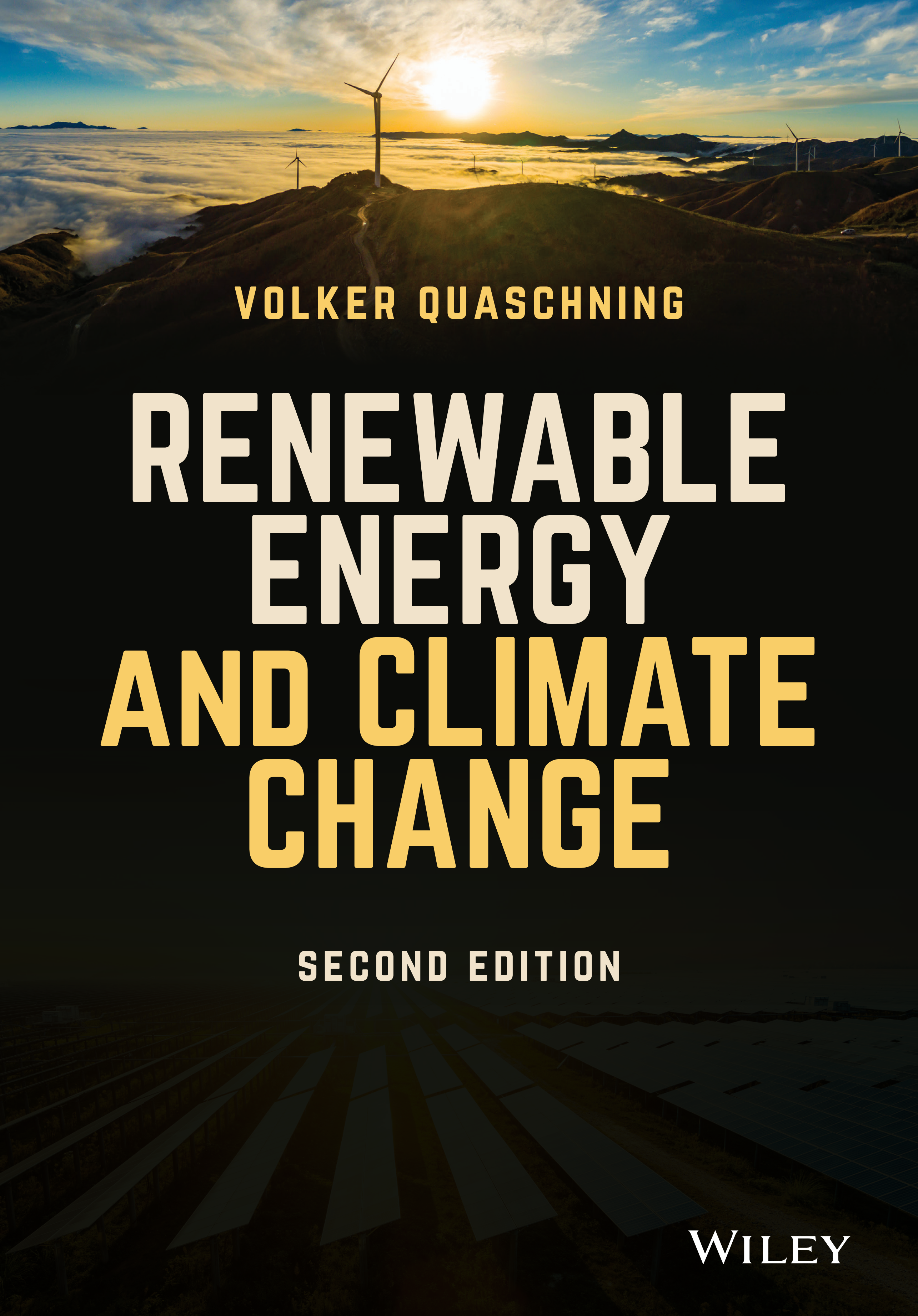

VOLKER QUASCHNING

RENEWABLE ENERGY AND CLIMATE CHANGE

SECOND EDITION

WILEY

Renewable Energy and Climate Change

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Second Edition

WILEY

This second edition first published in English 2020

Edition History
John Wiley & Sons Ltd (1e, 2010)

Registered Office(s)
John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Office
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

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Wiley also publishes its books in a variety of electronic formats and by print-on-demand. Some content that appears in standard print versions of this book may not be available in other formats.

Library of Congress Cataloging-in-Publication Data:

Names: Quaschning, Volker, 1969– author. | Eppel, Herbert (Translator), translator.
Title: Renewable energy and climate change / Volker Quaschning, Berlin University of Applied Sciences HTW, Germany ; (translator) Herbert Eppel.
Other titles: Erneuerbare Energien und Klimaschutz. English
Description: Second edition. | Chichester, West Sussex, U.K. ; Hoboken, N.J. : John Wiley & Sons Ltd, [2020] | English translation of German text. | Includes bibliographical references and index. |
Identifiers: LCCN 2018052859 (print) | LCCN 2018060578 (ebook) | ISBN 9781119514886 (Adobe PDF) | ISBN 9781119514879 (ePub) | ISBN 9781119514862 | ISBN 9781119514862 (hardcover) | ISBN 111951486X(hardcover)
Subjects: LCSH: Renewable energy sources. | Climatic changes.
Classification: LCC TJ808 (ebook) | LCC TJ808 .Q38913 2020 (print) | DDC 363.738/74–dc23
LC record available at https://lccn.loc.gov/2018052859

Cover Design: Wiley
Cover Images: Top: © BIHAIBO/Getty Images, Bottom: © WangAnQi/Getty Images

Set in 10/12pt WarnockPro by Aptara Inc., New Delhi, India

10 9 8 7 6 5 4 3 2 1

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Preface to First Edition

The problems of energy and climate change have finally ended up where they belong: at the heart of public attention. Yet the connection between energy use and global warming is something we have been aware of for decades. In the late 1980s the German federal government declared climate change to be one of its main goals. At the time numerous experts were already calling for a speedy restructuring of the entire energy supply. Despite the government's declaration, the official response was, at best, half-hearted. But the climate problem can no longer remain on the back burner. There is a growing awareness that climate change has already begun. The prognosis of the researchers studying what is happening to our climate is extremely serious. If we do not pull the emergency cord soon, the catastrophic consequences of climate change will far exceed even the power of our imagination. The fact that we have awarded the Nobel Peace Prize to Al Gore, the US climate activist, and to the Intergovernmental Panel on Climate Change, both of whom have been urgently warning of the consequences for years, could be seen as a sign of helplessness rather than optimism about our ability to solve the problem.

Just as climate change threatens our environment, new records for rising oil and natural gas prices show that current supplies will not last long enough to cover future demand, therefore, alternatives must be found as soon as possible.

And yet the solution is a simple one: renewable energy. Renewable energy could completely cover all our energy supply needs within a few decades. This is the only way to end our dependence on energy sources like oil and uranium – costly both economically and environmentally – while satisfying our hunger for energy in a sustainable and climate-friendly manner.

However, for many, the route required to reach that goal is still far from clear. Many people still do not believe renewable energy offers a viable option. Some underestimate the alternatives to such an extent that they predict a return to the Stone Age once oil and coal supplies have been fully depleted.

The aim of this book is to eliminate these prejudices. It describes, in a clear and intelligible style, how the different technologies work, which are now available, and the potential for implementing these various forms of renewable energy, with the focus on the interaction between the different technologies. By showcasing some examples of how Germany has tackled this issue, we can show the forms that sustainable energy supply can take and how it can be implemented. However, this book is designed to show all readers, no matter where they live, how they themselves can make a contribution towards building a climate-compatible energy economy. In addition to explaining different energy measures that individuals can undertake for themselves, this book provides concrete planning aids for implementing renewable energy systems.

This book has been consciously written to offer essential facts to a broad spectrum of readers. It introduces the different technologies to anyone new to the subject, while at the same time, providing interesting background information to those with some existing knowledge.

The book has been translated from the original German version. It is an important addition to my technical work 'Renewable Energy Systems', published by Hanser, and also supplements my many lectures on the subject. It is clear from the high level of interest generated by this technical book, now in its sixth edition in German and translated into both English and Arabic, that there is a real need for more literature on the subject of renewable energy. This book should fill this gap and provide support in the development of sustainable energy supply systems.

Berlin, 2009 *Prof. Volker Quaschning*

Preface to the Second Edition

Our excellent sales figures and the positive response to this reference book have shown that this topic and the style in which it is presented appeal to a broad readership. Despite careful checking, minor errors and inconsistencies are sometimes unavoidable. Special thanks are therefore due to all readers who have provided feedback. This second English edition is based on the fourth revised and enlarged German edition. It contains current data on renewable energies and has been expanded to include the latest trends. A dedicated section explains what steps are necessary to comply with the Paris climate protection agreement and thus preserve the livelihoods of future generations. We hope that this book can make a small contribution to accelerating our energy transition at the rate that is required.

Berlin, summer 2018

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Our Hunger for Energy

Most people will have heard of the cult TV series, Star Trek. Thanks to this programme, we know that in the not-too-distant future humans will start exploring the infinite expanses of the universe. The energy issue will have been resolved long before then. The Warp drive discovered in 2063 provides unlimited energy that Captain Kirk uses to steer the starship Enterprise at speeds faster than light to new adventures. Energy is available in overabundance; peace and prosperity rule on Earth and environmental problems are a thing of the past. But even this type of energy supply is not totally without its risks. A warp core breach can cause as much damage as a core meltdown in an ancient nuclear power plant. Warp plasma itself is not a totally safe material, as the regular viewers of Star Trek very well know.

Unfortunately – or sometimes fortunately – most science fiction is far removed from the real world. From our perspective the discovery of a warp drive seems highly unlikely, even if dyed-in-the-wool Star Trek fans would like to think otherwise. We are currently not even close to mastering comparatively simple nuclear fusion. Consequently, we must rely on known technology, whatever its drawbacks, to solve our energy problems.

In reality, energy use has always had a noticeable impact on the environment. Looking back today, it is obvious that burning wood was less than ideal, and that the harmful noxious fumes created by such fires considerably reduced the life expectancy of our ancestors. A fast-growing world population, increasing prosperity and the hunger for fuel that has developed as a consequence have led to a rapid rise in the need for energy. Although the resulting environmental problems may only have affected certain regions, the effects of our hunger for energy can now be felt around the world. Overconsumption of energy is the main trigger for the global warming that is now threatening to cause devastation in many areas of the world. However, resignation and fear are the wrong responses to this ever-growing problem. There are alternative energy sources to be tapped. It is possible to develop a long-term safe and affordable energy supply that will have only a minimal and manageable impact on the environment. This book describes the form this energy supply must take and how each individual can contribute towards a collective effort to halt climate change. But first it is important to take a close look at the causes of today's problems.

Renewable Energy and Climate Change, Second Edition. Volker Quaschning.

1.1 Energy Supply – Yesterday and Today

1.1.1 From the French Revolution to the Early Twentieth Century

At the time of the French Revolution at the end of the eighteenth century, animal muscle power was the most important source of energy. Around 14 million horses and 24 million cattle with an overall output of around 7.5 billion watts were being used as work animals [Köni99]. This corresponds to the power of more than 100 000 mid-range cars.

Power and Energy, or the Other Way Around

The terms 'power' and 'energy' are closely linked, and for this reason they are often confused with one another and used incorrectly.

Energy is stored work; thus, the possibility to perform work. It is identified by the symbol *E*. The symbol for work is *W*.

Power (symbol: *P*) indicates the time during which the work is to be performed or the energy used.

$$P = \frac{W}{t} \left(\text{power} = \frac{\text{work}}{\text{time}}\right)$$

For example, if a person lifts a bucket of water, this is considered work. The work that is performed increases the potential energy of the bucket of water. If the bucket is lifted up twice as quickly, less time is used and the power is doubled, even if the work is the same.

The unit for power is the watt (abbreviation: W) (The fact that the abbreviation for watt is the same as the symbol for work does not simplify matters.)

The unit for energy is watt second (Ws) or joule (J). Other units are also used for energy. Appendix A.1 provides the conversion factors between the different units of energy.

As the required powers and energies are often very high, prefixes such as mega (M), giga (G), tera (T), peta (P), and exa (E) are frequently used (see Appendix A.1).

The second staple energy source at this time was firewood, which was so important that it probably changed the political face of Europe. It is believed today that the transfer of the Continent's centre of power from the Mediterranean to north of the Alps came about because of the abundance of forests and associated energy potential there. Although the Islamic world was able to maintain its position of power on the Iberian peninsula well into the fifteenth century, one of the reasons why it lost its influence was the lack of wood. The problem was that there was not enough firewood that could be used to melt down metal to produce cannons and other weapons. This goes to show that energy crises are not just a modern phenomenon (Figure 1.1).

In addition to muscle power and firewood, other renewable energies were used intensively until the beginning of the twentieth century. Between 500 000 and 600 000 water mills were in operation in Europe at the end of the eighteenth century. The use of wind power was also widespread, particularly in flat and windy areas. For example, the United Netherlands had around 8000 working windmills at the end of the seventeenth century.

For a long time, fossil energy sources were only of secondary importance. Although coal from underground deposits was known to be a source of energy, it was largely

Figure 1.1 Firewood, working animals, wind and water power supplied most of the energy needed in the world as late as the eighteenth century.

avoided. It was not until a lack of wood in certain areas of Europe led to energy shortages that coal deposits began to be exploited. In addition, the higher energy density of coal proved to be an advantage in the production of steel. In 1800, 60% of coal was used to provide domestic heat, but 40 years later far more coal was used in ironworks and other factories than in homes.

Fossil Energy Sources – Stored Solar Energy

Fossil energy sources are concentrated energy sources that evolved from animal and plant remains over very long periods of time. These sources include oil, gas, hard coal, brown coal, and turf. The base materials for fossil energy sources could only develop because of their conversion through solar radiation over millions of years. In this sense, fossil energy sources are a form of stored solar energy.

From a chemical point of view, fossil energy sources are based on organic carbon compounds. Burnt in conjunction with oxygen, they not only generate energy in the form of heat, but also always produce the greenhouse gas carbon dioxide as well as other exhaust gases.

In around the year 1530, coal mines in Great Britain were producing about 200 000 tons of coal annually. By 1750 it was about 5 million tons, and in 1854 an astonishing 64 million tons. By 1900 three countries, Britain, the USA, and Germany, had an 80% share of world production [Köni99].

Renewable Energies – Not That New

The supplies of fossil energies, such as oil, natural gas, and coal, are limited, and they will be depleted within a few decades and cease to exist. Renewable energy sources, on the other hand, 'renew' themselves on their own. For example, if a hydropower plant takes the power of the water from a river, the river will not stop flowing. The energy content of the river renews itself on its own because the sun evaporates the water and the rain feeds the river again.

Renewable energies are also referred to as 'regenerative' or 'alternative' energies. Other renewable energies include wind power, biomass, the natural heat of the earth, and solar energy. Even the sun will eventually disappear in around four billion years. Compared to the few decades that fossil energy sources will still be available to us, this time period seems infinitely long.

Incidentally, renewable energies have been used by mankind for considerably longer than fossil fuels, although the current systems for using these fuels are vastly more advanced than in the past. Therefore, it is not renewable energies that are new, but rather the knowledge that in the long term renewable energies are the only option for a safe and environmentally compatible energy supply.

At the end of the twentieth century, worldwide coal production reached almost four billion tons. With an overall share of less than 3% of the world market, Germany and Britain had lost their former position of supremacy in the coal industry. China and the USA are currently the main coal-producing countries by a considerable margin. Most of the coal produced today is used in power plants.

1.1.2 The Era of Black Gold

Like coal, oil consists of conversion products from animal and plant substances, the biomass of primeval times. Over millions of years plankton and other single-celled organisms were deposited in sea basins. Due to the lack of oxygen, they were unable to decompose. Chemical processes of transformation eventually turned these substances into oil and gas. The biomass that was originally deposited originated from the sun, which means that fossil energy sources like coal, oil, and gas are nothing more than long-term conservers of solar energy. The oldest oil deposits are around 350 million years old. The area around the Persian Gulf where most oil is exploited today was completely below sea level 10–15 million years ago.

The oil deposits were developed much later than coal, because for a long time there were no practical uses for this liquid energy source. Oil was used in small quantities for thousands of years for medicinal and lighting purposes, but its high flammability compared to coal and charcoal gave it the reputation of being a very dangerous fuel. At the end of the nineteenth century petroleum lamps and later the invention of internal combustion engines finally provided a breakthrough.

Industrial oil production began in August 1859, as the American Edwin L. Drake struck oil whilst drilling at a depth of 20 m near Titusville in the US state of Pennsylvania. One name in particular is linked with further oil exploitation in America: John Davison Rockefeller. In 1862 at the age of 23 he founded an oil company that

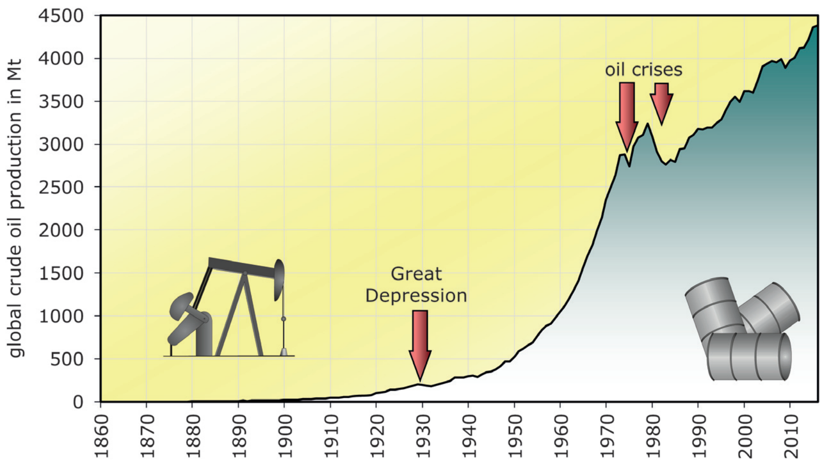

Figure 1.2 Oil production since 1860.

became Standard Oil and later the Exxon Corporation and incorporated large sections of the American oil industry.

However, it was still well into the twentieth century before fossil energy supplies, and specifically oil, dominated the energy market. In 1860 about 100 000 tons of oil were produced worldwide; by 1895 it was already 14 million tons. German government figures reveal that in 1895 there were 18 362 wind engines, 54 529 water engines, 58 530 steam engines and 21 350 internal combustion engines in use in the country [Gasc05]. Half of the drive units were actually still operated using renewable energy sources.

There was a huge rise in oil production in the twentieth century. By 1929 output had already risen to over 200 million tons and in the 1970s it shot up to over three billion tons (Figure 1.2). Today oil is the most important energy source of most industrialized countries. An average German citizen, including infants and pensioners uses 1700 l every year. This amounts to 10 well-filled bathtubs.

Being too dependent on a single energy source can become a serious problem for a society, as history shows. In 1960 OPEC (Organization of Petroleum Exporting Countries) was founded, with headquarters in Vienna. The goal of OPEC is to coordinate and standardize the oil policies of its member states. These include Algeria, Ecuador, Gabon, Indonesia, Iraq, Qatar, Kuwait, Libya, Nigeria, Saudi Arabia, Venezuela, and the United Arab Emirates, who between them at the end of the twentieth century controlled 40% of worldwide oil production. As a result of the Yom Kippur war between Israel, Syria, and Egypt, the OPEC states cut back on production in 1973. This led to the first oil crisis and a drastic rise in oil prices. Triggered by shortfalls in production and uncertainty after the revolution in Iran and the ensuing first Gulf War, the second oil crisis occurred in 1979 with oil prices rising to USD38 per barrel.

The drastic rise in oil prices set back world economic growth and energy use by about four years. The industrialized nations, which had become used to low oil prices, reacted sharply, resulting in schemes such as car-free Sundays and programmes promoting the use of renewable energies. Differences between the individual OPEC states in turn led to a rise in production quotas and a steep drop in price at the end of the 1980s. This also sharply reduced the commitment of the industrialized nations to use renewable energies.

From Alsatian Herring Barrels to Oil Barrels

Commercial oil production in Europe began in Pechelbronn in Alsace (now France) in 1735. Barrels that had previously been used to store herrings were cleaned and then used to store the oil, because in those days salted herring was traded in large quantities, which meant the barrels were comparatively cheap. As oil production increased, special barrels of the same size were produced exclusively for oil. The bottom of the barrels was painted blue to prevent any confusion with barrels used for food products. When commercial oil production began in the USA, the companies copied the techniques used in the Alsace region. This also included the standard size of herring barrels. Since then the herring barrel volume has remained the international measuring unit for oil. The abbreviation of barrel is bbl, which stands for 'blue barrel' and means a barrel with a blue base.

1 petroleum barrel (US) = 1 bbl (US) = 158.987 l (litres)

The dramatic collapse in the price of crude oil from almost USD40 a barrel to USD10 created economic problems for some of the production countries, and also made it unattractive to develop new oil sources. In 1998 unity was largely restored again among the OPEC states. They agreed on lower production quotas in order to halt any further drop in prices. In fact, prices rose even higher than originally intended. Now the lack of investment in energy-saving measures was coming home to roost. The economic boom in China and in other countries further boosted the demand for oil to such an extent that it was difficult to meet and, as a consequence, oil prices kept climbing to new record highs. Even though the oil price has fallen sharply again since the financial crisis, new record prices are expected again due to the limited supplies available.

Yet, there have been some fundamental changes since the beginning of the 1980s. In many industrialized countries, energy use has decreased despite rapid and sustained economic growth. The realization has set in that energy use and gross national product are not inextricably linked. It is possible for prosperity to increase even if energy use levels or drops. Nonetheless, the chance to develop true alternatives to oil and to make energy-saving options the norm was missed due to the long period of continuous low oil prices.

This is particularly apparent in the transport sector where cars became faster, more comfortable, heavier, and with more horsepower, but only minimally more fuel-efficient. Today, the fortunate drivers of company cars with 50 hp more than 20 years ago, regularly get stuck in traffic jams (made bearable by air-conditioning and high-tech stereo systems). The tank is also bigger, so that the heavier car, with virtually unchanged consumption, can reach the next petrol station selling cheap fuel. As a result of all the talk about climate change and high oil prices, car manufacturers are now scrambling to incorporate features into their cars that have not been demanded in decades: fuel efficiency and low emissions of greenhouse gases. Since many car companies are struggling with the new requirements, they continue to rely on tried and tested concepts. Because of their political influence, they are able to prevent or dilute the strict savings targets urgently needed for climate protection. Or, like the VW Group, they try to circumvent existing regulations with illegal methods. If Volkswagen had invested the fines paid in the USA in the development of emission-free electric cars, the company would no doubt have been a world leader in this field and would also have made an enormous contribution to climate protection. In retrospect, it is likely the VW scandal will turn out to be a great stroke of luck for Germany. It has shown the technical saving limits of conventional combustion engines and considerably accelerated the switch to electric cars. In the end, it may even have prevented German car makers from falling behind internationally by uncompromisingly sticking to old technologies.

As important as oil is as a fuel, that is not its only use, because it is also an important raw material for the chemical industry. For example, oil is used as a basic material in the production of plastic chairs, plastic bags, nylon tights, polyester shirts, shower gels, scents, and vitamin pills.

1.1.3 Natural Gas – The Newest Fossil Energy Source

Natural gas is considered to be the cleanest fossil energy source. When natural gas is burnt, it produces fewer harmful substances and climate-damaging carbon dioxide than oil or coal. However, this does not change the fact that the combustion of natural gas also produces far too many greenhouse gases for effective climate protection.

The base material for the creation of natural gas was usually green plants in the flat coastal waters of the tropics. The Northern German lowland plains were part of this area 300 million years ago. The lack of oxygen in coastal swampland prevented the organic material from decomposing and so it developed into peat. As time went by, new layers of sand and clay were deposited on the peat, which during the course of millions of years turned into brown and bituminous coal. Natural gas then developed from this due to the high pressure that exists at depths of several kilometres and temperatures of 120–180 °C.

However, natural gas does not consist of a single gas, but rather a mixture of different gases whose composition varies considerably depending on the deposit. The main component is methane, and the gas also often contains relatively large quantities of hydrogen sulphide, which is poisonous and even in very small concentrations smells of rotten eggs. Therefore, natural gas must often first be purified in processing plants using physiochemical processes. As natural gas deposits usually also contain water, the gas must be dried to prevent corrosion in the natural gas pipelines (Figure 1.3).

Natural gas was not seen as a significant energy source until relatively recently. It was not until the early 1960s that natural gas was promoted and marketed in large quantities. The reasons for this late use of natural gas compared to coal and oil is that extracting it requires drilling to depths of several thousand metres. It also requires complicated transport. Whereas oil was initially still being transported in wooden barrels, gas requires pressure storage or pipelines for its transport. Nowadays, pipelines extend for thousands of kilometres from the extraction sites, all the way to providing gas heating to family homes. The world's largest gas producer is Russia, followed by the USA, Canada, Iran, Norway, and Algeria.

However, the demand for natural gas is not constant over the whole year. In countries with cold winters the demand in winter is often double what it is in summer. As it is not economical to cut summer production by a half, enormous storage facilities are needed to balance the uneven seasonal demand. So-called salt caverns and aquifer

Figure 1.3 Left: Building a natural gas pipeline in Eastern Germany. Right: Storage facility for 4.2 billion m^3 of natural gas in Rehden, 60 km south of Bremen. Source: Photos: WINGAS GmbH.

reservoirs are used. Caverns are shafts dug in underground salt deposits from where the stored gas can quickly be extracted – for instance, to cover sudden high demand. Underground aquifer reservoirs are suitable for the storage of particularly large quantities of gas. Hence this rock is again filled with what it had stored for over 300 million years and taken from it in a few decades. In total, Germany has a natural gas storage capacity amounting to more than 30 billion cubic metres in operation, in planning or under construction. This corresponds to a cuboid with a base area of 20 by 20 km and a height of 75 m. Environmentally compatible hydrogen is expected to play an important role in future energy supply in the foreseeable future. The existing natural gas storage facilities are already sufficient to compensate for seasonal fluctuations in a completely renewable energy supply. Therefore, natural gas storage facilities and networks will very soon play a central role in securing a sustainable energy supply in the future.

1.1.4 Nuclear Power – Split Energy

In December 1938 Otto Hahn and Fritz Strassmann split a uranium nucleus on a simple laboratory bench at the Kaiser-Wilhelm Institute for Chemistry in Berlin-Dahlem, thereby laying the foundation for the future use of nuclear energy. The laboratory bench can still be admired today at the Deutsches Museum in Munich.

In the experiment a uranium-235 nucleus was bombarded with slow neutrons. The nucleus then split, producing two atomic parts, krypton and barium, as well as two or three other neutrons. With a large quantity of uranium-235, these new neutrons can also split uranium nuclei that in turn release neutrons, thus leading to a chain reaction. If enough uranium is available, the uncontrolled chain reaction will create an atomic bomb. If the speed of the chain reaction can be controlled, uranium-235 can also be used as fuel for power plants.

Germany as an Example of Nuclear History

The Paris Treaty of 5 May 1955 allowed Germany non-military use of nuclear energy. Expectations for the nuclear industry ran high. A separate ministry for nuclear energy was created, and the first minister was Franz Josef Strauss. On 31 October 1957, Germany put its first research reactor, called the nuclear egg, into operation at the Technical University in Munich. In June 1961 the Kahl nuclear power plant fed electricity into the public grid for the first time. In 1972 the Stade and Wuergassen commercial nuclear power plants began to provide electricity, and with Biblis the world's first 1200 MW block went into operation in 1974. In 1989 the last new power plant, Neckarwestheim, was connected to the grid. Until that point the federal government had invested over 19 billion euros in the research and development of nuclear energy. However, public concerns about the risks of nuclear energy continued to grow and prevented the building of new power plants. In 2000, Germany decided to phase out nuclear power. In 2011, another federal government significantly extended the operating times again, but the phase-out was reinstated in the same year, following the accidents at the Fukushima nuclear power plant. The last nuclear power plant in Germany is scheduled to be disconnected from the grid in 2022. Despite more than 50 years of nuclear energy use in Germany, the problem of end storage for highly radioactive waste has still not completely been resolved.

In nuclear fission there is a so-called mass defect, i.e. the total mass of the fission particles is less than that of the original uranium nucleus. A complete fission of 1 kg of uranium-235 produces a mass loss of a single gram. This lost mass is then completely converted into energy. An energy mass of 24 million kilowatt hours is thereby released. Around 3000 tons of coal would have to be burnt to release the same amount of energy.

After Hahn's discovery the use of nuclear energy was promoted mainly by the military. Albert Einstein, who emigrated to the USA in 1933 to escape Nazi persecution, sent a letter to US president Roosevelt on 2 August 1939 warning him that Hitler's Germany was making a serious effort to produce pure uranium-235 that could be used to build an atomic bomb. When the Second World War broke out on 1 September 1939, the American government set up the Manhattan Project with the aim of developing and building an effective atomic bomb.

The biggest problem turned out to be the ability to produce significant quantities of uranium-235 to maintain a chain reaction. If metallic uranium is refined from uranium ore, there is a 99.3% probability that it will consist of heavy uranium-235. This is practically useless for producing a bomb. It even has the characteristic of decelerating and absorbing neutrons, thus bringing any kind of chain reaction to a halt. Only 0.7% of available uranium consists of uranium-235, which must be enriched proportionally higher to create a chain reaction. No separation between uranium-235 and uranium-238 can be achieved by chemical means because chemically both isotopes are totally identical.

Consequently, other solutions had to be sought. Ultimately, this separation succeeded through the use of a centrifuge, because the isotopes have different masses.

The Manhattan Project cost more than USD2 billion between 1939 and 1945. The desired results were finally achieved under the direction of the physicist J. Robert Oppenheimer: on 16 July 1945, two months after the capitulation of Germany, the first test of the atomic bomb was carried out in the US state of New Mexico. Using the bomb on Germany was no longer up for discussion, but shortly before the end of the Second World War the atomic bomb was dropped on the Japanese cities Hiroshima and Nagasaki – with the well-known aftermath.

The non-military use of nuclear energy came some years later. Although physicists like Werner Heisenberg and Enrico Fermi had been conducting tests in reactors since 1941, it was not until December 1951 in Idaho that the research reactor EBR 1 succeeded in generating electric current using nuclear energy.

• www.bund.net/atomkraft	Friends of the Earth Germany info
• www.atomindustrie.de	Satirical site on the use of nuclear energy
• https://pris.iaea.org/pris	IEA Power Reactor Information System
• www.wiseinternational.org	World Information Service on Energy
• www.no2nuclearpower.org.uk	News and information about the UK nuclear industry

Unlike the uncontrollable chain reaction that occurs when an atomic bomb explodes, nuclear fission in a nuclear power plant should occur in a controlled manner. Once a chain reaction has started, the number of new neutrons resulting from the nuclear fission must be kept to a limit. Each splitting of a uranium nucleus releases two to three neutrons, only one of which is allowed to split another nucleus. Control rods that capture the neutrons reduce the number of neutrons released. If this number is too high, the process gets out of control. The nuclear power plant then starts to act like an atomic bomb and an uncontrolled chain reaction occurs. Technically (and this was the prevailing view at the time), nuclear fission can be controlled, and undesired reactions eliminated.

The early euphoria that came with the use of nuclear energy died down when an accident occurred with a reactor on 28 March 1979 in Harrisburg, the capital of the US state of Pennsylvania. Large amounts of radioactivity escaped. Many animals and plants were affected and the number of stillbirths among the nearby population increased dramatically after the tragedy.

On 26 April 1986 another serious accident occurred in a nuclear reactor at Chernobyl, a city in the Ukraine. What was thought to be officially improbable actually happened: the chain reaction got out of control and the result was a nuclear meltdown. The radioactivity that was released produced high radiation levels in places as far away as Germany. Many helpers who tried to contain the damage on site paid for their efforts with their lives and thousands of people died of cancer in the years that followed.

On March 11 2011, the Japanese nuclear power plant Fukushima Daiichi was hit by a strong earthquake and a severe tsunami. The plant was not designed for such an event, and the reactor cooling system failed. As a result, nuclear melts and several explosions occurred, which destroyed four of the six reactors and released considerable amounts of radioactivity. Around 150 000 residents of the area were evacuated and hundreds of thousands of animals, which had been left behind, starved to death.

Another problem with the civilian use of nuclear energy is the disposal of radioactive waste. The use of uranium fuel elements in nuclear power plants produces large quantities of radioactive waste that will create a deadly threat for centuries to come. No safe way has yet been found to dispose of this waste.

Technically, the use of nuclear energy is fascinating and the prospect of generating electricity from relatively small amounts of fuel is very tempting. But there are serious risks involved. Germany has therefore agreed to a general decommissioning of its nuclear energy plants. Once the last nuclear energy plant has been switched off, the country's venture into this field will have cost the German federal government alone more than 40 billion euros in research and development. Germany's most expensive leisure park has become a bizarre showpiece for the incredibly bad investment in nuclear energy. The prototype for a fast breeder reactor was erected at a cost of four billion euros in the North Rhine-Westphalian town of Kalkar. Due to safety concerns, including those relating to the highly reactive cooling agent sodium, the nuclear plant was never put into operation. Today the Kernwasser Wunderland Kalkar leisure park is located in the industrial ruins of the nuclear plant (Figure 1.4).

Conservative politicians and some companies have repeatedly cited nuclear energy as a technology of the future. However, only a small proportion of the many projects announced in recent years have been implemented. Above all, the enormous costs of new nuclear power plants usually quickly end any nuclear dreams. High subsidies are necessary in order to facilitate new nuclear power plants in Europe. For the controversial new Hinkley Point C project in Great Britain, guaranteed electricity prices have been offered that are significantly higher than those for solar and wind power plants. If nuclear energy, which after all is a highly controversial technology, can no longer even offer economic benefits, its days are certainly numbered.

In 2017 there were 449 nuclear power plants in operation worldwide. Yet nuclear energy is relatively unimportant for the global supply of energy. Its share is lower than hydropower and much lower than firewood. If a major effort were made to replace the

Figure 1.4 The Kernwasser Wunderland leisure park is in the grounds of a fast breeder reactor in Kalkar that was never put into operation. Source: Photos: Wunderland Kalkar, www.wunderlandkalkar.eu.

majority of fossil power plants with nuclear energy, uranium supplies would be depleted within a few years. In this sense, nuclear power plants are not a real alternative when it comes to protecting the environment – although this is how some politicians, and specifically the companies that would profit from the use of nuclear power, often like to present the option to the public.

In the long term there are high hopes for a totally new variant of atomic energy: nuclear fusion. The model for this technology is the sun, which releases its energy through a nuclear fusion of hydrogen nuclei. The aim is to duplicate this process on Earth without the danger of triggering an undesirable chain reaction like Chernobyl or Fukushima. But there is a hitch to this plan: the particles must be heated to temperatures of several million degrees centigrade to initiate the momentum of nuclear fusion. There is no known material that can permanently withstand such temperatures. Therefore, other technologies, such as the use of strong magnetic fields to contain reaction materials, are being tested. These technologies have seen some success, but despite the enormous amounts of energy used during the ignition, the reactors always go out by themselves.

Currently no one has seriously predicted whether this technology will ever actually work in practice. Critics point out that the proponents of nuclear fusion have been saying for years that it will take 50 years for a commercial functioning reactor to be connected to the grid. Despite the passage of time that 50-year time frame never reduces – the only thing about nuclear fusion that can be said with any certainty.

However, even if this technology became advanced enough to use, there are two good reasons for opposing the development of nuclear fusion. Firstly, this technology is decidedly more expensive than nuclear fission today. As already mentioned, financing conventional nuclear power plants is difficult today. For economic reasons, preference would be given to alternatives such as renewable energies. Greater investment in fusion testing means less investment in alternative energies. At present we would be happy if we could get a fusion reactor up and running at all. The use of this technology for balancing the grid is therefore hardly conceivable from today's perspective. However, this is precisely what would be needed for fusion power plants to operate in conjunction with renewable power plants, such as solar and wind. Fusion technology is therefore unsuitable for the age of renewables. Not to mention the fact that nuclear fusion plants also produce radioactive substances and waste that present a risk. So, there are very few reasons why government money should continue to be used for this technology.

1.1.5 The Century of Fossil Energy

Whereas traditional renewable energies covered most of the energy needs of mankind until the end of the nineteenth century, the twentieth century can be seen as the century of fossil energy. By the middle of the century fossil fuels in internal combustion engines had almost completely replaced the classic renewable energy systems, such as windmills, water wheels, and vehicles and machines driven by muscle power. Modern hydropower for the generation of electricity and biomass, which was mainly used as fuel, were the only renewable energies of any significance.

After the Second World War the demand for energy soared, and fossil energy sources were able to increase their share substantially. In 2016 fossil energies covered around 79% of the world's primary energy needs (see box p. and Figure 1.5). Hydropower and

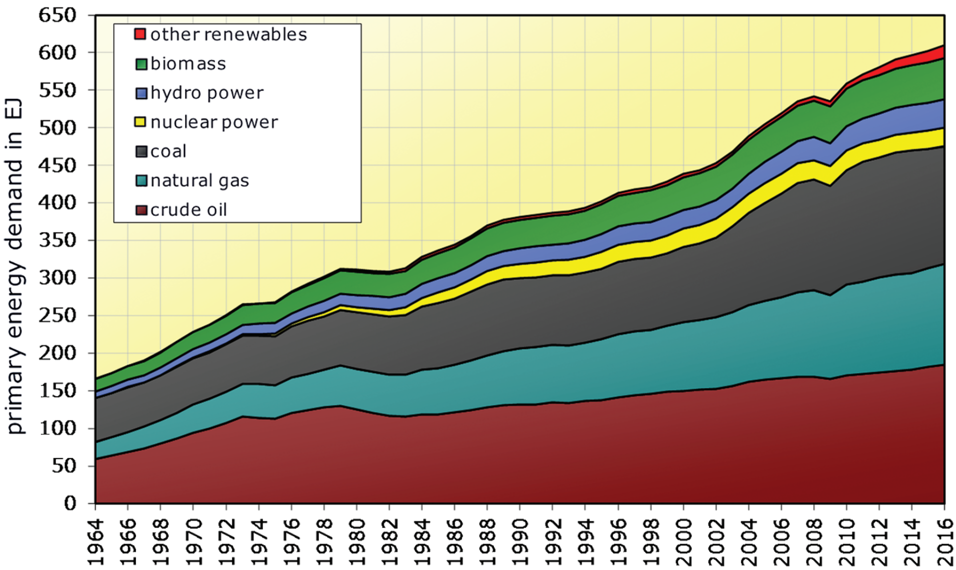

Figure 1.5 Development of primary energy demand worldwide.

nuclear energy had a share of around 6% and 4%, respectively, and biomass around 9%. The other renewable energies amounted to just under 3%. Meanwhile, the situation has started to change. Solar and wind power have continuously high growth rates for new capacity, so their contribution to meeting global energy demand will increase significantly in the coming years. There was a slight decline in the use of coal in 2015 and 2016, while the demand for oil and gas is currently still increasing. If this trend continues, renewable energies could stop the growth in fossil fuels in just a few years and thus initiate effective climate protection measures.

1.1.6 The Renewables Century

Although the share of renewable energies is still comparatively low at present, and the consumption of fossil fuels continues to rise despite all climate protection commitments, the twenty-first century is already on its way to becoming the century of renewables. Many cannot yet imagine a rapid change. Renewable energies share this fate with a multitude of new technologies. Emperor Friedrich Wilhelm II, for example, is said to have initially doubted the change in the transport sector: 'I believe in the horse. The automobile is a temporary phenomenon.'

The internet and mobile phones have shown us how quickly new technologies can become established. Wind power and photovoltaics are currently expanding rapidly, with growth rates reminiscent of the introduction of the internet and mobile communications. Germany has long been a pioneer in the use of renewable energies. The millionth solar plant was opened there as early as 2011 (Figure 1.6). However, since 2013, when the German government significantly restricted the expansion of renewable energies, other countries, for example China, have taken over Germany's lead role in the expansion of renewable energies. Yet there is no doubt: The age of renewable energies

Figure 1.6 Left: Despite the intensive use of fossil fuels, the expansion of wind energy is booming in the USA. Right: The one-millionth PV installation in Germany. Source: Photos: Dennis Schwartz/REpower Systems SE and BSW-Solar.

has already begun worldwide. Soon they will break the dominance of fossil energies. The only question remains whether the replacement will come in time to stop climate change, which is progressing at an ever-faster pace. Nevertheless, the chances of this happening may be better than many currently dare to hope.

1.2 Energy Needs – Who Needs What, Where, and How Much?

Demand for energy is distributed unevenly across the world. Six countries, namely China, the USA, Russia, India, Japan, and Germany, use more than half the available energy.

The USA alone needs one-sixth of the energy used in the world, even though less than one-twentieth of the worldwide population lives there. If every citizen of India were to use as much energy as the average American, global demand for energy would rise by about 60%. If all the people on Earth developed the same hunger for energy as the USA, demand would increase threefold (Figure 1.7).

Energy Cannot be Consumed, Actually

Anyone who has taken physics at high school will have learned about the concept of energy conservation. According to this principle, energy cannot be consumed or produced, but only converted from one form into another.

The car is a good example. The fact that cars consume too much is something we are keenly aware of each time we fill up with petrol. The petrol that a car needs, and we wince every time we pay for it, is a type of stored chemical energy. Combustion produces thermal energy. This is converted by an engine into kinetic energy and transferred to the car. Once