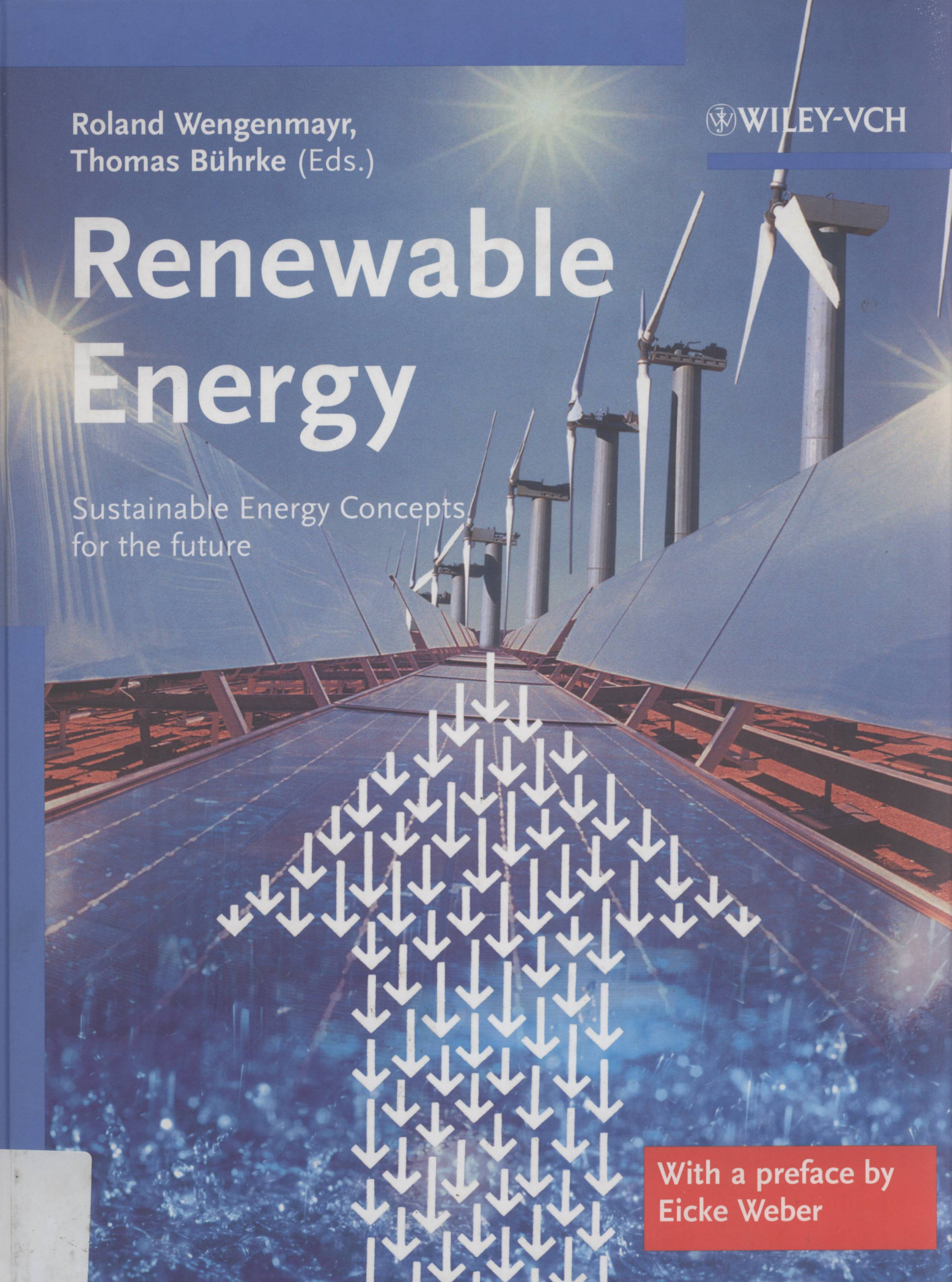
Roland Wengenmayr,
Thomas Bührke (Eds.)

WILEY-VCH

Renewable Energy

Sustainable Energy Concepts for the future



With a preface by
Eicke Weber

Renewable Energy

Sustainable Energy Concepts for the Future

Edited by
Roland Wengenmayr and Thomas Bührke

WILEY-VCH Verlag GmbH & Co. KGaA

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Library of Congress Card No.:
applied for

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

Bibliographic information published by the Deutsche Nationalbibliothek
Die Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at <http://dnb.d-nb.de>.

Typesetting TypoDesign Hecker GmbH, Leimen

Printing betz-druck GmbH, Darmstadt

Binding Litges & Dopf Buchbinderei GmbH, Heppenheim

Cover Design Adam-Design, Bernd Adam, Weinheim

Printed in the Federal Republic of Germany
Printed on acid-free paper

ISBN 978-3-527-40804-7

Renewable Energy

Edited by Roland Wengenmayr and Thomas Bührke

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Preface

The imminent threat of catastrophic climate change caused by anthropogenic, i.e. man-made changes of the composition of our athmosphere, especially the concentrations of carbon dioxide (CO_2), laughing gas (dinitrogen monoxide, N_2O) and methane (CH_4), has been widely recognized. The CO_2 concentration is today worldwide above 380 ppm, far above the maximum CO_2 concentration of about 290 ppm observed in the last 800,000 years. The recent report of the Intergovernmental Panel on Climate Change (IPCC) and the agreements of the Bali Climate Summit in December of last year demonstrate that the world starts to face the technological and political challenge poised by the requirement to reduce the emission of these gases by 80% in the next few decades.

This goal can only be achieved by substantial progress in the two big areas that affect this issue: Rapidly enhanced production of energy from renewable sources and increased energy efficiency, especially of buildings where a large amount of our total energy need is generated.

This book addresses both of these critical objectives with 19 contributions written by experts in their respective fields, covering the most important issues and technologies needed to reach these dual goals. This volume provides an excellent, concise overview picture of this important area, combined with interesting details for each topic for the specialists. The topics addressed include photovoltaics, solar thermal energy, geothermal energy, energy from wind, waves, conventional hydroenergy, bioenergy, hydrogen technology with fuel cells, building efficiency and solar cooling. In each chapter, the detailed discussion and references to current literature enable the reader to reach an own opinion concerning the feasibility and potential of these technologies. The volume appears to be well suited for the generally interested reader, but may be well used in advanced graduate classes on renewable energy. It seems to be especially well suited to assist students who are in the process of selecting an inspiring, relevant topic for their studies and later their thesis research.

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High-quality, First-hand Information

Renewable energy is a key concept for the 21st century. No other area of technology is accompanied by so much optimism and hope that humanity can meet the challenges of climate change and a secure energy supply in an intelligent manner. The increasing number of wind power plants, solar collectors and photovoltaic installations demonstrates perceptibly that many innovations for tapping renewable energy sources have matured. Hydroelectric plants with their dams and reservoirs have long since been a part of the landscape; in fact, we have them to thank for the second industrial revolution of widely-available electrical energy grids. Other technologies, such as the use of geothermal heat, which is abundantly available almost everywhere, are entering the stage of large-scale pilot projects. Very few technologies have developed so dynamically in the past years as have renewable and alternative energy supplies.

This book gives a detailed overview of the current state of the most important technologies which are already contributing significantly to our energy supplies – or will be able to do so in the future. Each technology is described by authors who as researchers, engineers, or entrepreneurs are experts in their fields, which makes this book an especially valuable and reliable source of information. Here, well-grounded explanations are given of e.g. how a solar-thermal power plant operates, or which new developments promise to solve the serious cost and energy problems of the established silicon technology for photovoltaic cells.

The book not only introduces technological methods for obtaining energy from renewable sources. It also contains important information about how energy can be efficiently stored, transported and converted to useful forms. How heavy must a battery be in order to store the same amount of energy as a tank full of hydrogen? Which pressing problems could be realistically solved by a hydrogen economy? How does a fuel cell work? These and many other questions are answered by our authors.

When we search for possibilities to allow us to make more intelligent use of the valuable energy resources, then an important human habitat comes into view: our dwellings. In particular, very large buildings where a large number of people live, work and do their business offer an enormous potential for saving energy – and for reducing emissions of greenhouse gases – by applying intelligent architectural and air conditioning concepts. Air conditioning counts worldwide among the notorious energy gluttons, and its market is practically exploding in the warm emerging nations. Thus, the question is becoming more and more pressing as to how to provide air conditioning for buildings in an environmentally-friendly and energy-conserving manner. There are fascinating answers to this question; even the Sun itself can be tapped for cooling. How that works is explained in this book, which also introduces the world's first and thus far only high-rise building to be air conditioned in an environmentally favorable and energy-saving way by applying intelligent ideas.

The attentive reader will notice that there are only two contributions to the subject of biofuels in this book. For several reasons, we have refrained from including more on this subject. For one thing, there are currently established technologies for producing biofuels which are, from the technical point of view, not particularly new or exciting. Secondly, the ecological balance of the bioethanol and biodiesel fuels – so-called first generation agro fuels – produced today must be considered critically: their cultivation, transport and processing consume a large amount of valuable land and water, and are anything but climatically neutral. But there are good ideas in this area as well for future second generation agro fuels, which can solve these problems. A patented high-tech process for converting plant waste into valuable energy carriers which promises a very positive energy and environmental balance is introduced in this book.

The authors of this book are from Germany, since the German Federal government has massively subsidized renewable energy technologies for many years, more than any other industrial nation thus far. Thanks to this cutting-edge role, German scientists, engineers and companies have conquered a leading position worldwide in many areas of renewable energy sources, for example in wind power and photovoltaic conversion.

All the contributions are written in a readily understandable style; readers with a general educational background in technology and natural sciences will be able to follow them without difficulty. Only a few articles include some mathematics for those who wish to penetrate the subject more deeply. These few, brief passages can be simply skipped over if desired, without losing the thread of the discussion. Extensive literature lists and Web links offer many possibilities for delving further into the topics.

All of the numbers and facts have been carefully checked, which is not to be taken for granted. Precisely in the area of renewable energy sources, there is much misinformation and misleading talk in circulation. Therefore, this book intends to offer to all those who are interested a reliable, solid base of information, and to be useful also as a reference work. Whoever reads it carefully will be able to discuss the subject competently, and in particular to make informed decisions.

We thank all the authors for their excellent cooperation, Dr. William Brewer for his careful translation, and the publishers for this beautifully designed and colorful book. In particular we thank Dr. Ulrike Fuchs and Nina Stadthaus of Wiley-VCH Berlin for their skill, support and patience with us. Without Ulrike Fuchs's commitment this wonderful book might have never been realized.

Roland Wengenmayr and Thomas Bührke

Frankfurt am Main and Schwetzingen, Spring 2008.

Photo: DLR

Photo: Voith Siemens Hydro

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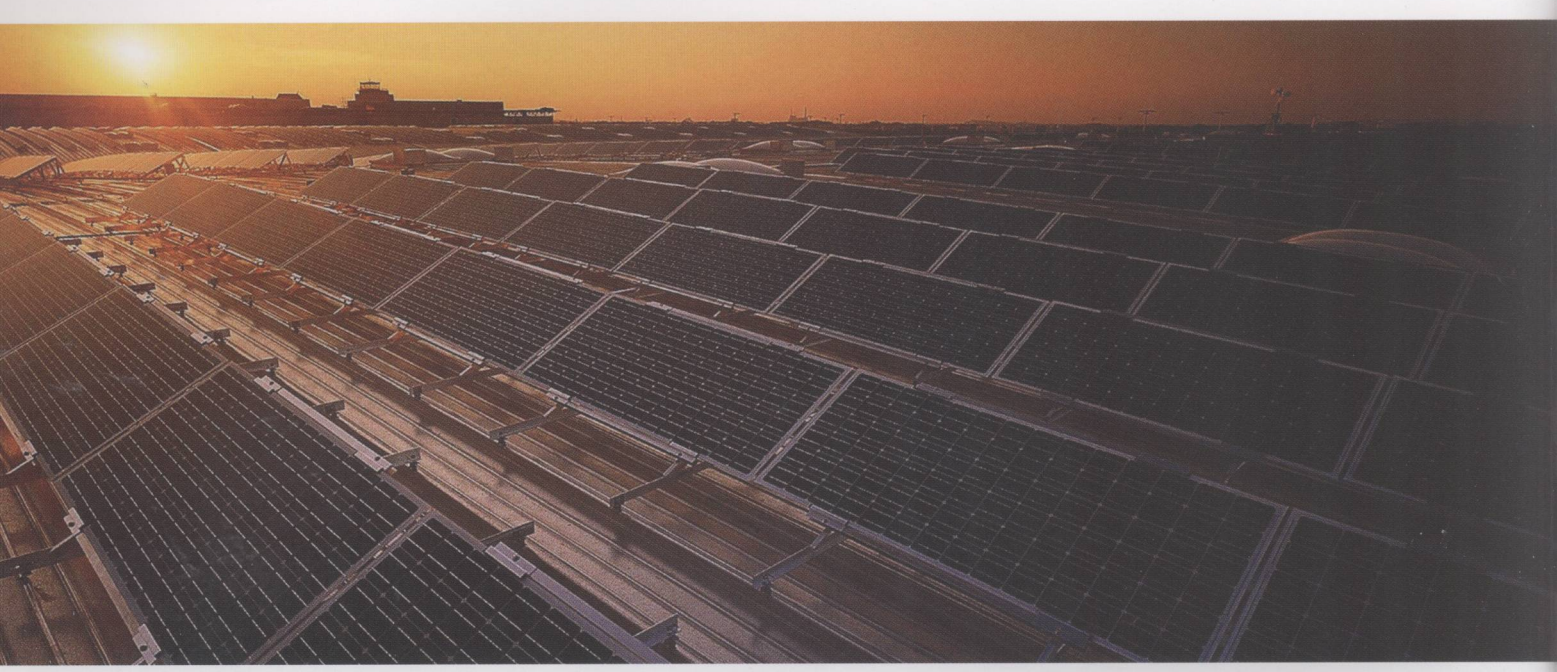
Photo: Vestas Central Europe

Photo: GFZ



This large photovoltaic roof installation, above the Munich Fairgrounds building, has a nominal power output of about 1 MWe l. In 2004, it fed around 1000 MWh of electrical energy into the power grid *(Photo: Shell Solar).*

The Development of Renewable Energy Carriers

Renewable Energy Sources on the Rise

BY HARALD KOHL

The threat of a catastrophic climate change and rising petroleum prices are putting renewable energy sources at the center of public interest. How large is their contribution at present in the world? How great is their potential for expansion? A progress report and a glance at Germany whose Federal Government has for years strongly promoted renewable energies.

Renewable energy is developing towards a recipe for success, in Europe, the USA, and Asia. As an example, let us start with taking a more detailed look at the political developments in the European Union. Here, it is chiefly the so-called "20-20-20" resolution of the European Council of March 2007, which has strongly promoted of renewable energy. The European heads of states and governments declared in it, among other things, that the share of renewable energy in the total energy consumption of the EU must increase to 20%. Today, it is 6.6%. This goal is to be achieved in equal mandatory national shares. For biofuel, additionally, a binding minimum goal of 10% was specified as the fraction of biogenic fuel in the total petrol and diesel consumption for all EU member states until 2020.

A further step will involve a comprehensive directive on renewable energy in the European Union. The first draft was announced for the second half of 2007. It will supplement the 2001 EU directive on regenerative electrical power production and will in future cover all areas of renewable electrical power, heat, and mobility.

Today's image of renewable energy usage in Europe is still dominated by a more traditional view. Sweden, Finland, and Austria, in particular, feature shares of 20 to 30 percent renewable energy out of the total primary energy consumption, due to high amounts of electricity from hydropower. Considering heat consumption, France also provides a substantial portion from renewable sources, mainly from biomass. Solar thermal usage is widespread particularly in Germany, Austria, and Greece. Markedly, conditions

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An offshore windpark on the high sea might look like this. *(Graphics: Nordex.)*

in the sunny South of the European Union vary significantly. Whereas approximately three million square meters of solar thermal collectors are installed in Greece, their number in Italy, Spain, and Portugal adds up to only a few hundred thousand square metres. Photovoltaics also are by no means a Mediterranean specialty. Here, Germany is far ahead with 1 910 000 kWp (kilowatt peak power), but Italy, in terms of kWp peak power, is even behind the not exactly sun-blessed Netherlands with 50 776 kWp.

Nevertheless, the rise of renewable energy is remarkably dynamic in many European countries. Belgium, for example, even though at a low level, has nearly tripled its share of renewable energy between 1997 and 2005, from 1.0 to 2.8 percent. Strong rises are discernible in the central and eastern European acceding countries too, such as Hungary and the Czech Republic, but here also in the low one-digit percentages. Thus, many countries will have to make considerable efforts to achieve the objectives for 2020.

Wind Energy is Booming in the USA too

Wind energy is a particularly good example showing the different degrees of success even under comparable initial situations. The general conditions of energy policy are vital here. The German Renewable Energy Sources Act (EEG) with its investment-friendly delivery and compensation regulations – together with the similar Spanish legislation – compares favorably on an international scale. 18 EU Member States have to date taken over such primacy and delivery regulations. As a result, wind energy usage has experienced a remarkably dynamic boom. Between 2002 and 2006, the installed power has more than doubled to approximately 48 000 MW. Two thirds of the European wind power are installed in Germany and Spain. And considering the world market, the USA represents the third largest market for wind energy plants (15.6% global market share), behind Germany (28%) and Spain (15.6%).

Considerable growth on the North American continent can be expected also for the coming years because the wind energy boom in the USA is continuing. The newly installed electric energy production capacity is expected to increase to more than 3000 MW in 2007, the American Wind Energy Association (AWEA) says. In the meantime, this is already leading to shortages because the number of suppliers is insufficient to cover the market's needs. This is an opportunity particularly for the European wind energy plant manufacturers and suppliers to foster exports to the United States. In turn, the European manufacturers can help US-American energy producers to overcome these bottlenecks.

The leading wind energy plant manufacturers include Danish and German companies. Particularly the German example shows how massive support of renewable energy promoted the rise of completely new high-tech industrial sectors that have grown to economically successful global players. This is why we will take a look at the interesting example of the German development in more detail.

Successful German Policy

In Germany, renewable energy (RE) sources have rapidly increased in importance in recent years, especially for the production of electric power [1]. In the year 2005, 10.2 % of the power from German electrical sockets originated from renewable sources, nearly three times more even than in 1990 [2]. This is due for the most part to the increased use of wind power. With an energy output of about 26.5 TWh per year, it has surpassed traditional hydroelectric power at 21.5 TWh (Figure 1). Power production using the biomass has also reached an all-time high of 13.1 TWh, and with an increasing tendency. Photovoltaic and geothermal power generation still play only a marginal role; nevertheless, power production by photovoltaic cells is growing rapidly: in Germany since the year 2000, it has increased by a factor of 15.

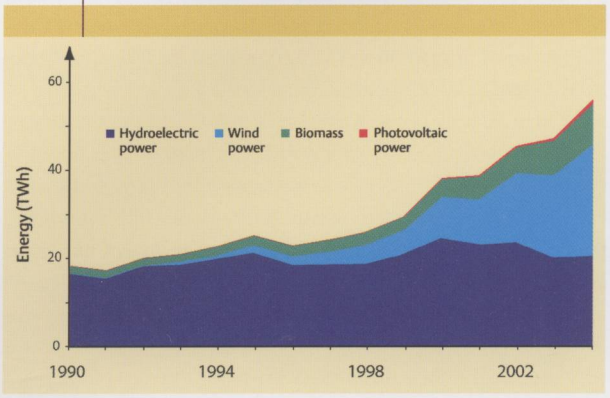
Germany is thus well on the way towards attaining the goal set by the previous Federal Government, that by the year 2010, renewable energy sources should supply at least 12.5 % of the power demands. The more distant goal of at least 20 % by 2020 could, with the current rate of growth, even be exceeded.

Heating from renewable energy sources is also on the rise. In 2005, the proportion of space heating from renewable sources in Germany was 5.4 %. The biomass is the unchallenged leader, with annually almost 76.5 TWh. Here, traditional wood burning is complemented by modern methods, for example wood-pellet heating systems. Solar thermal heating using collectors on roofs and other surfaces

INTERNET

Brochures [1,2] and other materials of the German Government (in English)
www.erneuerbare-energien.de

FIG. 1 | POWER FROM RENEWABLE ENERGY SOURCES



The time evolution of the fraction of renewable energy sources for electricpower production in Germany [2].

is also growing especially rapidly. Since 2000, it has more than doubled, and since the beginning of the 1990's, the increase has been more than twentyfold.

In the transportation sector, also, renewable energy carriers are slowly gaining ground. Automobile engines in Germany to be sure still consume a comparatively small fraction of biogenic fuels, mainly biodiesel, and small amounts of bioethanol. The proportion on the roads is only 3.4 % of the overall fuel consumption, but that is nevertheless a factor of eight more than in the year 2000.

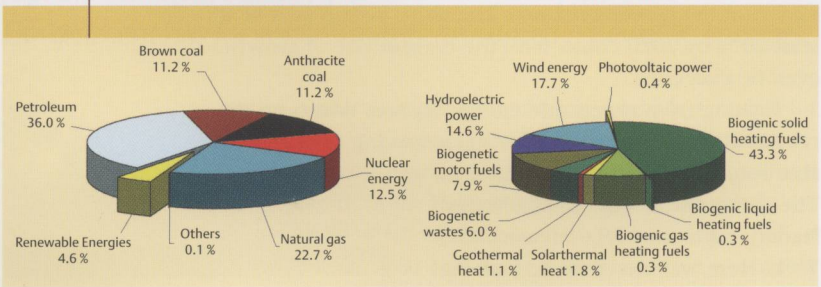
The Current Situation

Where do the renewable energy sources stand overall in Germany? Figure 2 shows the distribution of the primary energy consumption in Germany in the year 2005. It should not be surprising that fossil fuels still dominate the energy supply: brown coal, anthracite coal, petroleum and natural gas meet 82 % of the requirements. In addition, nuclear power delivers 12 % of the electric power generated. The renewable energy sources supplied only 3.6 % of the primary energy consumption; in the mid 1990's, this figure was only about 1.5 %. More than half of this renewable energy is due to the use of the biomass; wind energy contributes 14.6 % and water power 11.9 % (Figure 2).

The reason for the strong increase in the use of renewable energy sources in Germany is to be found mainly in political decisions. In the past ten years, a public legal and economic framework was set up to give the renewable energies a chance to gain a foothold in the market, in spite of their still relatively high power-generating costs. Along with various subsidy programs and the Federal Market Launch Program, these included in particular the Act on the Sale of Electricity to the Grid (StrEG) in 1991 and the Renewable Energies Law (EEG) in 2000, which set this development in motion. The principle: Power generated from renewable sources can be sold to the public power grid preferentially, and will receive a guaranteed price. The costs are covered by adjusting the price of the power sold.

The prices paid for renewable-source power are scaled according to the source and other particular requirements of the individual energy carriers. They are graded on a declining scale, i.e. they decrease from year to year. This is intended to force the renewable energy technologies to reduce their costs and to become competitive on the energy market in the medium term. The renewable energy technologies can accomplish this only through temporary subsidies, such as were given in the past to other energy technologies like nuclear energy. The renewable energy technologies will become strong pillars of the energy supply in the course of the 21st century only if they can demonstrate that they operate reliably in practice and are economically viable. To this end, each technology must go down the long road of research and development, past the pilot and demonstration plant stages, and finally become competitive on the energy market. This process requires public subsidies.

FIG. 2 | PRIMARY ENERGY USE AND SUPPLY IN GERMANY



Left: The distribution among the various energy carriers to primary energy consumption in Germany; all together, 14 238 PJ (Petajoule) was used in the year 2005. Right: The contribution from different renewable energy sources in 2005; all together they produced 164 TWh of heat and electrical energy [2].

Potential and Limits

Often, the potential of the various technologies which exploit renewable energy sources is regarded with skepticism. Can renewable energies really make a decisive contribution towards satiating the increasing worldwide appetite for energy? Are there not physical, technical, ecological and infrastructural barriers to their use?

Fundamentally, their potential is enormous. Most of the renewable energies are fed by solar sources, and the Sun supplies a continuous energy flux of over 1.3 kW/m^2 (0.12 kW/ft^2) at the surface of the Earth. Geothermal energy makes use of the heat from within the Earth, which is fed mainly by radioactive decay processes (see p. 57).

These energy sources are, to be sure, far from being readily usable. Conversion processes, limited efficiencies, and the required size of installations give rise to technical restrictions. In addition, there are limits due to the infrastructure, for example the local character of geothemal sources, limited transport radius for biogenic fuels, the availability of land and competition for its use. Not least, the limited availability and reliability of the energy supplies from fluctuating sources play a significant role. Furthermore, renewable energies should be ecologically compatible. Their requirements for land, potential damage to water sources and the protection of the landscape and the oceans set additional limits. All this means that the natural, global supply

of potential renewable energies and the technically feasible energy production from each source lie far apart (Figure 3).

In spite of these limitations, a widespread supply of renewable energies is possible. In order for it to be reliable and stable, it must be composed of the broadest possible mixture of different renewable energy sources. In principle, water and wind power, use of the biomass, solar energy and geothermal heat can together supply all the requirements. Germany is a good example of this. Although it is not located in the sunny South, and has only limited resources in the areas of hydroelectric and geothermal power, nevertheless renewable energy sources can supply a considerable portion of Germany's energy requirements. Estimates put this contribution at up to 6200 PJ per year [1]. This corresponds to about 40 % of the current primary energy consumption. In these estimates, the boundary conditions in the form of usable land areas for collectors and solar cells, for wind parks and the cultivation of energy-yield plants (biomass) were set very conservatively.

Taking into account that in the coming decades, many technologies will become much more efficient in terms of their energy consumption, Germany could potentially supply 60 % of its energy needs from renewable sources within its own borders. The required broad and multiple uses of the renewable energy sources however also demands that the different sources be exploited according to their particular properties and limitations. Let us therefore take a closer look at the various types of renewable energy.

Water Power

Water is historically one of the oldest energy sources. Today, hydroelectric power in Germany comprises only a small contribution, which has remained stable for decades: 3 to 4 % of the electric power comes from storage and flowing water power plants. Its potential is rather limited in Germany, in contrast to the countries in the Alps such as Austria and Switzerland. In future, it will therefore be possible to develop it further to only a limited extent. Presently, the roughly 5500 large and small plants deliver about 25 TWh of energy annually; 90 % of this in Bavaria and Baden-Württemberg. The worldwide potential for hydroelectric power is considerably greater: nearly 18 % of the power generated comes from hydroelectric plants (see pp. 22). Thus, water power – considered globally– is at about the same level as nuclear power. So far, it is the only renewable energy source which contributes on a large scale to the world's requirements for electrical energy. In particular, "large-scale water power" is significant. An example is the Chinese Three Gorge Project, which will generate more than 18 GW of electric power, corresponding to about 14 nuclear power plant blocks (see pp. 22).

In Germany the so-called "small-scale" water power still has limited possibilities for further development. New construction and modernization of this type of water power plants with output power under 1 MW has ecological limits, since it makes use of small rivers and streams and it can affect the ecosystems. This alone strictly limits the possibilities for further development.

The advantages of water power are obvious: The energy is usually available all the time, and water power plants have very long operating lifetimes. Furthermore, water turbines are extremely efficient, and can convert up to 90 % of the kinetic energy of the flowing water into electric power (see pp. 22). By comparison: modern natural gas combi-power plants have efficiencies of 60 %, and light-water reactors have only about 33 % efficiency.

Wind Energy

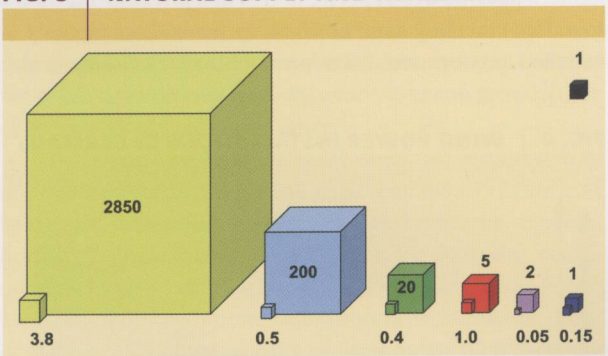
The second important renewable energy source is the wind. Modern wind power plants, whose rotors operate on the aerodynamic principle, achieve efficiencies of up to 50 %. Germany is world champion in the use of wind power: 17,574 wind power installations produced nearly 4.3 % of the electric power used here in 2005. Worldwide, nearly 48 GW of electrical wind power generating capacity are installed, more than a third of it in Germany. The rapid increase of recent years is slowing down, however, since the majority of suitable sites on land have already been developed. The next step will therefore be the construction of offshore wind energy installations on the oceans.

Wind energy has been criticized in particular because of noise pollution, disturbance of animal life, especially the birds, and blighting of the landscape. Furthermore, wind has the disadvantage that it is not continuously available. This disadvantage can however be minimized by improved wind forecasts and intelligent input management into a decentrally organized power grid.

Biomass

The utilization of energy from the biomass is often underestimated. At present, biogenic heating fuels are being rediscovered in Germany. Wood, biowastes, liquid manure and other materials originating from plants and animals can be

FIG. 3 | NATURAL SUPPLY AND AVAILABILITY



The natural supply of renewable energies in relation to the current world energy consumption (black cube, normalized to 1). Small cubes: The fraction of each energy source that is technically, economically and ecologically exploitable. Yellow: solar radiation onto the continents; blue: wind; green: biomass; red: geothermal heat; dark blue: water power *(Source: DLR).*

used for heating and also for electric power generation. The combination of the two uses is particularly efficient. In Germany, currently 94 % of the renewable heat originates from biofuels, mainly from wood burning – but increasingly also from wood waste, wood-chip and pellet heating and biogas plants. The contribution to power generation is also gradually increasing: in 2005, it was 2.1 %.

Biofuels are available around the clock and can be utilized in power plants like any other fuel. Biogenic motor fuels, as mentioned above, are getting renewable energy carriers rolling as suppliers for transportation.

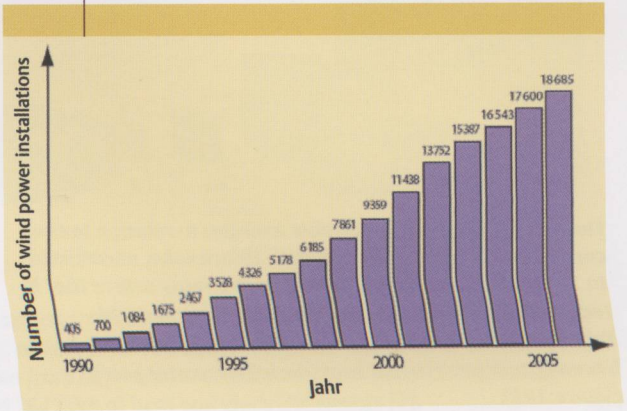
Solar Energy

Solar energy is the renewable energy par excellence. Its simplest form is the use of solar heat from collectors, increasingly employed for household warm water heating and for public rooms such as sports halls and swimming pools. More than 7.2 million square meters of collectors are currently installed on German rooftops.

Solar-thermal power generation is, in contrast, still in the development phase (see pp. 26). Parabolic trough collectors, solar towers or paraboloid reflector installations can produce temperatures of over 1,000 °C (1,832 F), which with the aid of gas or steam turbines can be converted into electric power. These technologies could in the medium term contribute to the electric power supply. They are however efficient only in locations with a high level of insolation, such as Spain. Germany would thus have to import solar power from solar-thermal plants via the common power grid, which initially could be laid out on a European basis; in the long term, North African countries could supply solar power via a ring line around the Mediterranean Sea [1].

The most immediate and technologically attractive use of solar energy is certainly photovoltaic conversion. From the point of the energy economy, its contribution is still marginal – mainly due to the still high power generating costs. Nevertheless, the market for photovoltaic devices shows by far the most dynamic growth: In the year 2005 alone, a peak power capacity of 600 MWp was installed. All together, currently over 1,400 MWp generating capacity is installed in Germany. New production techniques at the same time offer the chance to produce solar cells considerably more cheaply and with less energy investment, and thus to allow a breakthrough onto the market (see pp. 42 and pp. 50).

FIG. 4 | WIND POWER INSTALLATIONS IN GERMANY



The development of land-besed wind power in Germany exhibits a nearly exponential growth during some periods of time. Recently, however, there are indications of a turning point towards lower growth rates (Source: Deutsches Windenergie-Institut).

Geothermal Energy

The renewable energy resource which at present is the least developed is geothermal heat. Deep-well geothermal energy makes use of either hot water from the depths of the Earth, or it utilizes hydraulic stimulation to inject water into hot, dry rock strata (hot-dry rock process) (see pp. 54), with wells of up to 5 km (3 mi) deep. At temperatures over 120 °C (248 F), electric power can also be produced – in Germany thus far only at the Neustadt-Glewe site in Mecklenburg-Vorpommern. Favorable regions with high thermal gradients are in particular the North German Plain, the North Alpine Molasse Basin, and the Upper Rhine Trench.

Geothermal heat has the advantage that it is available around the clock. However, the use of geothermal heat and power production is still in its infancy. Especially the exploitation of deep-well geothermal energy is technically challenging and still requires intense research and development (see pp. 54). If geothermal sources can be successfully utilized, then they could make a considerable contribution towards meeting the base demand in view of their uniformity and reliability.

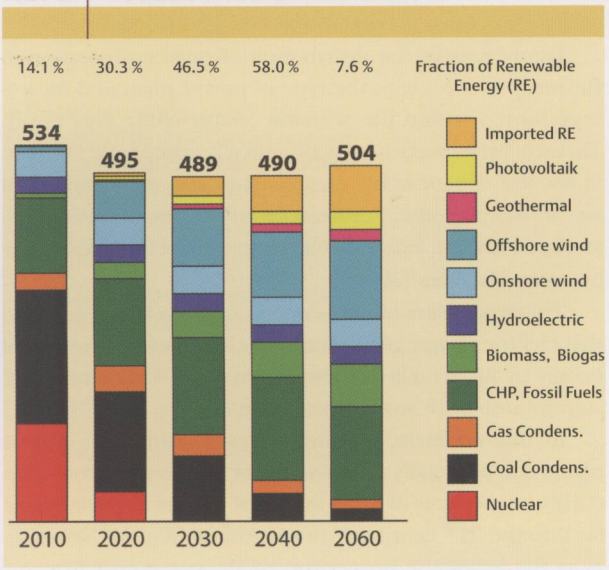
The Window of Opportunity

How will energy supplies in Germany develop in the future? Will all the renewable energy source options play a role, and if so, to what extent? A glance at the current situation shows that the energy economy and in particular the electric power suppliers are facing important investment decisions, since the German power generating plant is getting old. By 2020, production capacity of 40 to 45 GW_{el} will have to be modernized or replaced. This is after all a third of today's total installed capacity.

Thus, at present a window of opportunity for investment in the construction of renewable energy plants is opening. This is independent of the decision concerning the extension of the remaining operating lives of some of the German nuclear power plants, since that would delay the necessary renewal by only a few years. After 2020 at the latest, Germany will have to be supplied by a broad energy mix from a variety of sources. Among these will be highly efficient fossil fuel power plants. According to the opinions of some energy experts, "CO_2-free" plants can likewise make a contribution; in them, the CO_2 will be separated out of the exhaust gases and stored.

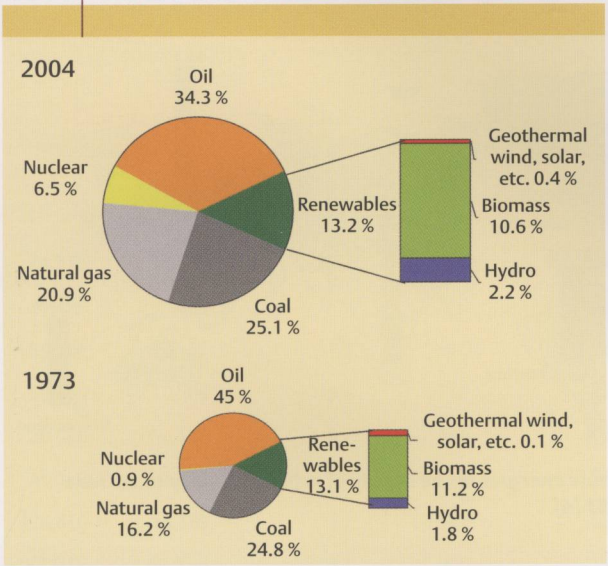
How well the renewable energies will be able to establish themselves has been the subject of investigation of various studies and simulations. The result is that they will successively increase their contributions to the overall energy supply. As a rule, they are initially immature and cost-intensive and thus remain at a low level. Following technological and economic development, they then move in-

FIG. 5 | FUTURE POWER GENERATION



Electric power production in Germany according to type of power plant and energy source in the future scenario „Naturschutz Plus I" [9] (RE: Renewable Energies).

FIG. 6 | WORLD CONSUMPTION OF PRIMARY ENERGY



The evolution of primary energy consumption by the world's population: In 1973, the total consumption was 253 000 PJ, and in 2004, it was 463 000 PJ [4].

to a phase of steady, at times rapid and nearly exponential growth. Only when technological, economic or structural limiting factors come into play does the growth level off, and stabilizes in the long term at a constant level. A good example for this model is the development of land-based wind power. Figure 4 illustrates its rapid growth in the past several years in Germany. But the turning point has visibly been reached, since the economically attractive sites with strong winds on land have for the most part already been exploited. There will certainly be some continued construction of wind plants on land, but within a few years the evolution of the proportion of wind energy in the overall mix will have reached its saturation level. There can then still be some continued growth through "repowering", i.e. the modernisation of older installations with new, more efficient rotors and generators. This will lead to some further increases in the power production capacity of land-based wind power.

The High Sea and the Open Field

The next major step in the modification of the energy systems in Germany will most likely be the introduction of offshore wind energy. Along the German seacoasts and within the "exclusive economic zone", a potential power-generating capacity of up to 25 GW of electric power output is predicted.

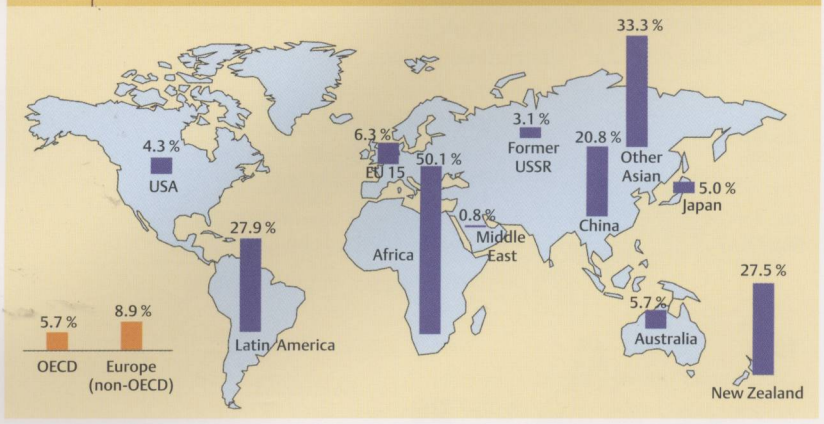
Such offshore wind installations will have to be built far from the coastline in water depths of up to 60 m (200 ft). This is particularly true of the North Sea, which has strong winds. In the shallow water near the coasts, there are no suitable sites due to nature protection areas, traditional exploitation rights such as gravel production, restricted military zones and ship traffic. Plants in deeper water, however, require a more complex technology and are more expensive. The high power sea cables for transporting the power to the coast over distances of 30 to 40 km (19-25 mi) will also drive up the investment costs.

Here, the offshore installations near the coast have a considerable advantage: the wind is stronger and steadier over the free water surface. This compensates to some extent for the higher costs of these wind parks. However, the individual plants must deliver high power outputs. Only when they produce around 5 MW_{el} can they be economically operated under such conditions. To construct the first German offshore test field in the North Sea, industry, associations and power grid operators have jointly formed an Offshore Foundation.

This first offshore windpark is to be built in 2007 near the research platform 'Fino' in the neighborhood of Borkum West. If it operates successfully, wind parks can grow up out of the waves one after the other.

The biomass will play an increasingly important role in the medium term. Taking the requirements of nature and landscape protection into account, and with the expectation of ecological compatibility, then by 2020 the consequent utilization of biogenic wastes will be a main focus. This includes the thermal utilization of wood waste products and agricultural wastes as well as an increased deployment of biogas installations. An increasing and ecologically compatible utilization of the biomass will also have structural consequences. It opens up new, long-term perspectives and possibilities for agriculture and forest management. Many a farm landlord will thus become an "energy landlord".

FIG. 7 | WORLDWIDE USE OF RENEWABLE ENERGIES



The fraction of renewable energies in the supply of primary energy to various regions in the year 2001 [4].

Liquid motor fuels from the biomass can substitute fossil fuels to a much greater extent than is presently the case in Germany. However, in the near term, there will be no new large agricultural areas for growing energy-yield plants. Protection of the fields from erosion, reservation of land for the interlinked biotopes which are legally required by the nature protection laws, and other sustainability goals will to a large extent prevent such land usage. After 2020, the population reduction and accompanying reduction in food requirements, as well as agricultural yield improvements, will probably allow significant increases in the production of energy-yield plants. This will in turn permit an increase in the proportion of biogenic motor fuels for transportation.

The remaining renewable energy carriers will be able to play a significant role in the energy economy in Germany only in the distant future. Photovoltaic power and imported power from solar-thermal power plants belong in this group.

Geothermal heat is currently a particularly hopeful energy source. It is, however, still too early to predict its future contribution to the primary energy supply, because of the technical challenges involved in its exploitation. The utilization of geothermal heat will become really efficient only when it is used for space heating in combination with the production of electric power (CHP, Combined Heat and Power). This will require the construction of local and regional pipe networks, i.e. additional investments.

Ecologically Optimized Development

Just how the proportion of renewable energies within the energy mix in Germany will evolve in reality cannot of course be precisely predicted. However, model calculations make it clear which paths this evolution might take under plausible assumptions. The Institute for Technical Thermodynamics at the DLR in Stuttgart carried out a comprehensive study in 2004, analyzing various scenarios [3]. They took technical developments, economic feasibility, supply security and eco-logical and social compatibility into account. This study shows up the essential trends.

Figure 5 gives the distribution of power generation in Germany according to the type of power plant and the energy source within the scenario "Naturschutz Plus I" [3]. This scenario aimed at an economically acceptable increase in the use of renewable energies, but also took ecological factors into account. Furthermore, it assumed that the utilisation of nuclear energy will come to an end in Germany between 2020 and 2030.

The developers of this scenario came to the conclusion that electric power generation, which at present is supplied mainly by fossil fuels and nuclear reactors, will be renewed step by step with sustainable energies.

In this scenario, coal-fired power plants, gas power plants and especially combined heat and power generation (CHP) on the basis of fossil fuels will play an important role far into the 21st century. Towards the middle of the century at the latest, the proportion of electric power from renewable energy sources should surpass the fifty percent level. Major contributions will be made by offshore wind parks and power generation from the biomass and biogas. The contributions of photovoltaics and geothermal heat will be perceptible but not of primary importance. In addition, imported power from renewable sources will be significant.

It is however also clear that the changes in the power mix will have to be accompanied by a clearcut improvement in overall energy efficiency and thus a decrease in the total power consumption. Only when energy conservation, improved efficiency, and the increased utilization of renewable energies are all promoted at the same time will a sustainable energy supply for Germany become feasible.

Renewable Energies on a Worldwide Scale

A long-term solution in terms of climate policy, supply security and an equitable access to energy can be achieved only on a global scale. Today, we are far from such a solution (Figure 6). The proportion of renewable energies in the world's primary energy consumption is currently 13.4 %. It has remained practically constant since the beginning of the 1970's. This is due to the increased consumption by the world's population, since the overall capacity from renewable energy carriers has nearly doubled in the same time period.

The utilization of renewable energies varies widely in different regions. In some European countries and in North and South America and Japan, conventional hydroelectric power traditionally plays a strong role. Countries such as Austria, Switzerland, Norway or Canada profit from their favorable topographical situations. Hydroelectric power dominates the contribution of renewable energies to the worldwide electric power supply.

Worldwide, approximately 60% of the renewable energy is consumed for heating in private homes, the public sector, as well as the service sector. The use of wood and

FIG. 8 | WORLDWIDE USE OF RENEWABLE ENERGIES 2004

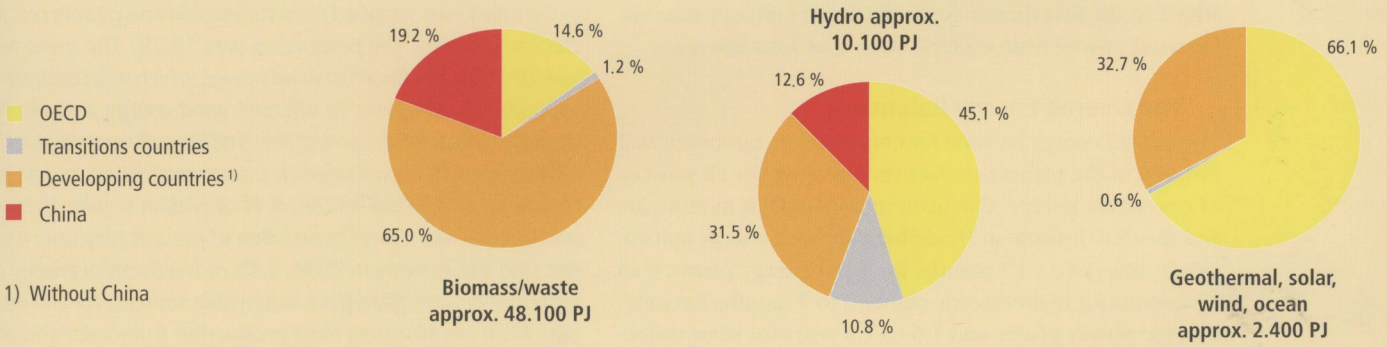
Transition countries: countries in the transition from state-directed economy to market economy; under this category, the IEA summarizes countries from non-OECD Europe and the countries of the former USSR.

1) Biogenic portion of waste; in the non-OECD countries, a clear distinction between biogenic and non-biogenic waste is not always possible.

2) Geothermal, solar, wind, ocean.

3) Latin America without Mexico and Asia without China.

	PEC	RE thereof	Share RE of PEV	Shares of most important RE of total RE [%]		
	[PJ]	[PJ]	[%]	Hydro	Biomasse / waste 1)	Others 2)
Africa	24,535	12,021	49.0	2.6	97.0	0.4
Latin America 3)	20,327	5,870	28.9	36.1	62.4	1.4
Asia 3)	53,986	17,187	31.8	4.0	92.4	3.6
China	68,100	10,509	15.4	12.1	87.9	0.0
Middle East	20,089	138	0.7	43.4	32.2	24.4
Transition countries	45,369	1,712	3.8	63.7	34.6	1.6
OECD	230,610	13,189	5.7	34.6	53.4	12.0
World	**463,017**	**60,626**	**13.1**	**16.7**	**79.4**	**4.0**



Global overview of regional usage of renewable energies (Source: IEA).

charcoal is dominant. Whereas the Western industrial countries (OECD) use half of the renewable energy sources for production of electricity, the non-OECD countries use only 14.1% for this purpose. Here, the share of approximately 70% used for decentralized heat supply is correspondingly high, as opposed to about 18% in the OECD countries.

In the developing countries, renewable energy sources do not have exclusively positive effects. This is shown in part by the history of large dams, with their often very negative social consequences and their impact on local ecosystems. A second serious problem is the traditional burning of biomass. It makes the statistical contribution of renewable sources to the primary energy supply appear high, especially in Africa, but also in many countries in Asia (Figure 8). However, it is not really sustainable, since the forests are often irreversibly cleared in the process. It is thus especially important for developing and emerging nations that renewable energy sources be utilized with a critical view to the local conditions.

Investment Costs

The discussion of the use of renewable energy sources takes place within a balancing act between technical arguments on the one hand, and economic and political arguments on the other. This becomes particularly clear when one considers the question of costs.

Most renewable energy sources today are more expensive than the corresponding fossil-fuel and nuclear sources. That is, as described above, the reason for the financial subsidies to renewable energies, be it through pay-as-you-go financing as in the case of electric power, or be it through targeted subsidies as in the market launch program of the