplemental subsidy loan for larger systems utilising solid biomass, biogas, and deep geothermal plants. So far, ca 2500 loans with a volume of 740 million Euros have been approved. A total of more than 485,000 projects have been supported by the market stimulation programme between its start in 1999 and the end of 2005. Subsidies of 588 million Euros and loans set 4.9 billion Euros worth of investments in motion. The Federal Environment Ministry, in cooperation with the BINE information service (www.bine.info), published a detailed brochure informing about all of the subvention possibilities on the European (EU), German, state, and communal levels and from the power supply industry. An extensive subsidy databank is offered by the Federal Ministry for Economy and Technology (http://db.bmwi.de).

Biofuels are also being promoted. Originally, only pure biogenic fuels were freed from the mineral oil tax. Since the 1st of January 2004, also bio-heating fuels and the proportion of biogenic fuels like biodiesel, bioethanol, or bio-ETBE mixed in with fossil fuels are included. The introduction of an admixture requirement for biogenic fuels is prescribed by the coalition contract.

➔ Electricity feed and reimbursement payments

Sources: VDEW, VDN, ZSW



Electricity fed into the grid and reimbursement payments according to the Electricity Feed Act (Stromeinspeisungsgesetz, StrEG) and the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG); (1) Private and public electricity feed; (2) Projection

The possibility to admix bioethanol, which can be produced from sugar beets or energy crops, is particularly important, since, unlike biodiesel, it can not be employed in its pure form in normal engines. Admixtures of up to 5 % however are easily possible. While the production of bioethanol at 65,000 t in 2004 was still rather low, it already increased to over 200,000 t in 2005.

Further plants with a capacity of several hundred thousand tonnes per year are under construction or being planned. In a parallel development, the use of pure vegetable oil and biodiesel increased to 150,000 t and 1.7 million t, respectively.

Innovation strategy "renewable energy"

Research and development are key elements, along with the market development, the further deployment of renewable energy. A central goal of the German Federal Government's 5th Energy Research Programme from 2005 is therefore to "further reduce the costs of renew-

The process of innovation

According to the founder of innovation research, Joseph Schumpeter, innovation is the "success of new combinations". This definition contains three elements: "new", i.e. creating something, "combinations", i.e. that new arrangements of present knowledge are also innovations, and finally "success", i.e. the commercial market success.

Not only technological ideas but also political instruments, institutions, and modified behaviour count as innovations. Technological and political innovations are often closely interwoven and can mutually promote each other. An example for a technologically induced innovation is wind power – a technical innovation (e.g. the development of high-performance wind power plants) brings about a political innovation (Renewable Energy Sources Act), which in turn increases the technological diffusion (construction of wind power plants in Germany). Afterwards, the political diffusion takes place (international introduction of electricity feed reimbursements).

The German Federal Environment Ministry pursues an innovation strategy which promotes all three elements of the innovation process. It promotes research into fundamentals, materials, and processes. It supports the realisation and scientific monitoring of pilot projects, components of quality assurance, and studies of markets and systems which are necessary for the transfer of the inventions to the market. Instruments for technology diffusion, e.g. the market stimulation programme or the Renewable Energy Sources Act, play a similarly important role.

Activities already being undertaken by the German government: Measures and instruments supporting renewable energy

- The Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG) has proven to be an extremely successful instrument – also in international comparison – for expanding renewable energy in the electricity market. Not only are the national goals being met, but also the European guidelines for the promotion of electricity generation from renewable energy from 2001. The EEG guarantees operators of renewable energy systems priority for feeding their electricity into the grid and payment at a fixed reimbursement rate over an assured period of time (usually 20 years). This arrangement provides investment security. The reimbursement payments are apportioned to all electricity consumers through a national equalisation mechanism, which also disencumbers power-intensive companies so that they do not suffer any competitive disadvantages. The degression of the reimbursement rates for future systems provides an incentive for innovations and cost reductions. Renewable energy sources are thus quickly guided to a competitive state.

- The market stimulation programme to promote measures for the utilisation of renewable energy is financed with revenues from the ecological tax reform. It supports the construction of systems to generate heat from renewable energy sources. It is the largest subsidy programme of its kind in Europe, with a volume of ca 200 million Euros per year. The financing of the renewable energy systems is subsidised by various loan programmes which are handled by the Reconstruction Loan Corporation (Kreditanstalt für Wiederaufbau, KfW). Examples include the "KfW Environment Programme", the "ERP Environment and Energy-Saving Programme", "Generate Solar Electricity", "Ecological Building", and "Modernisation of Living Spaces".

  Furthermore, a portion of the consulting costs are reimbursed for those who use the detailed energy advisory service for older residential buildings. Information about grants within the market stimulation programme is available from the Federal Agency for Economy and Exports (Bundesamt für Wirtschaft und Ausfuhrkontrolle, www.bafa.de). Questions about receiving low-interest loans for commercial or communal applicants are answered by the information centre of the Reconstruction Loan Corporation (KfW, www.kfw.de). In order to provide a wider basis for the expansion of renewable energy sources, the Federal government is planning a Renewable Heat Sources Act.

- In the transportation sector biofuels are favoured by the mineral oil tax. An admixture requirement to diesel and gasoline fuels will give biofuel producers access to an important new marketing path. The regulations also serve to comply with the European guidelines for promoting the utilisation of fuels from renewable energy sources from 2003.

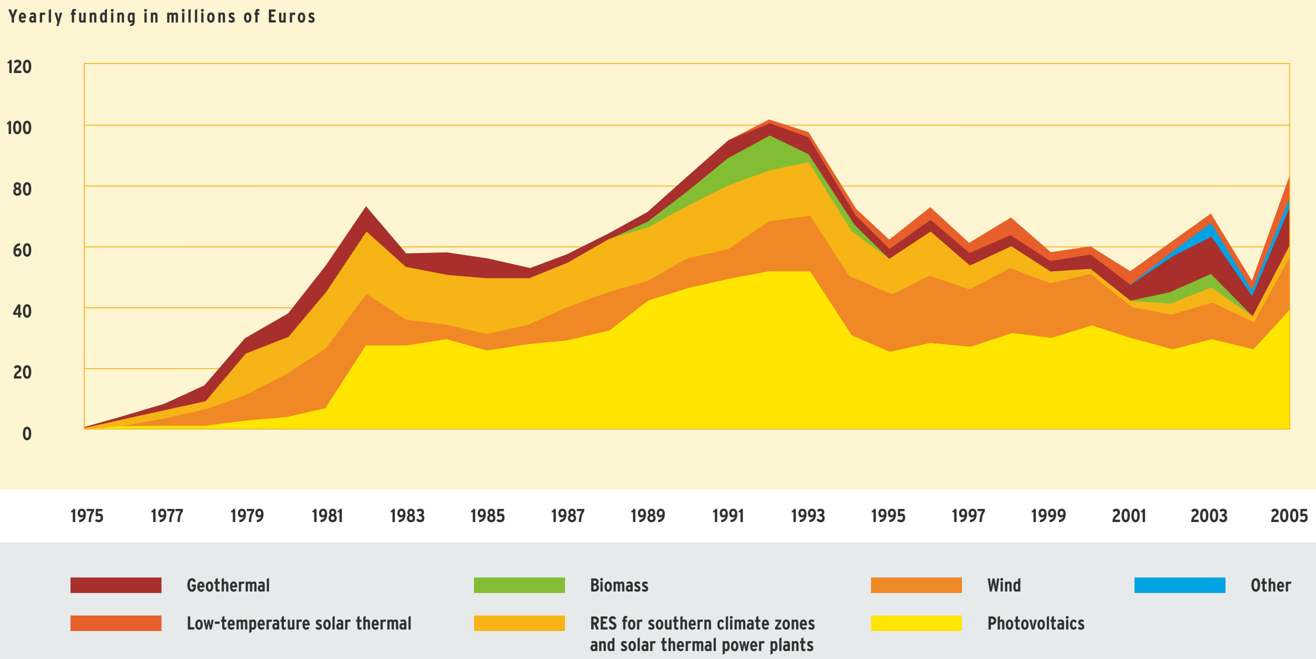
- The German government provides numerous publications on all topics regarding renewable energy through its information and public relations work. An overview is available on the German Federal Environment Ministry's topic webpage www.erneuerbare-energien.de.

able energy and thus to improve the starting conditions for the expansion of renewable energy". The efficiency and lifetime of the components and systems must be further increased, but also the production processes must become more efficient and therefore more cost effective. Germany leads the world-wide research in renewable energy sources – in 2005 a total of 100 new projects with a total volume of 98 million Euros were approved. The focus is on photovoltaics and wind power. Photovoltaics – because the reimbursement rates from the EEG have the highest degression rate and the cost reductions must still be achieved. Here is also the largest potential for innovation. The great importance of wind power research results from the fact that especially in the offshore area, large technical challenges must still be mastered and also because research is still necessary on the nature-compatible development of the wind-power potential. Furthermore, grid integration also plays a decisive role for wind power. The Research funding in the other areas continues at a high level as well. All renewable energy sources will be required in order to achieve the ambitious expansion goals set by the German government. An overview of all supported projects can be found under www.erneuerbare-energien.de.

Expanding renewable energy serves both ecological and economical goals. They are domestic energy carriers which reduce the dependency on imports of fossil energy carriers, and therefore represent a stabilising factor for the GNP and the security of the energy supply (see

→ Project funding development

Source: BMU



Development of funding for renewable energy research projects in Germany

the "Sustainability and Energy Supply" chapter). The strongly increasing oil prices in the recent past have again drawn this interrelation to public attention. The ongoing increased energy demand in China and India, together with the high consumption levels in the industrialised countries, means that we can continue to expect high mineral oil prices in the future.

Research funding is also important when considering employment policy. It helps German companies to secure top positions in the fast-growing international markets for renewable energy, and thus also creates employment. In this respect, Germany's research strategy is oriented to also develop technologies which primarily find application abroad.

Prospects for renewable energy by 2020

The German government is anticipating a dynamic expansion of renewable energy – with good reasons (see "Sustainability and energy supply" chapter). They have therefore set concrete goals for the medium term:

- Increase the share of renewable energy in primary energy consumption to at least 10 % by 2020, and afterwards a continuously increasing rate according to the national sustainability strategy. In 2050 renewable energy sources should supply 50 % of the primary energy requirement.

- Increase the share of renewable energy in electricity generation to at least 12.5 % by 2010 and to at least 20 % by 2020.

- Increase the share of biofuels in the fuel consumption to 5.75 % by 2010.

In a complementary process, an energy efficiency strategy is also pursued with the goal of increasing the energy efficiency of the national economy by 2020 to twice its value from 1990.

These are ambitious, but realistic goals. They are supported by what has already been achieved – by 2005 the share of renewable energy in electricity generation has nearly doubled within six years. The resulting market dynamics lead us to expect that the 20 % goal set for 2020 will also be achieved or even exceeded. If the current or a modified EEG remains in effect over a longer time period, and if the urgently necessary savings in power consumption are successful, then the share could even lie above 25 %. With a total installed output power of ca 56,000 MWel in 2020, renewable energy will be an equal and essential partner in the electricity market.

It is a remarkable fact that the so-called baseline predictions, which illustrate the most probable development under the currently effective conditions, are always more closely approaching the desired constellation. Thus the baseline development suggested by the Enquête commission in 2002 was still much more pessimistic considering the expansion of renewable

> The goal of the German government is that "renewable energy should meet about half of the energy demand by mid-century".

energy than the baseline development in a current study from 2005, the Energy Report IV (see Figure: Possible development of electricity generation).

The German government adopted the EU goal of a 5.75 % share of renewable energy in fuels for 2010 and is also making good progress to achieve it. One cause for concern, however, is that the efficiency potential available in the transportation sector is still very high – and an optimal strategy involves mobilising the efficiency potential together with the expansion of biofuels. Otherwise the possible contributions of biofuels to the total consumption will ultimately remain limited due to the potential not accessed (see "Biofuels" chapter).

The share of renewable energy in the heat supply sector has also notably increased over the last years, to 5.4 % in 2005. Just the same, their need to catch up is significantly larger than for the electricity and fuel sectors. If an effective instrument to accelerate the development is passed in the near future, contributions of renewable energy in the heat market of 13 % by 2020 and 20 % by 2030 are deemed possible. In terms of a consistent overall strategy, additional measures for heat insulation and for heat supply with district heating grids, together with the expansion of combined heat and power generation are required in parallel.

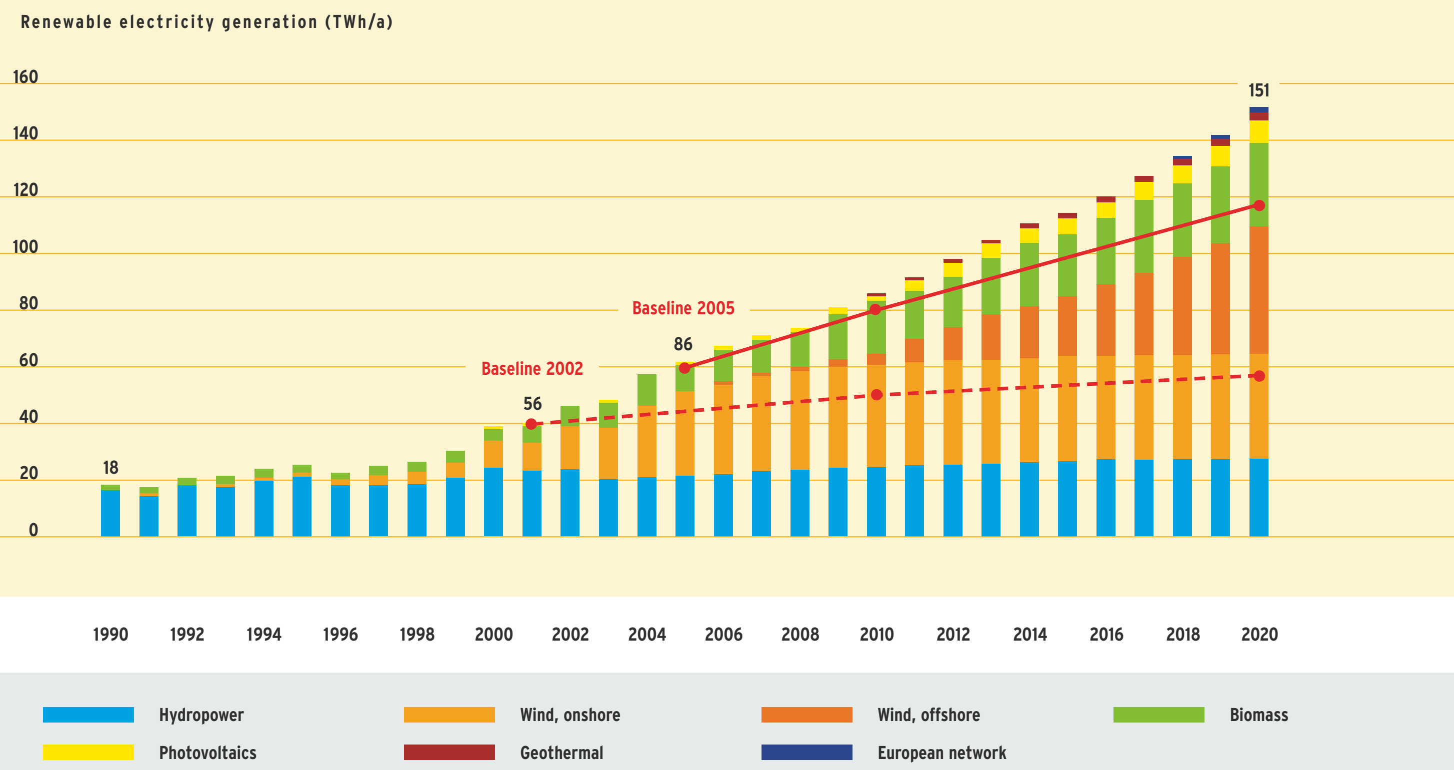
Thus renewable energy sources are increasingly meeting the energy requirement in Germany. If the described growth dynamics in the individual sectors can be sustained, then a share of over 6 % in 2010 and the German government's goal of 10 % by 2020 can be achieved. Together with the aspired reduction of the total primary energy input, these shares could even increase to 7 % (2010) and 13 % (2020).

The longer-term prospects

The aspired increase in renewable energy by the year 2020 will have considerable effects on Germany's emissions balance. Already today, ca 83 million tonnes carbon dioxide are not emitted each year due to their use (see "Ecological qualities of renewable energy" chapter) – this amount will more than double by 2020. By mid-

→ Possible development of electricity generation

Source: BMU



Possible development of electricity generation from renewable energy by 2020 with the EEG in effect

Efficiency and saving: a necessary prerequisite for the optimal utilisation of renewable energy

Measures to reduce energy consumption have always been implemented in the course of technical progress. **However, the potential for increasing energy efficiency is still far from being exhausted.** Unfortunately, the same holds for the economic potential. Even at the current energy price levels, investments in measures to improve energy efficiency do not appear attractive enough.

In an economy which is primarily directed by a liberalised and globalised market, very short amortisation times (the time period in which an investment pays for itself) of just a few years are demanded. It is not taken into account that the lifetime of efficient systems and devices, and therefore the time when the energy savings are profitable, represents a multiple of the amortisation time.

A further reason is that **energy costs represent only a small factor in both private households and in most businesses**. The possible cost reductions are therefore low compared to other expenditures (e.g. labour costs). As a result of various external effects, the energy costs are also not reflected in the total economic costs of the energy supply. But even energy-saving measures which are economic in terms of today's increasing energy prices and which could be implemented with short amortisation times are frequently not realised.

There are many sources of inhibition or inertia – e.g. insufficient information about possible technical improvements or careless consumption. One problem is that the microeconomic optimisation process only concerns the energy production, processing, conversion, and transfer. An economic evaluation of the actual benefit, the energy service, generally is not undertaken.

For example, the residents of a building do not care about the natural gas or the heating oil; they want to feel warm and comfortable in their home. This energy service can be provided by a suitable heating system, but improved insulation and proper construction design can work just as well. The initial investments required for the changes must be balanced with the long-term energy savings.

Energy-related renovations are often neglected even though they are profitable over their lifetime. Reasons for this behaviour include the lack of capital and the insecurities resulting from the unclear development of energy prices. Furthermore, the landlord – tenant dilemma often plays a role – it must be possible for the landlord to pass on the additional costs for an investment to the tenant, who is the one saving on heating costs.

The **conversion efficiency** can be considerably increased through the implementation of modern gas and steam power plants and further-developed coal-fired power plants. Above all, the **increased utilisation of waste heat from power plants** by means of combined heat and power generation (CHP) together with local and district heating grids will significantly reduce the high conversion losses of power generation.

The potential for energy saving is substantial. Thorough investigations assume that in total a further 35 to 45 % of the current energy consumption could be saved without cutting back on energy services.

A large share of the potential could be mobilised through the **accelerated energy-related modernisation of old buildings**; another considerable share through the **rapid adoption of more fuel-economic vehicles**.

But important energy-savings can also be realised in other areas such as electric household appliances and in industry. In total, a reduction of the energy intensity of 2.5 to 3 % per year is considered possible over a longer period of time. At this rate the absolute energy consumption could decline, even while economic growth continues at its current pace. This prerequisite is necessary for fossil energy resources to be sufficiently conserved and impacts of renewable energy to be developed quickly.

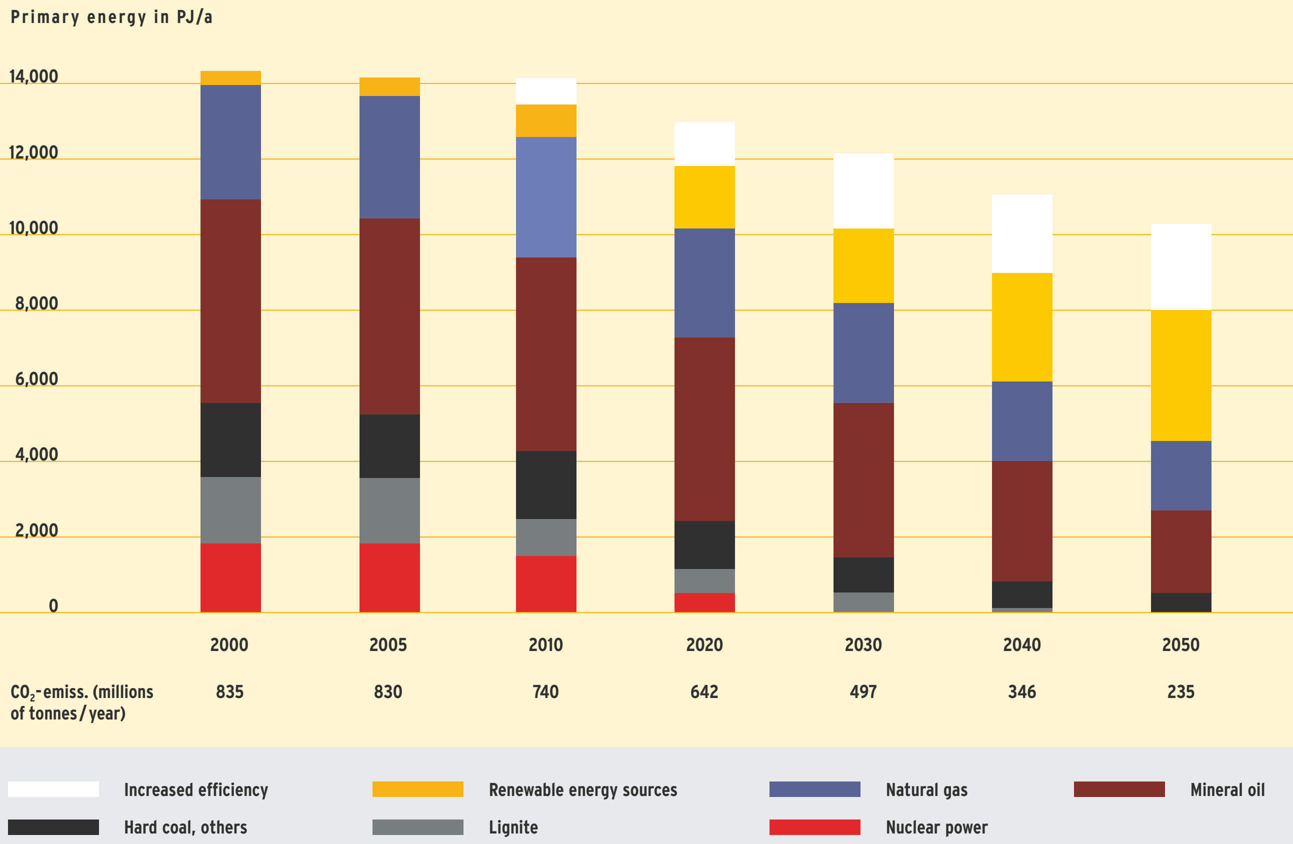
Modern efficiency technologies are also excellent exports, especially to economies with a large need to catch up on energy services. However, **considerable political and social efforts are required to realise the large number of individual measures** necessary to activate the efficiency potentials which are economical but not yet implemented.

century, however, the total energy-related CO_2 emissions should be reduced to 80 % of their level in 1990. These recommendations from national and international experts are accommodated in the German government's sustainability strategy. In order to achieve these goals, the support of both pillars "increased efficiency of energy conversion and use" and "renewable energy" are equally required.

The long-term scenario indicates that the primary energy consumption must decrease significantly more than purported by the currently foreseen baseline develop-

➔ Primary energy in the long-term scenario for Germany

Source: DLR



Development of primary-energy consumption according to energy carriers in a long-term scenario for Germany, the resulting CO_2 emissions, and share of renewable energy (RES). The savings in primary energy (white bars) is based on the baseline scenario from the Energy Report IV.

ment (white bar in the Figure "Primary energy in the long-term scenario for Germany"). A consistent efficiency strategy brings about a reduction of the primary energy consumption by 2050 to nearly half its value in 2005 and thus makes it possible to fulfil the long-term goal for expanding renewable energy utilisation without exhausting the individual potentials. Since every type of energy use also impacts our natural environment – with disproportionately higher impacts from fossil and nuclear energy than from renewable sources, however – this strategy also guarantees extensive protection of natural habitats.

Since the nuclear energy phase-out must also be compensated for, extensive structural changes are required in the electricity market to be able to meet the CO_2 reduction goals for 2020. Renewable energy can accomplish this task if the use of efficient combined heat and power generation (CHP) is also expanded according to the scenario – increasing its share of the total electricity generation from 14 % today to 30 % by 2020 and to ca 40 % after 2030. Above all, decentralised systems can play a special role. They open up new application areas for CHP in the lower power ranges, enabling the increased supply of smaller individual objects. In the long term, the capacity of these decentralised power plants could grow to a total of 20 GW.

In the next decades, the power plant sector will have to execute substantial renewal and efficiency-boosting measures, affecting some ten gigawatts of capacity, as a result of the age distribution of the plants and also the decommissioning of nuclear power plants. Estimates indicate that less than half of the power plants from 2000 will still be operating in the year 2020. This situation offers renewable energy, CHP, and more efficient conventional power plants enough room to enter the market. According to the long-term scenario, 95 GW of new power capacity must be installed in order to meet the electricity demand, which will also have decreased by then. Only 20 GW of new conventional large-scale power plants are required, since 20 GW of fossil-fuelled CHP plants will be constructed and 55 GW will come from renewable energy sources.

Practically the entire power station pool will have been renewed by the year 2050. The largest share of installed capacity, at 100 GW, will be provided by systems utilising renewable energy. A further 34 GW will be supplied by block-type thermal power stations and larger cogeneration plants. Only 10 GW will still come from large power stations whose capacity will then be used mainly for regulation and compensation purposes. Through these various measures, the CO_2 emissions from the conversion sector alone will decrease from its value in the year 2000 to 40 % less by 2020 and to 85 % less by 2050. These figures demonstrate that nuclear energy is not required to achieve the climate protection goals.

The long-term scenario assumes that similar combinations of increased efficiency and the expansion of renewable energy can also be realised in the heat supply and transportation sectors. All together, by 2010 the energy-related CO_2 emissions are successfully reduced to 100 million tonnes per year less than the baseline development and thus clearly surpass the goal set in the Kyoto protocol. By 2050 a reduction to 24 % of the value from 1990 will be possible. In the short to medium term the effects of increased efficiency efforts dominate; the importance of contributions from renewable energy will grow in the medium to long term.

If other countries follow this or a similar strategy – an integral prerequisite for a successful transformation of the energy supply in Germany, considering the coalescing markets – then cheaper resources from foreign countries could also be utilised along with the domestic renewable energy sources. Such imported resources could include wind power from high-yield European coastal regions primarily in the medium term, but in the long term "solar" energy in the form of electricity could be fed into a European network from solar thermal power stations located in the Mediterranean as well. Since the shares of natural gas and mineral oil in consumed primary energy will be considerably reduced, the dependency on energy imports will still be significantly less than today.

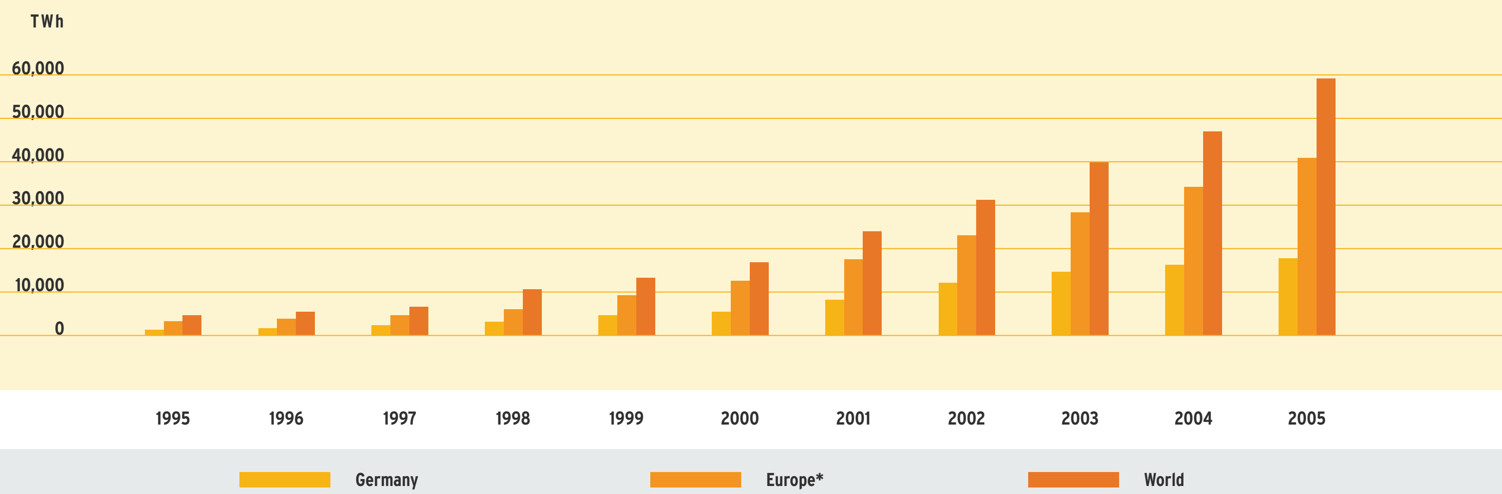
Renewable Energy in the European Union

The European Parliament and the European Commission have already set important goals for the expansion of renewable energy in Europe in the past. The goal already set in 1997 to double the contribution of renewable energy by 2010 is exemplary. The EU guidelines for promoting renewable energy in the electricity sector, which came into effect in 2001, established indicative goals for the member states. The EU plans to thereby increase the share of renewable electricity from 14 % in 1997 to 22 % in 2010 (EU-15: 22 %, EU-25: 21 %). Finally, fuels from renewable sources should achieve a share of 5.75 % by 2010 according to a guideline from the year 2003.

The share of renewable energy in the primary energy consumption of the European Union (EU-25) amounted to ca 6.1 % in 2004. The largest contribution comes from biomass, which is primarily used for heating purposes. About 430 TWh of electricity were generated from renewable energy sources, corresponding to a share of 14 % of the gross power generation. Three fourths of this amount (304 TWh) are provided by hydropower and 57 TWh come from biomass. The contribution of wind power is growing continuously and also amounted to 57 TWh in 2004. The share of solar electricity is still insignificant for the energy economy at 0.7 TWh/a, but exhibits relatively strong growth.

→ Installed wind power capacity

Sources: EWEA, BWE, GWEC



Development of installed wind power capacity in Germany, in the EU, and world wide from 1995 until 2005
*as of 2003 including the installed capacities in the new member states

Support models for renewable electricity

The German Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG) is a feed regulation: the EEG guarantees grid access to operators of renewable energy systems and prescribes a defined reimbursement over a long period of time. The operator receives a fixed sum for every kilowatt hour of electricity fed into the grid. The conditions are therefore clearly defined for investors and credit institutes. In a quota model, on the other hand, the reimbursement for electricity feed is not specified, but rather the amount of renewable energy which must be supplied each year. The quota is generally combined with certificate trading: each kilowatt hour of electricity from renewable energy sources is documented with a certificate. If a company does not fulfil its prescribed renewable energy quota, then it must purchase a corresponding number of certificates. The investment conditions are therefore more difficult to estimate.

In the last 10 years, the growth of renewable energy in Europe has accelerated considerably. The average growth rate amounted to 3.2 % per year. Increased use of wind power is especially responsible for this growth: thus the installed capacity of wind power stations in the EU-25 increased by an average of 25 % per year over the last 5 years. Over 6,000 Megawatt (1,800 MW in Germany) were installed in 2005, corresponding to an investment volume of ca 7 billion Euros.

Changes of the energy supply structure need time.

However, the example of wind power also shows that renewable energy development differs widely in the individual EU states and that we are still far from a successful, even pace. This fact is less a result of the natural potentials, but more a result of different energy policy conditions in the individual member states. Especially the EEG is well-positioned in international comparison. Thus the European Commission determined in a report from December 2005 that electricity feed regulations like the German EEG are very effective in the promotion of wind power. In contrast, the quota systems with tradeable certificates implemented in some other countries could not demonstrate similar success so far (see box: Support models). The costs are also higher than in the countries with electricity feed regulations, although the market mechanisms established by the quota systems theoretically lead to lower levels of reimbursement. The higher risks for system operators are however reflected here. While the German EEG guarantees a legally fixed reimbursement over 20 years, the proceeds from selling the electricity and the certificates are very insecure in the quota system and depend on a multitude of factors which are difficult to estimate.

With the EEG, Germany will most probably meet its national goal to achieve the expansion goal formulated by the European Union in due time. It appears today that only Denmark and Spain, as well as Finland, which granted tax exemptions for renewable energy, will also presumably be able to meet this goal.

Structural changes in the energy supply need time. Therefore, the signals for the future must be set today. The comparison of a baseline scenario with a scenario of a European energy supply transformed under sustainability criteria shows how important this is. “European Energy and Transport – Scenarios on key drivers”, a 2004 report from the European Commission presents a baseline development of the European energy supply until 2030 with no changes in the energy policy conditions. The basic raw data includes the gross domestic product of the EU-25 countries doubling by 2030, an approximately constant population of 460 million people, and only a slight increase in energy prices. Nuclear electricity generation is assumed to decline by 20 % by 2030. Under these conditions, the development in the EU-25 countries leads to a 19 % increase in energy consumption by 2030, a further increased dependence on imports from 48 % at that time to 70 %, and 4,300 million tonnes of emitted CO_2, an increase of 14 % compared to the value from 1990, resulting from the increased use of fossil energy carriers. This scenario clearly indicates that without a significant change in the instruments and policies in Europe, no substantial impulses for the growth of renewable energy are to be expected even after 2010.

In view of the challenges faced by Europe in the next years and decades, and in view of the most recent developments in the international energy markets, in September 2005 the European Parliament called for improved conditions to promote efficient energy use and mandatory objectives for the long-term expansion of renewable energy. Surpassing its previous requirement of increasing the contribution to 20 % by 2020, the Parliament now considers 25 % as a possible goal. Both sectoral and national objectives must be defined according to these goals. The EU Commission presented the Green Paper on a "European Strategy for Sustainable, Competitive and Secure Energy" in March 2006 which also urges an increased use of renewable energy sources and calls for long-term commitment.

The individual structural changes which appear necessary for the EU-25 energy supply to achieve a sustainable development were studied in different ways.

Accordingly, half of the energy demand can be supplied by renewable energy by mid-century, both in Germany and in Europe, if the full existing potential for increasing the energy efficiency is also tapped at the same time (see Figure: Possible expansion of renewable energy in Europe). Despite the nuclear power phase-out, such a development could reduce the CO_2 emissions by more than 70 % (based on values from 1990) by 2050. The share of renewable energy in the total electricity generation of 2,730 TWh per year at that time will have increased to 74 %, whereby wind power provides the largest amount of 850 TWh/a.

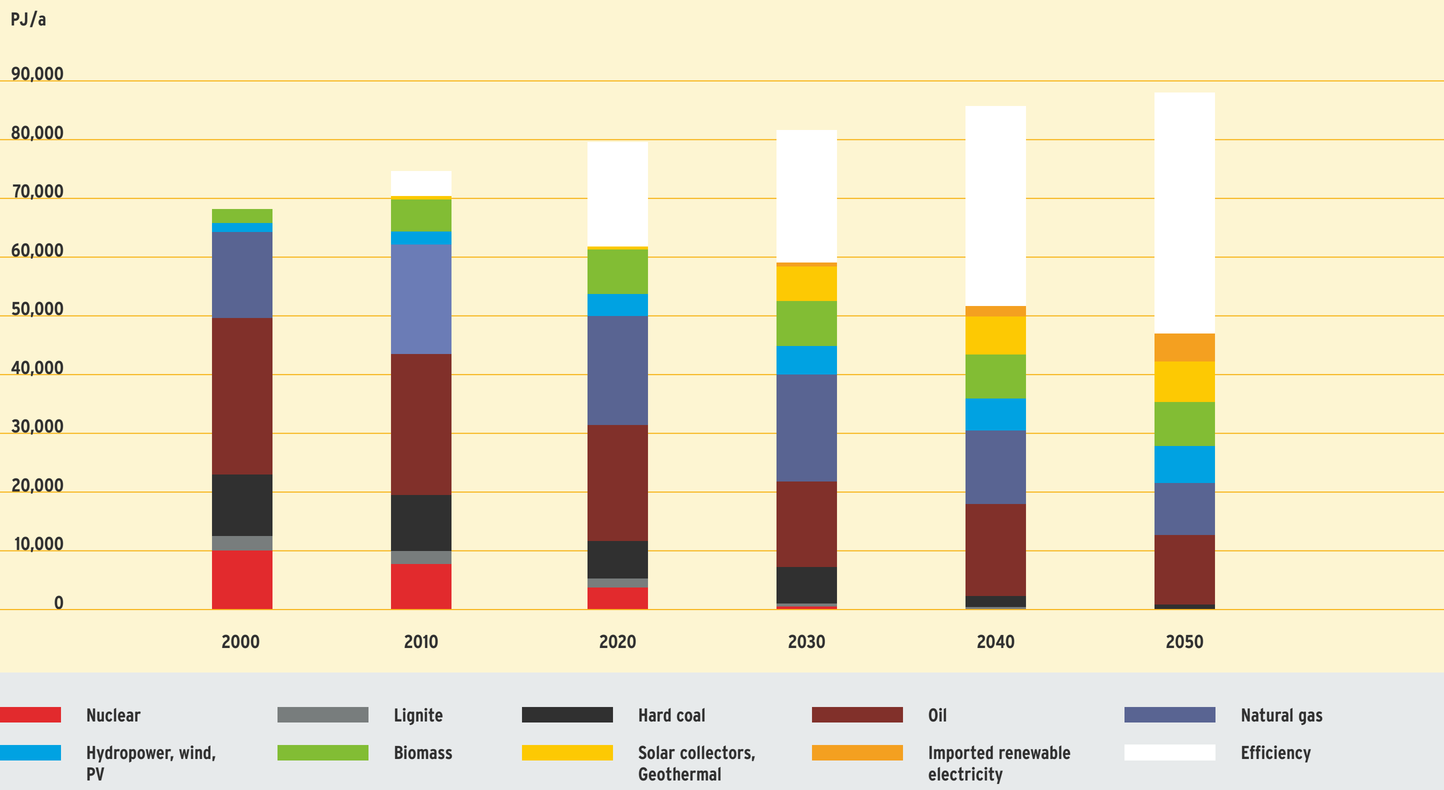
Solar thermal electricity generation in South Europe and North Africa play an increasingly important role, providing 520 TWh solar electricity per year for the European network by mid-century. The share of renewable energy in the heat supply will also increase to over 50 %. The largest contributors here are biomass, solar collectors, and geothermal sources.

"North" and "South" – beneficiaries of a common energy strategy

Due to the predominance of radiant energy, it is precisely the southern countries that have an extremely high renewable energy potential, exceeding by far even the level of consumption they might attain in the future. Thus it would be possible, for example, to generate enough electricity to meet today's global demand just in Morocco alone with the help of solar-thermal power plants. Therefore, just developing renewable energy sources for their own consumption is not the only prospect for today's developing countries. In the long term, a transcontinental energy exchange based on renewable energy sources will be technically possible using electricity or chemical energy carriers – like those already present today for natural gas and to a certain extent also for electricity. Thus e.g. solar-rich countries could become "exporting regions" within a few decades time,

→ Possible expansion of renewable energy in Europe

Source: DLR



Possible expansion of renewable energy in Europe. Development of primary energy use in a development path for the energy supply of the EU-25 countries which is based on sustainability goals. "Efficiency" = Energy saved compared to the 2004 baseline development from the EU Commission.

Renewable energies can make a lot of countries in sunbelt regions energy supplying countries. Such energy partnerships would be equally profitable for Noth and South.

exporting cost-effective and inexhaustible energy carriers produced from renewable energy sources. This arrangement provides considerable benefits for all partners.

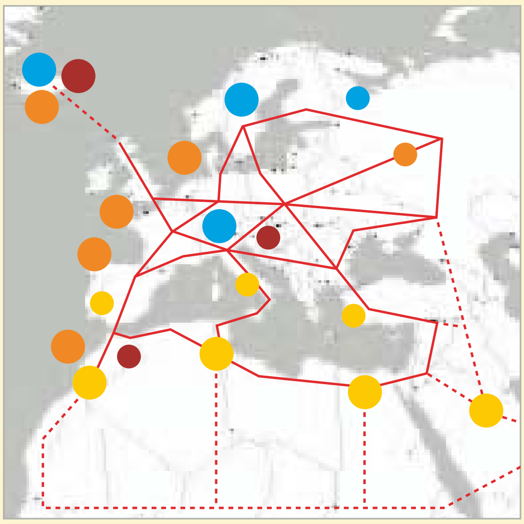
Energy is not the only scarce commodity. In many countries, it is already apparent that there will be a considerable lack of clean water in the coming decades. A major contribution to the sustained development of countries in the arid regions of the world would therefore be the combined production of electricity and drinking water. Solar-thermal power plants for combined heat and power generation can serve this purpose. The decoupled heat is used for the thermal desalination of seawater which, unlike the competing "reverse-osmosis" method, supplies water with a sufficiently low salt content that it can be used for agricultural irrigation purposes. The production of desalinated water could even be the prime objective here: Electricity accumulates practically as a by-product, and can be used either domestically or exported to Central Europe by means of high-voltage DC transmission. The transmission costs, e.g. from Morocco, lie in the region of a few Cents pro kilowatt-hour, meaning that costs for imported solar electricity of less than 6 Cents/kWh could be achieved in Central Europe. To this end, high-capacity transmission lines are needed like those which have already been realised with some 60 GW power world wide and transmission distances up to 2,500 km.

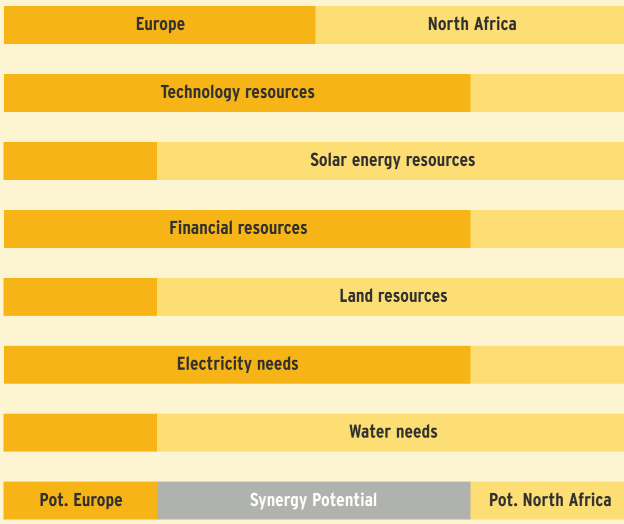
Renewable energy world wide

Internationally, renewable energy plays a widely differing role, depending on the region. It is particularly important in the less-developed regions, like Africa, where nearly half of the energy demand is met with renewable resources – mainly through the traditional use of biomass, which is by far not sustainable. Simple methods of cooking and heating with an open fire cause health problems and often lead to irreversible deforestation. The use of hydropower with large dams represents another non-sustainable use of renewable energy sources in the meantime, since it is associated with serious social and ecological consequences.

→ Potential for synergy

Source: DLR



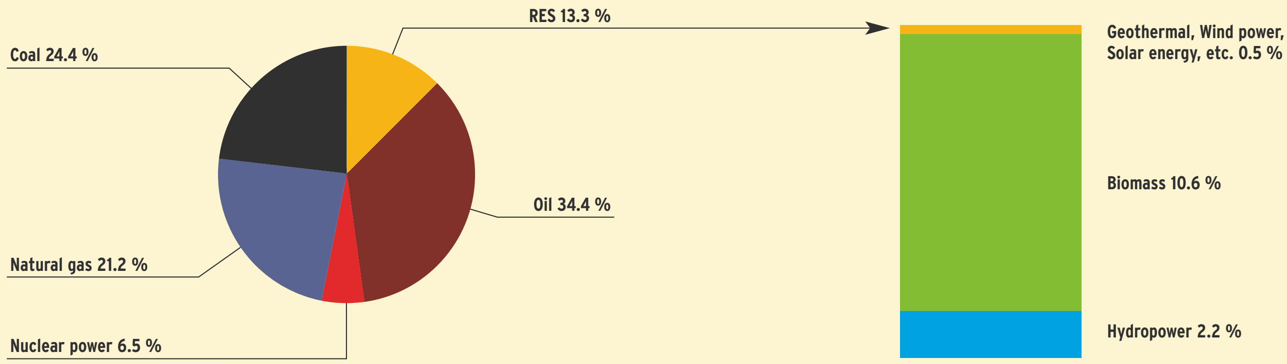


Solar-thermal generation of electricity, desalination
Wind power
Hydropower
Geothermal energy
High-voltage DC transmission line network
Expanded network

Potential for synergy between Europe and North Africa for the joint development of a sustainable energy supply. A transcontinental power network enables the common use of the most plentiful renewable energy source from this region.

→ Structure of global primary energy consumption

Source: IEA 2005



Today's global primary energy consumption is still dominated by fossil energy carriers.

A basic prerequisite for the construction of a sustainable energy supply is to fight poverty. Nowadays, however, increasing revenue in the developing and newly industrialised countries generally leads to an increased demand for fossil energy carriers.

Many of these countries are therefore in danger of becoming the losers of trying to catch up on industrialisation because their energy consumption is increasing while oil and gas resources are becoming ever scarcer. Although attempts have already been made in the past to prevent this development through a more intense and sustainable use of renewable energy sources, the results so far have been sobering. Although the supply of energy from renewable sources nearly doubled over the last 30-some years, the use of coal, oil, natural gas, and nuclear power also increased at the same time. The share of renewable energy in the global energy consumption has therefore not increased from its level of just over 13 %.

A global perspective

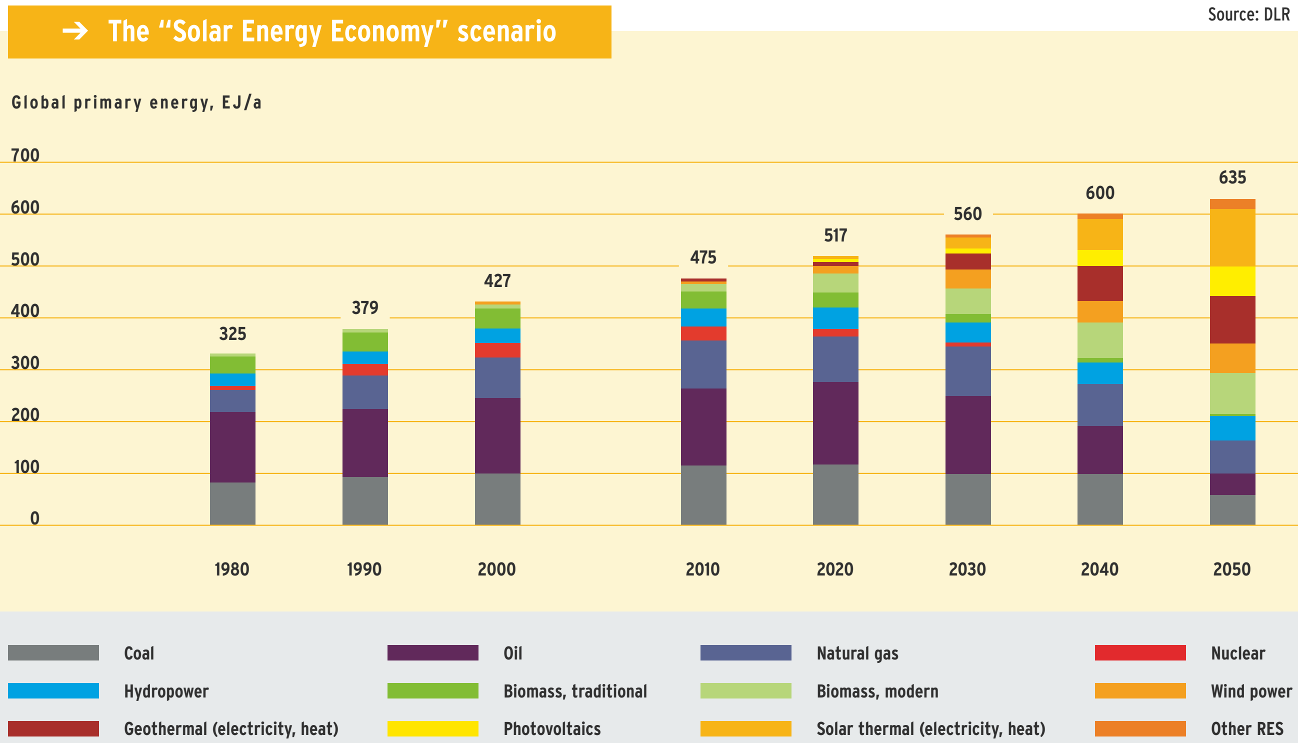
In contrast to Germany and Europe, where on the short to medium term the energy demand can be reduced by exploiting the existing efficiency potential, the global energy demand will still increase significantly. Fundamental reasons for this development include the population growth and a further increase of the gross world product. The absolute amount of the energy consumption, however, depends strongly on the development of the energy intensity. The German Advisory Council on Global Change developed a scenario with a very dynamic, growing world economy in its report "World in Transition – Towards Sustainable Energy Systems". It assumes a six-fold increase of the gross world product by 2050 while the energy intensity declines by 1.5 % per year, so that the demand for primary energy nearly triples – a result similar to other scenarios with significant growth. The pivotal importance of renewable energy is clearly indicated since it makes the largest contribution to meeting the energy demand in 2050.

The challenges of a "Solar Energy Economy" are formidable. Such a structural change can only have a chance for success if the large majority of the international community of states decides on concerted, quick, and effective action.

The scenario of a "Solar Energy Economy" assumes a constant per-capita energy consumption, so that further economic growth is associated with a significant decline in energy intensity. The modern industrialised countries halve their energy use as a contribution to moderate the unfair distribution of the global energy consumption. In this way, the per-capita consumption of today's developing countries can double and thereby secure a share of 75 % of the primary energy consumption for their growing population in 2050.

The removal or reduction of further sustainability deficits demands a reduction of the fossil energy use by one half by 2050, phasing out of nuclear energy use, and a transformation of "traditional" biomass use (firewood collection), which often damages the environment, to an environmentally compatible "modern" biomass usage. Employment of modern technologies for the utilisation of renewable energy must accordingly meet nearly 75 % of the total energy demand by 2050. Corresponding to the potential, the solar technologies (photovoltaics, solar-thermal power plants, and solar collectors) deliver together the largest contribution of 30 %.

→ The "Solar Energy Economy" scenario



Development of primary energy consumption in the global "Solar Energy Economy" scenario. Increased energy efficiency and a balanced mobilisation of all renewable energy sources lead to a 50 % reduction of the fossil primary energy contribution by 2050.

Fossil primary energy use will continue to grow until 2020, drops back to the current levels by 2030, and supplies only slightly more than a fourth of the primary energy demand by 2050.

From the potential point of view, this level of contribution is possible, since the technical potential for renewable energy is about six times the current global energy consumption, even while complying with strict environmental regulations (see "Potential for Renewable Energies" chapter).

From the structural point of view, the challenge is formidable, since the timely mobilisation of these technologies requires them to double their current contribution every ten years, while at the same time the energy supply and usage structures in all regions must become significantly more efficient. The required transformation of the global energy supply within a half century can therefore only have a chance to succeed if the large majority of the international community of states decides on concerted, quick, and effective action.

The importance of the developing countries

The energy supply in developing countries is usually considered "decentralised", i.e. with little or no network between supply structures. The consumers are isolated, with no access to an electricity grid, and possess only small amounts of fossil energy sources due to their low income. This description indeed applies to nearly 3 billion people in developing countries, corresponding to half of the world population.

About 2 billion people have no access to electricity grids. Most of these people live in the least-developed countries, where the consumption of non-commercial energy, i.e. firewood mostly for cooking purposes, is the highest. In many countries, this consumption is just as high as the consumption of commercial energy. Many people in these countries can only survive thanks to the collection of firewood – a time-consuming, physically exhausting, but nonetheless non-productive and ecologically questionable undertaking.

At the same time, the developing countries are undergoing an unstoppable process of urbanisation. Already in 15 years, half of their population (a total of 6 billion people in 2015) will live in cities which are often considerably larger than those of the northern hemisphere. Today there are 15 cities with more than 10 million inhabitants each. With a total of 140 million inhabitants, 11 of them are located in developing countries. Mexico City, Sao Paulo, and Bombay are the largest among them. In 2010 more than 20 cities in developing countries will have reached this size, with a total of 350 million residents. Another billion people will live in cities with populations exceeding one million inhabitants.

This development is of great importance for the design of the future energy supply in these countries. They must face much larger challenges than the industrialised countries in order to approach a sustainable energy supply. They must offer sustainable solutions in equal measure for both areas – strongly growing urban centres and rural regions. Although an abundant potential for renewable energy is available to these countries, they can only be developed to the necessary degree with technical and, above all, financial assistance from the industrialised countries.

The global challenges of the energy supply for the next years and decades can only be overcome through a joint effort. The development of renewable energy is a key factor for success.

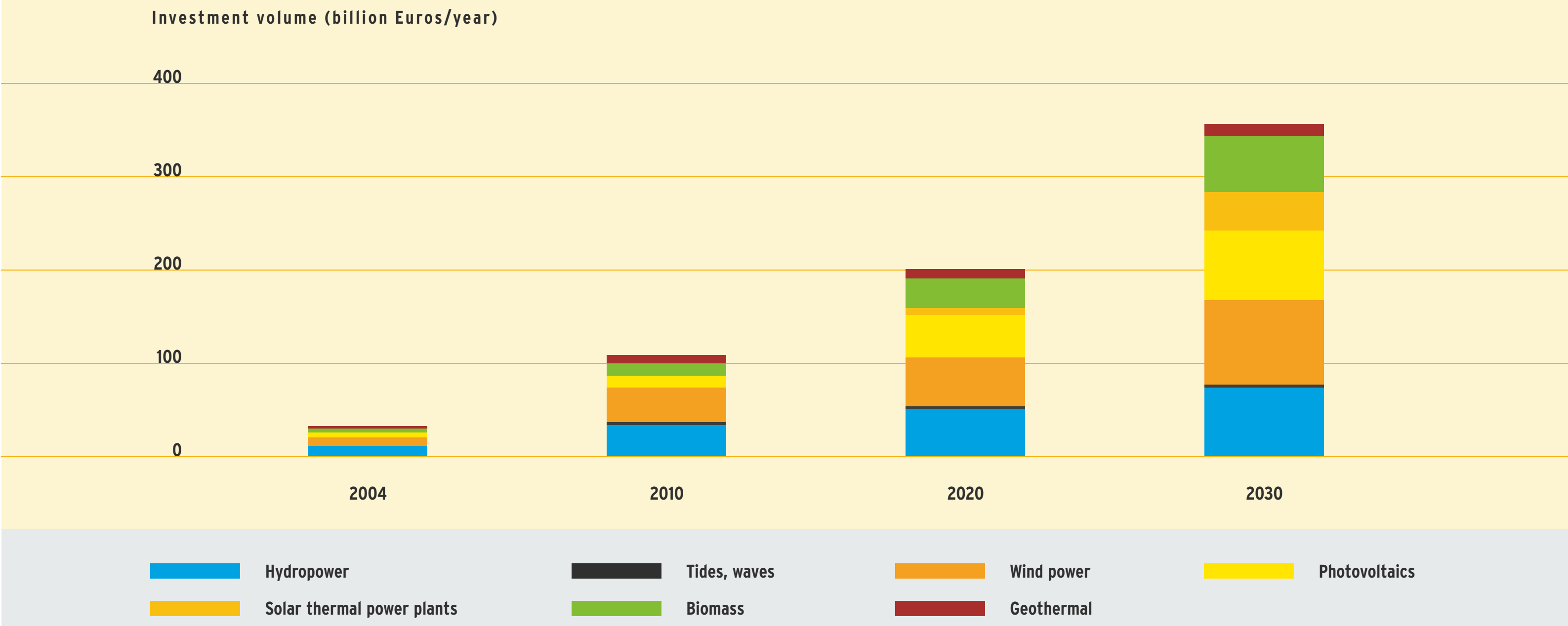
Increased efficiency is also tremendously important – during generation (combined heat and power in the industrial and commercial areas, highly efficient gas power plants) and even more so during the use of the energy. The existing infrastructure must also be modernised and improved.

In the rural regions of less-developed countries, the renewable energy sources located "on-site" are already today the only reasonable supply possibility, since poor transportation infrastructures would only make the already scarce fossil energy carriers even more expensive. The goal is therefore to satisfy the basic energy needs of the rural population as quickly as possible with suitable decentralised technologies based on renewable energy sources, such as small hydroelectric generators, photovoltaics, wind power, and efficient biogas and biomass systems. This way, it might also be possible to slow down the urbanisation trend. The realisation of such a strategy, however, currently faces a number of obstacles. The lack of possibilities in the developing countries to finance the investment costs for renewable energy systems is of particular importance. For this reason, different financing mechanisms are already being explored: small solar systems can, for example, be financed in advance and then get activated by using a password after paying a monthly fee.

However, that is not all which must be done. Another part of the development strategy in the energy sector is just as urgent – large central power stations based on renewable energy, like large grid-connected wind farms, hydroelectric power stations of suitable size, and solar thermal power plants – in order to supply the existing and quickly expanding urban regions to a sufficient degree. Integrated system solutions are necessary which are specifically designed to fit the particular needs and which are composed of a large number of different systems. Production knowledge and capacity in these countries must also be taken into consideration.

→ Possible development of investment volumes

Sources: ZSW, DLR



Investment volume scenario for renewable energy sources in the global electricity sector up to the year 2030

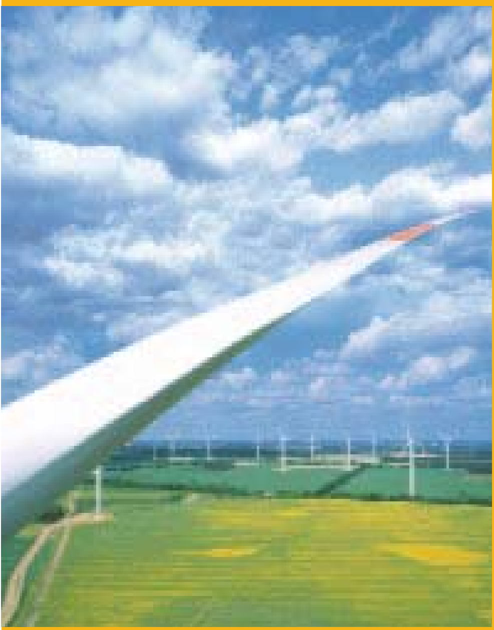
Production of wind turbines in German Indian joint venture.

Solar system in India

In terms of international division of labour, but also in terms of the development policy goals of the German government, the global expansion of renewable energy must occur in such a way that all parties benefit.

At the same time, attractive opportunities for the renewable energy industry will result from growth of the international renewable energy market. The investments in the power generation sector alone are probably in the range of 30 billion Euros per year world wide. About a sixth of this amount is from Germany. It can be assumed for the future that about 5 billion Euros per year will continue to be invested in Germany in order to meet the expansion goals in the power sector. The international market will grow strongly at the same time. It is by all means conceivable that an international volume of 200 billion Euros will already be invested in 2020. On the one hand, this means that the share of the German market will relatively decline. On the other hand, export opportunities are enormous.

WIND POWER



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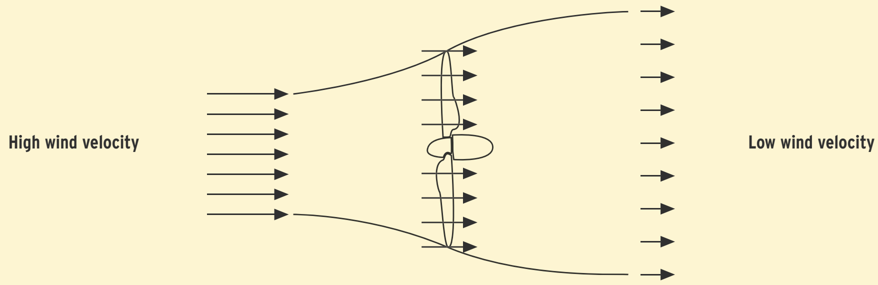


4

Resource:	Kinetic energy from the wind
Sites:	World-wide; preferably in coastal regions and hilltops, as well as offshore installations
Field of application:	Electricity generation
Capacity:	0.05 kW to 6 MW per wind turbine; wind farms of 100 MW and more
Electricity costs today:	5 to 12 Cents/kWh
Figures:	1. Onshore wind farm, 2. Offshore wind farm, 3. Erection of a wind turbine, 4. Interaction between wind velocity and rotor motion

WIND POWER – A STRONG UPWARDS TREND

Wind power has been used by man from time immemorial. Before the steam engine was invented, trade across the oceans was only possible by means of sailing vessels. Windmills ground grain and drove water pumps for irrigation and drainage purposes. In 1900 there were reportedly some 30,000 windmills still operating in Northern Germany alone. Only once electricity became available and affordable everywhere in Germany did the windmill disappear from everyday life.

The first endeavours to revive this climate-friendly and resource-conserving technology were started in the fifties by German pioneers. However, it was the oil crisis of the seventies, together with an increased awareness of the environment, which led to the renaissance of wind power in recent times.

Modern wind turbines utilise the **lift principle** rather than the resistance principle. The wind does not push against a resistance, but rather the wind flow passing over the rotor blades of the wind turbine generates a lifting force, like for an aircraft, which makes the rotor turn around. While only a maximum of 12 % of the wind energy can be withdrawn by applying the resistance principle, a 59 % yield can be achieved by applying the lift principle. At their optimum, modern wind power stations already achieve an efficiency of 50 %. Modern wind turbines therefore already produce electricity with an energy yield very close to the theoretical maximum.

Depending on the wind velocity, it is possible to differentiate between **four phases of operation**. At very low wind speed, the wind energy is not sufficient to overcome the system's moments of friction and inertia, and the rotors remain stationary. Starting at a certain wind velocity – about 3 m/s depending on the design – the wind turbine will turn. In this phase, the power output increases as a function of the wind speed cubed, i.e. twice the wind velocity produces eight times the electrical power. If the wind velocity increases further, then the generator will reach its maximum capacity. The surplus energy from any further increase in wind velocity must be bypassed. The maximum power of the system is thus determined by the flow over the rotor area, and does not depend on the number of rotor blades.

There are different specific characteristics of the various wind turbines. Some systems already start running at very low wind velocities and soon reach their nominal capacity. These systems are well suited for regions with average wind speeds, e.g. onshore sites with favourable wind conditions. In contrast, areas where strong winds prevail are more suitable for wind turbines which reach their nominal capacity at higher wind speed, and are thus capable of converting even strong wind into electricity.

Wind turbine technology

While in other regions of the world wind power is also used in mechanical form for driving pumps, wind turbines in Germany are used exclusively for **grid-connected electricity generation**. The **technical development** of wind power stations over the last 20 years has mostly concentrated on constructing larger and larger systems in order to optimally exploit locations with good wind conditions. This goal has spurned on fast technical development. While the average capacity of the installed wind power systems was less than 50 kW in 1987, it increased by more than a factor of thirty to 1,720 kW by 2005. It is difficult to predict today which system size will represent the technical and economical optimum. The largest systems today have a maximum capacity of 6 MW. The yield of such a plant corresponds to the yearly electricity consumption of up to 5,000 households.

The wide majority of wind turbines installed today have **three rotor blades**, since the mechanical loads are easier to control with this design and because most people perceive three-blade rotors as optically more balanced than single or two-blade rotors. The blades themselves are usually made of plastic and are more than 60 metres long for large turbines. The area covered by the rotor blades of the largest turbines on the market cover more than 10,000 m^2, nearly as large as two football pitches.

Three different concepts are available for power regulation. Their rigidly fixed blades and the constant rotor speed cause **stall-controlled turbines** to stall above a certain wind velocity. Even if the wind speed increases further, the rotor performance will remain nearly constant. The simple construction of stall-controlled turbines led to its widespread installation in the early years of wind energy use. In the megawatt range, the blade-controlled turbine design (also referred to as **pitch control**) dominates. In these systems the rotor blades can rotate about their longitudinal axis. Although pitch-controlled turbines are more complicated to construct, their energy efficiency is higher with less stress on the rotors than for stall-regulated turbines. **The active-stall control** is a compromise between the two concepts in which the rotor blades can be slightly adjusted according to the wind speed after reaching the rated capacity. Since the mechanical load on the rotors will be too high during a windstorm, pitch-controlled and active-stall turbines are then taken off the grid and the entire rotor is turned out of the wind so that the rotor spins with no load. Stall-regulated systems are halted aerodynamically with blade-tip brakes. Modern turbines are slowly shut down at wind speeds above 25 m/s so that they are only throttled and not completely shut down when a storm front passes by.

Assembly of a 6-MW wind power station

Modern large-size rotors turn at 10 to 30 revolutions per minute, depending on their rated capacity. This rotor speed is slower than for smaller wind turbines and thus produces an appreciably "calmer" landscape image. Since, particularly for large turbines, control and constancy of the power output are of major importance, the number of turbines with a **variable rotor speed** has increased significantly in recent years. By matching the speed to the rotor aerodynamics, the operating point for the greatest efficiency can be maintained over a large wind-velocity range.

Gears are needed if common generator types are used to transform the low rotor speed to the required generator speed of 1,500 revolutions per minute. The losses attributed to the gears are about 2 % per stage and, additionally, the gears are themselves a source of noise emissions. **Gearless systems** do not have these problems; however they require specially manufactured multi-pole generators.

The **towers** of the largest wind turbines today are more than 120 metres high, so that together with the rotor blades the wind turbines reach a height of up to 170 m. As a rule: the higher the tower, the less interference from air turbulence caused by ground roughness and the mean wind velocities are higher. The towers are generally realised as steel-jacketed constructions which least influence the surrounding countryside due to their slim design. However, concrete towers are sometimes also employed since they attenuate noise emissions.

In recent years wind power stations have been further developed for offshore use. The largest economic challenge in the development of offshore wind power technology is to minimise the additional costs for the relocation to the open sea. The **underwater cables** and the special **foundation technologies** cause a wind farm at sea to be more expensive than one on land. Especially floor-mounted constructions are reasonable for the wind farms of the near future constructed at moderate water depths of 40 to 50 m. Different constructions include the monopile foundation, tripod structures, and gravity-based foundations. Floating constructions can be employed at greater water depths.

The **grid connection** of offshore wind farms depends on the size of the wind farm and its distance from the

2-MW offshore wind turbines in the North Sea

coast. Within an offshore wind farm the individual turbines are connected to one another with a medium-voltage line, just like for wind farms on land. Small offshore wind farms close to the coast can also be connected to the grid with a medium-voltage line. A high-voltage three-phase connection for larger capacities and greater distances from the coast can cause technical problems with the connection to the land-based grid due to the high idle power. For distances exceeding 50 km, the high-voltage DC transmission is a technically and economically reasonable alternative to AC connection. Large offshore wind farms must operate as power plants within national or international networks. **Fast controllability** of individual turbines or the entire wind farm, excellent **grid compatibility**, and **grid stabilization capability** are essential specifications which require additional technical configurations. The optimal size of an offshore wind farm is larger than a land-based one due to the higher costs for the foundation and grid connection. Since the limited accessibility of offshore turbines leads to a longer downtime in the case of malfunction, their reliability must be improved. Early error detection systems and special operation and maintenance strategies can increase availability.

Exploiting new offshore potential

Since suitable areas to further expand wind power on land are becoming scarce, work has already started to develop the very large **potential at sea** (offshore). Wind farms operating offshore have a minimal impact on landscape and the environment. Additionally, the wind speed is considerably higher than on land, so that the electricity yield can be increased by up to 40 % over that from a good site near the coast on the mainland. By operating offshore wind farms, new “locations” can be exploited. Nonetheless, potential negative impacts on the ocean habitat must be avoided.

The potential for **offshore wind power** is considerable: in the long term it seems possible to install wind parks with a total capacity of up to 25,000 MW along the German coast and in the Exclusive Economic Zone. **The annual yield is estimated at 85 to 100 TWh, which is equivalent to about 15 % of the present-day electricity consumption in Germany.**

When selecting a specific site, not only economic aspects but also **environmental and nature conservation** and the interests of navigation, of certain industries (like e.g. fishing, mineral resources) and military use have to be considered. Taking into account the various nature conservation and usage concerns, suitable areas for exploiting offshore wind energy have been identified in collaboration with several ministries of the German federal government. The Bundesamt für Seeschifffahrt und Hydrographie (Federal Maritime and Hydrographic Agency) identified **particularly suitable sites for wind power stations in the North and Baltic Seas** for the first time at the end of 2005. In cooperation with numerous environment and nature conservation associations, nearly 700 km² of suitable area in the so-called Exclusive Economic Zone were selected following a strategic environmental audit and a fauna-flora habitat compatibility audit. At the same time, conservation areas were identified in the Exclusive Economic Zone where wind power use will not be allowed. So far, a total of ten wind farm projects in the North Sea and one project in the Baltic Sea have been authorised. Since the impacts from offshore wind farms on the ocean environment can not yet be finally evaluated, only pilot projects with a maximum of 80 individual wind turbines have been authorised so far. **Any future expansion presupposes a positive evaluation of the first installations with regard to their environmental and nature conservation compatibility.**

Continuously lower costs

Thanks to the positive framework conditions, the costs for wind turbines have dropped from nearly 4,000 Euros/kW in the early eighties to 800 to 900 Euros/kW today. In addition to the **costs for the wind turbine** itself, there are costs for the **foundation, grid connection,**

access to the site, the land, and planning. The auxiliary investment costs amount to approximately 30 % of the costs for the wind turbine itself. The total project costs for a 2-MW wind turbine thus amount to about 2.2 million Euros.

An even stronger price reduction tendency can be recognised if the efficiency increase possible through further technology development is also considered in the price development. Since the energy yield of a system does not just depend on the generator size, but also on the rotor area, the hub height, the control system, and on various aerodynamic factors, it is reasonable to **normalise the investment costs to the expected annual power yield**. Since 1990 the specific costs per kWh yearly power yield have halved. Including the operation and maintenance costs, **electricity generation costs** between 5 and 12 Cents/kWh are achieved in Germany for the typical annual wind speeds averaging 5 to 6 m/s on the coast and 4 to 5 m/s at favourable inland locations (at 50 m above ground).

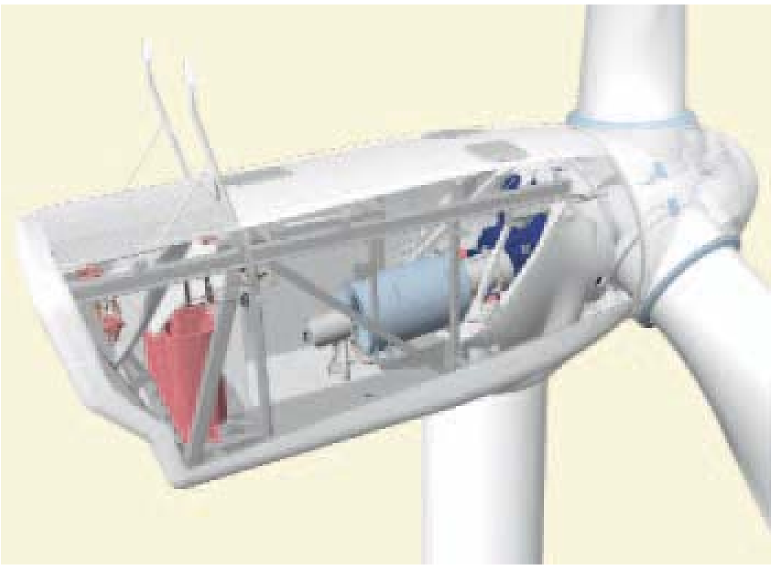
Depending on the distance from the coast and the depth of the water at the site, the **additional investments** required for grid connection and foundation of an offshore wind park amount to up to 200 % of the costs for the wind turbines. Since the additional costs depend in the first instance on the depth of the water and the distance from the coast, and only to a lesser extent on the capacity of the wind turbine, offshore wind parks are planned to be as large as possible for economic reasons. Due to the high costs for grid connection, an offshore wind park will be much larger than its counterpart on the mainland. Electricity generation costs of 6 to 8 Cents/kWh have been determined for the first small offshore wind farms close to the coast. As experienced with onshore wind installations, a large cost reduction potential is expected with the large-scale introduction of offshore wind power, so that the costs for electricity generation from offshore wind parks will be reduced significantly in the long term.

In Klettwitz (Brandenburg) one of the largest European windparks (38 turbines) was built on the top of mining waste heaps.

Wind power, nature conservation, and environmental protection

In the process of increasing wind energy use, its compatibility with nature and the environment is often questioned. This discussion, however, requires careful balancing of the advantages and disadvantages of wind energy as compared to the alternatives along with the concrete examination of specific cases and locations. It is particularly important to also consider which environmental damage was avoided at other locations through the operation of the wind power station. Environmental impacts from wind turbines include noise emissions, disturbances for animals (especially birds and bats) and their habitats, and detraction of the landscape.

Noise emissions from modern wind turbines could be reduced significantly compared to early installations as a result of aerodynamic improvements, a more effective insulation of the nacelle, and by avoiding certain components. Whereas a sound power level of about 100 decibel is measured directly at a typical modern wind turbine, the level is only 55 decibel at a distance of 50 m – which is equivalent to a radio at low volume. At a distance of 500 m, which is the generally required minimum distance from a residential area, the noise from the wind turbine is virtually inaudible. Often the natural rush of the wind is louder than the noise emitted by a wind turbine. All wind turbines must comply with



View into a wind turbine nacelle

the stringent German technical requirements concerning noise (TA Lärm).

Many years of observation have shown that **birds** in flight will bypass a wind turbine during the day, and it is rare that a bird impact actually takes place. However, it is possible that migratory birds, flying in the dark and in fog, could also collide with a wind turbine. Moving rotor blades are detected by birds through the changes in the air flow, so that a wind turbine can usually be avoided even in poor visibility. Nevertheless, certain species of birds and bats, e.g. the red kite or the common noctule bat, seem to be particularly affected by impacts with wind power stations. As a result, wind turbines may not be installed in the main routes of migratory birds or in nature conservation areas. Since a building license is always required to build a wind turbine, compliance with such requirements is always reviewed as a part of the approval process. Since 2001, wind parks with three or more units require approval according to the Federal Imission Control Act and a formal environmental impact assessment.

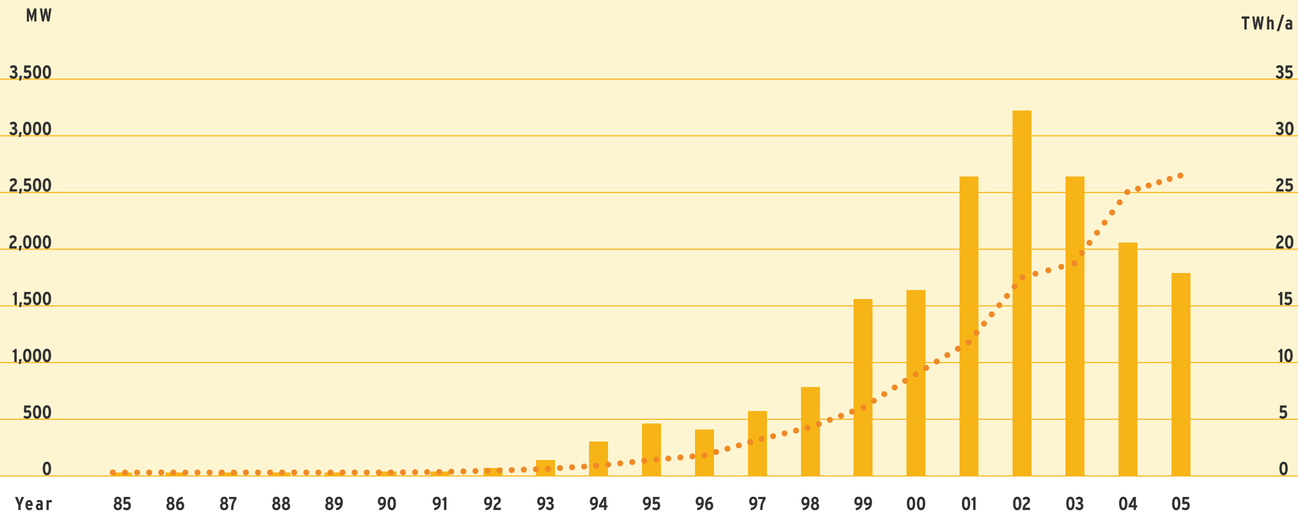
The cumulated electricity during a wind turbine's lifetime avoids burning coal in a conventional power plant. Piled up, this amount of coal would form a hill as high as the wind turbine itself.

The influence of wind turbines on the **appearance of the countryside** is assessed differently. Some people see a detrimental change being made to the countryside, whereas others consider a wind turbine a positive sign of the energy policy reorientation. The conflict between different subjective perceptions cannot be ultimately resolved. From the view of nature conservation, a landscape is not exclusively a question of subjective perception, but also describes the overall context of a particular habitat. In this respect, landscape considerations also play a role in choosing sites; the evaluation takes place on site.

Besides the location-specific deliberations, the related ecological benefits of wind power must also be taken into consideration. Just one wind turbine with a capacity of 1.5 MW prevents some 64,000 tons of CO_2 being emitted into the atmosphere during its technical lifetime of 20 years. The contribution to conserving our resources is considerable as well: a single 1.5-MW wind turbine can prevent more than 80,000 tonnes of brown coal being consumed in conventional power plants. Piled up, this quantity of brown coal would form a hill as high as the wind turbine itself. It is therefore the task of the land-

→ Wind power capacity and electricity yield

Sources: ISET/DLR/BMU



Annual installed capacity in MW

Annual yield in TWh

Wind energy in Germany – a stormy development.

use regulation authorities, and hence of the German federal states, to assess the various aspects of nature conservation and environmental protection, also considering optimisation possibilities, in the process of identifying areas of priority and suitability for wind power use, as well as areas which are not to be used for wind energy.

Even if future offshore wind parks produce electricity out of sight from the beach tourist, the operation of these installations is still associated with certain effects on nature which cannot be completely avoided through technical measures. The ecological monitoring being carried out at the first offshore pilot plants will help to better understand the influences on migratory bird flight or the effects of low-frequency noise emissions on marine fauna. The Federal Environment Ministry BMU, the Federal Environment Agency UBA, and the Federal Nature Conservation Agency BfN, together with relevant environmental and nature conservation organisations, have identified specific areas that are **suitable for offshore wind farms in the North and Baltic Seas.** Areas inside "Important Bird Areas" are principally not suitable for setting up wind farms. Wind turbines are also not allowed in areas with the status of a de facto bird protection area.

Wind power in Germany

The wind power capacity installed in Germany has been growing considerably for years now. New wind turbines with a capacity of 1,810 MW were installed in 2005, thereby increasing the number of wind power stations to some 17,570 installations with a total installed capacity of 18,428 MW by the end of 2005. With a total **electricity yield** of 26.5 TWh , wind power now provides some 4.3 % of the electricity generated in Germany, which is equivalent to a **reduction of CO_2** emissions of about 24 million tons.

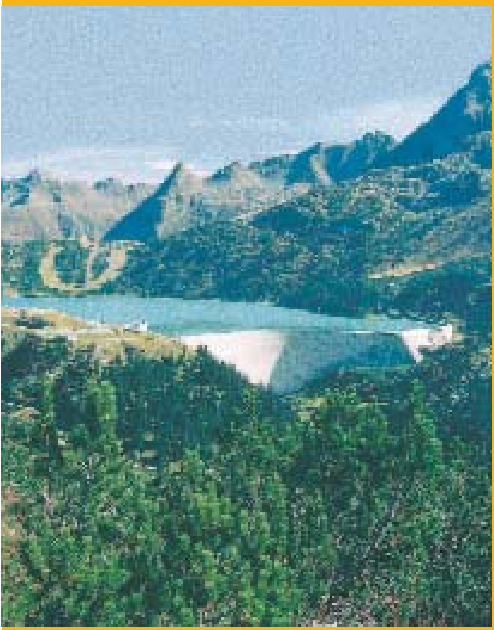
Although the rate of wind power expansion has declined somewhat since 2003, **no country in the world has more wind turbines than Germany** (see Figure: "Wind power capacity and electricity yield"). More than half of the installed capacity is in the wind-rich coastal states. The state of Schleswig-Holstein can thus meet almost one fourth of its electricity demand with power from wind turbines. Thanks to the technical developments made in recent years, the use of wind power has also increased in inland regions.

However, especially good sites are often already occupied by old turbines from the 1980s and 1990s. Old systems can be replaced by larger and more efficient systems. This so-called **repowering** relieves the landscape. Thus wind power stations in Germany would provide about 50 TWh of electricity in the future, about 10 % of the German electricity demand. The potential for German offshore wind farms is estimated to be up to 100 TWh per year. All together, about 30 % of the present gross electricity generation could be replaced by wind power.

Information about wind energy utilisation

- → **Current issues of wind energy utilisation: www.eneuerbare-energien.de/inhalt/4591**
- → **Bundesverband WindEnergie e.V.: www.wind-energy.de**
- → **European Wind Energy Association: www.ewea.org**
- → **Deutsches Windenergie-Institut (DEWI): www.dewi.de**
- → **BUND – Position on wind power: www.bund.net/lab/reddot2/pdf/windenergie.pdf**

HYDROPOWER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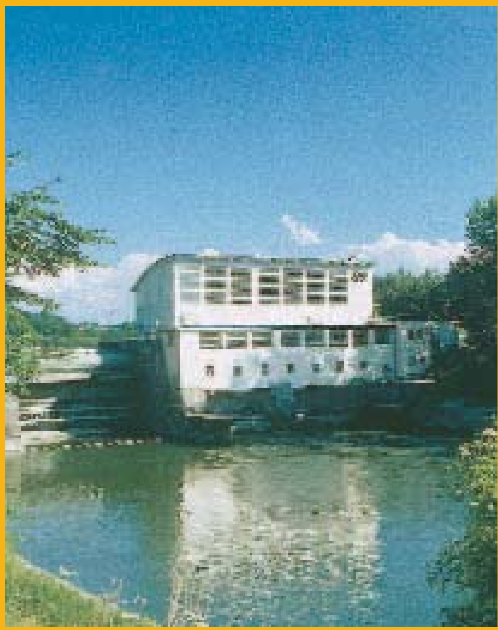
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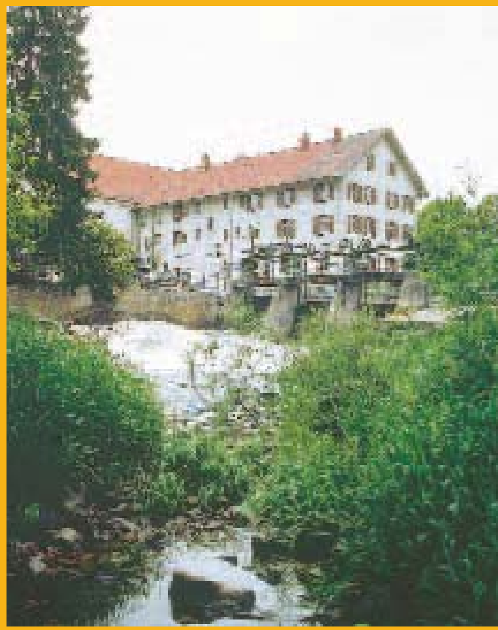
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Resources: Kinetic energy and water

Sites: High- and medium-altitude mountains, rivers, streams

Field of application: Electricity generation, energy storage

Capacity: Storage and run-of-river power stations: up to 18,000 MW
Small-scale hydropower stations: up to 1 MW

Electricity costs today: Storage and run-of-river power stations: 3 to 10 Cents/kWh
Small-scale hydropower stations: 10 to 25 Cents/kWh

Figures: 1. Storage power plant, 2. Run-of-river plant, 3. Small-scale hydropower plant, 4. Function of a water turbine

HYDROPOWER – ESTABLISHED AND UP-TO-DATE

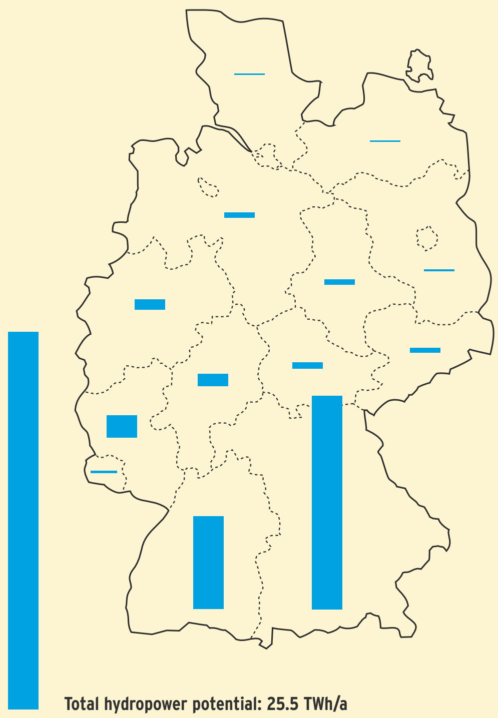
Hydropower was already used in preindustrial times for driving mills, sawmills, and hammer works. Both the kinetic energy and the potential energy from flowing water can be converted into mechanical rotational power by a turbine wheel, which in turn can drive machines or generators. Today, hydropower is used almost exclusively for generating electricity in Germany.

Hydropower is a mature technology which, world-wide, generates the second largest share of energy from renewable sources, after the traditional use of biomass. 17 % of the electricity consumed in the world today is generated by hydroelectric power stations! Of all the sources of renewable energy, hydropower still provides the largest contribution to the generation of electricity in Germany today. The proportion of the total electricity production attributed to water power is about 4 %.

Almost 90 % of the electricity from hydropower is generated in Bavaria and Baden-Württemberg, because of the plentiful precipitation and favourable slopes in the low mountain ranges and foothills of the Alps located in these states. There are currently some 5,500 small-scale hydropower stations with a capacity of less than 1 MW each operating in Germany today, the majority of which are owned by small companies and individuals. The contribution from these stations is, however, relatively small. More than 92 % of the electricity from hydropower comes from the ca 400 hydroelectric power stations with a capacity exceeding 1 MW, and which are mainly operated by the utility companies.

This water turbine system in Cottbus has a capacity of 280 kW.

→ Hydropower potential



Potential for using hydropower in Germany

There are different types of water turbines with different areas of application, depending on the flow rate and the head (pressure) of the water.

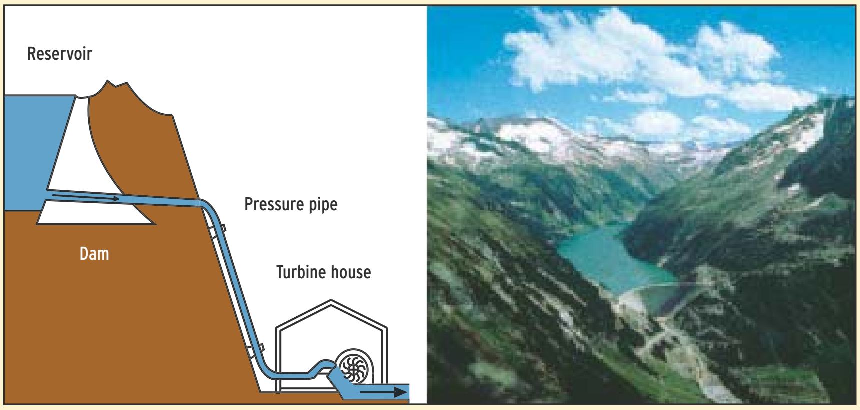
The Kaplan water turbine functions like a marine screw propeller on a vertically suspended axle. Both runner blades and distributor are adjustable and can be optimally adapted to the flow conditions. The water flows along the axis through the runner. A variation of the Kaplan water turbine is the tubular turbine in which the axis of rotation is horizontal. Kaplan and tubular turbines are used for low heads and high flow rates.

The conventional Francis water turbine is one of the oldest types of turbines and is still mainly being used in small-scale hydropower plants. Typical for the Francis turbine is the spiral-shaped housing. It is used for small heads and medium flow rates. Only the distributor is adjustable with this type of turbine. The water flows radially into the runner and exits along the axis of rotation. Special forms of the Francis turbine can also be used for large heads and high flow rates.

The Pelton turbine is suitable for large heads and low flow rates. After passing through a penstock, the water is injected at a high rate through the nozzles onto the paddles of the turbine.

→ Storage power plant

Source: Company photo Tauernkraft/Verbund



Example and principle of a dam storage power plant

Direct flow turbines are used for low head and low flow rates and generally have a low power capacity. The water passes through the running wheel at a tangent.

Storage power plants

Storage power stations utilise the large heights of fall and the storage capacity of dams and mountain lakes for electricity generation. In the case of a dam-type storage power station, Kaplan or Francis turbines are commonly used and these are usually located at the base of the retaining wall. In the case of a mountain-lake storage power station, a lake at a higher altitude is connected by pressure pipes to a power station located in the valley. Pelton-type turbines are normally used in this case due to the very high water pressure. Storage-type power stations can be used both for meeting the electrical base load as well as for peak-load operation.

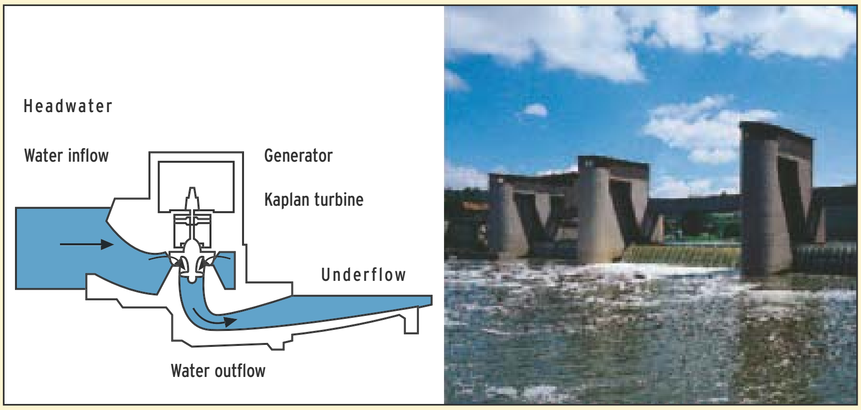
Pump storage power stations are not fed by naturally accumulating water, but rather are filled by pumping water up from the valley. In this way the electrical power generated in low-load times can be stored intermediately through the potential energy of the water, to be reclaimed from a turbine during peak-load times.

Run-of-river power plants

Run-of-river power stations use the flow of a river or a canal to generate electricity. Characteristic here is the

→ Run-of-river power plant

Source: ExpoStadt



Example and principle of a run-of-river power plant low head for a relatively large volume of water, which often fluctuates seasonally. For economic reasons, these kinds of power stations are often built in combination with sluices. Run-of-river power stations mainly use a Kaplan turbine, tubular turbine, or direct flow turbine.

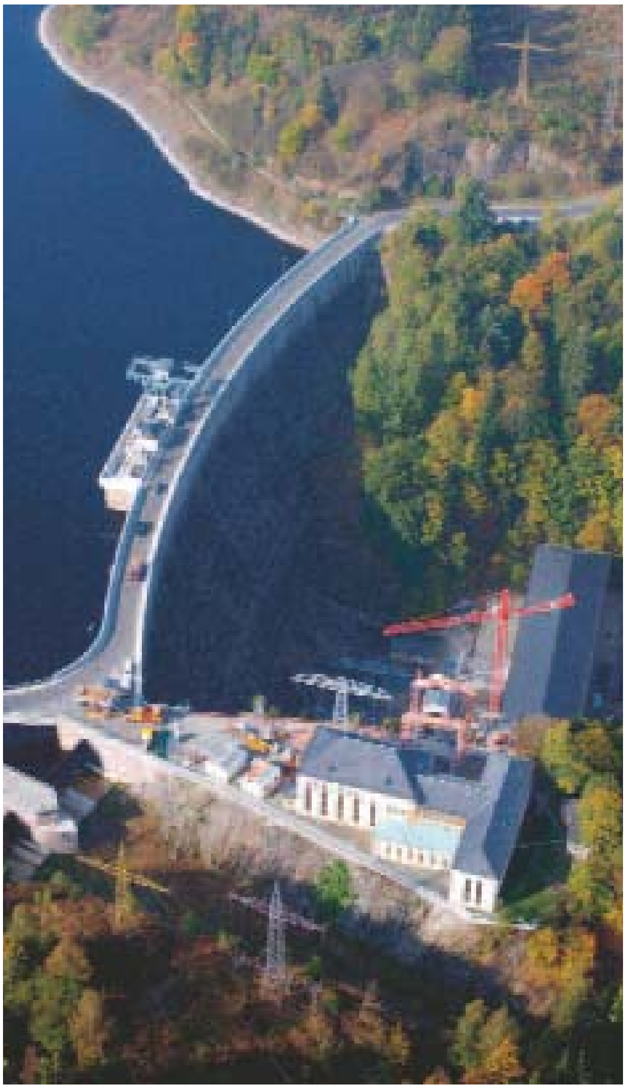
Small-scale hydropower plants

Besides modernising large run-of-river power stations, there is also a certain development potential in small-scale power stations. This case is particularly true for modernising and reactivating existing plants which have regained economic viability as a result of the Renewable Energy Sources Act (EEG) and partially through subsidies for investments. However, environmental protection and the ecological requirements of the water system must also be considered. Small-scale hydroelectric plants can be either run as a stand-alone application or connected to the grid.

From the technical point of view, such plants are also storage or run-of-river plants with a small capacity because of the lower heads or flow rates, and which therefore use only Pelton-, Francis-, or direct-flow turbines.

Costs

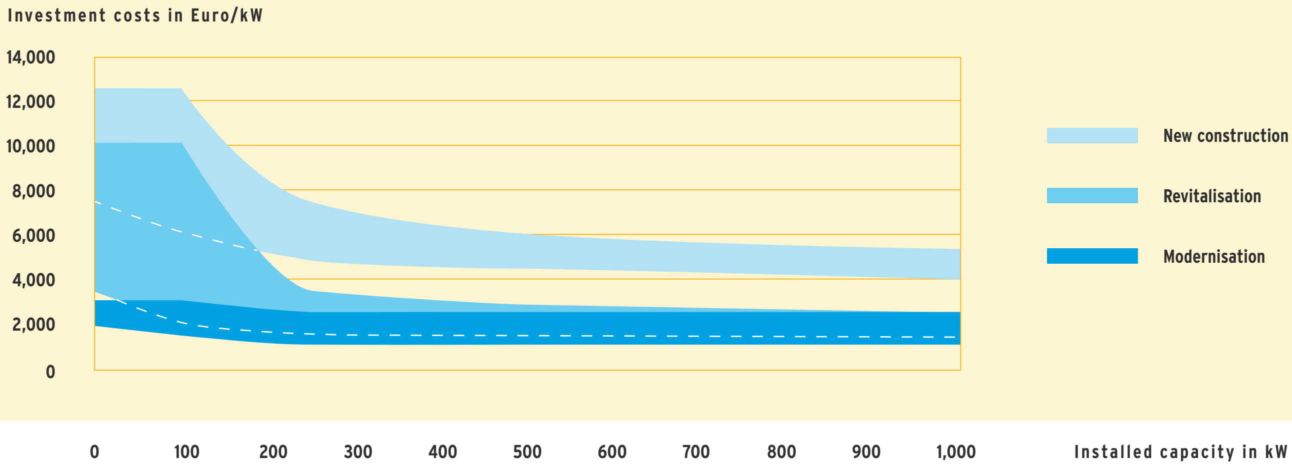
The costs of a hydroelectric power station are mainly determined by the installed capacity and local conditions like, for example, the height of fall. New small- scale hydropower plants with a capacity of 70 to 1,000 kW cost between 8,500 and 10,000 Euros/kW (see Figure: Investment costs for small-scale hydropower stations). When modernising existing plants, electricity costs of as low as 2.5 to 6.6 Cents/kWh can be realised.



Pumped-storage power station at the Bleiloch Dam near Schleiz. The pumping station is located in the power house at the base of the retaining wall.

→ Investment costs for small-scale hydropower stations

Sources: IÖW/ISET



Investment costs for new and reactivated small-scale hydropower stations as a function of the installed capacity.

Photo caption: The renewable twin-power plant in Grenzach-Wyhlen uses hydropower and solar energy to generate electricity; bottom: Water steps at the hydroelectric power station Einsal an der Lenne

Information about hydropower

- → Bundesverband Wasserkraft: www.wasserkraft.org
- → Guidelines from the Federal Environment Ministry for the construction and operation of hydropower plants: www.erneuerbare-energien.de

Ecologically compatible expansion and modernisation

In 2005 a total of 21.5 TWh of electricity was generated from hydropower plants in Germany with an installed capacity of 4,660 MW (excluding pumped-storage power plants). Even though the existing potential for hydropower in Germany is not yet completely exploited, new constructions are only possible to a limited extent. Operating a hydropower station is always associated with a significant intrusion into ecological systems. Aspects of nature conservation must therefore be considered before further expanding the use of hydropower.

Modernising or expanding existing hydropower stations should therefore always involve improving the ecological condition of the water body, a goal which does not conflict with accessing new hydropower potential. Through the expansion and modernisation of existing hydroelectric power stations alone, an additional potential of more than 2 TWh/year can be exploited in an ecologically compatible way.

By realising appropriate ecological compensation measures like setting up separate migration routes for fish, improving the structural diversity in the reservoir of the power plant (e.g. with crushed rock beds), reshaping the river bank, or a suitable minimum water control, the ecological condition of the water body can be selectively improved.

The Renewable Energy Sources Act regulates the reimbursement of electricity from new or modernised plants so that the ecological condition of the water body must be improved by the construction or modernisation. For example, new small run-of-river power plants will only receive reimbursement if they are constructed where a barrage or weir already exist and without cross-construction, and therefore achieve a good ecological condition.

PHOTOVOLTAICS

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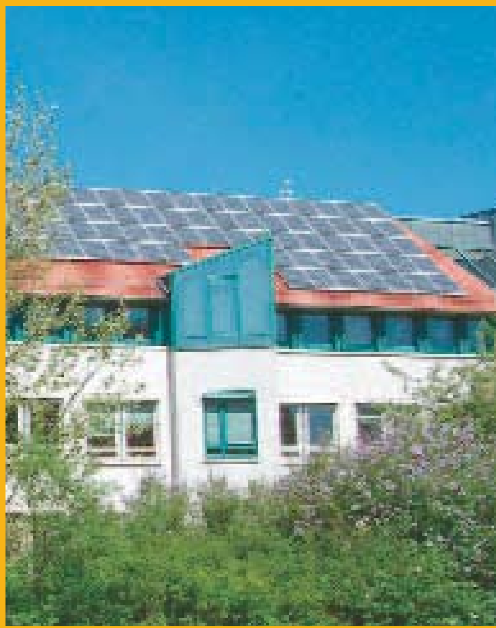

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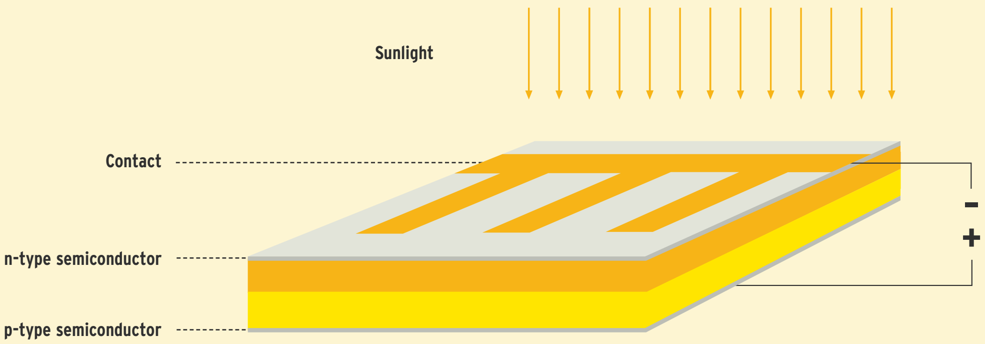

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Resources:	Direct sunlight and diffuse solar radiation
Sites:	Worldwide; especially on roofs and façades
Field of application:	Electricity generation
Capacity:	A few watts to several MW
Electricity costs today:	40 to 55 Cents/kWh (Central Europe), 25 to 35 Cents/kWh (North Africa)
Figures:	1. Photovoltaic power plant, 2. Photovoltaic façade, 3. Grid-connected system, 4. Cross-section of a solar cell

PHOTOVOLTAICS – SOLAR POWER EVERYWHERE

Solar cells directly convert sunlight into electrical power without any mechanical, thermal, or chemical intermediate steps. At the core of all solar cells is a semiconducting material, usually silicon. Solar cells utilise the photovoltaic effect: for certain arrangements of superimposed semiconductor layers, free positive and negative charges are generated under the influence of light (photons). These charges can then be separated by an electrical field and flow as electrons through an electrical conductor. The direct current thus generated can be used for powering electrical devices or stored in batteries. It can also be transformed into alternating current and fed into the public electricity grid.

From milliwatts to megawatts: a dynamic market

There are solar cells in all conceivable sizes. Miniature cells can be found in pocket calculators and wristwatches. In the kilowatt range, whole households can be supplied with power from solar cells. Put together in solar fields, solar cells also penetrate the megawatt range.

Although sunshine is less profuse in Germany than in the southern countries, photovoltaic (PV) systems are also useful at our latitudes since solar cells can also convert diffuse solar radiation into electrical power. The annual average solar radiation is higher in the south than in the north of Germany (see Figure: "Total radiation in Germany"), amounting to between 900 and 1,200 kWh of radiant energy per square meter each year. A modern solar cell can convert, on the average, one tenth of this solar energy into electricity.

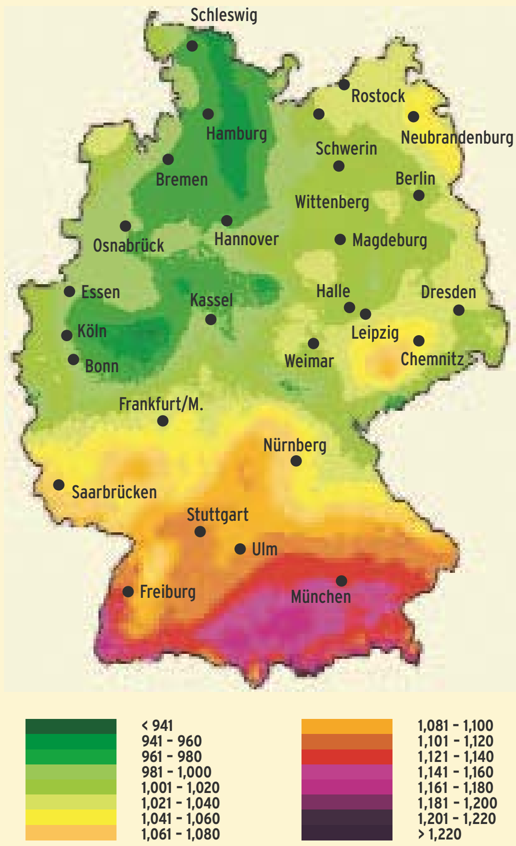
There is no lack of space either: In Germany there is a total of 2,300 km^2 available for solar-technical utilisation on roofs and façades of buildings and at other locations in developed areas. Assuming that this area is divided equally between photovoltaic systems and solar collectors, then 135 TWh of electricity could be produced each year from solar cells – nearly one third of the current electricity consumption in Germany.

PV systems are however not just installed on buildings, but also on open spaces. Thus in 2005 ca 7 % of the total installed solar cell capacity was installed on open areas. By the end of 2005, a total of 300 ha area was occupied with 70 MW of PV systems. The reimbursement for the electricity generated by these systems, as regulated by the Renewable Energy Sources Act (EEG), is a fifth less than that foreseen for building-integrated systems. The reimbursement is also subject to a higher degression than for building-integrated systems. In this way open-field systems present a clearly more cost-effective alternative to building-integrated systems. Germany is also the world-wide leader in open-field systems. Accordingly, the German suppliers are well positioned in this sector of the international markets. In order to avoid wasting valuable area, only systems on areas which have been previously used are reimbursed according to the EEG, e.g. former landfill sites, industrial and military waste lands, but also farmland which has been converted to grassland (see Section "Renewable energy and nature conservation").

Solar cells with a potential capacity of 1,200 MW were produced world-wide in 2004 – 60 % more than in the previous year. The volume of the German PV market rose from 0.6 MW_p/a to 600 MW_p/a in the period from 1990 to 2005. Germany is thus the leading market world wide for PV.

Lower growth rates are expected temporarily world wide since the production of high-purity silicon, the raw material for most solar cells, currently can not keep pace

→ Total radiation in Germany



Source: Deutscher Wetterdienst

Annual average solar radiation in kWh/m^2

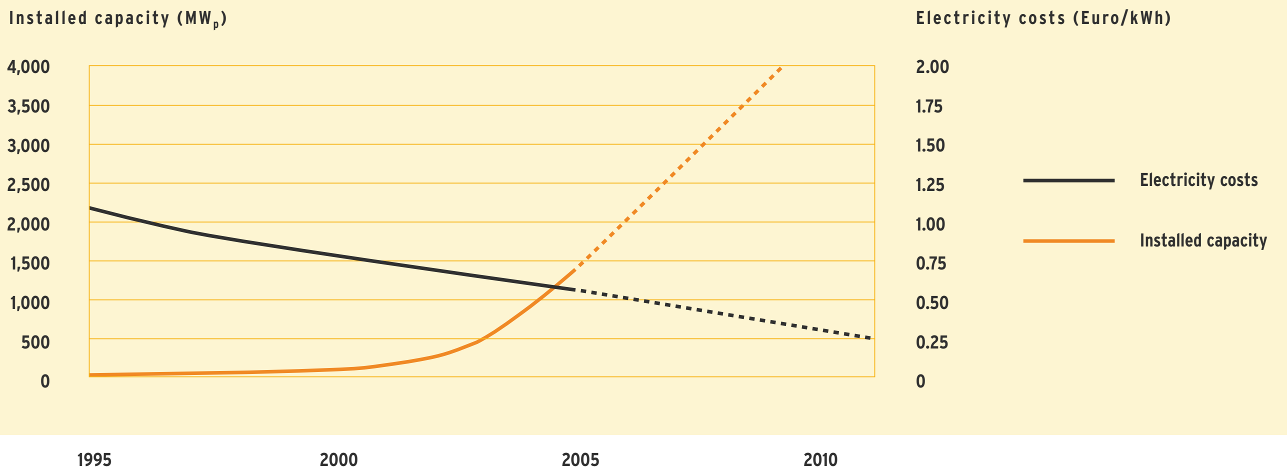
Production of solar modules in the Solara Sonnenstromfabrik in Wismar

with the demand. It is estimated that the current supply bottleneck will not be solved until 2008.

During recent years we could not only observe a **drastic increase in demand** for photovoltaic systems, but also **notable cost reductions**. The costs for a PV system now are about half of what they were in the early nineties. The investment in a roof-installed system on a house today costs about 6,000 Euros per kilowatt of installed capacity, larger systems are about 25 % cheaper. Whereas electricity from PV systems cost about 1.5 Euros/kWh in 1985, the electricity generation costs in Central Europe today are between 0.40 Euros/kWh for large grid-connected generators and 0.55 Euro/kWh for small-scale systems on single-family houses, depending on the particular application and technology.

→ Market development

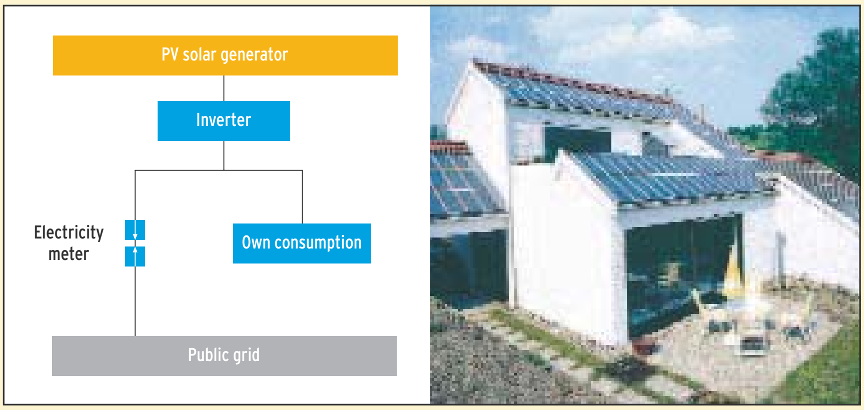
Source: DLR



Market development in Germany, trend of the electricity generation costs for PV systems and possible future development

→ Grid-connected photovoltaic system

Sources: Pilkington Solar International GmbH; ExpoStadt



Principle of a grid-connected photovoltaic system for the power supply of a house

Considerable cost reduction is expected in the future as well. It is assumed that present-day costs will be halved by the year 2012, especially as a result of significantly increased mass-production volumes. Improved materials yield – today a large proportion of the semiconductor material is lost by sawing the wafers and during other processing steps – and higher efficiencies will help to lower the costs associated with this innovative source of electricity.

In the meantime, many different kinds of semiconductor materials are available for making solar cells. Silicon is still the most important element. It is produced in three variants:

— Very pure **mono-crystalline silicon** is expensive due to its complicated manufacturing process, but it enables the highest conversion efficiencies;

— **Poly-crystalline silicon** is more simple and cheaper to produce. However, the grain boundaries between the crystallites in the silicon cell lead to a somewhat lower efficiency, which in turn requires larger expenditures for the generator area and mounting for the same electricity production;

— The thin-film cells from **amorphous silicon** are even cheaper to produce. However, both the efficiency and the long-term stability are much lower than for crystalline cells, a fact which largely cancels the cost advantages.

Besides silicon there is a variety of other materials and material combinations being developed and undergoing testing. Considerable cost reductions are expected especially in the field of **thin-film technology**, where considerably less material is needed than for crystalline cells. Besides amorphous silicon, the most important materials for solar cells are e.g. gallium arsenide (GaAs), germanium (Ge), cadmium telluride (CdTe) and copper indium diselenide (CIS).

A promising concept for the future is the so-called **tandem cell**, in which several semiconductor materials are combined in such a way that a larger range of the solar spectrum can be converted. The highest confirmed solar cell efficiency measured so far was with a laboratory tandem cell under concentrated light.

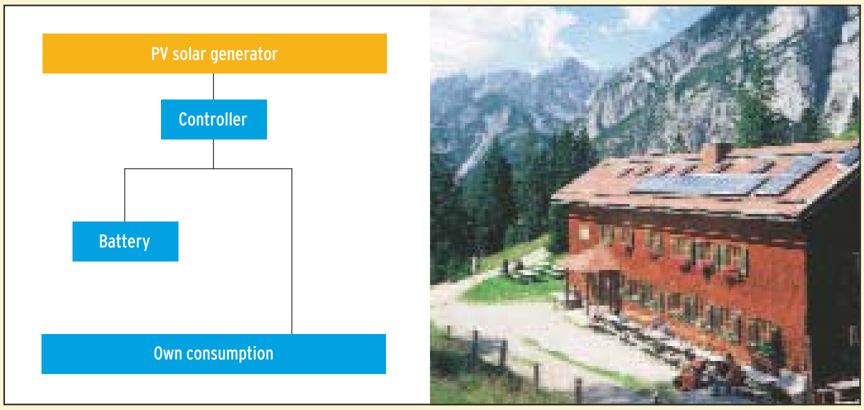
Grid-connected systems

A typical system consists of a solar generator integrated into the roof or the façade of a building. When irradiated, the generator provides direct current power which is transformed into alternating current by means of an inverter, and can then be used directly by domestic appliances or fed into the grid. The capacity of a typical solar installation on normal buildings is between 2 and 5 kW_p. The largest building-integrated system so far was installed on the roof of a logistics company in Bürstadt, Hessen, in 2005. It is as large as five football pitches and provides up to 5 MW_p solar electricity. The annual power production is enough to supply about 1,500 households.

The reimbursement of solar electricity is regulated by the Renewable Energy Sources Act (EEG). Systems installed on normal buildings in 2006 receive 51.80 Cents/kWh, guaranteed for 20 years. The reimbursement for systems installed later will decline by 5 % per year. In this way the cost degression for photovoltaic systems continues to be stimulated.

→ Small-scale grid-independent system

Source: Fraunhofer ISE, Freiburg



Principle of a stand-alone system

Small-scale stand-alone systems

A further major application of photovoltaic systems is for grid-independent small-scale systems, e.g. for supplying power to remote radio and measurement stations, emergency call boxes, summer houses, and cabins. An inverter may be needed, depending on whether the devices require direct current or alternating current. A battery and a charge controller are usually also necessary in order to bridge fluctuations in the irradiation as well as to make solar electricity available at night.

In developing countries, where the utility grids provide little coverage, photovoltaic systems are already successfully powering individual houses (solar home systems), supplying villages with power, or used for pumping systems. In many cases, the fuel-independent and low-maintenance PV systems represent the most appropriate and often also the most economical solution for decentralised small-scale applications that are far from the grid.

Ecological advantages

Solar cells have no chimney: there are no emissions, no fuel consumption, and no noise associated with electricity generation. The production of conventional solar cells is, however, still an energy-intensive process. In Germany, the cells must operate for between three and five years to produce the amount of electricity which was consumed to manufacture the cell. Each kilowatt hour afterwards, however, is ecologically “free of charge” (see “Ecological qualities of renewable energies” chapter).

If the energy required to produce the solar cells is provided by the conventional power plant mix, then logic indicates that they indirectly impact the environment. There are, however, two aspects to be considered: On the one hand, these emissions are a problem of the present not of a future energy system. If the energy for producing the solar cells were also generated by solar cells, then there would not be any of these emissions. On the other hand, the reduction potential is immense. Through advanced technologies and series manufacturing, but also by switching to less material-intensive processes, the “ecological rucksacks” of solar cells can be reduced even further.

Information about photovoltaics

- → General information about solar energy: www.solarserver.de
- → Bundesverband Solarwirtschaft: www.solarwirtschaft.de
- → International Energy Agency (IEA): www.iea-pvps.org
- → ForschungsVerbund Sonnenenergie: www.fvs-sonnenenergie.de
- → Deutsche Gesellschaft für Sonnenenergie: www.dgs.de

SOLAR THERMAL POWER PLANTS

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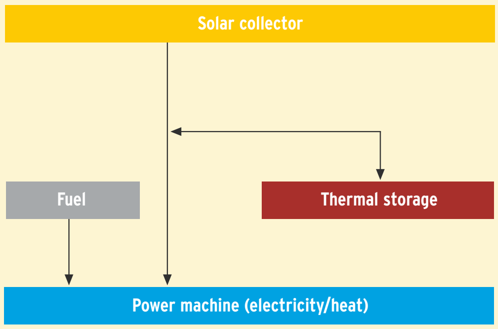

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Resources: Direct solar irradiation, possibly with storage system; hybrid operation with fossil and bio-fuels also possible

Sites: Arid regions in Southern Europe, North Africa, the Arabian Peninsula, North America

Field of application: Electricity generation, combined heat and power generation for additional cold production, water desalination, and process heat

Capacity: Paraboloid/dish system: ca 10 kW per module; Tower or trough power plant: 5 to 200 MW

Electricity costs today: Solar only: 9 to 22 Cents/kWh, hybrid: 4 to 10 Cents/kWh

Figures: 1. Dish-Stirling system, 2. Solar tower, 3. Parabolic trough power plant, 4. Basic principle of energy generation with a solar collector

SOLAR THERMAL POWER PLANTS – CLEAN ENERGY FROM THE EARTH'S SUN BELT

Solar-thermal power plants use the high-temperature heat from concentrating solar collectors to drive conventional types of engines. Some plants generate just electricity, but others use the combined heat and power cycle to generate electricity and process heat at the same time. In this way, a solar-thermal power plant can simultaneously produce electricity, provide cooling by means of an absorption chiller, generate industrial processing steam, and produce drinking water with a seawater desalination plant, thereby converting as much as 85 % of the absorbed solar heat into useful energy.

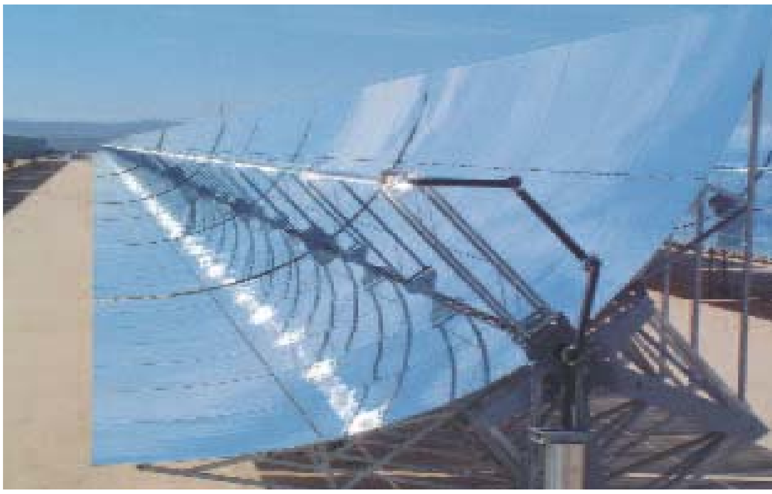
Through efficient storage of the generated solar heat and the additional firing of biomass or other fuel, the power plant can run continuously and guarantee a quality of electricity supply like that from conventional power plants. The dual use – as a solar power plant during the day and as part of the conventional power system during the night – not only avoids the construction of conventional back-up power plants, but also the costs of electricity generation can be halved compared to purely solar operation. Thermal storage reservoirs are already technically feasible today and will be first included in a parabolic trough power plant in Spain in 2006.

Suitable sites for these plants are mainly located in the sun-rich regions of the world south of the 40th latitude, because only the direct share of the radiated sunshine can be concentrated by mirrors. The high proportion of diffuse irradiation and the overall lower irradiation levels limits their economic feasibility at northern latitudes.

Parabolic trough power plants

Parabolic mirrors, mounted on collectors which are up to 6 meters wide and 100 meters long, concentrate sunlight onto an absorber pipe, causing it to heat up to about 400 °C. The absorber pipe is insulated to prevent heat losses with selective coatings and an evacuated glass tube. The thermal oil flowing through the tube transfers the absorbed heat to a heat exchanger where it is then used to produce steam. This steam then drives a conventional steam turbine generator system. Integration in the steam section of a modern gas and steam power station is also possible.

Parabolic trough collectors have been operating in California since the mid-eighties. A total capacity of 354 MW is installed, with individual systems rated up to 80 MW. A peak efficiency of more than 21 % for the conversion of solar radiation into alternating current



European parabolic trough collector SKALET undergoing testing at a solar power plant in Kramer Junction (USA)

has been demonstrated during operation. Since their commissioning, these plants have been supplying some 150,000 households with electrical power every year and have already generated revenues exceeding one billion US$.

Current research work being conducted in this field is on lowering the costs by improving the structure of these collectors, optimising the operational strategy, and substituting the intermediate thermal oil circuit by direct steam generation in the absorber pipes. A new

Collector system of a Fresnel system. Below: the mirror sections of the Fresnel reflector, Above: the absorber pipe at the centre of the secondary-stage concentrator. One collector branch is 24 m wide and can be as long as 1 km in the power plant version.

Solar tower power plant in Barstow, California

Receiver and engineering systems in operation at the top of the tower

parabolic trough collector developed in Germany (SKALET) started operation for research purposes at one of the Californian power plants in April 2003, proving that German companies are technological leaders for the basic components of solar thermal power plants (collectors, absorber pipes, and mirror elements).

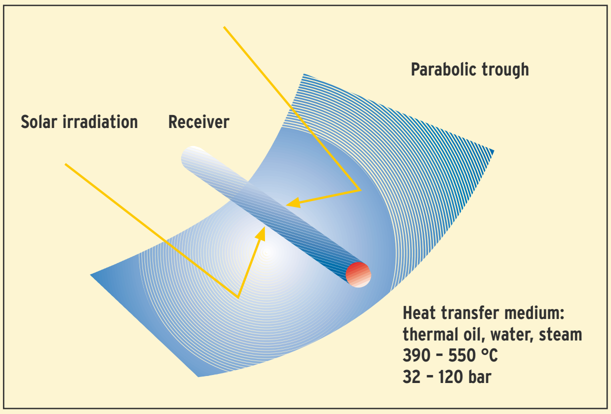
Fresnel trough power plants

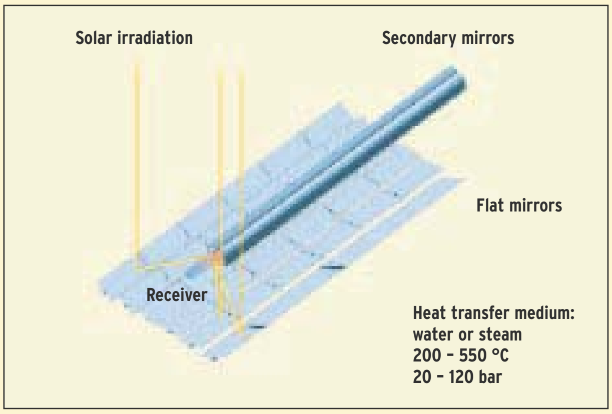
In the beginning of 2001, a trough collector design was presented in which the concentrator consists of individual panes of flat mirrors. Since the light concentration of this system is weaker than for a parabolic trough system, a secondary concentrator is installed above the absorber pipe to concentrate the light a second time. Water is directly evaporated in the absorber pipe. The system is characterised by a simple and cost-effective construction and can be expanded to capacities of several 100 MW. A prototype for steam generation has been operating for several years and successfully tested. The next step is to realise a fully functional, semi-commercial pilot plant for electricity generation.

Solar tower power plants

In a solar tower power plant, the solar radiation is concentrated by a field of individually tracking mirrors (heliostats) onto the top of the tower. Temperatures of 1000 °C and more can be achieved with this concept. An absorber at the top of the tower converts the irradiation into heat, which is then delivered to a conventional power plant process by a heat-transfer medium. The first commercial European solar power plant "Planta Solar 10" is currently under construction near Sevilla, Southern Spain. Water is evaporated

→ Basic principles of concentrating solar systems



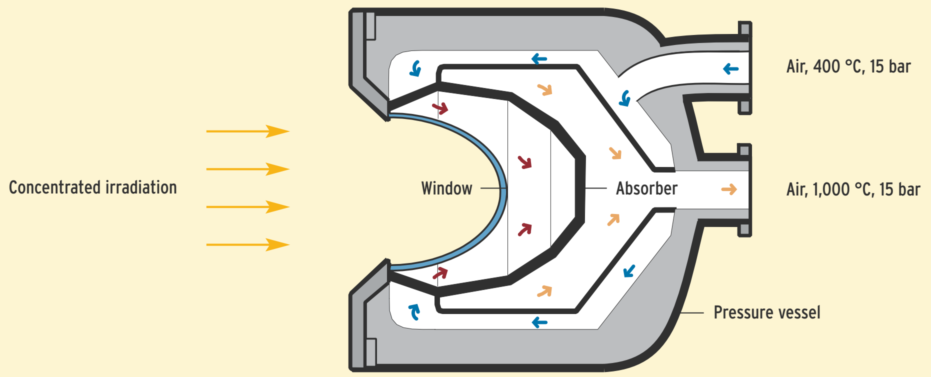


Parabolic trough collector

Fresnel collector

→ Principle of a compressed-air absorber

Source: DLR



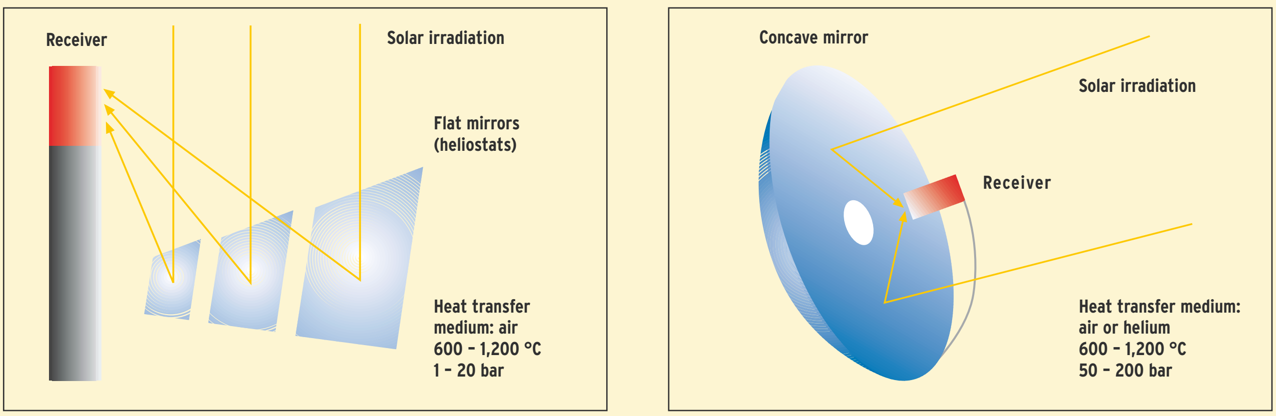
Pressurised volumetric receiver REFOS): highly compressed air is heated up to 1,000 °C in order to directly drive a gas turbine or a modern gas-and-steam turbine power plant.

directly at the top of the tower of the so-called PS-10 plant in a tube bundle heat exchanger. The saturated steam then runs a steam turbine with 11 MW electrical capacity, generating 24 GWh of solar electricity per year.

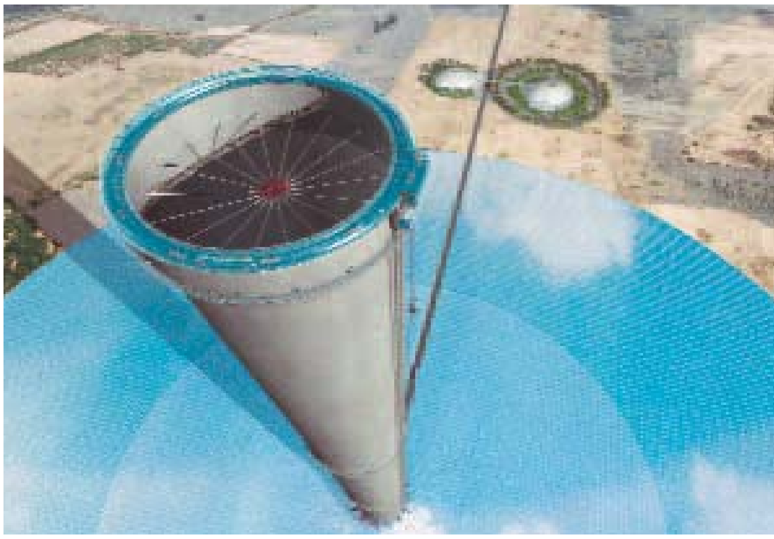
An open air receiver – a German development – uses a metallic or ceramic sponge instead of the pipe-bank absorber. The sponge is also referred to as a volumetric absorber, since the incident radiation can be absorbed both at the surface and in the interior of the porous body and converted into heat. Outside air is sucked through the sponge into the interior and heated to temperatures as high as 800 °C. It is subsequently used to generate steam in a conventional power plant. The advantage over pipe-bank absorbers is that the heat does not have to pass through a wall, allowing higher energy-flow densities, operating temperatures, and efficiencies.

Another new development from Germany is the sealed or pressureised volumetric receiver (REFOS concept). Compressed air from the compressor stage of a gas turbine is heated in this absorber by solar energy and then drives the turbine. The principle was successfully applied to generate electricity for the first time at the end of 2002 at the Plataforma Solar in Spain, thereby making the operation of solar-fired gas turbines possible. A pilot plant for the combined generation of electricity and cooling by absorption is currently being manufactured for a semi-commercial application in Italy. With this technology, it is also possible to feed solar energy directly into a modern, high-efficiency gas-and-steam turbine power plant where it is con-

→ Basic principles of concentrating solar systems



Solar tower plant **Dish system**



Parabolic-dish power plants ("Dish system") with a Stirling motor generator undergoing testing and demonstration operation at the Plataforma de Almeria, Spain: up to 30 % solar-electric efficiency is achieved with these systems.

Tower of the planned 200-WM solar chimney power plant (height 1,000 m, with special spoked wheels for support), Below: the collector roof (diameter 6 km)

verted into electricity with a high degree of efficiency exceeding 50 %.

Parabolic dish power plants

With typical capacities of several 10 kW, parabolic dish power plants, also known as dish systems, are particularly suitable for decentralised use. This concept involves a parabolic mirror (dish) which tracks the sun using two axes and concentrates the solar energy directly onto an absorber suspended at the focal point of the mirror. In this way, a working gas (helium or air) is heated to temperatures of up to 900 °C, and can then drive a Stirling engine or a gas turbine located directly next to the absorber.

Dish systems have successfully proven their technical maturity during many years of test operation and, with values of up to 30 %, have achieved the best solar-electrical efficiencies ever demonstrated. The next step is to realise series production of these plants and thereby to lower their costs.

This type of power plant is especially suitable for the power supply of villages in developing countries. Several parabolic dish stations can be linked together to give a small power plant farm. In combination with biomass combustion or a storage system especially developed for this technology, operation around the clock is also possible.

Solar chimney power plants

Another power plant type is the solar chimney power plant. In contrast to the previously described concentrating systems, the solar rays are not reflected or bundled by a mirror system. In the solar chimney power plant, the sun heats the air under a large collector roof made of glass or plastic foil. The warm air flows to a chimney located at the centre of the collector roof where it then ascends. The ascent of hot air drives the wind turbines installed at the base of the chimney, generating electricity. Three well-known physical effects are thus combined:

1. The greenhouse effect, causing the air under the glass roof to heat up.

2. The chimney effect, causing the air heated under the glass roof to ascend through the chimney.

3. The turbine, which removes energy from the air flowing in the chimney and converts it into electrical energy through a generator.

Upwind power plants function solely with air and do not need any cooling water. This fact is a major advantage in many sun-rich countries which already have serious problems with water supply. Since, unlike the plants described above, the solar irradiation is not concentrated, diffuse radiant energy can also heat the air underneath the glass roof. The power plant can therefore operate even when the skies are partly or completely overcast.

Additionally, the ground underneath the collector can serve as a natural heat storage medium and hence ensure uniform electricity generation. The heat stored during the day is released at night so that electricity can still be generated after sunset. The technical feasibility of this concept has already been demonstrated in a Spanish experimental power plant over many years of operation. There are currently several projects being developed for large-scale chimney power plants. The greatest progress has been made by a project in Australia where a 200-MW plant with a 1,000-meter-high chimney and a collector diameter of between 6 and 7 km is planned.

Storage technologies

A particular advantage of solar thermal power plants is the possibility to store the absorbed solar energy as heat. Storing heat is considerably simpler and cheaper than storing electricity. In the simplest case, a medium such as concrete or molten mineral salts is heated up during the day by the heat transfer medium from the solar collector. At night or during cloud passage the heat is removed to produce steam for the generating unit and the storage medium cools off. The heat can be stored even more efficiently if the storage medium can change its state (e.g. from a solid to a liquid – called a "phase transition" in physics) and storage concepts based on phase transitions are therefore being developed. In the future, advanced storage technologies will enable the free regulation of solar thermal power plants to cover both the base and peak loads without requiring additional fuel.

Solar combined heat and power generation

Like all conventional heat and power machines, the turbines of solar thermal power plants can also be used for combined heat and power generation (see "Future supply structures" chapter). After electricity generation, some of the steam from a steam turbine, or the waste heat from a gas turbine, is diverted and used further, for example as a heat source for industrial processes, to generate cold with absorption chillers, or to desalinate seawater. These plants can convert solar heat to useful energy with an efficiency of over 80 %.

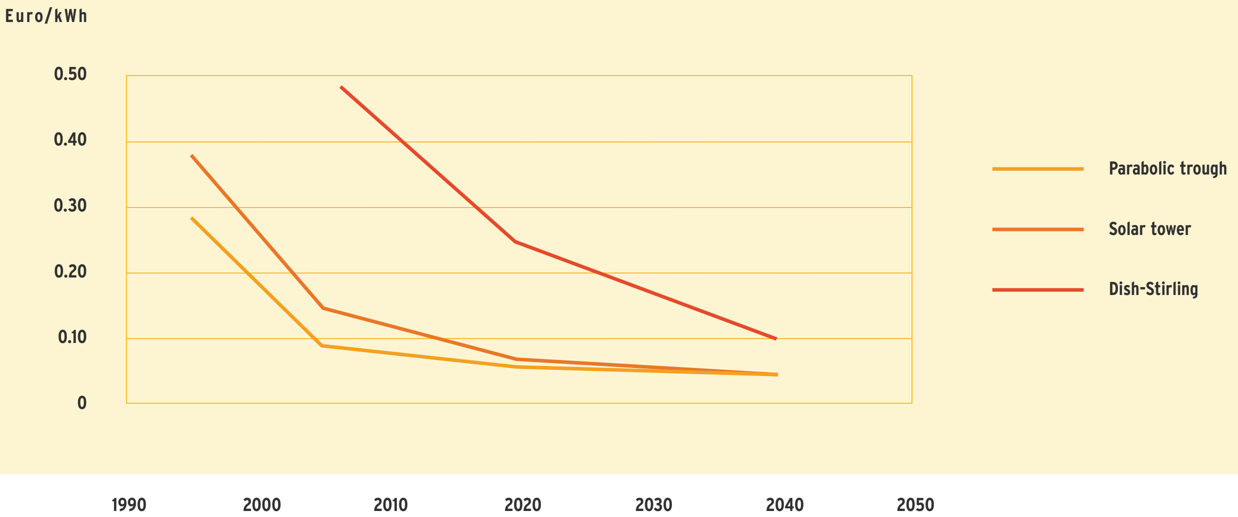
The costs of solar-thermal power plants

Well-sited solar thermal power plants can operate for about 2,000 to 3,000 hours per year in the purely solar mode without an energy storage medium, resulting in present-day electricity generation costs between 9 and 22 cents/kWh depending on the location and the interest rate. These costs can be approximately halved within the coming decade if the existing cost-reduction potential is realised through the pending global market introduction.

Hybrid operation, i.e. with additional fuel combustion, leads to a better utilisation of the thermal engine, since it can operate for more hours in this way, and considerably improves its ability to compete with conventional power plants. Depending on the proportion of additio-

→ Electricity costs

Source: DLR



Electricity cost development for solar thermal power plants in purely solar mode (8 % interest rate, an economical lifetime of 25 years, and 2,300 kWh/m²a assumed solar irradiation)

Information about solar thermal power plants

- → Solar thermal electricity generation – clean energy for a sustainable development: www.solar-thermie.org
- → Solar research and studies on solar thermal power plants: www.dlr.de/tt
- → Solar thermal power plant projects: http://www.solarpaces.org/
- → Trans-Mediterranean Renewable Energy Cooperation: http://www.trec-eumena.org/
- → Solar irradiation data: www.solemi.de

nal firing required and on the fuel prices, the costs for generating electricity can be as much as 50 % lower than for purely solar operation (see Figure: Electricity costs). In this way, costs for electricity generation can already be reached today which are only a few cents higher than those from conventional power plants, as long as their fuel is not subventioned.

Energy storage increases the solar share of the power plant. It also enhances the operational behaviour, enables a higher utilisation of the power plant block, and improves the revenue situation. Resulting from the interaction of the above-mentioned factors, the solar electricity produced from solar-thermal power plants with integrated storage techniques is cheaper than from a plant operating without any storage capacity. Commercial solar-thermal storage concepts are currently being developed to this end and the first plants are under construction.

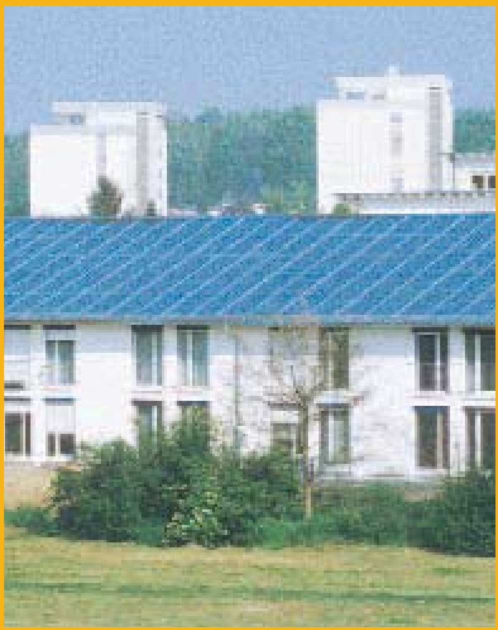
The global market introduction of solar thermal power plants

In February 2006 construction began for a new 64-MW parabolic trough power plant in Nevada, USA. The introduction of an electricity-feed-in law for solar electricity in Spain initiated a whole series of interesting new project developments there, some already with integrated thermal energy storage.

Solar-thermal power plants constitute an important link between the fossil-based supply of energy today and the “solar” energy sources of the future, because they unite major elements of both. They use conventional power plant processes combined with solar technology to transform the radiant energy. As hybrids, they can realise the step-by-step transition from the fossil era into the solar age, both technically and economically. Furthermore, through combined heat and power generation (in particular for the purpose of processing seawater to drinking water) they allow extremely efficient utilisation of the collected solar primary energy.

SOLAR COLLECTORS

1



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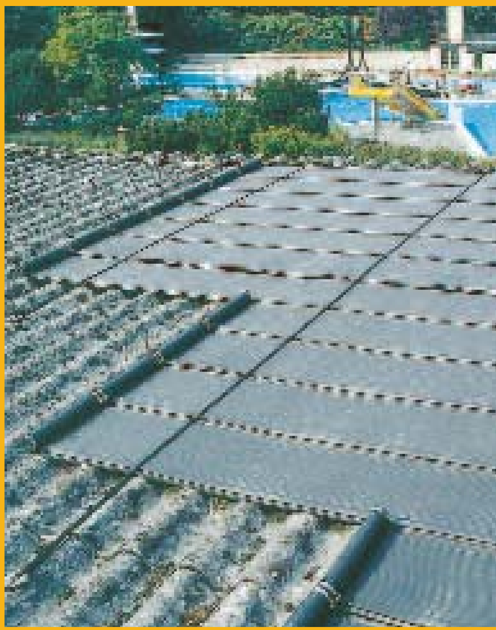

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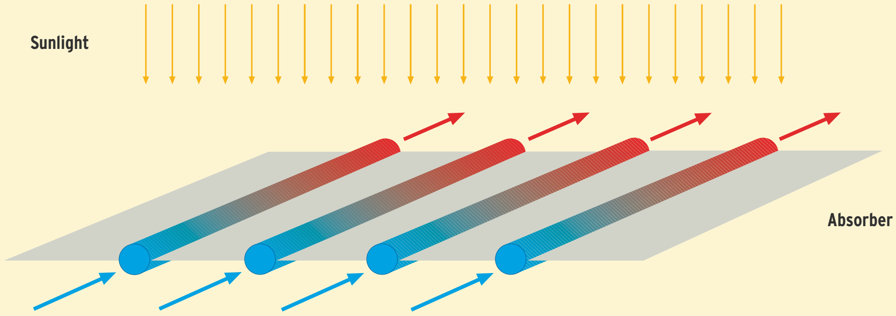


4

Resources:	Direct and diffuse solar irradiation
Sites:	Worldwide
Field of application:	Heating, hot water, cooling
Capacity:	1.5 to 200 MWh/a, no real upper limit
Heating costs today:	8 to 20 Cents/kWh
Figures:	1. Vacuum tubes, 2. Flat plate collector, 3. Plastic mat absorber, 4. Basic principle of absorbers

SOLAR COLLECTORS – BRINGING THE SUN INTO THE HOUSE

Solar collectors transform the solar irradiation into heat, e.g. for hot water for daily use, or for heating the building. The heat from a collector can also be used to cool and dehumidify indoor air. The principle can be simply understood by imagining a garden hose filled with water which is left out in the sun: the water is hot after a short period of time.

In the simplest technical version, a heat-transfer medium flows through black plastic mats, so-called absorbers, which are exposed to the sun. High temperatures cannot be reached with this type of system. However, the initial costs are low and they are already used for heating the water in outdoor swimming pools. Since this method is usually cheaper than running a fossil-fired boiler, it already contributes to lowering the costs for the swimming pool operator.

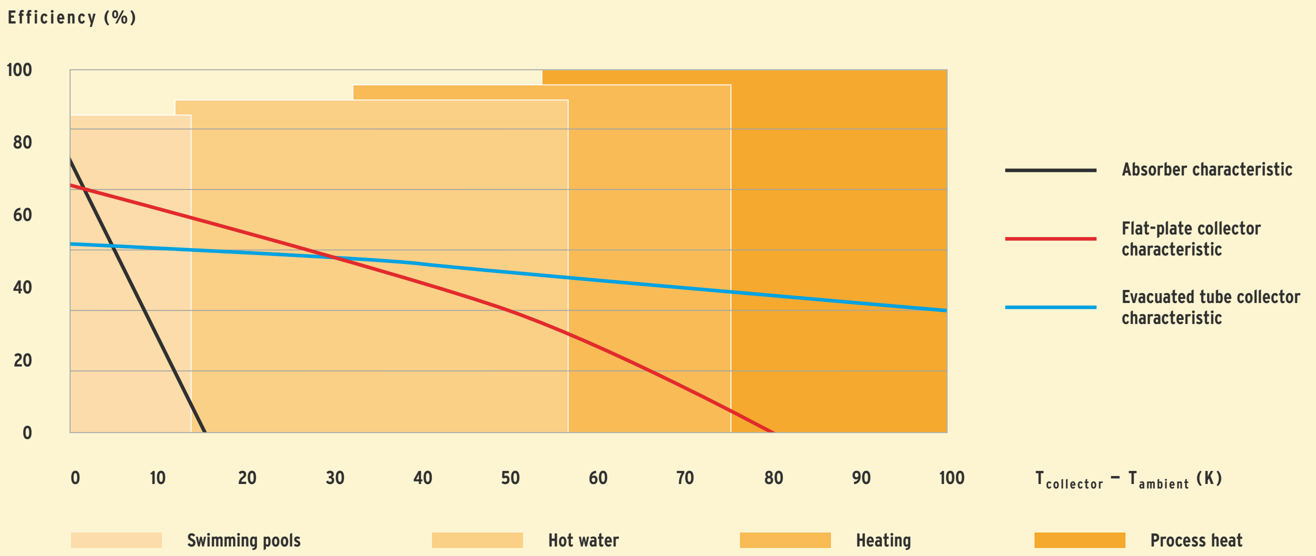
Flat-plate collectors are technically more refined. To prevent heat losses from the collector by convection and conduction, the absorber in this type of collector is made of metal and is well insulated. The side where the sun shines onto the absorber is covered with a pane of glass and the back side is covered with a thick layer of insulating material. Losses due to reradiation of the heat already absorbed can be prevented by applying black solar lacquer or efficient selective coatings.

Exposed to the same solar radiation, this type of flat collector can reach temperatures that are higher than those achieved using the black plastic mats mentioned above. Since they can still supply heat even when it is already colder outside, flat collectors are the preferred choice today for solar water heating in households (see Figure: Efficiency curves). The collectors currently available on the market normally have a useful surface area of between 2 and 6 m^2. Several modules are put together to obtain the required heat output. A typical hot water system for a single-family home will usually require **6 m^2 roof area**, meeting **60 % of the annual domestic hot water requirement**. The collector completely meets the demand in the summer and, during the rest of the year, the conventional boiler must further heat the water already warmed by the collector (see Figure: Collector system).

Heat losses by conduction and convection are almost completely prevented in **evacuated tube collectors**. Here the absorbers are enclosed in evacuated glass tubes, insulating like a thermos bottle. This design has the highest efficiency amongst the collector technologies. They can still supply heat even at low outside temperatures in winter, when flat plate collectors lose the heat gained from the sun. Evacuated tube collectors are thus particularly suited for heating buildings and supplying process heat.

→ Efficiency curves

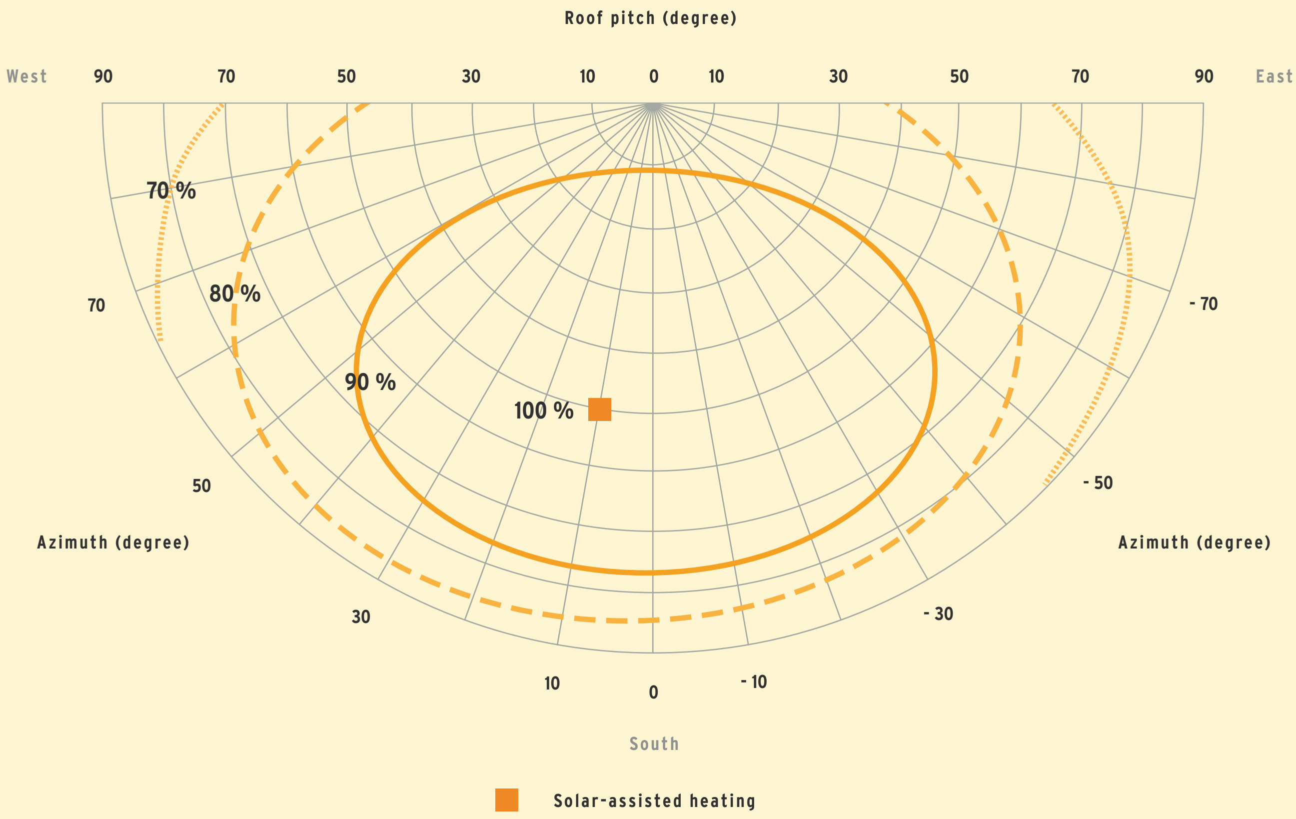
Source: DLR



The better the insulation of the collector, the higher the temperature of the heat produced. Characteristics of different collectors at 500 W/m^2 irradiation and the resulting application areas are shown.

→ Thermal yield and southern alignment

Source: DLR



The thermal yield (max. 100 %) only modestly decreases if the collector is not aligned due South.

In order for any collector to work efficiently, regardless of the type, the required output temperature level should be kept as low as possible. If rooms are also to be solar heated, then underfloor or wall-heating systems are recommended. Furthermore, the building must also be very well insulated in order to keep the heat requirement as low as possible. For a well-insulated house, a solar collector system with 11 m^2 (evacuated tubular collector) or 14 m^2 (flat plate collector) can supply some 20 to 30 % of the total heat demand. Solar collectors are particularly effective during the transitional spring and autumn seasons.

The southern alignment of the collector and its angle of inclination play a far less significant role than is generally assumed (see Figure: Thermal yield and southern alignment). Simulations indicate that deviations of +/– 60° from true south lead to losses of only about 10 % in the solar yield. If the inclination differs by 20° from the 50° inclination optimal at our latitudes, then the energy yield is only reduced by approximately 5 %.

A heat store is indispensable for a solar collector system. It stores the heat provided by the collector during periods of no demand, and releases it again when heat is required. Solar collector systems for heating domestic water typically need to store 350 litres in a single-family house. If the solar collector is to be used for heating purposes as well, then a larger storage capacity of approximately 70 litres per square meter of collector surface area will be needed. These heat stores can only compensate for the difference between the available energy and the required energy over a few days. They are not large enough to store the solar heat until winter.

Considerably larger heat stores and also larger collector surface areas are needed for storing summer heat into the winter. There are various demonstration projects in Europe with this goal. The currently largest German project in Neckarsulm will, when completed, supply 1,200 dwellings with solar heat – even in winter – from 15,000 m^2 collectors and a 150,000 m^2 reservoir. Some of the collectors are installed on school roofs, the sports hall, and several residential buildings, others are mounted over car parks or along noise-protection walls.

A similar project is currently being realised in Crailsheim (see “Future supply structures” chapter). Cost-effective solutions are necessary for the seasonal stores used with such projects because, in contrast to the normal stores in the boiler rooms, they are only charged and discharged once a year. Besides the approach chosen in Neckarsulm, which uses the natural ground clay as a cheap storage medium, there are also other very

Collector system for domestic hot water

promising developments. Examples include feeding the heat into underground layers carrying water (aquifer storage), using pits filled with coarse-grained gravel and water, or constructing concrete tanks which are filled with water and partially embedded in the ground. Each of these storage concepts has both advantages and

In Neckarsulm even the parking spaces are used for generating heat.

disadvantages. The successful development of cost-efficient long-term storage will lead to further application areas for solar energy, which will extend far beyond the predominant application of today of providing hot water for domestic purposes in summer.

Technical trends

Tests prove that solar collector plants have, in the meantime, reached a high degree of maturity such that **dependable service over 20 years** is now possible. Nevertheless, further technical improvements have been made recently. Heat reradiation can be reduced by using new selective coatings on the absorber surface, improving the efficiency. Furthermore, these selective coatings are more environmentally compatible than the electroplated layers used so far and are also less sensitive to mechanical disturbances and high temperatures. Losses due to reflection off the cover glass on flat plate collectors could be reduced by applying a special surface treatment. Lower flow rates through the collector allow the use of smaller-diameter pipes, which in turn allows the use of thinner pipe insulation, reduces the materials expenditure, and less electricity is required to run the pump. The trend is towards ever larger individual modules for further cost reduction. Additionally, the roof mounting systems are being simplified, even to the point that the collectors can even replace the conventional roof, i.e. the roofing tiles and gutter, so that the costs for these parts of the roof structure can be saved. Control units and pumps are delivered in pre-mounted and integrated subassemblies. No-braze pipe connections are available, considerably simplifying the on-site installation for the talented amateur (do-it-yourself).

Costs

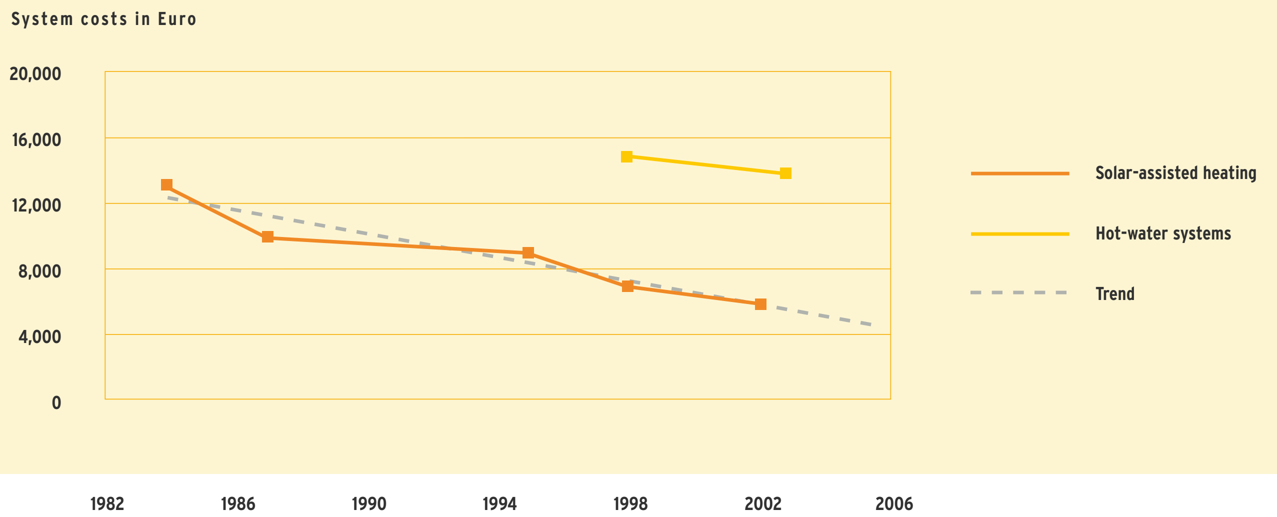
Total system prices have sunk considerable over the past 18 years as a result of technical progress and market expansion. At the present time, the specific investment costs for a complete system including storage, piping, and installation are about 750 Euros/m^2 collector area (see Figure: Costs of solar-thermal systems). Even though solar collectors cannot quite compete with the current prices of fossil energy carriers, they can provide dependable protection against the risk of future increases in the price of energy. Another point: **the energy payback time is only 1 or 2 years**, by then it has harvested the energy originally expended for its production.

Market developments

At the end of 2005 there were a total of **7.2 million m^2 of collectors** installed on German roofs. More than 3.0 billion kWh of fossil fuels were thereby substituted, equivalent to 300 million litres of heating oil (see Figure: Installed collector area). In 2005, about 950,000 m^2 of

→ Costs of solar-thermal systems

Source: Drück/ITW



The costs for solar thermal systems are falling continuously. The figure shows the development of the average costs for complete solar systems for domestic water heating and for solar-assisted heating.

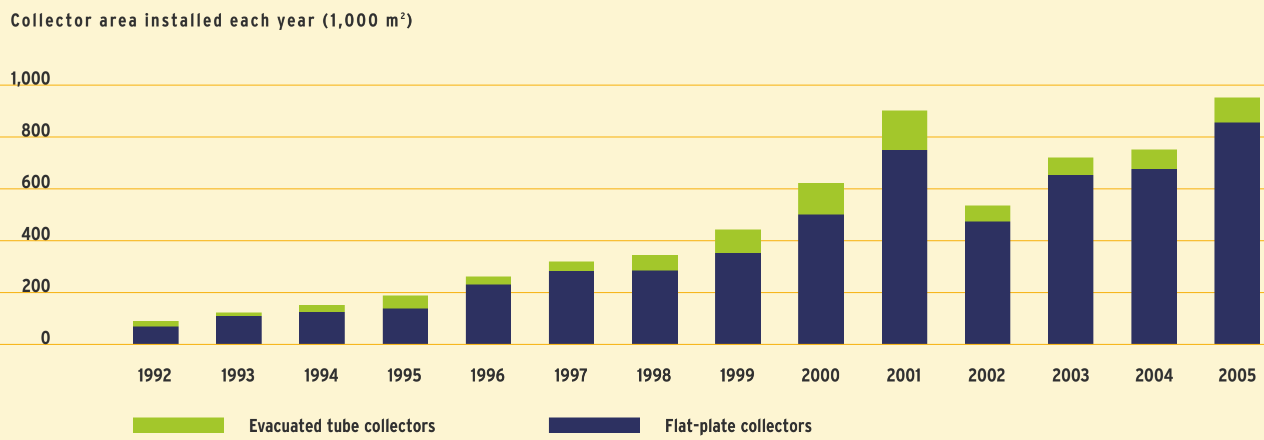
collectors were newly installed in Germany, indicating that the market has recovered from the massive drop in 2002. The market potential for renewable energy in the heat sector is to be better developed by continuing the market stimulation programme with the same coverage and by introducing new instruments, like a renewable heat sources act.

In contrast to the photovoltaic sector, Germany is by far not leading in solar heat utilisation. There are four times as many solar collectors installed per capita in neighbouring Austria, where the collectors have become a very lucrative export item. Other EU countries like France, Italy, and England are further behind in these developments at the moment. By far, the largest market for solar collectors in the world is in China.

Further market expansion is expected if the demand for even larger plants and systems increases. Solar collector systems are still overwhelmingly installed on the roofs of single-family houses. There are hardly any such systems to be seen on the roofs of apartment buildings or other large buildings so far, although the solar heating costs, especially for larger-scale systems, can be considerably lower. Nevertheless, the marketing for these systems is more difficult: It is not the owners who benefit from the solar heat, but rather the tenants. In this case, the owner's delight while showering using "home-grown"

→ Installed collector area

Source: DLR



Sales of collectors have increased by a factor of ten since 1992.

heat generated from an inexhaustible source is lost. Instead, the economic criteria are increasingly dominating. Some housing construction companies have decided in favour of solar systems for their rental properties. In this way, the dwellings are easier to lease and the numbers of unoccupied flats can be reduced.

Cooling with heat from solar collectors

The heat supplied by a solar collector can also be used to drive an air conditioner. Since the demand for building cooling is particularly high when the sun shines the strongest, the combination of collector and chiller is especially advantageous. Fossil energy carriers can be saved in this way, since conventional air conditioners usually run on electricity or natural gas. With the growing desire for improved living comfort, together with the trend to constructions with large glass façades, the demand for environmentally compatible air conditioning is expected to increase.

Solar cooling can be realised with different technologies. Two main technologies can be distinguished: one produces cold water which can be used for cooling purposes (the so-called "cold-water technique" or "closed technique") and the other one cools and dehumidifies the air which must be exchanged anyway in a ventilation system for reasons of hygiene (the so-called "open technique" or "desiccant technique"). The core piece of both techniques is the chiller or the dehumidifier, since well-conditioned air does not only have a comfortable temperature, but also the proper humidity.

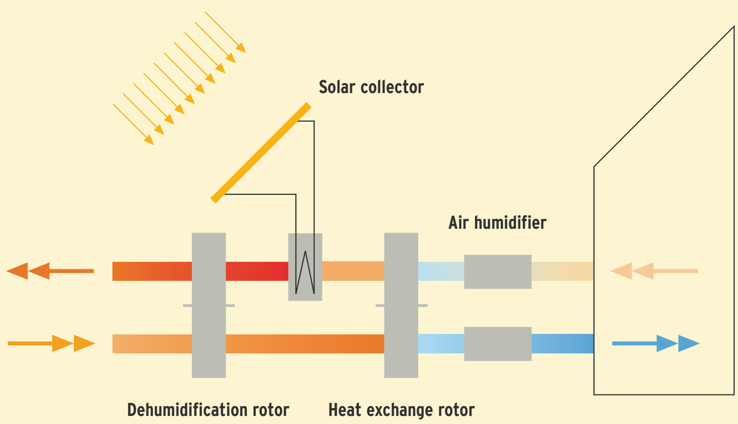
In the open technique, for example, the incoming warm ambient air is first dehumidified by passing a rotating cylinder which is coated with a very porous material (dehumidification rotor, see Figure: Cooling with the open technique). The water vapour in the air is adsorbed on the porous surface and is thus removed from the airflow. The warm, now dry air inflow subsequently delivers some of its heat to the cooler exhaust air when passing another rotating cylinder (heat exchange rotor). Then a humidifier sprays water into the dehumidified fresh air. The water evaporates and further cools the inflowing air, raising the humidity to a comfortable level again, and the fresh air finally flows into the rooms. The heat from the solar collector is used to drive the adsorbed water vapour out of the porous material again.

The technologies for thermal air conditioning are still in their infancy. So far, almost only large systems with cooling capacities of over 50 to 100 kW are available on the market. They are suitable for the air conditioning of buildings like department stores, office buildings, or convention centres. Smaller systems with cooling capacities of a few kilowatts for single-family homes or top floors are just starting to be offered commercially. These systems belong to a whole **new market segment**. Since solar collectors for hot water and heating assistance often supply much too much heat in the summer, using this excess heat for air conditioning, and therefore for increasing living comfort, represents a very promising application for the future.

In most cases, the operator of a solar-assisted air conditioner must currently pay more for it. Considering the total cost, the solar variant is about 10 to 40 % more expensive than a conventional air conditioner. There is however a large potential for technical improvements and cost reductions for solar-assisted air conditioners, as already shown for larger systems which are not yet designed for individual households. Especially for the complex coordinated regulation of solar collector and chiller can be greatly improved and optimised. Thus, the use of

→ Cooling with the open technique

Source: DLR



Air is cooled and dehumidified with this technique, also known as the "desiccant" technique. The technical core piece is the dehumidification system.

solar energy for cooling small houses or top floors could become more common in the next years. The largest market share will however not be in Germany, but rather in southern, sun-rich countries with a high demand for air conditioning.

Prospects

In the long term, solar heat can contribute to a sustained energy supply in Germany to a considerable extent. There is enough space on the roofs of buildings for 800 km² of collectors. Additional spaces for installations are on south-facing façades, above parking spaces, and on road embankments (see Figure: Noise-protection wall with solar collectors). In total, as much as 1,300 km² collectors could be installed, already taking into account that some of the roof area must be kept reserved for solar cells generating electricity (photovoltaic systems). With this potential collector surface area, it would be theoretically possible to meet approximately half of the present-day heat demand for heating and hot water. Today, solar heat contributes only 0.2 % to the total heat needed in Germany.

In order for solar heat to be a major contributor to the energy supply, it will not suffice to cover every roof with collectors and install a storage system in every cellar. It is rather necessary to link up a large number of buildings within a district heat network and then to connect the network to one large and common storage system. Only in this way can the heat from the summer sun be stored for use in the winter months at reasonable costs. The collectors supply heat to the storage system from where it is then transferred as required to the buildings within the system.

Setting up district heating networks is a crucial prerequisite for the extensive use of solar heat (see “Future supply structures” chapter). District heat can also contribute to the cost-effective use of wood chips, straw, miscanthus, and geothermal energy to a considerable degree. A good example here is Denmark where today already 60 % of all homes are heated by means of block or district heating. More than one third of the heat being fed into the networks originates from renewable energy sources, and the remainder is mostly produced with the equally environmentally compatible method of combined heat and power generation. District heat is flexible and open for the future. For the benefit of a sustainable heat supply, a decisive expansion of such systems in the next decades is to be strived for in Germany as well. This task will not however be an easy one.

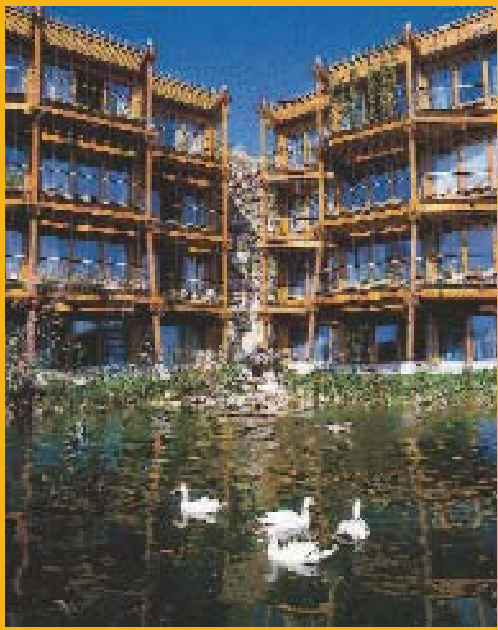
Solar collectors both heat residential areas and protect them from noise.

Information about solar collectors

- → **Bundesverband Solarwirtschaft**
  www.solarwirtschaft.de
- → **European Solar Thermal Industry**
  www.estif.org
- → **Large systems and seasonal storage**
  www.solarthermie2000.de
- → **Solar cooling:**
  “Klimatisierung mit Sonne und Wärme” Booklet
  http://www.bine.info/pdf/publikation/pro0104internetx.pdf
- → **Deutsche Gesellschaft für Sonnenenergie: www.dgs.de**

PASSIVE USE OF SOLAR ENERGY

1



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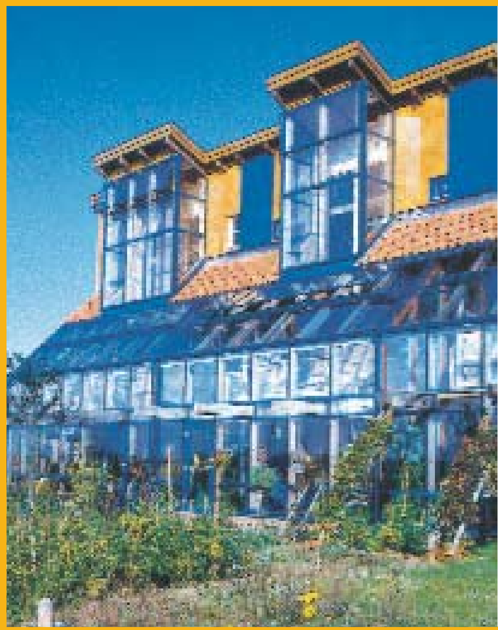

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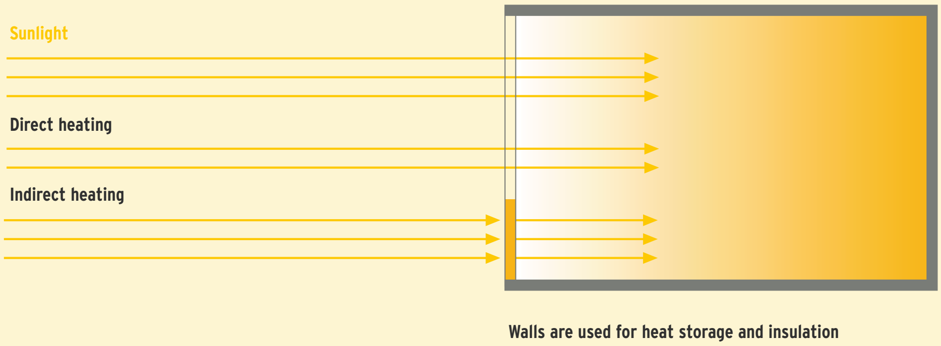


4

Resources: Direct and diffuse solar irradiation

Sites: Worldwide

Field of application: Heating buildings

Capacity: 1.5 to 200 MWh/a, no real upper limit

Costs today: As a rule, the saving in fuel costs compensates for the additional investment

Figures: 1. Transparent insulation, 2. Architectural measures, 3. Translucent façades, 4. Basic principle of passive solar energy use

PASSIVE USE OF SOLAR ENERGY – POSSIBLE THROUGH BUILDING DESIGN

Passive use of solar energy is characterised by the fact that the **solar energy is used without any technical support** like e.g. pumps. The prime example is of shade-free windows facing directly south through which, especially in winter, the rays of the low-lying sun can reach the interior of the house and warm it: the building itself acts like a solar collector.

Included in the area of passive use are also other transparent parts of the outer building shell, like conservatories or transparent thermal insulation. The architect's task is thus to design the building to maximise the gains from passive solar energy, without overheating the building in the summer, and to keep any additional losses due to enlarged window areas within acceptable limits. The passive use of solar energy, more than any other technology, requires the holistic consideration of the building structure and energy supply (see Figure: Characteristic energy values of buildings).

Windows: Sources of heat or of heat losses?

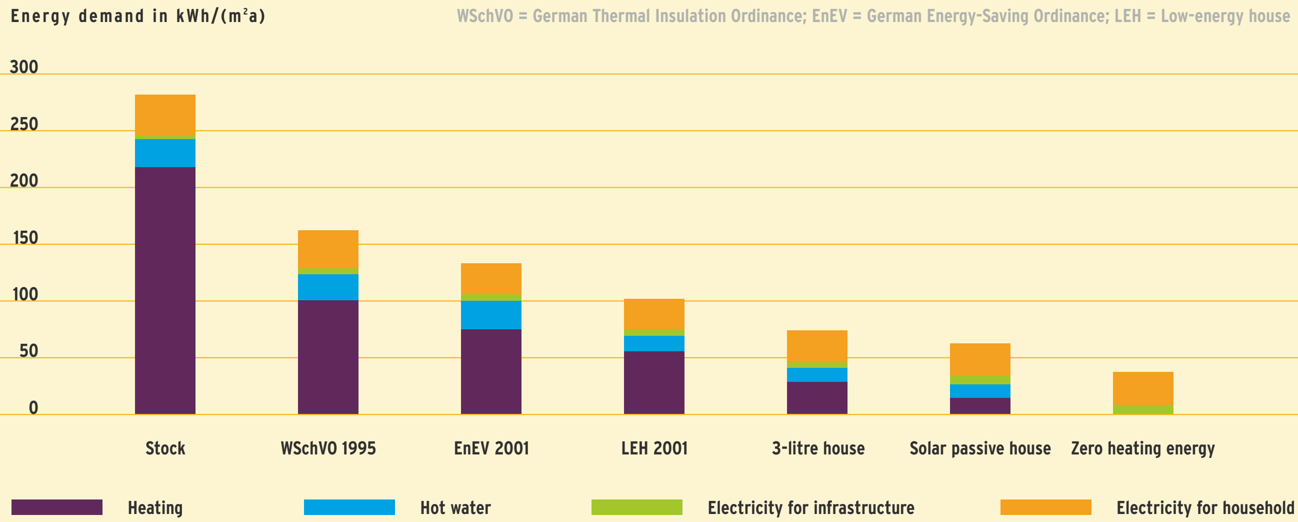
During the day, solar irradiation can make a considerable contribution to heating a house. The better the house is already thermally insulated, the more pronounced are the effects. During the night, on the other hand, there is more heat lost through even the best of windows than through a well-insulated wall. Whether an overall positive or negative energy balance results from an enlarged window area depends considerably on the **quality of the glazing** (see Figure: South-facing window area). An enlargement of the south-facing window area does not necessarily improve the building's heat requirement. In particular, passive-energy houses can only be realised by using first-class glazing constructions.

The additional costs of heat protection

A new construction with a lower heating requirement will also have a lower annual heating bill. On the other hand, its construction also incurred higher costs (see Figure: Additional costs). **Low-energy houses** can already be realised for low additional costs. For **passive houses**, additional investment costs of 200 Euro per square meter of floor space have to be assumed. In return, these houses provide reliable protection against future increases in the price of energy and – at a lower room temperature – can manage without any extra heating, even in winter. Further thermal insulation, together with a solar collector and a very large heat store inside the house, would meet all of the building's requirements, so that no external fuel or electricity is needed for heating. This construction is, however, still very costly.

→ Characteristic energy values of buildings

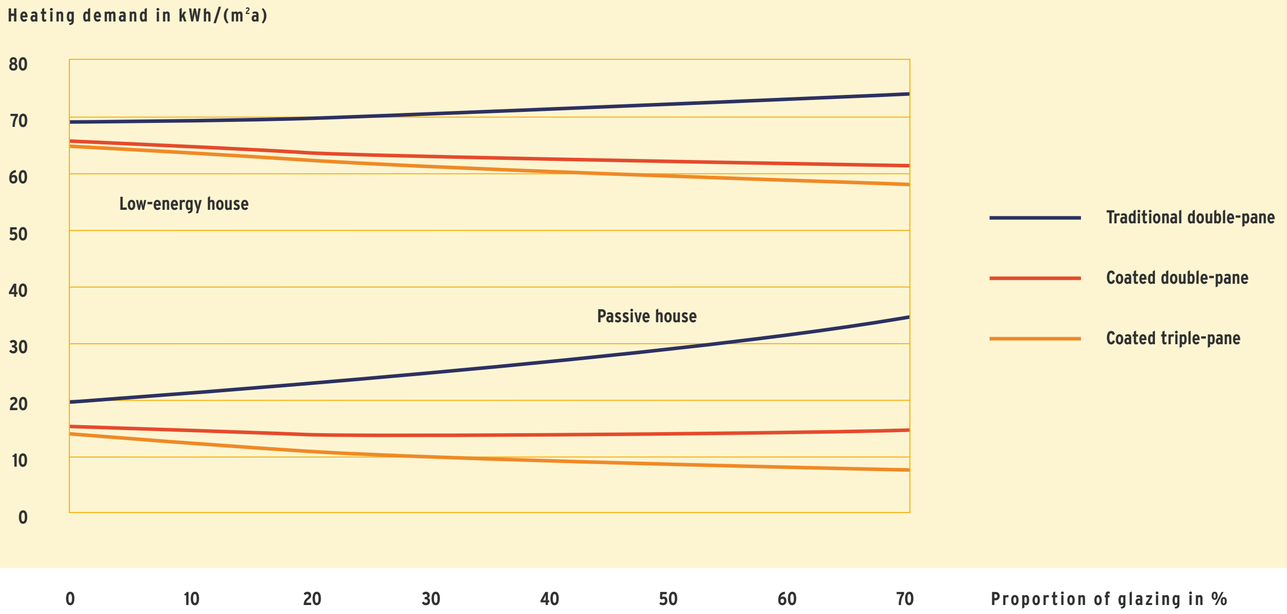
Source: Luther 2001



Characteristic energy values for various thermal insulation standards, taking the single-family house as an example

→ South-facing window area and heating demand

Source: IWU 1997



The windows as a means of heating: For good glazing (triple-pane glazing), the heating requirements fall as the proportion of south-facing windows increases.

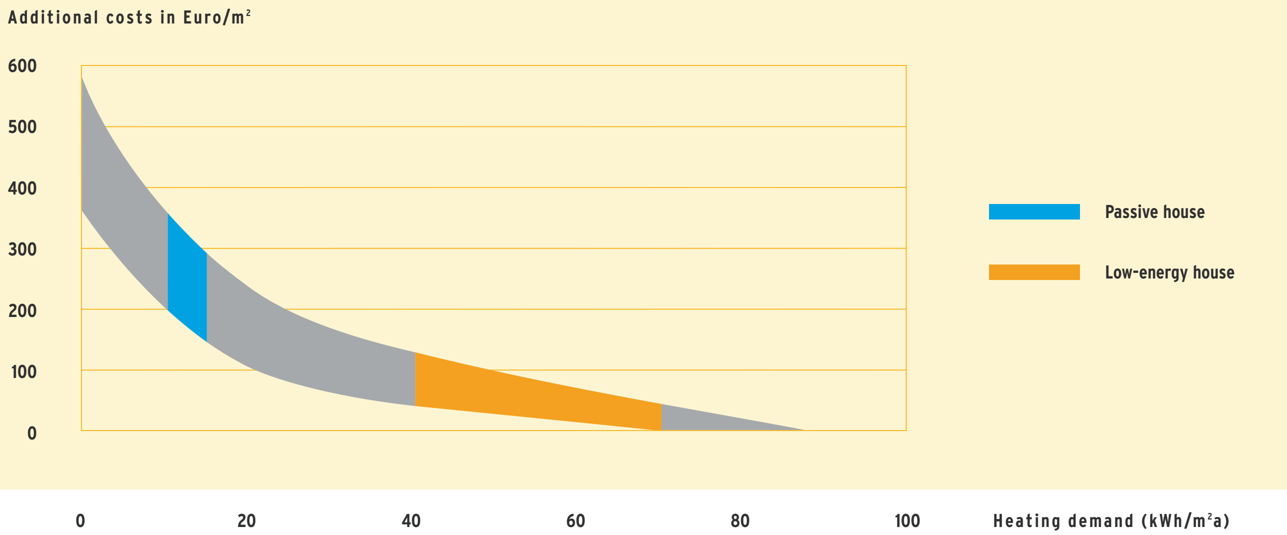
Improvements in older buildings are even more important for a sustained development than in new constructions. When modernisation is necessary anyway, additional heat protection can be included for only slightly higher costs which are quickly amortised. Particular attention should therefore be given to the thermal insulation when renovating a building, since the next favourable opportunity will only be during the following renovation in about another 30 years time.

Conservatories and thermal insulation

Conservatories are generally very popular. In the transition months, a conservatory provides additional unheated living space which is illuminated with natural daylight; it is close to nature and yet protected. In winter, energy for heating purposes can be saved as well. This effect is however low and can easily be reversed –

→ Additional costs for heat protection

Source: Gertis 2001



Additional costs for heat protection per square metre of floor space e.g. by occasionally leaving the door to the heated living quarters open in winter.

Transparent thermal insulation can be added to the façades and panels of old and new buildings alike. Transparent thermal insulation consists of a layer transparent to light yet is of good thermal insulation, made, for example, of fine glass or plastic tubes (see Figure: Transparent thermal insulation). The incident light passes through the transparent insulating layer and is absorbed on the structural wall, thereby heating the wall. Since this heat is already behind the insulating layer, it can no longer escape to the environment and thus – with a time delay – heats the living quarters behind the wall. In the summer, a system of shades may be necessary to protect from overheating.

The usefulness of transparent thermal insulation depends on the wall's cardinal orientation, on the quality and the orientation of the other transparent components (windows), as well as on the structure of the wall behind the transparent thermal insulation. Accordingly, appropriate planning is absolutely necessary.

Information about passive solar energy use

- ➔ Passivhaus Institut: www.passiv.de
- ➔ BINE: Information service about energy technologies www.bine.info
- ➔ Institut Wohnen und Umwelt: www.iwu.de
- ➔ Fraunhofer-Institut für Bauphysik: www.ibp.fhg.de

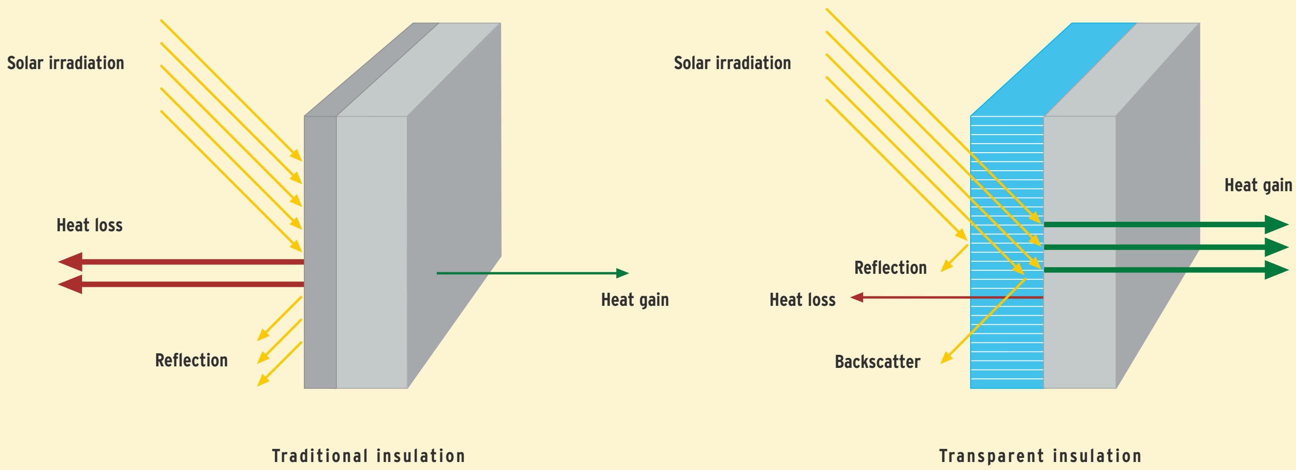
The German Energy-Saving Ordinance

The new German Energy-Saving Ordinance (Energieeinsparverordnung = EnEV) has been in effect since February 2002. This new legislation replaces all previous heat-protection and heating-system laws. Instead of regulating the heating requirement, i.e. the quantity of heat provided by the heaters, it now limits the primary energy requirement. Primary energy is the quantity of energy contained in the amount of coal, oil, gas, or uranium which is necessary to heat the planned new building and to supply it with hot water. A transitional exception was made for electrical heaters.

The energy-saving regulation gives the property developers the choice of whether to meet the more demanding goals of the new regulation by better thermal insulation, by energy-saving heating systems, or by using sources of renewable energy. The property developer can now optimise the entire system – the decisive advantage of the new regulation. For example, a projected single-family house can reduce the demands on the thermal insulation or the heating requirements by 15 % by installing a well-designed solar water-heating system.

➔ Transparent thermal insulation

Source: FhG-ISE



Functionality of transparent insulation

BIOMASS COMBUSTION

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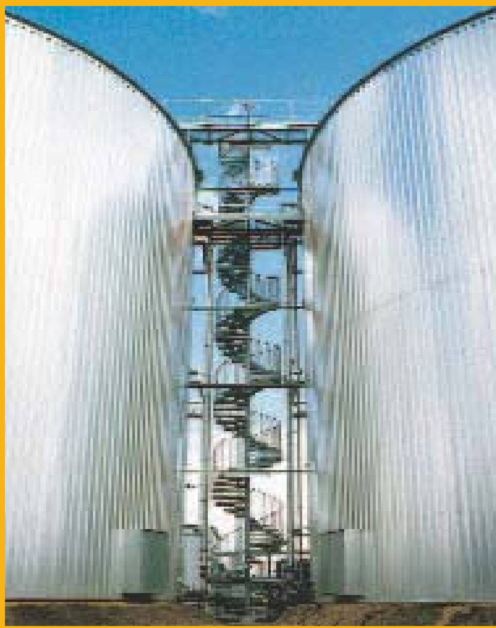

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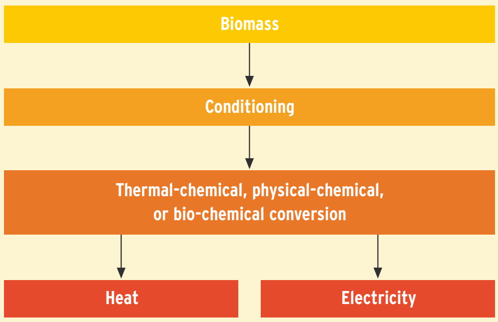


4

Resources:	Wood, grain, vegetation containing sugar and starch, plants containing oil, organic leftovers, and bio-waste
Sites:	Worldwide, depending on the availability of the biomass
Field of application:	Electricity generation, heating purposes, combined heat and power generation
Capacity:	1 kW to 50 MW (thermal)
Costs:	Heat: 1 to 10 Cents/kWh Electricity: 5 to 30 Cents/kWh
Figures:	1. Wood-fuelled cogeneration plant, 2. Biogas plant, 3. Pellet stove, 4. Processes for generating electricity and heat from biomass

BIOMASS – A LONG-TERM ALTERNATIVE FOR HEAT AND ELECTRICITY

The use of biomass for generating electricity and heat is a particularly attractive form of energy conversion from the climate point of view. When growing, the biomass first removes the greenhouse gas CO_2 from the atmosphere and binds the carbon in the biomass. This carbon is later released into the atmosphere again – e.g. as a result of combustion or when the biomass is rotting. Therefore, when biomass is used for energy purposes, then only that CO_2 is released which was previously removed from the atmosphere when the plant was growing.

Not all biomass is equal. Organic waste, wood, liquid manure, but also cereals, maize, or other materials originating from plants or animals and their consequential and secondary products can be employed for climate-compatible energy production.

Included among the most important biogenous fuels are of course wood and leftover timber accumulating from forestry, in sawmills or as old timber. Fast-growing trees, e.g. poplars and willows, can be planted in so-called short-turnaround plantations and be harvested within a few years.

Reed (miscanthus) is potentially a very high-yield regenerative raw material, however it requires high-quality fertile land and a good water supply. Residuary straw, as well as special grain plants like e.g. the wheat-rye hybrid triticale, are also suitable for producing energy. Plants which contain sugar and starch, like maize and sugar beets, can be used for making bio-alcohol. Also included as biomass are those oil-containing plants which, by pressing and subsequent processing, can be converted into liquid energy carriers (see the “Biofuels” chapter).

Organic leftovers are also suitable energy sources. Liquid manure, bio-waste, sewage sludge, and municipal sewage and food leftovers can be converted into high-energy biogas. Even landfills release biogas which can also be utilised.

The oldest form of use: Burning

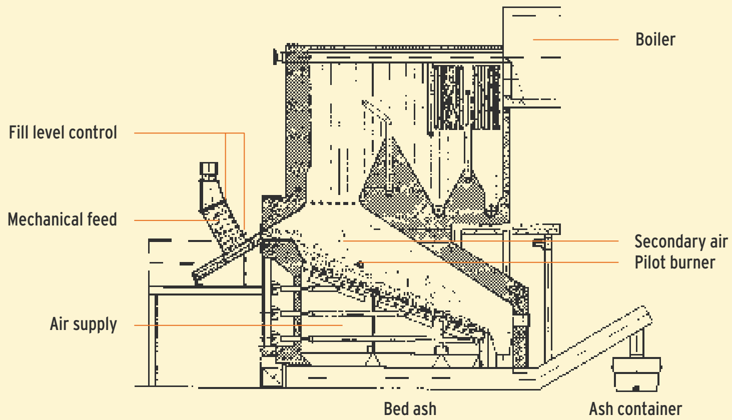
The oldest and simplest way of using energy is to burn the biomass. Different types of burning were developed for various plant sizes to assure complete combustion and low emissions, considering the ash content, the fuel composition, and the shape and size of the fuel particles. They essentially differ in the type of fuel processing and the fuel feed method.

Present-day use of biogenous solid fuels in Germany is mostly in very small systems (less than 15 kW) or in small-scale systems. Automated fuel feed, together with a suitable combustion control system, have increased the ease of operation. Small-scale plants are thereby subject to the emission limits of the emission control legislation in Germany.

Wood-pellet furnaces are currently enjoying a wave of popularity. Wood pellets are small compressed beads of untreated wood, usually from sawdust and plane

→ Biomass furnace

Source: Flaig 1998



The stoker-fired furnace is an example for an all-round biomass furnace. By adjusting the speed of fuel transportation and the air flow, the furnace can be precisely controlled.

Stock of wood chips in Thuringia. One kilogram of dry wood contains as much energy as half a litre of heating oil.

shavings. They can be delivered like heating oil by tank trucks, or sold in sacks. Pellets can be fired in chimney stoves just like in large-scale, fully-automated and low-emission central heating systems. The pellets are automatically transported from a storage container to the furnace chamber by means of screw conveyors or suction feeders. The space needed for storing this type of fuel is hardly larger than for an oil-fired central heating system.

Generating heat is not limited to small-scale systems only. Firing wood can also be used for district heating networks. In Austria, a country which has been systematically supporting the use of biomass for many years now, there are already several hundred district heating plants running on biomass. It is worthwhile to invest in greater technical optimisation of these larger incineration facilities.

Both the efficiencies and the emissions of modern furnaces have been improved. For example, the efficiency can be increased considerably by condensing the flue gases, since the transformation energy when the water vapour condenses into liquid can be used, and by pre-drying the biomass. The exhaust-gas values can be improved by a continuous combustion process and efficient dust recovery. In recent years, it has also been possible to considerably reduce the emissions of carbon dioxide and unburned hydrocarbons in small systems (see "Ecological qualities of renewable energy" chapter).

Electricity from biomass

The interest in producing electricity from biomass has increased considerably since adoption of the biomass regulation in 2001 and the Renewable Energy Sources Act in 2004. The electricity generation from wood alone has multiplied over the last years to more than 5 billion kWh. More than 120 such biomass power plants and cogeneration plants are operating in Germany. The preferred fuel in the newly constructed power stations is almost exclusively cost-effective **old timber**. Economic operation of the plants is not possible with the more expensive untreated wood. The days of being able to charge a disposal fee for accepting contaminated wood are long gone because of the considerably increased demand for this wood.

Biomass for electricity generation is particularly important to the power industry because it is always available and can be converted to electricity according to the demand. In modern wood-fuelled power plants, the biomass is burned and steam is usually generated with the heat. This steam then drives a turbine or a motor (see Figure: Generating electricity from biomass). It is particularly efficient to use the waste heat for heating buildings or for drying processes, instead of simply dissipating it into the surrounding environment. This method is known as **combined heat and power generation** (see "Future supply structures" chapter).

The efficiency levels which can be reached today are still, however, unsatisfactory, particularly for small plants. New technologies are therefore being developed like the Stirling engine, which, unlike the steam turbine, still exhibits high electricity and heat yields in the output range of less than 1 MW. Its commercialisation is, however, still in its infancy (see Figure: Generating electricity from biomass).

The innovative Organic Rankine Cycle (ORC) is already further along. It is particularly suited for heat sources at a low temperature level. In this process the combustion heat – or heat from any other source, e.g. geothermal – is not used to generate steam for a steam turbine. Instead, an organic solvent, e.g. toluene, pentane, or ammonia, is evaporated and used to drive a turbine. The first biomass-fired ORC plant in Germany was constructed in 2002; 8 such plants were already operating in 2004. Of the plants under construction at the end of 2004, already 42 % employ the innovative ORC method which is particularly suitable for central biomass cogeneration plants.

A promising alternative to burning is the **gasification** of biomass. In this process, the biomass is decomposed at high temperatures and transformed into a gas, which is then cooled off, cleaned, and then fired in a motor cogeneration plant or a turbine. The future use of biomass in fuel cells, which provide high yields of electricity even from small-power units, is possible with gasified wood. The principle of wood gasification is not new. It was used e.g. after the war for powering lorries due to the lack of more motor-gentle fuels. The trick is to produce a high-quality and tar-free gas, whose continuous use is tolerated by motors, from varying fuel qualities. Newly developed wood-gasifier pilot plants coupled with cogeneration units are currently undergoing long-term operation tests.

Biogas – bacteria at work

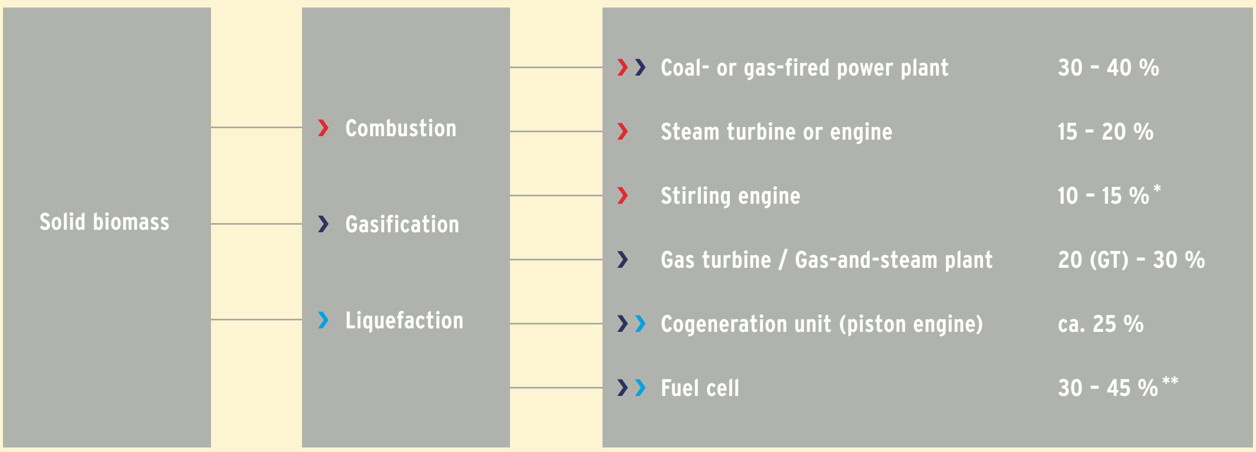
Biogas can also be used to generate electricity, preferably in cogeneration units. Biogas is liberated when organic material is decomposed by special methane bacteria. This process is called fermentation. Two major prerequisites must be met to obtain an energy-rich gas: anaerobic (oxygen-free) conditions must prevail, and the temperatures in the biogas reactor must be suitable for the desired bacteria. Most biogas systems operate at temperatures between 30 and 37 °C.

Biomass cogeneration plant in Demmin

The bacteria decompose the organic matter in several stages. The final products of this decomposition chain are the gases methane (CH_4) and carbon dioxide (CO_2). One hundred cubic meters of biogas develop from between a half and one ton of bio-waste, corresponding to the daily excrement from 90 cows or 12,000 chickens.

The first German biogas plant was already built in the Odenwald in 1948. Since then, the process engineering has improved continuously. However, the core components are still the same (see Figure: Large co-fermentation plant): In the conditioning phase, the organic mass is comminuted and interfering materials are removed. The heart of the plant is the methane reactor where the actual bacterial decomposition takes place. Depending on the size of the plant, this reactor can be made of concrete, plastic, or steel. For agricultural small-scale plants in the developing countries, the biogas reactors are often brick constructions buried in the ground. The organic substrate stays in the reactor between 10 and 35 days before the fermentation leftovers are ejected and processed, for example, as fertiliser or compost. The resulting biogas is subsequently cleaned with a gas purifier and, if necessary, also desulphurised. With a calorific value of about 6 kWh, one cubic meter of biogas is equivalent to 0.6 litres of heating oil or 0.6 m^3 of natural gas. Biogas is suitable as a fuel for combustion engines. In Germany, reactor-formed biogas is almost exclusively used in cogeneration units. To begin with, the cogeneration unit covers the plant's own energy

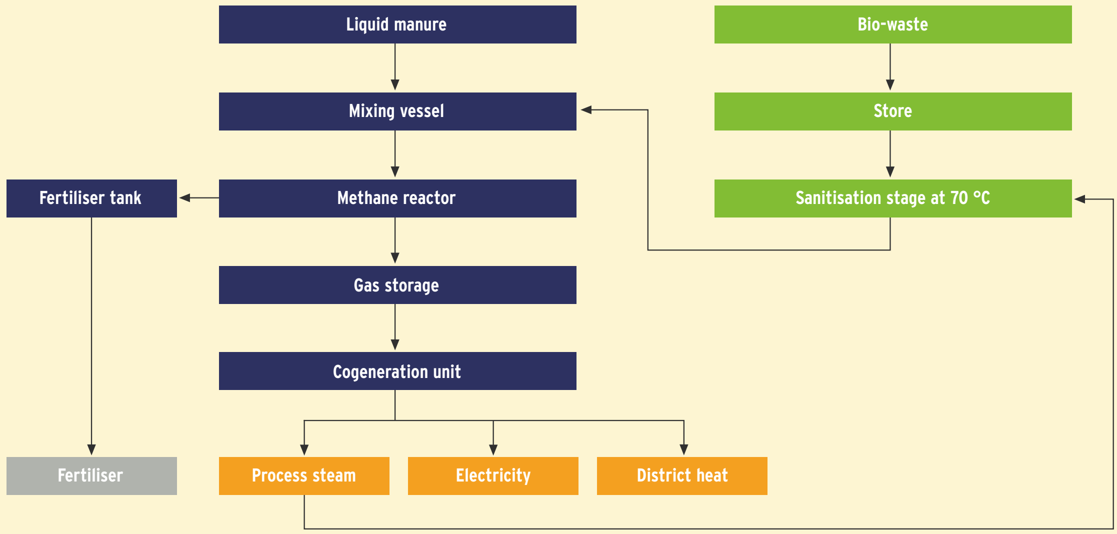
→ Generating electricity from biomass



Various technologies are available to produce electricity from biomass (* less power output than steam turbine; ** depending on the fuel cell type).

→ Large co-fermentation plant

Source: Haase



From manure to electricity – schematical diagram of the process

requirements for electricity (for mixers and control systems) and heat (for heating the reactor). However, the biogas can also be cleaned and fed into a natural gas grid. The benefits of biogas plants for the farmers are severalfold: The largest economic benefit is given by the electricity generated in the cogeneration unit. Some of this power is used locally, whereas the remainder is fed into the national grid at the price regulated by the Renewable Energy Act. The heat is used for heating the buildings and sheds. Larger plants can also distribute this heat in a district heating network. Also, the liquid manure is processed into an upgraded, reduced-odour fertiliser.

By co-fermentation, i.e. simultaneous fermentation of manure and organic waste from households or industry, the yield of biogas can be increased, resulting in additional revenue from the electrical power thus generated. Additionally, there are revenues in terms of fees for the environmentally compatible disposal of bio-waste materials. The hygiene regulations are, however, much more stringent for co-fermentation plants, and the legal conditions are much more complicated as well. Furthermore, the electricity is reimbursed at a lower rate if not produced exclusively from renewable raw materials, thereby reducing the economic benefits of co-fermentation.

Costs

The diversity of the biogenic starting substances is also reflected in the costs of generating electricity from these sources. Decisive for the economic efficiency of the plant are, as a rule, the costs of providing the fuel, ranging from "negative" costs – from credits for landfill and disposal costs not incurred – through to 3 Cents/kWh for grain-type whole plants. The costs of regenerative raw materials are currently around one-and-a-half to two times higher than those of most leftovers.

The costs for heat generation can be derived from the investment and fuel-production costs, whereby the electricity from combined heat and power generation is reimbursed according to the Renewable Energy Act (see Figure: Economic efficiency of biogenic heat generation). Low heat-production costs are mostly achieved by large steam-based cogeneration plants and district heating stations running on cost-effective residual wood.

Under favourable conditions, for example with a high level of personal contribution and cost-effective fuel sources, even small-scale systems can exhibit lower heat-production costs than comparable plants running on fossil fuels. This case is often true for firewood boilers.

On the other hand, it is much more convenient to use wood pellets for heating purposes. The price of these "energy sticks" has been dropping continuously for several years now due to increasing production amounts and short transportation distances. A delivery of pellets is nearly half as expensive as the corresponding delivery of heating oil. However, despite national subsidisation, the investment in a pellet-fired heating system is still several thousand Euros higher than for an oil-fired heating system.

The costs of biogas systems depend largely on the size of the system, the co-fermentation percentage and the potential disposal revenues, the gas yield, the quantity of electricity the plant itself needs, the external heating requirements, and any other uses (like e.g. fertiliser enhancements).

Many agricultural systems are profitable due to the feed-in tariffs set by the Renewable Energy Sources Act. Additionally, farmers can save considerably on the construction by personally erecting them. It is important for the plant to run at its maximum capacity. For example, in Denmark communal systems shared by several farming operations are built to enable a better utilisation and due to the economies of scale.

Landfill gas accumulates continuously and in a predictable manner. The gas must be collected by a pipeline system anyway. An appropriate dimensioning of the system can assure profitable operation. Sewage-gas systems are profitable if a fermentation tower (biogas reactor for the sewage sludge) is already included in the design.

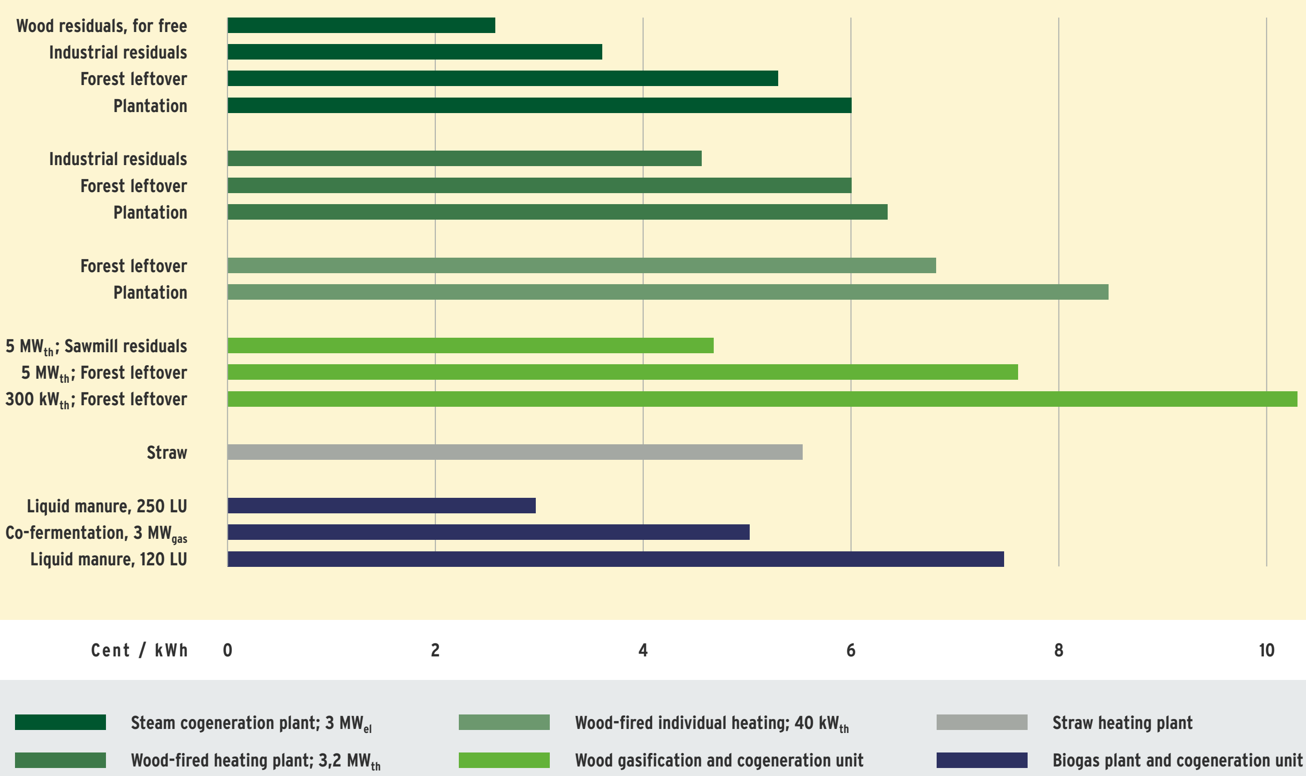
"Energy sticks" – biomass pellets

Potential

Wood today provides by far the largest contribution of biomass for energy purposes. This situation will remain in the future as well. Part of the wood that has been grown in the forests cannot be sold to the timber-processing industry. This leftover material includes young slender tree trunks from thinning out plantations, and thick branches and other waste from felling mature forestry stock. Other sources of untreated timber are

→ Economic efficiency of biogenic heat generation

Source: DLR



Systems fuelled with cheap residuals and large district heating plants are the most economic choice for producing heat from biomass today. Real interest rate 4 % and amortisation within 15 to 20 years (LU = Livestock unit).

the waste and residuals in sawmills (the so-called "by-products") and in the remaining wood and timber-processing industry. A large proportion of this wood can be processed in the papermaking and particle-board industry, so that only the surplus can be used for energy purposes.

Furthermore, wooden products at the end of their useful life are usually available as contaminated old timber, some of which can still be materially recycled. The borderline between using wood as a material or for its energy shifts depending on the selling price. Fully exhausting the possibilities for using the energy in wood would result in a potential of 170 billion kWh/a. Additional potential can be developed by using straw, biogas, and energy crops.

Straw is needed as litter for animal husbandry and must often be returned to the fields in order to maintain the quality of the soil. Only approx. 20 % of the total amount of available straw could be used as a source of energy. Straw is a problematical fuel and is therefore – unlike in Denmark – hardly used in Germany today. Its future use is possible through the cost-effective and efficient co-firing in coal-fired power plants.

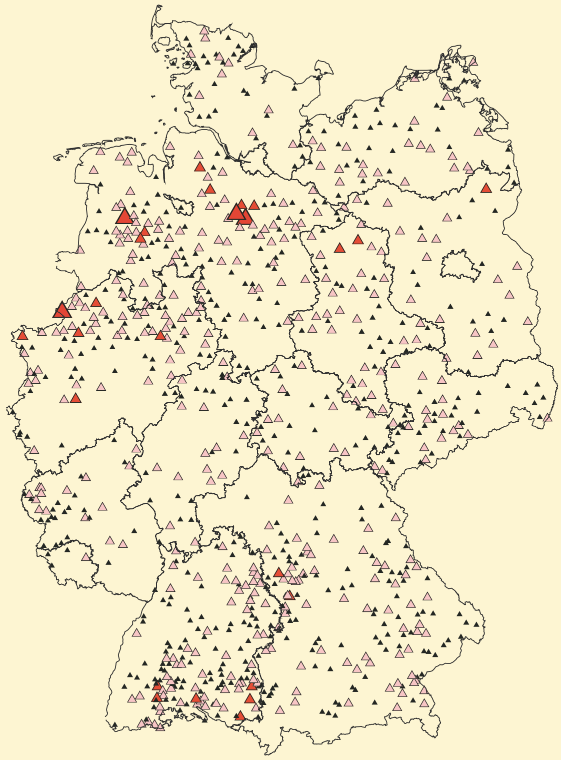
The largest potential for producing **biogas** is to be found in agriculture. More than 200,000 plants could be realised in Germany with agricultural waste alone – considerably more than the ca 2,700 plants in operation at the end of 2005 (see Figure: Biogas plants in Germany).

Besides using residual and waste materials, there is also the possibility to systematically cultivate biomass. The potential for **energy crops** in Germany depends largely on how much land is available – therefore also depending on how much agricultural land is not farmed, how we nourish ourselves, how high the yield is, and how much organic farming we want to have. Furthermore, it is by no means obvious that free areas will be used for growing energy crops. The appeal to moderation in agriculture would also require large amounts of additional area. Moreover, land is also required for the creation of biotope areas and other necessities of nature, soil, and water conservation (see "Ecological qualities of renewable energy" chapter).

Since the amendment of the EEG in 2004, cultivated biomass is increasingly employed in biogas plants due to the financial motivation. According to a survey of operators, renewable raw materials amounted to only 4 % of the input substrate in late 2004, and already 22 % by the end of 2005. Especially silage from whole maize and grain plants, grass silage, and grain seeds.

Assuming that the 2 million hectares of farming land and all the residual and waste materials were available, then a proportion of about 9 % of the current primary energy consumption could be met with biomass (see Figure: The potential of biogenic fuels).

→ Biogas plants in Germany



Source: IE Leipzig 2005

Many biogas plants exist in Germany. The size of the triangle indicates the number of systems in a region.

Uses today

We are presently still far from these goals. It is only in the cases of landfill and sewage gas, in the near future with old timber as well, that more than half of the potential is already being used. While biomass utilisation is more prevalent in countries like Austria and Finland, it is only slowly developing in Germany. All the same, 2.2 % of the electricity consumption, and 3.4 % of the fuel consumption in Germany is met with biomass (status 2005).

About 9 million small biomass boilers and other systems meet 4.8 % of the heat supply. 1.4 million hectare – 12 % of the German farmland – is used for cultivating energy and industrial plants. Germany is even the world champion in producing biodiesel from rapeseed (see "Biofuels" chapter).

All together, biomass contributes approximately 1.7 % to the primary energy demand in Germany. This proportion is subject to considerable fluctuations, since approximately one in five German dwellings has either an open fireplace or a similar type of wood-burning oven in addition to central heating.

How intensively these furnaces are actually used depends also on the price of heating oil. The most recent jump in oil prices and the debate about the natural gas supply led to noticeable market growth in 2005. For example, the sales of wood pellet heaters nearly doubled to 14,000 units in 2005.

Environmental benefits of biogenic fuel

Common to all forms of using biogenous fuels is the considerable contribution to climate protection and resources conservation. Only fractions (of the order of one tenth) of the energy contained must be expended in the form of fossil energy for biomass production. This value applies both for the residual and waste materials which are collected, transported, and processed, as well as for the energy crops where the cultivation and production of operating materials (fertilisers, pesticides etc., depending on the type of agriculture) must also be included in the balance. Not only does this positive energy balance protect the reserves of finite energy carriers, it also reduces the climate-active CO_2 emissions because fossil energy carriers are being substituted by sources with a closed CO_2 cycle – the net greenhouse-active CO_2 emissions are null (see above). Even when considering the greenhouse gases methane and nitrous oxide – the latter is produced when cultivating energy crops through the production of fertilisers and the material processes taking place in the soil – the overall balance still remains clearly positive.

There is a further benefit for the climate when using biogas for energy purposes. In a poorly ventilated bio-

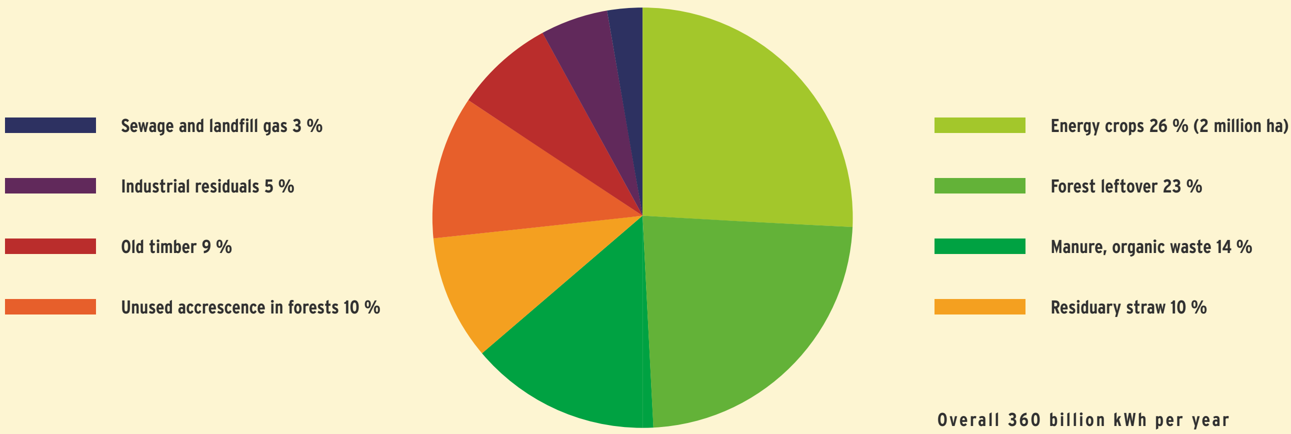
Brandenburg's most modern biogas plant in Pirnow

waste compost site, and in waste landfills or putrification tanks, the gas methane develops as a fermentation product which is then released in an uncontrolled manner. The greenhouse effects of methane are however 21 times higher than those of CO_2. The combustion of this methane to CO_2 in the biogas plants thus "defuses" the greenhouse gas.

The environmental balance is not decisively positive for all environmental problems (see Table: Ecological balance for biomass). In the case of regenerative raw materials, e.g. the method of growing these, the locations, and the fertilisers used, all have a large influence on the

→ The potential of biogenic fuels

Source: DLR



Biomass can be used in many different forms for producing energy. The potential value represents an upper limit. The range in which biomass fluctuates is rather large, between 140 and about 400 billion kWh per year.

Sources: Kaltschmitt/Reinhardt 1997

→ Ecological balance for biomass

Biofuels substituting coal	Consumption of resources	Global warming effect	Stratospheric ozone depletion	Acidification	Toxicity (example NO_x)
Winter wheat	+	+	–	+ / –	–
Miscanthus	+	+	–	+	+
Poplar (energy crop)	+	+	–	+	+
Wheat straw	+	+	+ / –	+	+
Wood leftover (fir)	+	+	+ / –	+	+
Biofuels substituting natural gas					
Winter wheat	+	+	–	–	–
Miscanthus	+	+	–	–	–
Poplar (energy crop)	+	+	–	–	–
Wheat straw	+	+	–	–	–
Wood leftover (fir)	+	+	–	–	–

Environmental effects of the energetic use of biomass in comparison to fossil fuels: + advantage of biofuel; + / – balanced or depends on evaluation method; – disadvantage of biofuel

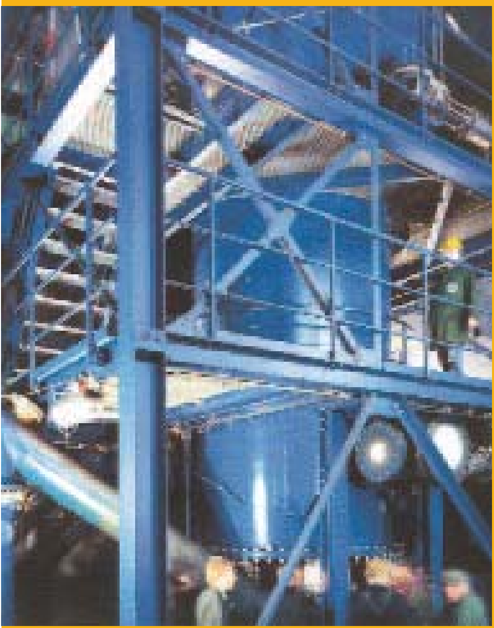
emission of harmful substances. Aspects of the area and raw materials use regarding their compatibility with the environment and with nature must be closely considered, just like for biofuels (see "Ecological qualities of renewable energy" chapter).

The conflicting goals between conserving the stocks of fossil raw materials and protecting the climate on the one hand, and certain other ecological problems areas on the other hand, cannot be resolved from the scientific viewpoint alone. The decision-making process must also include weighting factors. At the political level, a high value is currently assigned to climate protection. The ecologically optimised extensive farming of biological energy carriers, where the use of fertilisers and pesticides is kept low, by using leftovers as much use as possible, and by improving utilisation technologies, the goals can be harmonised.

Information about biomass

- → Information service about biomass and renewable resources: www.carmen-ev.de
- → Association of the biogas industry: www.fachverband-biogas.de
- → Fachagentur Nachwachsende Rohstoffe: www.fnr.de
- → Current information and tests of biomass plants for private households are available in consumer magazines. In the mean time, many companies in the heating trade offer biomass-fired heating systems.

BIOFUELS



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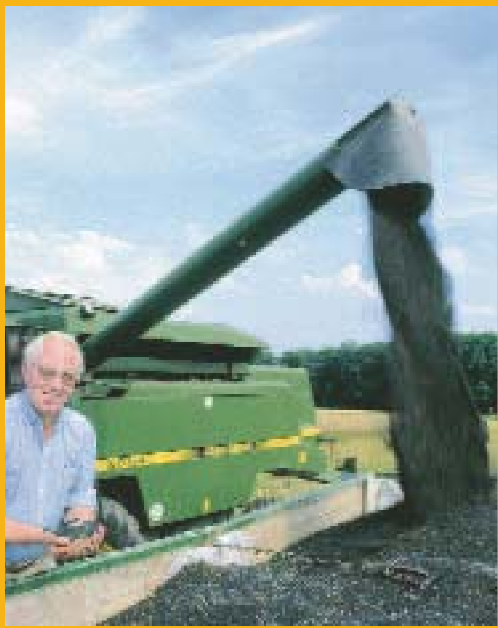

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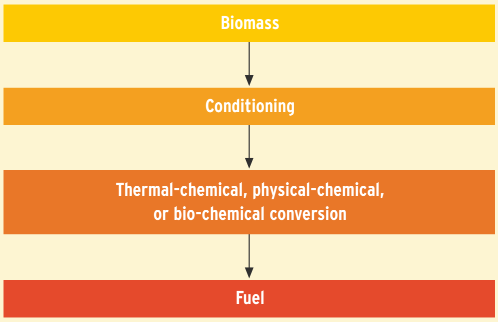

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Resources: Various biomass sources

Sites: Worldwide

Field of application: Combustion engines, in the future: fuel cells

Costs: More expensive than fossil fuels

Figures: 1. Wood gasifier, 2. Rapeseed harvest, 3. Sugar beet processing, 4. Processes for producing fuel from biomass

BIOFUELS – A CONTRIBUTION TO MOBILITY FROM PLANTS AND WASTE

Transportation requires a lot of energy. In 2004, more than 59 million tonnes of petroleum-based fuel were purchased in Germany, combusted, and finally emitted into the atmosphere as carbon dioxide. Some 85 % was consumed for road transportation and 10 % by aircraft. All in all, transportation is the second largest energy consumer after households, closely followed by industry (26 %).

Three problems are providing incentives to change this situation: The dependency on imports of petroleum products, the finite nature of fossil resources, and the problem of global warming. Although the climate-polluting CO_2 emissions from road transportation have declined slightly since 1999, the growing traffic volume and increased emissions from air traffic are limiting this success. Furthermore, the share of environmentally friendly transportation means like trains, busses, and barges is declining. Goods traffic is also problematic. The desired decoupling of transportation and economic growth has not yet occurred.

Biofuels offer a good opportunity to partially substitute petroleum as an energy carrier in the transport sector, since its use addresses all three problems at once. The feedstock can be produced in the country of consumption – the reliance on imports is thus reduced, and they grow again – so they are renewable. Finally, a further enormous advantage given by biofuels is that they are in principle CO_2-neutral, because the CO_2 emitted by their combustion was absorbed from the atmosphere during cultivation (see “Biomass combustion” chapter).

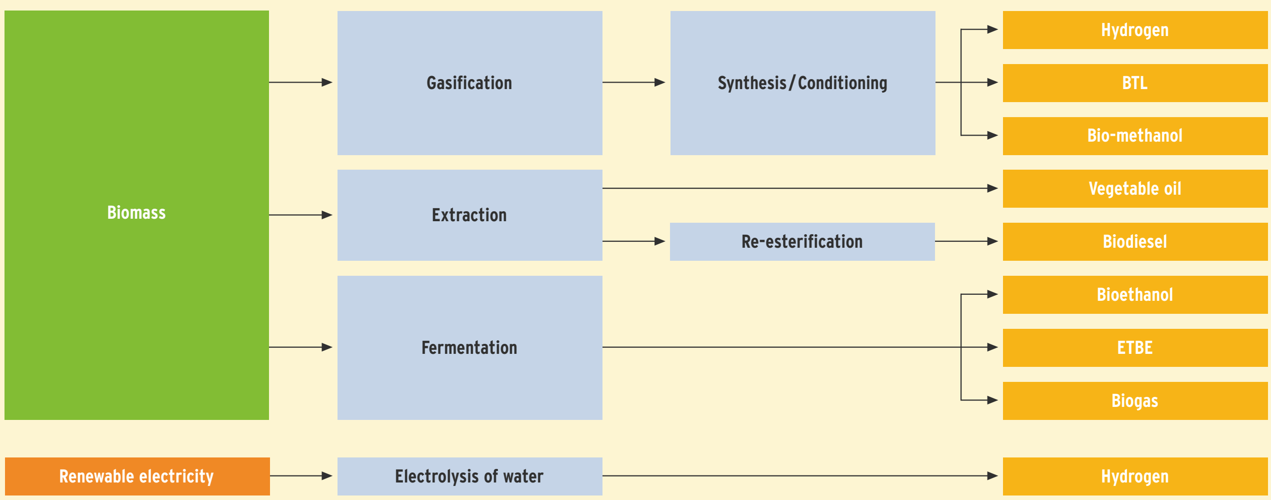
Full of possibilities

There is not just the one biofuel, but rather a whole range of liquid and gaseous bio-energy carriers which can be used in the transportation sector (see Figure: Fuel production paths). Best known among the liquid biofuels are the vegetable oils from rapeseed and sunflower seeds, and the processed form of rapeseed oil called biodiesel (methyl ester from rapeseed oil). Ethanol from sugar beets, grain, potatoes, etc., and fuels made from lignocellulosis material like the so-called biomass-to-liquid (BTL) fuels are major liquid biofuels.

Several kinds of gaseous biofuels are being discussed, like e.g. biogas, sewage gas, and landfill gas, as well as bio-hydrogen and wood gas, which are more or less suitable for use in transportation. The feedstock is equally diverse, as they originate from agriculture, forestry, and fishery, from residual and waste materials, or as products from thermo-chemical processes.

The biogenic fuel sector has been growing strongly since 1990. In 2005, biofuels supplied 3.4 % of the total fuel consumed in Germany, largely with biodiesel (2.88 %).

→ Fuel production paths



Some of the possible pathways to produce fuels from renewable energy carriers

Germany is the world leader in biodiesel production. Other biofuels are only present in application niches and pipeline-bound transportation.

Raw material rapeseed: Rapeseed oil and Biodiesel

Right from the start, the inventor of the diesel engine foresaw the use of biofuel for his engine. “The use of vegetable oil as a fuel might be insignificant today. Yet, over time, these fuels could become as important as paraffin and the coal-tar products of today”, noted Rudolf Diesel 1912 in his patent. Rape-seed biodiesel (RME), also known as FAME (fatty acid methyl ester), is the most widespread biofuel in Germany – with a strongly increasing trend. The sales of biodiesel increased from 130 thousand tonnes in 1999 to 1.7 million tonnes in 2005. The production capacity will probably increase to approximately 2.9 million tonnes in 2006.

A third of the biodiesel was admixed with conventional diesel; the rest was used in its pure form to fuel lorries (40 %) and passenger cars. More than 1,900 filling stations throughout Germany sell biodiesel. One reason for this success: biodiesel is much cheaper than fossil diesel due to its exemption from the mineral oil tax. Since a litre of biodiesel contains less energy than conventional diesel fuel, however, the fuel consumption is higher, partly diminishing the price advantage.

Biodiesel is a high-grade diesel fuel – and can therefore be used for a small vehicle as well as for the 40-tonne lorry. Yet not all biodiesel vehicles are equipped for biodiesel. One should therefore consult the manufacturer about whether the particular model has in fact been approved for running on biodiesel, or check the owner’s manual. Otherwise damage may occur e.g. to the fuel injection system, since biodiesel attacks certain plastics which are replaced by biodiesel-resistant plastics in the vehicles which have been approved to run on biodiesel. Furthermore, new vehicles are no longer allowed to use pure biodiesel if they are fitted with particulate filters since the burning-off process to clean the filters is not residue-free. Biodiesel, however, can be admixed with fossil-based diesel.

Pure rape-seed oil cannot be used directly in conventional diesel vehicles. Special engines are technically possible, e.g. the so-called Elsbett engines, yet the use of rape-seed oil will hardly gain acceptance for the standard passenger car. Unresolved problems are the cold-start properties of the cold-sensitive oil and compliance with the more stringent EURO-4 emission control requirements, so that its use will remain limited to niche applications.

Besides rapeseed and other oilseeds like soy or sunflower, imported palm oil is also being considered, and to a certain extent already employed, as a raw material for the production of biodiesel. However, new oil palm plantations must be cultivated in order to achieve an appreciable market share – in no way at the expense of tropical rainforests.

Fuel from the farm – rapeseed and its processing to biodiesel (rapeseed oil methyl ester)

Environmentally friendly on the road – with bio-alcohol

The alcohols ethanol and methanol are very suitable for use as fuels in transportation, proven by years of experience. Even Nikolaus August Otto, the inventor of the spark-ignition engine, used ethanol as the fuel when developing his engine and Henry Ford also designed his famous Model T to run on ethanol.

Pure ethanol can only run special motors, like those found in Brazil’s vehicle fleet in the eighties, or those used in the so-called “Flexible Fuel Vehicles”. A small

This plant gasifies biomass to produce a synthetic biofuel

fleet of these is operating in Sweden and in the United States. A more simple method is to add bioethanol to petrol, by which means bio-ethanol could be introduced into the market with little effort. Up to 5 % by volume are allowed by the German standards without causing any problems to today's vehicles. Pure bio-ethanol can be used or – with an additional positive environmental effect – its derivative ETBE (ethyl tertiary butyl ether). ETBE could replace the octane enhancer MTBE (methyl tertiary butyl ether), which is added to petrol, and thereby reduce the emission of air pollutants. However, it has not yet been clarified whether ETBE, compared to MTBE, is less hazardous to the ground water. In any case, MTBE has already been banned in both California and Denmark for this reason.

The almost legendary Brazilian bio-ethanol vehicle fleet is however declining strongly. Nevertheless, Brazil is the world's largest producer of bio-ethanol today (ca 10 million tonnes in 2003), which, however, is now mostly mixed with petrol.

Spain was the largest producer of bio-ethanol in Europe in 2004 (nearly 200,000 t/a). Here the bio-ethanol is converted to ETBE and admixed directly with petrol. This development had its origins in the year 1995 when ethanol was exempted from tax. In France bio-ethanol is also admixed as ETBE with the petrol. About 600 filling stations in Sweden should offer bio-ethanol by the end of 2006. In Germany, two new plants started operation in 2005 – ca 250,000 tonnes were sold that year. The annual production capacity increased to 600,000 t/a, catapulting Germany to number 1 in Europe.

Second-generation biofuels

Besides biodiesel and bio-ethanol, both of which are already commercialised, other processes are still being developed. The development goals for these "second-generation biofuels" are to expand the range of possible application, to develop efficient processes, and to lower the production costs.

Some of the processes rely on the gasification of biomass. If wood, straw, or other biomass sources are converted into a liquid fuel by means of a so-called Fischer-Tropsch process after gasification, then the energy of the entire plant can be utilised – which is not the case for biodiesel production from rapeseed. Experts call this fuel BTL, for "biomass-to-liquid"; marketing experts named it "SunDiesel".

These fuels possess excellent combustion properties, which is why the automotive industry is waiting for these fuels to be produced. Unfortunately, none of the many manufacturing techniques have reached technical maturity yet. Various research and pilot projects are currently underway for all of these processes, so that we will have to wait and see whether and which of these processes prove to be feasible.

Gasified biomass does not necessarily need to be converted into a liquid fuel. The gas can also be conditioned and fed into the natural gas grid – known as biomethane – or the hydrogen can be separated from it and used in fuel cell vehicles or special hydrogen combustion engines.

The Iogen Corporation employs innovative technology to process cellulose to ethanol in its fermenter

Biogas which is not produced through the gasification of biomass, but rather through the bacterial fermentation of manure, maize, or other energy plants (see "Biomass combustion" chapter) can be employed in motor vehicles just like natural gas or bio-methane. For this purpose, it must then be conditioned until it has the same quality as natural gas and is chemically identical with bio-methane from biomass gasification. Although this option is technically possible, it is prohibitively expensive so far. However, the interest in biogas (bio-methane) is clearly increasing with the growing popularity of natural-gas vehicles in Germany. Biogas has already been employed as a fuel for some years in Switzerland, Sweden, and other countries. A feature of biogas, like BTL, is that the energy content of the entire plant is utilised through the fermentation of energy plants.

The processes in bioethanol production are also being optimised. A technique is being developed which allows the utilisation of cellulose from wood and straw to produce fuel. It uses, e.g., enzymes to break down the cellulose molecule. The cellulose treated in this way can then be fermented.

Biodiesel production plant in the Bio-Ölwerk Magdeburg

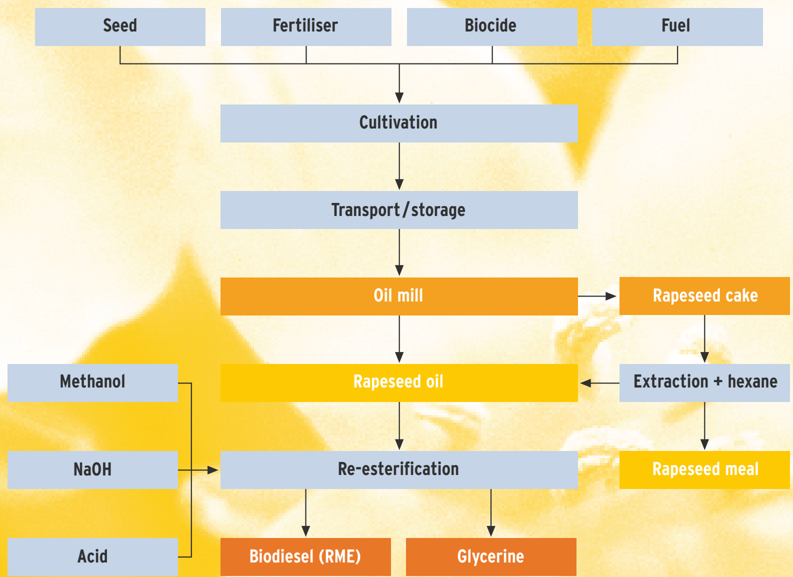
Life cycle analysis of biofuel

Environmental and resource protection are two major components of sustainable development. Therefore, the ecological benefits of each new fuel must also be assessed. Crop cultivation, fuel extraction and conditioning, distribution, and combustion emissions are all important issues for the life-cycle analysis of biofuels.

First and foremost in the use of energy crops is their cultivation. One hectare of land can produce between 3 and 4 tons (dry weight) of rape seed, from which approx. 1,300 to 1,700 litres of biodiesel can be produced. A space the size of a football field will thus suffice to provide enough fuel to run the average car for a year. The rapeseed is pressed and refined – thereby removing undesirable secondary products – and, in the case of biodiesel, then chemically modified. In this re-esterification process, the large rapeseed molecule is broken down into three fragments by adding methanol.

→ Biodiesel production processes

Source: Ifeu



From the farm to the filling station: biodiesel production

Controlling biodiesel

This method not only forms molecules resembling those of diesel fuel, but also glycerine – a raw material in the chemical industry.

Ethanol can be produced in Germany from sugar beets, wheat, or rye, whereby the highest yield is given by sugar beets. The sugar beets are chopped up so that a sugar solution can be extracted from the vegetable. When using starch-containing plants, the starch must first be dissolved out of the plants and then saccharified. The sugar-containing solution is then first fermented using yeast. Finally, the energy-containing alcohol is separated. An average of 62 tonnes of beets per hectare was harvested in Germany in 2004/2005, an amount sufficient to produce ca 6,600 litres of bio-ethanol. Considering the energy content of the harvested ethanol, the yield is almost double that of RME.

The process of producing fuel, however, also requires both energy and materials – and this is where the life-cycle analysis plays an important role. A large part of the energy demand for growing energy crops is due to fertiliser production. And working the fields also requires energy. In the production of biodiesel, the re-esterification process consumes the most energy mostly because of the large quantities of methanol needed.

And yet: the overall energy and climate balance for biodiesel is significantly positive (see Figure: Life-cycle assessment for biofuels). The result does however depend on whether the secondary products, in particular rapeseed meal and glycerine, are used. Rapeseed meal can be used as animal fodder instead of soybeans. Glycerine is primarily used as a raw material in the chemical industry, e.g. in cosmetics production. When glycerine produced from fossil sources is replaced by the regenerative glycerine, a CO_2 credit is given for the biodiesel, which offsets the additional efforts needed for re-esterification. Since glycerine is not a by-product of rape-seed oil production, biodiesel gains a considerable advantage on this point. An excellent energy balance is also found for bio-ethanol from sugar beets, wheat, and rye.

Whereas all bio-energy carriers make a considerable contribution to conserving fossil resources and to reducing greenhouse gases, there are also some ecological disadvantages associated with using biofuels (see Table: Life-cycle assessment for biofuels compared to fossil fuels). For example, the use of biofuels leads to higher acidification of the soil and waters, as well as to increased emissions of nitrogen compounds.

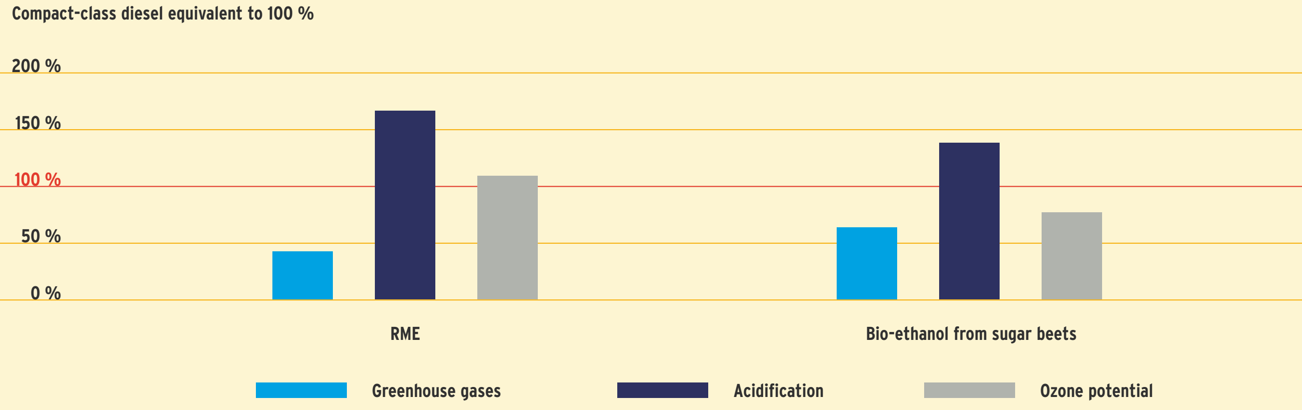
Source: Ifeu

→ Life-cycle assessment for biofuels compared to fossil fuels

Criterion	Advantages for bio-energy carriers	Disadvantages for bio-energy carriers
Consumption of resources	• Savings in fossil energy	• Consumption of mineral resources
Greenhouse effect	• Lower emission of greenhouse gases	
Stratospheric degradation of ozone		• Higher N_2O emissions
Acidification		• Greater acidification
Photo-smog		• Higher potential for ozone to develop
Eutrophication		• Higher NO_x and NH_3 emissions • Possible hazards to surface waters
Human and eco-toxicity	• Lower SO_2 emissions • Lower marine contamination from the exploration and transportation of crude oil • Less contamination from oil spills after accidents • Lower toxicity and better biodegradability	• Possible strain on the surface waters from pesticides • Possible strain on the ground water from nitrates

→ Ecological comparison of RME and biofuels

Source: Ifeu 2003



Ecological pros and cons of biofuels shown relative to a diesel passenger car of the compact class (ethanol as the petrol substitute; RME as the diesel substitute). Interpretation example: If a diesel passenger car of the compact class were to be fuelled with biodiesel instead of fossil diesel, then, although the ecological balance is worse for acidification and summer smog, less than half the amount of greenhouse gases are emitted.

Costs

Bio-energy carriers must not only be ecologically competitive, their costs have must also be comparable to those of fossil fuels. It is not surprising that biofuels are currently more expensive than conventional fuels. Crude oil is cheap compared to agricultural raw materials, only the costs for exploration, conditioning, and distribution must be paid. In the case of rapeseed, wheat, or sugar beets, however, the entire agricultural production must be financed – and of course all of the other processing steps as well. These costs can not be compensated by the revenues from selling the by-products, e.g. the rapeseed extraction meal sold as fodder, and the glycerine from the biodiesel production. Today the production costs can be twice as high as the cost of producing conventional diesel fuel. Only after the exemption from the mineral oil and eco-taxes, granted in Germany in the summer of 2002, can biodiesel compete with normal diesel on the fuel market. Since the beginning of 2004, all biofuels in Germany enjoy tax concessions. In the future, the admixture of biofuels to conventional fuels will be required.

Three independent factors determine the economic efficiency to a large extent: the costs of the feedstock, the prices which can be realised for by-products, and the price of petroleum on the international markets. On the one hand, the development of new breeds can lead in time to increased yields of energy crops, thereby reducing the costs of the raw materials. On the other hand, the price of crude oil will increase in the future because it is a limited resource – it has already tripled over the last four years. Both effects, together with the increasing experience in the production of biofuels, will contribute to reducing the costs of providing biofuels in the future.

A look at the future of biofuels

The European Commission anchored the use of biofuels in European legislation by a directive issued in 2003. Member states are committed to promote biofuels in the transportation sector in two steps. Initially 2 % of all petrol and diesel fuels shall be replaced by the end of 2005; and 5.75 % by the end of 2010. The current German government also included this directive in its coalition contract. The biofuel proportion will mostly be achieved through admixture of biofuels in fossil fuels and only to a small extent with pure biogenous fuels. In their “Biomass Action Plan”, the European Union recently strengthened its stance on biofuels.

The reasons for this support are manifold: A vital farming industry, a contribution towards supply security, the creation of jobs, and last but not least a means of fulfilling obligations to lower greenhouse-gas emissions. The potential alone given by utilising farmland not being used otherwise would lead to 1.2 % to 5 % of the total consumption of petroleum products. Yet not all biofuels are necessarily linked to agricultural farmland. Organic waste in the form of oils and fats, as well as wood-like raw materials, can also be used. Considering the predicted growth in transportation of 2 % over the next ten years, then the use of biofuels could, in any case, offset the effects from this growth in a climate-neutral manner.

The potential for biofuel production, however, strongly depends on the future of German agriculture. Other developments which are also desirable in terms of sustainability require area – e.g. extensive agriculture through ecological farming or the realisation of compensation areas and biotope networks (see “Ecological qualities of renewable energy" chapter). Furthermore, the utilisation of biogenous waste materials and energy crops for fuel production purposes competes with CO_2 savings intended with these materials in other sectors. For example, the combustion of biomass in efficient heat and power cogeneration plants contributes more to climate protection than using the biomass as fuel.

In the long term, the area situation will however relax since agricultural yields per unit area are increasing and the number of people to be nourished is decreasing. At the same time, the second-generation fuels yield significantly more energy. Importing biomass – as a raw material or as a commercial bio-energy carrier – could gain importance.

However, the full development of the efficiency potential, especially in road traffic – both with efficient vehicles and by avoiding and transferring traffic – is an indispensable, robust, and cost-efficient pre-requisite for achieving high shares of alternative fuels in the total fuel demand, and also for achieving the climate protection goals.

Information about biofuels

- Biofuel gateway from the Fachagentur Nachwachsende Rohstoffe: www.bio-kraftstoffe.de
- Union zur Förderung der Öl- und Proteinpflanzen e.V. (promoting particularly biodiesel): www.ufop.de
- Association of biofuels (Bundesverband Biogene und Regenerative Kraft- und Treibstoffe e.V.): www.biokraftstoffe.org

GEOTHERMAL ENERGY

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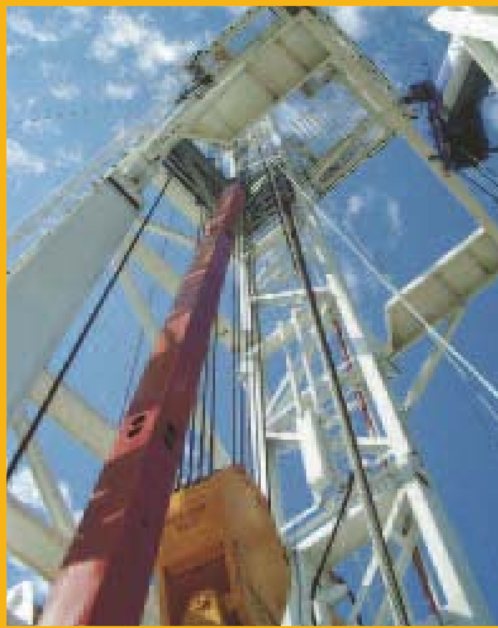

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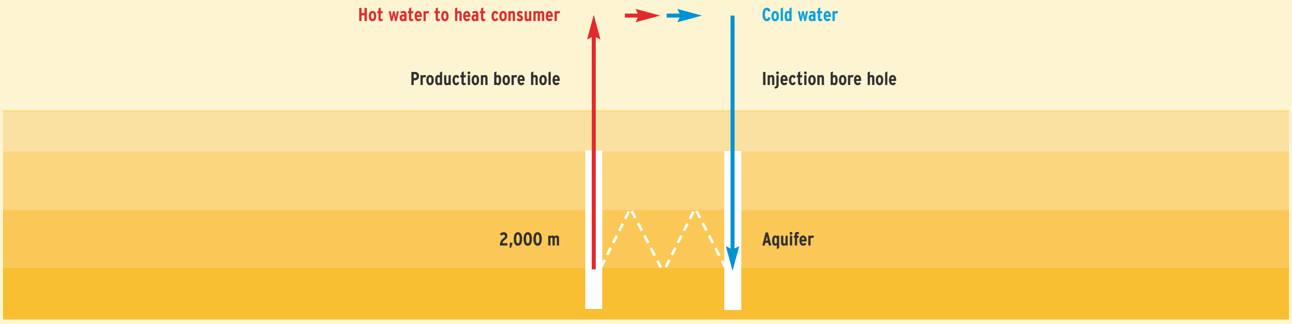

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Resources:	Geothermal: **near surface** (down to 400 m) 7 to 25 °C, **hydrothermal** 25 to 120 °C, **Hot-Dry-Rock systems** depend on the depth
Sites:	Near surface: worldwide; hydrothermal: worldwide, in Germany: North German Lowlands, Upper Rhine Valley, region between the Danube and the foot of the Alps, Swabian Alb, Upper Franconia; Hot-Dry-Rock systems: almost everywhere in the future
Field of application:	Heating and cooling, seasonal storage of heat and cold, ice prevention, process heat, electricity generation
Capacity:	**Near surface:** geothermal probes 6 to 8 kW; **hydrothermal:** 1 to 30 MW thermal; **Hot-Dry-Rock:** 1 to 50 MW electrical
Production costs:	Heat: < 2 to 6 Cents/kWh; Electricity: 7 to 15 Cents/kWh
Figures:	1. Drill bit for drilling at the geothermal power station in Bad Urach, 2. Turbine system at the geothermal power station in Neustadt-Glewe, 3. Hydrothermal geothermal energy, 4. Principle of geothermal energy production

GEOTHERMAL ENERGY – ENERGY FROM WITHIN THE EARTH

Geothermal energy, or heat from the Earth, is heat from the Earth's molten core which reaches the surface. On the way, layers of earth and the rocks are heated, as well as any underground water reservoirs. In some locations, hot water and steam reach the Earth's surface in the form of hot springs or geysers.

The deeper one penetrates the interior of the Earth, the warmer it becomes. In Central Europe the temperature increases by an average of 3 °C per 100 m depth. The temperature in the uppermost mantle is approximately 1,300 °C; in the Earth's core it is probably around 5,000 °C.

The heat stored in the Earth is inexhaustible by human standards. Every day, an amount several times the global energy demand ascends from the depths of our planet and escapes unused into space. Most of this heat flow originates from the continuous decay of radioactive elements in the mantle and in the Earth's crust, a process which will continue for billions of years. This source of energy can be used practically everywhere.

A transportation medium is normally needed to tap this underground heat. The basic principle is simple:

- The transport medium is either already available underground in the form of steam or hot water. In this case, it is extracted to the surface where it cools down and then normally returned back underground again;

- Or a transport medium, e.g. water, must first be pumped to the required depths where it is heated and then returned to the surface again.

The heat thereby acquired can then be used directly for heating purposes or for other heat consumers. Equally attractive is to use geothermal energy for electricity generation, because it is available around the clock and can be regulated according to the demand. Geothermal energy power stations could thus provide a major contribution to the basic supply of renewable electricity.

Large quantities of heat are also produced during geothermal electricity generation. In the majority of cases, this heat can only be used by the buildings nearby when they are connected to a local heating grid. A large increase in the numbers of local heat grids is thus a major prerequisite for developing the considerable potential of geothermal energy.

We distinguish between four principal types of geothermal energy use:

Hot-Dry-Rock method

The use of hot dry rock layers (HDR) at depths as far down as 5 km is one possibility for geothermal generation of electricity and heat. A heat-transfer medium must be circulated through the usually crystalline rock to bring the heat to the surface. Without any additional measures, the heat-exchange area and the permeability would be far too low to pass water through the layers of rock. For this reason, a deep bore hole is first made from which the water is forced into the rock under very high pressure and at a sufficiently high rate to provide a so-called "hydraulic stimulation". Naturally occurring cracks and gaps are thereby expanded and sheared hydraulically to give new cracks, which increases the permeability of the rock. A "natural heat exchanger" is obtained in this way.

→ Geothermal energy

Basin with proven hydrothermal resources

Basin with potential hydrothermal resources

Basin probably without hydrothermal resources

Bedrock without or with little sediment coverage

Source: GeoForschungsZentrum

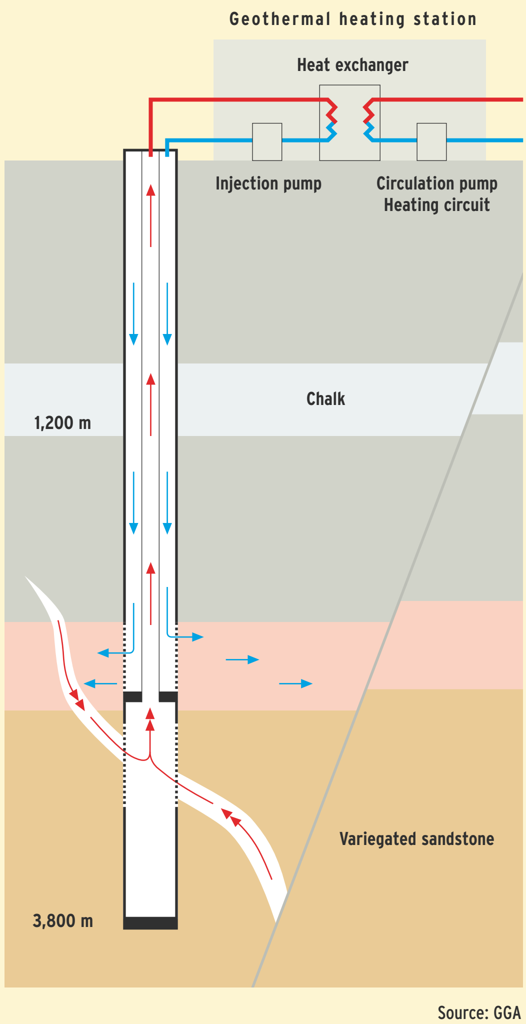
Geothermal resources in Germany

A HDR plant is operated by pumping cold water to the depths through an injection drill-hole and returning it to the surface again through a second (production) bore. The water heated by the hot rocks at these depths can be fed into district heating networks or provide steam for industrial purposes. It is particularly attractive to generate electricity from this geothermally heated water. So-called ORC turbines (ORC = Organic Rankine Cycle), which work essentially like a steam turbine, are used for this purpose. However, due to the comparably low temperature of the heat transfer medium, between 100 °C and a maximum of about 180 °C, it is necessary to use an organic liquid with a low boiling point (e.g. ammonia) instead of water in the steam turbine circuit. The electrical efficiency of this cycle is between 8 and 12 %. Crystalline rock layers can be found underground almost everywhere in Germany. The HDR technique can therefore exploit 95 % of the geothermal potential, an amount which is sufficient to cover the entire base load of Germany's electricity needs.

The exploitation of this potential is still inhibited by a lack of economic efficiency. Just a bore hole down to a depth of 5,000 metres costs several million Euros. Thus locations are preferred where crystalline rock and high temperatures are to be found at comparatively shallow depths. This case is true in the Upper Rhine Basin. The total investment costs are estimated at about 2,500 to 5,000 Euros/kW. The costs for generating electricity are then – for 8,000 full-load hours per year – about 7 to 15 Cents/kWh.

In a research project in Soultz sous Forêts (Upper Rhine Basin), three bore holes were sunk to depths of 5,000 m. Temperatures exceeding 200 °C were encountered there. Attempts are currently underway to further improve the underground circulation system between the injection bore hole and both production bore holes which are each 700 m away, and to prove the long-term stability. In the medium term, 1.5 MW electric power should be generated in a pilot plant by 2007. The system should be further expanded in the long-term future. One goal of the project is to introduce standardised and cost-effective HDR systems to the market.

→ Energy production from deep plutonic rock



Basic principle of geothermal energy production from deep plutonic rock

High-temperature hydrothermal systems

Under certain geological conditions, hot water can also be extracted from water-carrying layers – the aquifers – and then used for electricity and heat generation. However, the temperature should exceed 100 °C for electricity production. A sufficient quantity of thermal water must also be available. In some European countries, e.g. Iceland and Italy, suitable thermal water deposits can already be found at moderate depths. In contrast, it is necessary to bore to depths of at least 4,000 meters to reach adequately high temperatures and water quantities in Germany, and that only at special locations like the Upper Rhine Basin (Upper Rhine Basin) and at the base of the Alps in Bavaria.

The first German geothermal power station started operation in Neustadt-Glewe near Schwerin in November 2003. The existing hydrothermal heat plant constructed in 1995 was supplemented by an ORC turbine with an electrical capacity of 210 kW. A considerably larger power station with a capacity of 3360 kW is planned to start operation in 2007 in Unterhaching, Bavaria. A bore well sunk already in 2004 delivers 150 litre thermal water per second at a temperature exceeding 120 °C. Excess heat is fed into the local district heating grid.

The thermal water is extracted to the surface through bore holes, and the heat is transferred to a steam turbine or other heat consumer. Again the ORC cycle

Capping a bore hole and preparing for hydraulic tests

is implemented here. The water is then returned to the depths through a second bore hole in order to maintain the underground water balance. These highly mineral-ised thermal waters cannot normally be disposed of above ground for environmental reasons.

Low-temperature hydrothermal systems

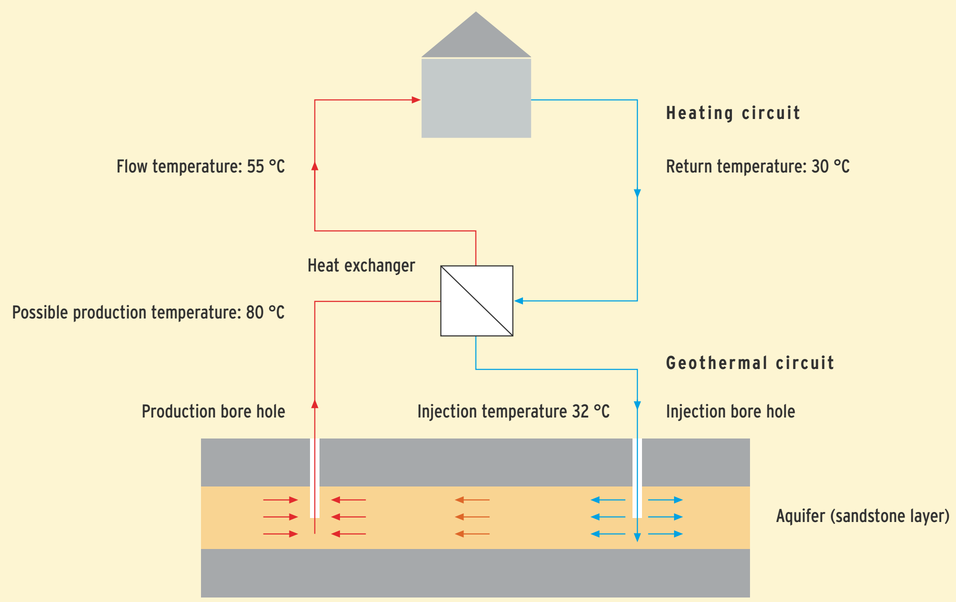
In other regions of Germany, especially in the South-German Molasse (malmkarstic) Basin, in the Upper Rhine Basin, the Swabian Alb, and in parts of the North-German lowlands, the temperature of the underground water can reach between 40 °C and 100 °C, too low for electricity generation at most sites. Instead, this geother-mal energy is used for heating buildings and for hot water, in thermal baths, and for commercial purposes (e.g. for heating greenhouses). In Southern Germany, especially in the region between the Danube River and the Alps, the thermal water can also be used as drinking water once it has cooled down because enough water is flowing underground and the mineral content is low.

In Pullach, thermal water at a temperature of 94 °C was found after drilling only 42 days to a depth of 3,300 m. A second drill hole found 107 °C water. A marketing campaign has been running since September 2005 with the goal of convincing as many customers as possible to join the new local heat grid.

The investment costs for a geothermal heating plant lie in the range of 400 to 1,000 Euros/kW for an installed heat capacity between 3 and 30 MW. A heat distribution system incurs additional costs. Depending on the tem-perature level and the abundance of the source, the costs for heat production can be between 2 and 4 Cents/kWh, assuming utilisation of between 2,500 and 3,000 full-load hours per year. For industrial customers with a higher utilisation (more than 5,000 h/year), the costs of producing the heat can fall to under 2 Cents/kWh.

Hydro-geothermal energy has long been tapped as an energy source in Germany. Nearly 30 systems produced ca 0.12 billion kWh of geothermal heat (excluding thermal baths) in 2005.

→ Hydrothermal system



Production and utilisation of geothermally heated water

Deep geothermal energy probes

Existing deep bore holes sunk during explorations for natural gas, geothermal energy, or to find possible final-storage facilities for nuclear waste, can also be used in harnessing geothermal energy. Presumably there are between 5,000 and 7,000 such bore holes in Germany. So-called double-tube probes are fed into these deep bores down to depths as far as 4 km. Water circulates through these probes in a closed circuit. Deep underground, the water is heated; at the surface the heat is delivered to a heat-pump circuit (see "Heat pumps" chapter).

The technically potential of such probes is about 800 billion kWh/a in Germany. The heat capacity per probe is however much lower than that of a similarly expensive hydrothermal bore hole. Therefore, the high costs are currently the main problem associated with this technology. The economic conditions are more favourable if an existing bore hole can be used.

Near-surface geothermal energy

The so-called near-surface geothermal energy, heat from the uppermost layers of the Earth or ground water, is also useful in heat pumps, as is described in the following chapter entitled "Heat pumps".

Research needed

Intensive research and development is necessary to make progress in the production of energy, especially electricity generation, from geothermal sources. Moreover, the creation of large-scale heat-exchanger areas deep under ground (HDR technique) and improving the ORC process are to be optimised in future projects. Drilling technology has to be adjusted to the needs of geothermal energy. Also, the methods of determining and registering the occurrences of hydrothermal reservoirs must be improved.

The Federal Environment Ministry supports several projects on deep geothermal energy within the scope of the German government's Energy Research Programme. Systems for geothermal electricity generation and combined heat and power generation are to be constructed in the various regions in Germany which have suitable geothermal resources. Different technologies will be used – depending on the location – such as the Hot-Dry-Rock technique, exploiting existing deep bore holes, and using the hot water from aquifers and karst regions. The first German geothermal power station, supported by the Federal Environment Ministry, began operation in Neustadt-Glewe in November 2003.

Geothermal bore hole in Groß Schönebeck

Information about geothermal energy

→ Geothermische Vereinigung: www.geothermie.de

→ GeoForschungszentrum Potsdam: www.gfz-potsdam.de

HEAT PUMPS

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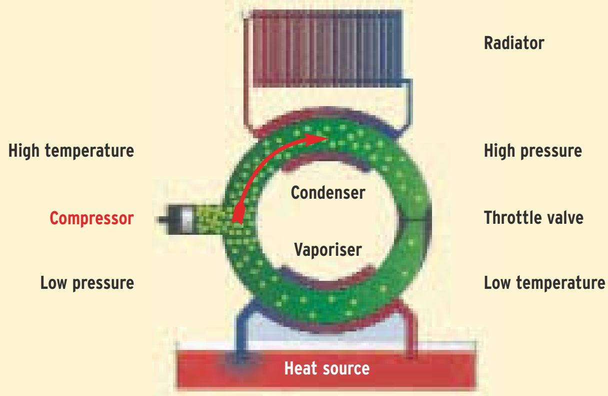

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Resources:	Ambient heat in the ground, water, and air
Sites:	Worldwide
Field of application:	Hot water, heating
Capacity:	1 kW to 1 MW
Production costs:	15 to 20 Cents/kWh
Figures:	1. Ground as a heat source, 2. Water as a heat source, 3. Air as a heat source, 4. Basic principle of a heating system with a heat pump

HEAT PUMP – A HYBRID

The utilisation of ambient heat with the help of heat pumps differs in one major aspect from using other sources of renewable energy. Namely, a heat pump is driven by a considerable amount of external energy, amounting to anywhere between a quarter and one half of the energy which is used as heat, depending on the exterior conditions. This technology is therefore also considered as a **rational use of energy**, i.e. the same category as low-energy heating boilers. Yet there is also a major difference from these techniques: Heat pumps use more than just the energy supplied for running the pump, but also energy from the surroundings. The decisive factor is whether or not the renewable energy proportion predominates. Thus the heat pump is a hybrid between an economical conventional use of energy and a source of renewable energy!

The principle of the heat pump

A heat pump is not any more mysterious than a refrigerator. Both devices transport heat. In a refrigerator the heat is removed from the cooling compartment and released again through the heat exchanger at the back of the unit. A heat pump removes ambient heat, usually from the surrounding ground, and releases it to the heating system of the house. The functional principle is the same for both devices.

There are different technical variants of heat pumps. The most widespread are the so-called **compression heat pumps**. Small-scale heat pumps for space and water heating in single-family houses are normally driven by electric motors; larger systems can also be driven by gas-powered engines. The advantage of these gas-powered engines – which resemble conventional combustion engines – is the high-efficiency transformation of primary energy, together with the added advantage that the cooling water needed for the engine can be used to further increase the heating temperature. The specific investment costs are however generally higher, as are the operational and maintenance costs. Work is continuing to further develop small-output heat pumps driven by gas-powered engines. Also, the heat pumps driven by electric motors are subject to ongoing developments, especially so that they can better adjust to the immediate heating needs and the momentary temperature of the heat source, and in this way attain a higher efficiency. The units currently available on the market are considered technically mature.

Air, earth, and water contain useful energy

Heat pumps can tap the ambient heat in different ways. **Ambient air** is most frequently used. Its advantage is that air is available everywhere and at all times. A drawback is that the ambient air is always coldest when the need for heating is greatest, namely in winter, which lowers the yield from the heat pump. The greater the difference in temperature between the heat source, i.e. here the air, and the useful heat, the more energy is needed to drive the pump and obtain the same result.

It is energetically more favourable to use e.g. the **ground** as the heat source. At a depth between 1 and 2 meters under ground, the temperature in winter does not generally drop under 5 °C. With pipes lain in the ground carrying brine as a medium, the energy can be absorbed and brought to the heat pump. In this way, the temperature range in the heat pump can be kept relatively constant over the year and the amount of energy required is kept low. These ground collectors – referring to the pipes in the ground – are however more costly than those using ambient air. The area needed for horizontal ground collectors can amount to between one and one-and-a-half times the floor space of the dwelling to be heated. The garden surrounding the house can be

Maintenance work on a heat pump which uses ambient air for heat production

used for this purpose and, once the collectors have been laid, then still serve as the garden. If this area does not suffice for the heating purposes – and this is often the case considering the land plots nowadays for new constructions - then the collectors can also be sunk vertically as probes in the earth. For this purpose, bore holes are sunk into the ground to a depth of as much as 150 m into which the brine-filled pipes are then inserted. One major disadvantage is that these earth probes are even more cost-intensive than horizontal ground collectors and, furthermore, permission concerning the water rights must be obtained from the authorities. The energy thus collected by earth probes originates primarily from the surroundings whose average temperature is determined by the annual solar irradiation.

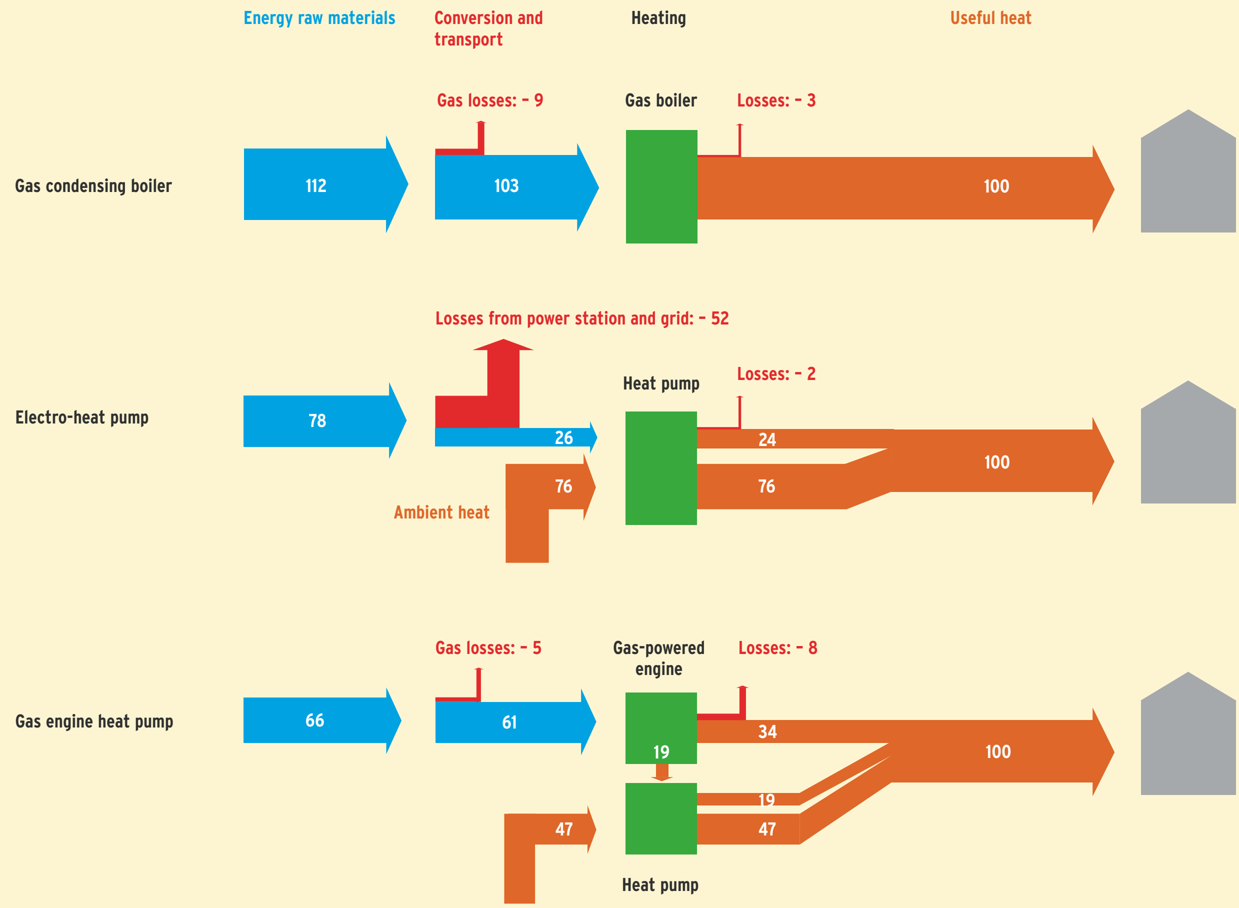
If the heat provided is to be used for heating purposes, then a low flow temperature in the heating system is advantageous. If the flow temperature is lowered by one degree, then the heat pump needs 1 % less energy. Underfloor heating and wall heating systems are therefore very suitable. Hot-air heating systems also require only low flow temperatures and they may become more common in the future, especially combined with controlled ventilation.

Costs and prospects

Initial costs of ca 11,000 Euros must be calculated for a heat pump installed during the new construction of a well-insulated single-family house. Depending on the local conditions, an additional 9,000 Euros must be invested in the ground collector so that the total investment costs for the entire heat pump system are about 20,000 Euros. The costs for old buildings will be higher, since a larger heat pump will be necessary to meet the higher heating requirement. Additional costs will be incurred for construction measures to reduce the flow temperature to that required by the heating system. The resulting heating costs will then depend on the extent to which the local electricity supplier offers special tariffs for electric heat pumps. The specific costs per kilowatt-hour heat range between 15 and 20 Cents/kWh.

Source: DLR

→ Energy balance for heat pumps



Energy flow and efficiency of different heat pump systems compared to a gas condensing boiler. An annual performance coefficient of 4 is assumed for the heat pump in these calculations.

At the end of 2005, there were approximately 151,000 heat pumps for heating systems installed in Germany; a third of them were installed before 1984. Following a boom in the early eighties, when high oil prices made heat pumps look like a good economical choice, the demand for heat pumps first declined considerably. Since the beginning of the nineties, however, the demand has increased again, not the least because of greater marketing efforts by the electricity companies. In 2005, 18,200 of these systems were newly installed, a 44 % increase over the previous year. Three fourths of these heat pumps withdraw the required heat from the ground or the ground water, the rest from the ambient air. An additional 4,860 units are only used for domestic water heating. Heat pumps enable the use of an estimated total of 1.5 billion kWh of ambient heat.

Some series of heat pumps are designed to fit easily in the interior decoration of a house, e.g. in a kitchenette

Heat pumps – part of a sustainable energy supply?

A considerable amount of external energy is required for running the heat pump. For this reason, it is important to determine the ratio of input energy to the yield of useful energy for this technology, thereby considering the entire chain from the energy source, its processing, and its use in the heat pump. If electricity is the external energy running the pump, then, because of the losses during electricity generation (currently about two thirds of the initial primary energy), it is necessary to at least triple the heat yield if the amount of fossil or nuclear energy is to be less than the amount of used heat. This ratio, designated as the performance coefficient, determines whether renewable energy will be used at all in the overall energy balance. Since the losses incurred in the natural gas supply system are less than those in the electricity supply, and in particular there are no losses from the power stations, the required annual performance coefficient needed for heat pumps driven by gas-powered engines need only be 1.1 in order for the system to have a positive energy balance (see Figure: Energy balance for heat pumps).

Electric-powered heat pumps save fossil energy carriers or carbon dioxide (CO_2) only for a performance coefficient of 3.0 or higher. Regarding pollutant emissions – for example nitrogen oxides and carbon monoxide – they can however offer advantages over conventional heating boilers, in particular oil-fired boilers, even for low performance coefficients, since the specific emissions from power plants in the Federal Republic of Germany are low thanks to the efficient pollution control measures already in force.

The intensified use of electrical power for heating is, however, problematic for energy policy, since nuclear power is being phased out and the electricity supply is predominately based on fossil energy carriers. But with electricity being generated increasingly from renewable energy sources and from combined heat and power plants, the electrical heat pump will become more and more interesting from the ecological point of view.

Information about heat pumps

- → Bundesverband Wärmepumpe: www.waermepumpe-bwp.de
- → Schweizer Bundesamt für Energie: www.waermepumpe.ch

FUTURE SUPPLY STRUCTURES – DECENTRALISED GRIDS, COMBINED HEAT AND POWER GENERATION, VIRTUAL POWER PLANTS, AND HYDROGEN

The structure of our energy supply has rapidly changed in recent years. The share of renewable energy carriers has increased greatly within just a few years. Flexible, high-efficiency gas power stations have become more important. Small combined heat and power units are entering the market for the simultaneous generation of electricity and heat. The electricity trading activities have increased through the liberalisation of the electricity market and the introduction of an electricity exchange market. Finally, the current power station park is ageing and needs to be modernised. This restructuring process will keep proceed further, since the expansion of renewable energy is progressing successfully. Our power generation structure is thereby becoming more decentralised.

The integration of renewable energy in the power grid presents no problems, even for the high shares already being generated today. It is indeed true that wind farms do not generate electricity in a lull, or solar cells in the darkness of the night, and that a small cogeneration plant operates according to the heat demand of the operator and not according to the electricity market requirements. However, the renewable energy carriers already partially compensate among themselves: if there is no wind at one particular site, the network of German wind turbines will still be generating electricity.

In this control room belonging to the STEAG Saar Energie, power plants and disengageable consumers are linked nationwide. The STEAG markets this power for grid regulation.

Moreover, wind power can be closely predicted in the meantime. Wood, manure, and other biomass, as well as the heat of the Earth, can be converted to electricity around-the-clock whenever electricity is required. In technical jargon we say they are base load capable.

The integrated electricity grid in Germany already enables a certain equalisation of capacity excesses and deficits due to the numerous generators, consumers, and storage possibilities connected to it. All the same, the discrepancy must be compensated for if the generated power and the consumption should sometime not agree. This “energy gap” does not occur just for renewable energy. Disturbances in conventional power stations, shut-downs for inspections, and fluctuations in the energy demand – the proverbial half-time break during an international soccer match – also cause such gaps. Regulating power plants are required to compensate between power generation and its consumption. Nowadays, besides storage power plants, throttled steam and gas power stations are also used for this purpose.

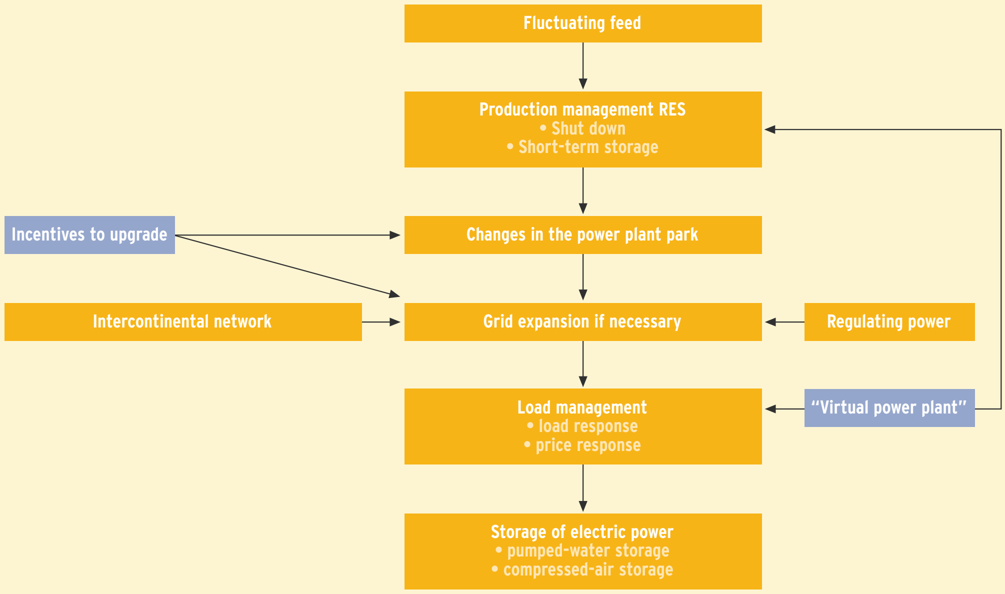
Optimised integration of renewable energy

The subject of this chapter is the long-term modification of the energy system to accommodate significantly higher shares of renewable energy. Incidentally, a similar modification process was also necessary in the 1970s and 1980s, when most of the nuclear power plants were constructed. At that time, new high-voltage lines were installed to a considerable extent, night-storage heaters were marketed, and large electric-powered hot water boilers were installed in order to sell the electricity produced by the nuclear power plants at night. Examples from other countries demonstrate that it is possible to smoothly integrate large shares of decentralised energy carriers.

For example, Denmark’s electricity supply is characterised by the highest percentage of combined heat and power generation and wind power in Europe. Resulting from the forceful political promotion of cogeneration, 50 % of electricity and 80 % of district heat are supplied by cogeneration plants. The contribution of wind power in the total power supply exceeds 18 % of the electricity demand in Denmark. Under some conditions, the electricity generation from cogeneration and wind turbines even exceed the demand. The load compensation required for grid stability in Denmark is managed both

➔ Optimal integration

Source: Ifeu



Optimal integration of renewable energy in the power supply mix.

through regulating the capacity of the few large power generators and through the appropriate import and export of power. A three-stage tariff system adjusts the power generation from the decentralised power plant to the electricity consumption each day.

It is important to optimise the energy system as a whole through intelligent management by producers and consumers, by an appropriate power station mix, and with expanded possibilities for storing electric power.

— **Appropriate power station mix:** Whereas Germany's power supply is mostly generated by slow-regulating coal and nuclear power stations, modern gas power stations, for example, are not only highly efficient, but at the same time are also easier and faster to regulate and are thus better able to compensate for the fluctuating load and generation trends. The fast regulation capability is not the only feature in favour of the combination of gas power stations and renewable energy; the low investment costs are also a benefit of this power station type. Lignite or nuclear power stations have lower fuel and operation costs, but comparably high investment costs. They must therefore run around-the-clock ("base load power stations") in order to "earn back" their investment costs. Modern gas power stations, on the other hand, are so-called medium-load power stations. They are already profitable for low operation time and are therefore well-suited to equalise renewable energy.

— **Load management** involves systematically influencing the level and time structure of the electricity demand. If the supply is low or the demand is high, certain consumers can be shut off for a few hours. The electricity customer is financially rewarded for his flexibility. For example, supplier and customer can agree that an appropriate control technology will be used to shut off the consumer. This arrangement is already in practice for several industrial customers.

A Norwegian power supplier even involves private household customers by sending them a text message with a signal to shut down. Each household can decide in advance, whether or not they want to participate in the flexible shut-downs. First experiments with time-flexible tariffs are also underway in Germany. Washing at night, automatic refrigerators which turn off temporarily during periods of high demand – such technical finesse reduces the necessity for the supplier to compensate for fluctuations with regulating power stations.

The advances in communication technology simplify this type of load management considerably. For example, 30 million innovative electricity counters are already installed in Italy. They have communication interfaces and not only do they allow remote reading, but also the remote control of consumer and service information.

A variety of electricity-consuming machines exist which can easily be shut off temporarily, e.g. refrigerators, or storage heaters, water pumps, or melted metal. Cooling applications and ventilation/air conditioning are each

This family in Stutensee near Karlsruhe is participating in an experimental test: their electricity tariff is communicated to them by text message – it varies day-by-day depending on the wind conditions, electricity demand, and other conditions.

responsible for about 9 % the total German electricity consumption. These segments are generally easy to offset in time. Circulating pumps in heaters are also possible offset loads. They can shut off depending on the frequency of the grid and thus serve as an immediate reserve. The household consumer segments laundry, dish washing, and electrical heating are suitable for load management.

— **Generation and feed management.** Not only consumers can be involved in the optimisation. Renewable electricity generation systems can also be integrated in the power station utilisation planning by means of modern communication technologies. For example, wind farms can be temporarily switched off in overload situations. The specific conditions and time limitations for this case must be guaranteed by contract.

— **Energy storage.** Another method to equalise electricity feed and demand is the intermediate storage of electric power. The storage can be decentralised, e.g. in batteries, or centralised. So far, especially pump-storage hydropower stations have been used for storing large amounts of electric power. They exploit the height difference between water bodies (see "Hydropower" chapter). Large pumps transport water into storage lakes. The water flows back later and drives power turbines in the process. 280 such pumped-storage plants exist worldwide. The giant among the German systems is the Kraftwerk Goldisthal in Thuringia. It has a power capacity of over 1,000 MW and started operation at the end of 2003, four decades after beginning the first plans.

Pumped-storage power stations already provide an important contribution for the security of the power supply and for the quality of the electricity today. Their operation mode can be better adjusted to the requirements of renewable energy in the future. Pumped-storage power stations, however, require a large amount of area and sufficient height difference. The environmental impacts must be carefully examined prior to construction and they require a long preliminary lead time. The potential for this storage technology is limited in Germany.

In the long term, the compressed-air storage power stations, which are still being developed, appear to be an interesting alternative. In these systems, the electricity to be stored is used to run an electrically powered compressor to compress air into deep salt domes, 600 m underground, to pressures of up to 70 bar. At peak times, when the electricity demand is high, this air flows back out of the caverns and drives a turbine. This type of power storage is known as CAES, Compressed Air Energy Storage. Whereas the current compressed-air storage plants still require fossil auxiliary power, a so-called "adiabatic" plant is being developed which does not require fossil fuel. For this purpose, the heat from the compressed air is intermediately stored in a giant heat store. Such a power station can achieve a storage efficiency of 70 %.

— The **prediction** of renewable electricity generation is also continuously improving. Regulating energy is especially expensive when it is unexpected and must be acquired on short notice. Prediction techniques for wind power generation have considerably improved in the last years and are still being improved. The specific demand for regulating energy will therefore decrease in the future.

— In the long term, further measures will improve the total energy system. By restructuring the regulating energy market, for example, a Germany-wide coordination of the balancing effects of today's four dif-

Pumped-storage power station Hohenwarte an der Saale

ferent regulating zone could reduce the demand for regulating energy. Transferring electricity past Germany's boundaries will also increase the equalisation effects between North and South, West and East. Importing solar electricity from southern countries would further increase the regularity of renewable electricity production.

The "virtual power station"

The rapid development of information technologies is helping to pave the way to a decentralised energy supply based on cogeneration plants, renewable energy systems, and conventional power stations. Already today, manufacturers of small cogeneration plants offer internet interfaces for them which enable a remote control of the system. Self-learning systems are also employed. The unit's control system notices, for example, when the household requires more electricity. At these times the excess heat is then used to charge the heat store. In this way the expensive electricity drawn from the grid can be minimised – and the electricity-demand profile is smoothed. Such a cleverly controlled small power station fits in with the trend to a "smart house". The mini-cogeneration plant is then the energy management centre.

We can go one step further with the "virtual power station" which links a number of small power stations with data links using ISDN, GPRS, cellular radio, or Powerline so that the systems can operate like a single power plant. Virtual – "to be in effect, but not in appearance", according to the Oxford English Dictionary – does not mean that the power station does not produce real electricity. It refers to the fact that there is no large, spatially localised power house with turbines and generators. The hub of the virtual power station is a control unit which processes the data of the decentralised power stations, compares them with predictions of the power demand, power generation, and weather, retrieves the prevailing power market prices, and then intelligently optimises the overall power station activity.

Some public utilities already use such systems. They integrate cogeneration plants, wind farms, photovoltaic systems, and other power stations into one system. The virtual power station can link more than just producers. It is even more intelligent to also integrate consumers into the management system.

Future power grids

The **power grids** must also change to realise decentralised structures with high shares of renewable energy. Whereas today's grids are designed to transport power from a few, localised power stations to the consumers, the future system must be more versatile. Large power stations will feed electricity into the high-voltage grid; small decentralised systems – e.g. solar power systems, cogeneration plants, or wind turbines – will deliver their power to the low- or medium-voltage grid; and the data streams will optimise the system operation. In order to transport the electricity from wind turbines in North Germany and from offshore systems to the consumption centres, a limited number of high-voltage transmission lines will also need to be constructed. These power lines will also be available for power trade.

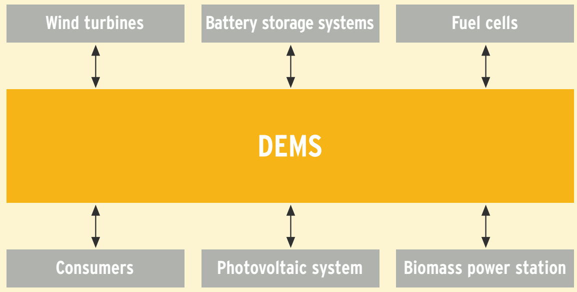
Combined heat and power generation – efficiently using renewable energy

Decentralised supply structures offer more possibilities. When a large power station generates electricity, large amounts of steam are produced and converted to electricity using turbines. High losses are incurred during conversion. Despite continuous improvement, the mix of large power stations in Germany has an average efficiency of only 36 %. In other words: nearly two thirds of the energy in the fuel is wasted – released to the ambient air through large cooling towers or heat up our rivers.

Through combined heat and power generation we make a virtue of necessity and also use the exhaust heat from power generation to heat homes, swimming pools, or to provide industrial process heat. In this way the energy contained by the fuel is used two-fold: to produce electricity and to heat. In principle, every power station can be converted into a "heating-power station". Decentralised small power stations are however particularly suitable, since then the heat does not need to be transported as far.

In Germany, 14 % of the electricity demand is supplied with combined heat and power. A large majority of it originates from large power stations which deliver their heat to district heating grids, from industrial heat and power coupling, and from steam turbine systems.

→ Decentralised energy management system



Source: Konwerl 2003

Example for components of a decentralised energy management system (DEMS)

Motor cogeneration plants come in different sizes: large (above) and small (below).

However, block-type cogeneration plants – compact and small systems for simultaneous electricity and heat supply – also contribute.

Cogeneration plants exist in all sizes, from one kilowatt to several megawatts. Different technologies are suitable for cogeneration: spark-ignition engines, fuel cells, gas turbines, Stirling or steam engines. However, so far only spark-ignition engines are commercially available. The Stirling engine is nearing market maturity, while the other types still need further development.

Motor cogeneration plants are just the same as sparkignition or diesel engines like those used in automobiles. In the sparkignition engine a fuel, e.g. natural gas, is mixed with air and compressed in a cylinder. This mixture is ignited with a spark plug and explodes. The kinetic energy released during the explosion is not used to drive a vehicle, but rather to drive an electricity-generating turbine. The heat of the exhaust, the lubricating oil, and the cooling system is transferred to a circulating water system through a heat exchanger.

The electrical efficiency of these cogeneration plants – the percentage of the fuel energy which is converted into electricity – is generally between 25 % for small and up to 40 % for large units. Adding in the heat use, a total of between 80 and 95 % of the fuel energy is utilised. As a result of these high efficiencies, even cogeneration plants running on natural gas are more environmentally compatible than fossil-fuelled power stations without heat and power coupling. Cogeneration plants can however also be run on renewable fuels, e.g. biogas, sewage and landfill gas, vegetable oil, or gasified wood.

A small cogeneration plant can be installed in a boiler room. Larger plants are not used for a single home, but rather for larger objects, e.g. nursing homes, swimming pools, or hospitals. The heat can also be fed into local or district heating grids, supplying many individual homes.

Ticket to the heat market: local heat

New supply and distribution structures are also necessary in the heat sector. A particularly important example for new heat supply structures are local heat grids.

They are the "ticket" to environmentally compatible energy technologies. They can link, for example, woodchip-fired boilers, straw-fuelled heating plants, solar collectors with long-term stores, biogas plants, or block-type cogeneration plants with biogas gasifiers together along with fossil-fuelled heating systems. Local heat grids are therefore the "missing link" between a centralised and a decentralised energy supply as well as between today's fossil-based heat supply and one supported by renewable energy in the future. Local heat grids not only offer a higher degree of comfort for the customers, but also simplify the integration of renewable energy for the following reasons:

- conversion technologies can be implemented which for technical reasons can only be realised, or which perform better, for high capacities, e.g. gasifiers or deep geothermal energy;
- large systems can use cheaper fuels;
- storage technologies can be implemented, thereby enabling seasonal storage – summer heat for the winter months;

– by coupling various types of renewable energy carriers, fluctuating heat supply can be equalised (e.g. coupling solar collectors with an auxiliary wood furnace);

– large aggregates can be implemented, which have more cost-effective specific investment costs and characteristics than small ones. For example, the heat costs for a large solar system are a factor of four less than those for a small system;

– flexible investment decisions can be made; different systems or energy carriers can also be installed retroactively so that the transition from a fossil to a renewable heat supply can develop successively.

A large solar collector field supplies a local heating grid in Neckarsulm.

Looking to the future: the hydrogen supply

Hydrogen from solar energy and water: this tempting vision of a completely new supply infrastructure was already formulated by Jules Verne in 1874. Today, hydrogen is experiencing another renaissance, mainly due to the combination of the following three developments:

– Renewable energy is, in the meantime, being taken seriously as a major option for energy in the future. The time- and space-dependent supply characteristics of heat and electricity generation from renewable energy sources need to be better harmonised with consumption patterns. As a consequence, the further expansion of renewable energy is necessarily associated with the rapid introduction of hydrogen.

– The transportation sector is almost completely dependent on the scarcest fossil resource, mineral oil. The demand for petrol, diesel, and kerosene is increasing from year to year. Primarily hydrogen is being proposed as a possible new fuel, produced from other energy resources, to satisfy the globally increasing demand.

– The third reason for the renaissance of hydrogen is the fuel cell: This innovative and very efficient energy converter transforms hydrogen and oxygen into water while generating electrical and thermal energy and without producing any of the pollutants associated with conventional fuels and engines. An ideal symbiosis between electricity and hydrogen thus appears to be possible.

This fuel cell runs on natural gas. Hydrogen is produced in the unit and then converted to electricity and heat in the cells. A similar system is currently being equipped to run on biogas.

It's the process that counts

The use and significance of a hydrogen economy depend first and foremost on the source of the hydrogen. The economic and environmentally friendly production of hydrogen is the key problem, even though hydrogen is the most abundant element in the universe and also the fuel of our sun. Yet because it is so reactive, it is only present on the Earth in bound form: for example in water, in carbohydrates, in biomass, or natural gas. Hydrogen, therefore, must first be chemically separated, a process requiring energy. Hydrogen is only as clean as the process which produces it. We distinguish between two fundamentally different methods:

This electrolyser splits water into its components hydrogen and oxygen (below). Hydrogen filling station (above).

electrolysis and reformation/gasification (see Figure: Principles of hydrogen generation):

- electrolytic production from water: the most simple and efficient method for hydrogen production is the electrolysis of water in which electricity is used to break down water into its components hydrogen and oxygen. Hydrogen forms at the cathode and oxygen forms at the anode of an electrolysis cell under DC voltage. Advanced electrolysers have efficiencies of ca 70 % today; values of ca 80 % are expected in the future.

- reformation of natural gas or mineral oil and coal gasification: the by far largest share of hydrogen is produced today from fossil energy sources by using carbon or carbonaceous energy carriers (natural gas, crude oil) to reduce steam to hydrogen. The efficiency for steam reformation lies between 67 % and 74 % for today's plants – depending on the size – and could increase by 3 or 4 more percentage points in the long term.

On the one hand, however, reformation requires additional energy, and on the other hand, it also inevitably liberates the greenhouse gas carbon dioxide. As a result, the specific greenhouse gas emissions for hydrogen produced from fossil fuels are always going to be higher than those of the original fuel. Unless a particularly efficient energy converter can compensate for this disadvantage – a case which is true for several applications of fuel cells run on natural gas – it is not reasonable to use hydrogen of fossil origin. Hydrogen which is generated using renewable energy, however, is responsible for only low emissions of greenhouse gases.

The process of separating the CO_2 emitted during the generation of hydrogen right at the source, liquefying it, and storing it in underground caverns is known as "CO_2 sequestration". Large-scale production of hydrogen with this "clean coal" technique is, however, not likely before 2025. The hydrogen produced in this manner, at approximately 7 to 8 Cents/kWh, would be more expensive than the relatively cheap hydrogen from natural gas available today at ca 4 Cents/kWh.

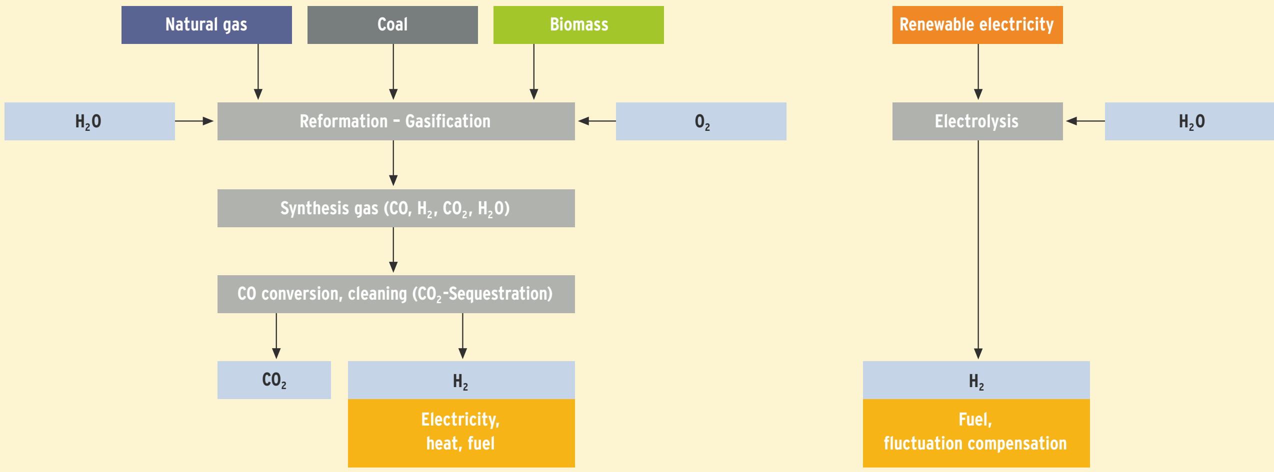
Hydrogen generated from electrolysis with renewable electricity, which is also still relatively expensive, will likely enter the same cost region as "clean coal" in the medium term due to the economies of scale – it is also unlimited (see Figure: Hydrogen costs).

The energetic use of hydrogen

As a chemical energy carrier, hydrogen can in principle be used for all of the energy purposes that are currently served by natural gas, mineral oil products, and coal (see Figure: Hydrogen-based energy converters). Hydrogen can be combusted in combustion engines, gas turbines, or special burners. However, its electrochemical conversion in fuel cells is particularly important for the future use of hydrogen. For this reason, the fuel cell has practically become a synonym for "hydrogen economy". This energy converter transforms the chemical energy released during the reaction between hydrogen and oxygen into electric power and useful heat directly, efficiently, and without emissions. As the inverse of electro-

→ Principles of hydrogen generation

Source: DLR

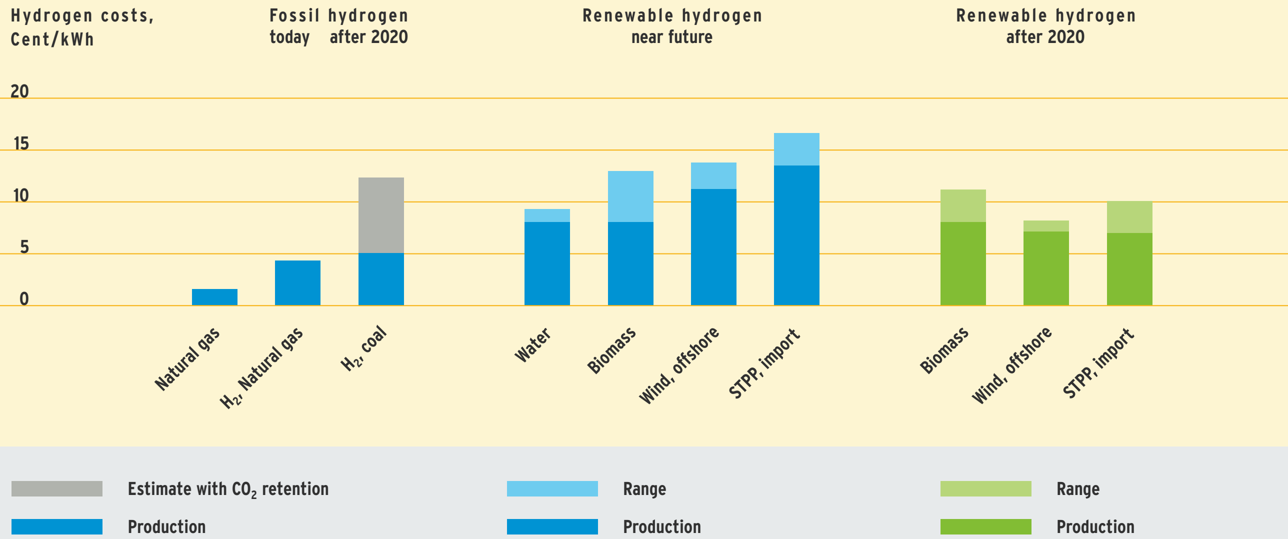


Methods for producing hydrogen from renewable and from limited primary energy sources

lysis, the fuel cell is therefore the ideal conversion technology for a hydrogen-supported energy economy. Fuel cells are distinguished by their type of electrolyte and their operation temperature. The various fuel cell systems are being developed for very different application areas: membrane fuel cells for portable and stationary power supply and for hydrogen-fuelled electric vehicles; fuel cells in the intermediate temperature range are designed for decentralised power generation aggregates and combined heat and power generation in the range up to a few hundred kW electrical capacity; and high-temperature fuel cells in the MW range are designed for efficient electricity generation. As long as hydrogen is not available as a fuel, natural gas, biogas, or other hydrogen-containing gases can be used. These gases must first be “reformed” to a hydrogen-rich fuel gas before they can be combined with oxygen from the air and directly converted into electricity in the fuel cell.

→ Hydrogen costs

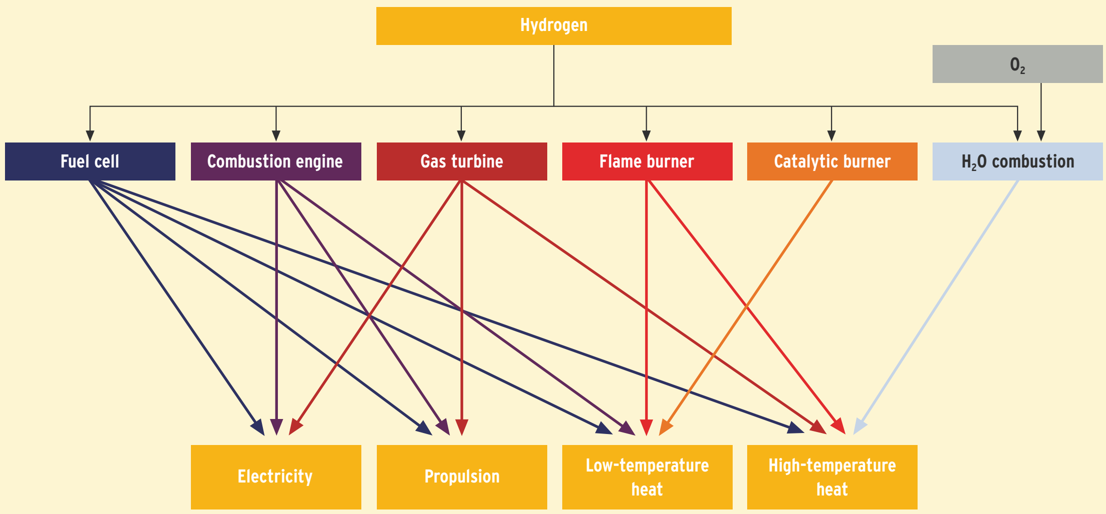
Source: DLR



Cost of hydrogen production from fossil and renewable energy sources for large-volume consumers. Costing some 2 Cents/kWh, natural gas is unrivalled today as a low-cost energy carrier. In the future, however, renewable hydrogen will be the most cost-effective carbon-dioxide-free fuel at costs between 7 and 10 Cents/kWh (STPP = Solar thermal power plant).

→ Hydrogen-based energy converters

Source: DLR



Hydrogen-based energy converters for supplying final or useable energy

Information about combined heat and power generation, hydrogen, and fuel cells

→ Brochure "Kleine Kraft-Wärme-Kopplung für den Klimaschutz. Jeder kann Energie doppelt nutzen", can be ordered from the Federal Environment Ministry at www.bmu.de

→ BHKW-Infozentrum: www.bhkw-info.de

→ Bundesverband Kraft-Wärme-Kopplung: www.bkwk.de

→ The hydrogen and fuel cell information system HyWeb: www.hyweb.de

Fuel cells are currently available as pilot and demonstration plants and to some extent also in (not yet economic) small series production.

Intense efforts are underway especially in the automotive industry to develop fuel cells to series-production maturity for use as emission-free drive aggregates for electrical motors in vehicles. The prerequisite, however, is that the power density is further increased and that the production costs can be reduced by one to two orders of magnitude. The aspired goals are under 1,500 Euros/kW for household energy systems, 1,000 Euros/ kW for block-type cogeneration plants, and about 50 Euros/kW for propulsion drives.

The optimal strategy

A special feature of power supplied from renewable energy sources is that the useful energy – with the exception of biomass – is at first available "only" as electricity and, in the case of solar irradiation and geothermal energy, as heat at different temperatures. Energy in chemical form, when needed, requires a second conversion step. The present-day conversion chain from chemical energy (coal and hydrocarbons) to electricity is thus reversed, leading to considerable consequences for the final-energy supply structure.

The traditional methods for load management will not suffice if the share of renewable energy in the power supply increases significantly over 50 %. A storable energy carrier is therefore required into which the existing electricity can be relatively easily and flexibly converted, i.e. at very different capacities and with the greatest possible efficiency, in both centralised and decentralised systems. The energy carrier should also be multifunctional, i.e. both in the heat sector (medium- and high-temperature area) and as a fuel. Furthermore, its efficient use in a wide range of advanced combined heat and power technologies (fuel cells) should be possible.

All of these specifications can be met with hydrogen. In order to surmount the constraints set by the renewable energy supply structure and to guarantee all energy consumers a secure energy supply at all times, hydrogen has a clear advantage over other chemical energy carriers (e.g. methanol). A further advantage is that another gaseous energy carrier, natural gas, is currently gaining significance. The present expansion of its share

– which however must be limited in the medium term to protect resources – is compatible with the simultaneous expansion of renewable energy. The natural gas infrastructure can be used for a gradual introduction of hydrogen along with the construction and later integration of decentralised, local hydrogen grids. However, since losses are unavoidable during hydrogen production, and these cause additional costs, it is obvious that all other cheaper methods for using renewable energy should be exploited first. The introduction of renewable energy therefore opens the door for hydrogen – not the other way around.

GLOSSARY OF ENERGY UNITS

1 J (joule) is the basic unit for energy. 1 J = 1 Nm (Newton-metre) = 1 Ws (watt-second).

Since 1 J is just a small amount of energy, multiples of this unit are usually used.

kJ	=	10^3 joules	=	Thousand joules (Kilo-)
MJ	=	10^6 joules	=	Million joules (Mega-)
GJ	=	10^9 joules	=	Billion joules (Giga-)
TJ	=	10^{12} joules	=	Trillion joules (Tera-)
PJ	=	10^{15} joules	=	Quadrillion joules (Peta-)
EJ	=	10^{18} joules	=	Quintillion joules (Exa-)

A common unit is also the kWh (kilowatt-hour). It is especially used for electricity.

1 kWh	=	3,600 kJ	=	3.6 MJ				
1 GWh	=	10^6 kWh	=	1 million kWh	=	3,600 GJ	=	3.6 TJ
1 TWh	=	10^9 kWh	=	1 billion kWh	=	3,600 TJ	=	3.6 PJ

A very large energy unit occasionally used is:

1 TWa = 8,760 TWh = 31.54 EJ

1 W is the basic unit for the capacity of energy systems, derived by dividing the energy unit by the time:

1 W	=	1 J/s		
1 kW	=	1 kJ/s	=	1 kWh/h etc.

Primary energy: The original energy source (lignite, hard coal, uranium, natural gas, biomass, et al.) employed to produce usable energy carriers (heating oil, petrol, electricity, district heat, et al.).

Final energy: The above energy carriers used by the final consumer (= primary energy less all of the conversion and distribution losses, the own consumption of power stations and refineries, and the input of raw energy for non-energetic purposes).

Examples of energy amounts:

Global primary energy consumption 2000: 423 EJ/a; Germany: 14.2 EJ/a= 14,200 PJ/a

Global final energy consumption 2000: 285 EJ/a; Germany: 9.2 EJ/a= 9,200 PJ/a

Global electricity production 2000: 15,400 TWh/a; Germany: 563 TWh/a

Electricity consumption in a large city (Stuttgart): 4.0 TWh/a = 4,000 GWh/a

Fuel consumption for space heating and hot water (Stuttgart): 25 PJ/a = 25,000 GJ/a

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It is distributed free of charge and is not intended for sale.
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