Chapter 2
Renewable Energy: Resources and Technologies

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Renewable energy or regenerative energy technologies attract an enormous attention today. New technologies, new projects and new energy stakeholder groups are emerging everywhere. Countries, regions and cities are competing about the top range in energy rankings. Where does this movement come from and which role can renewable energy technologies take in a given energy system?

There are three main arguments. First, renewable energies are—ex ante—considered to be 'green', advantageous and beneficial. And this is in fact true. The term 'renewable' points out the main feature of these technologies: the inexploitable and regenerative nature and availability of the underlying energy resource in human dimensions. It also implies the important role of renewables for greenhouse gas mitigation. Second, the use of the mostly regional renewable energy resources leads to the expectation of an increasing regional added value and high yields for local stakeholders, administrations and people and the development of high technology innovations for the regional economy and business. And third, there is such a high number of different renewable energy technologies available that we can also speak of a reliable and projectable energy resource: even when the wind is not always blowing and the sun is not always shining, the portfolio of the different renewable energies allows a reliable supply with energy.

All arguments are valid. There are numerous project examples, and there is widespread proof that both the vast resource potential of renewables and the economic and other benefits for the regional economies are coming true. However, today we also have to realize that the implementation of renewable energy technologies may have ambiguous, if not negative effects. This has become evident, for example, in the area of biofuel production through the largely practiced conversion of natural habitats into heavily exploited agriculture land or low greenhouse gas mitigation effects, in the area of wind energy through the transformation

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of formerly less intense used land into ‘energy production sites’ or in the area of special geothermal energies through the activation of geological pores with the ‘fracking’ method.

There are, in fact, many different effects associated with the use of renewable energies. The question truly arises whether all renewable energy technologies are sustainable per se and how sustainability of renewable energies can be measured under the many partly contradictory frame conditions.

However, these factors contributing to the overall performance of renewable energies have to be evaluated intensively and with care. Not all factors are contributing in the same way. The different technologies and utilization pathways have very different characteristics and conclusively very different degree of sustainability.

The following chapter attempts to provide an integrated, holistic view on renewable energy technologies, taking into account a number of indicators and parameters.

2.1 Energy resources

All renewable energy technologies are based on three principles and base energy resources (see Fig. 2.1 and [1]).

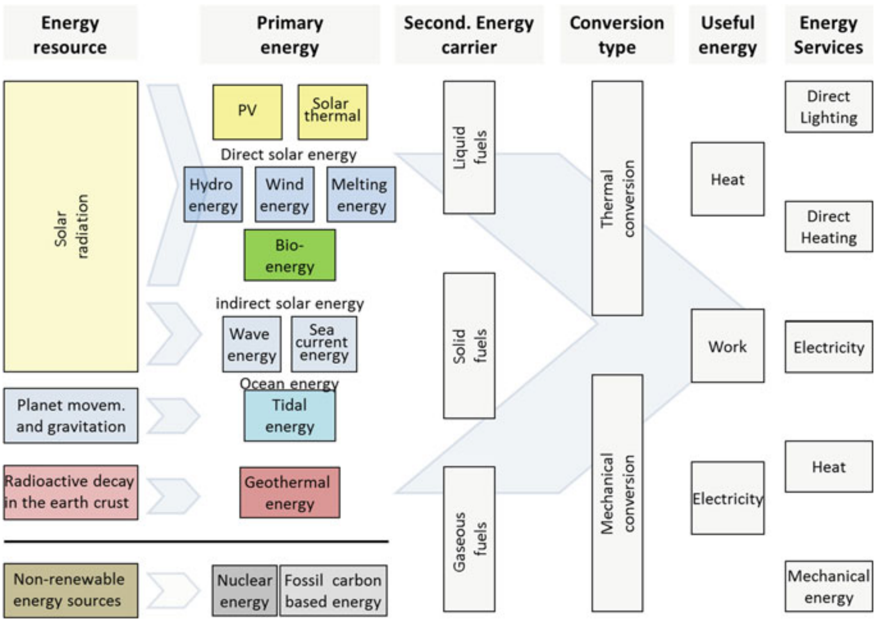


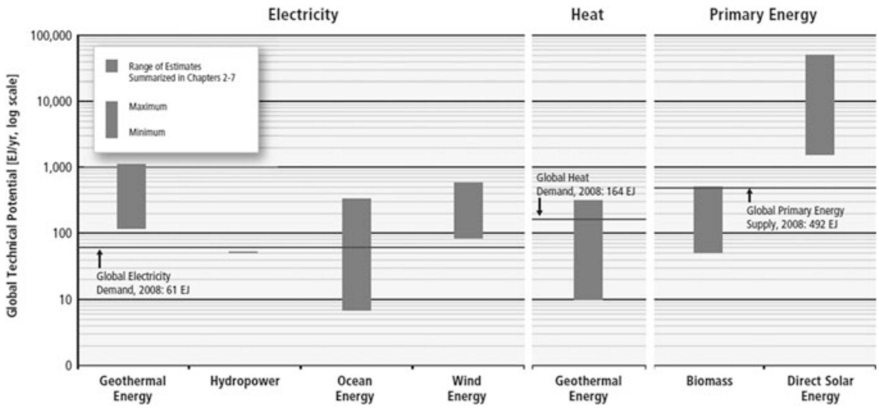
Fig. 2.1 Base energy resources, technologies and provision pathways for renewable energy

1. Solar radiation is the primary of the thermonuclear conversion of elements in the sun. This is the main renewable energy resource and responsible for the majority of energies on earth. The solar radiation is also responsible for the existence of most forms of life. Based on this source, we distinguish two groups of technologies: the direct solar energy technologies, such as photovoltaics, and solar thermal energy technologies, which are based on using the solar beams of the radiation directly. Wind, hydro or wave energy technologies, in turn, are indirect outcomes of the solar radiation making use of the transformed energy in the form of wind or the water cycle and water movement. Even bioenergy is—through the process of photosynthesis—an indirect solar resource, often characterized as stored solar energy.
2. The movement of the planets and gravitation is responsible for the tide and the corresponding power plants based on utilizing the movement of water in the oceans.
3. Thirdly, the radioactive decay of materials in the earth's crust such as uranium and potassium and the remaining heat from earth formation are the original and basic energies to supply and drive the heat source in the earth, commonly known as geothermal energy. Here, also various forms of energy resources, for example, the heat of underground water or of geological rock formations and technologies (heat exchangers, heat and power plants, etc.) are summarized under the expression 'geothermal energy'.

All of this energy (technologies) can be converted either directly into a useful form of energy, for example, heat or electricity, or can be converted into a secondary energy carrier (liquid, solid or gaseous fuels) to be then converted into 'heat', 'electricity' and 'work' as the useful energy through mostly thermal conversion (combustion). Figure 2.1 describes these different forms of energy and transformation pathways in a conclusive manner.

'Renewable energy' is a quite broad and undifferentiated term used for both, the energy resources and the renewable energy technologies. At a more strict level, both terms need to be differentiated: the term 'renewable energy resource' as an expression for the material and the energy carrier (such as wood, wind, solar radiation or water) and the term 'renewable energy technology' for the appliance and the converting technology or power unit.

In 2012, the Intergovernmental Panel on Climate Change (IPCC), a group established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988 with the task to give scientific proof for the causes and effects of climate change, published a remarkable report on 'Renewable energy sources and climate change mitigation' [2]. In this report, the renewable energy technologies are characterized, their development over the years are analysed, and they are evaluated and benchmarked against the target of mitigating greenhouse gas emissions on a worldwide scale. For this evaluation, a number of indicators were chosen, mainly the energy potential, the contribution to energy generation, the emission of greenhouse gases, but also economic figures such as generation costs or price levels. These factors can be



Range of Estimates of Global Technical Potentials

	Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Geothermal Energy (Heat)	Biomass	Direct Solar Energy
Max (in EJ/yr)	1109	52	331	580	312	500	49837
Min (in EJ/yr)	118	50	7	85	10	50	1575

Fig. 2.2 Ranges of global technical potentials of renewable energy sources ([2, 3], p. 39)

seen as suitable factors or indicators to describe the role and effect of renewable energy technology in a given energy system. They should allow, when monitored over a period of time, to estimate the contribution to the various aspects of energy provision, environmental integrity and socio-economic effect—in one word, for the sustainability of the renewable energy development.

With respect to the energy potential, clearly the direct use of solar radiation shows the highest value (see Fig. 2.2). On the basis of primary energy, this resource (with a potential range between 1.575 and 49.837 EJ/yr) is outbalancing the present global primary energy demand (of 492 EJ) by an order of magnitude. Wind energy (with a range between 85 and 580 EJ), geothermal energy (between 118 and 1.109 EJ/yr.) and ocean energy (between 7 and 331 EJ/yr) for electricity production show a potential in the range of and even considerably higher than the present electricity demand (of 61 EJ/yr). Hydropower has a very distinct potential (52 EJ/yr) in the same range than the present electricity demand. For heat provision, geothermal energy has a potential (range) which will most likely meet the present global demand for heat. Clearly, the uncertainty in potential, here expressed as the range, is very high with the less developed technologies such as geothermal and ocean energy, compared to the more developed technologies like biomass, wind energy and especially hydropower.

The share of the global renewable energy compared to the overall energy use in the world is presently at around 16.7 % [4]. It is mainly dominated by the use of biomass, particularly in traditional form and often with a low efficiency. Hydropower has the second largest share in this portfolio, constituting the base renewable energy form for many countries such as in China, Canada, Brazil or India and Vietnam.

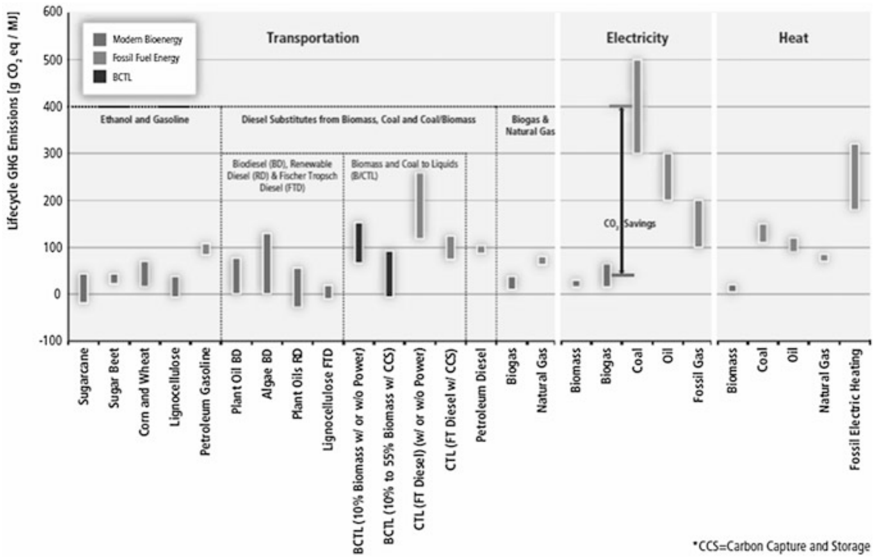


Fig. 2.3 Ranges of GHG emissions per unit energy output (MJ) from major modern bioenergy chains and conventional fossil fuel energy systems ([2, 3 p. 52])

2.2 Contribution to GHG Emission Reduction

When compared in terms of greenhouse gas (GHG) emissions, renewable energy systems show a particular but differentiated picture ([2], see Fig. 2.3).

The comparison of the GHG emissions, based on a life cycle approach, shows that all renewable bioenergy technologies have lower life cycle emissions than the conventional fossil-based technologies. The range of emissions, however, shows a high variation and bandwidth, representing the different process options within one technology. The difference between the renewable- and the fossil-based systems is highest in electricity generation. It is relatively close between biogas and natural gas or ethanol and gasoline, showing that first-generation biofuels such as bio-ethanol and plant oils have relatively low effects on the mitigation of GHG emissions. Likewise, also the other renewable technologies are evaluated and assessed, for example, direct solar electricity generation ([2, p. 67]).

2.3 The Economics of Renewable Energy

In terms of the economics, the costs for renewable energy generation are still higher than those for conventional fossil-based energy. For electricity generation, the IPCC [2] has identified a cost level for conventional energies between 3 and 10 UScent_{2005} (equivalent to 3.9–13.2 EURcent), per kWh. For bioenergy, the range is given at 4–21 (5.8–27 EURcent), for solar electricity between 19 and 37 (25–49 EURcent), for geothermal between 6 and 7 (7.9–9.2 EURcent), for wind between 8 and 14 (10.5–18.5 EURcent) and for ocean electricity at around 21 UScent_{2005} (27.7 EURcent) per kWh. Only hydropower generation clearly ranges with 4 UScent_{2005} (5.2 EURcent) per kWh in the area of the conventional energies. For heat generation, biomass and geothermal heat are available at a cost level comparable to the conventional energies, only the upper range of solar thermal heat ranges above the level of conventional energies (all data taken from [2] Fig. 1.9).

All of these numbers represent a short glance at energy costs, respectively prices, under the present economic and partly specific technical frame conditions. Depending on the specific economic situation and specifically also the taxation in each country, and the energy market situation, the price for energy services or a kWh of electricity may differ considerably from the given energy generation costs. The costs are also expressed on a global average, which may be true for some technologies, for example, when based on the (world) oil market, but which may not reflect the situation for every country or conditions. For example, average levelized energy generation costs of 5–6 UScents_{2005} (6.6–7.9 EUR Ct) per kWh are projected for geothermal electricity generation. This may be true for some of the high potential geothermal sites such as in the United States, the Philippines, New Zealand or Iceland, but certainly not for countries like Germany or France, where high drilling costs under the special geological situation dominate the total price development and the failure rate is at 20 % or higher; especially the new ‘enhanced geothermal systems’, where the underground reservoir needs to be stimulated to yield enough energy may have increased investment cost of up to 4.000 US$ (5.280 EUR) per kW, compared to the regular geothermal sources such as geothermal aquifers, which are in the range of 3.500 US$ (4.620 EUR) per kW or less.

2.4 Role and Performance of Renewable Energy Technologies

Renewable energy appliances and technologies are often grouped according to size and field of application. Accordingly, small-scale appliances for the provision of energy to individual homes and buildings can be distinguished from (grid based) medium- or large-scale-sized technologies to provide energy, for example, to larger districts, cities, industries or even countries. However, renewable energies are available in any market segment, in the small- and the large-scale technologies, in electricity and/or heat generation, as well as in fuel generation for mobility and transport. In the following chapter, only renewables for electricity and heat generation are considered.

2.4.1 Small-Scale Appliances for Energy Provision to Individual Homes and Buildings

Renewable energy technologies are frequently considered to be ‘small scale’, ‘decentral’ and ‘local’. However, the term ‘decentral’ is ambiguous. Renewables can also function as ‘central’ technologies. In a district heating network, a biomass CHP plant, serving the energy needs for many hundred homes, is a ‘central’ technology. It depends on the system boundary or system integration, even on a personal opinion, whether a technology is considered ‘decentral’ or ‘central’.

Small-scale appliances are considered to be limited to a capacity of 100 kW. They are well suited to supply energy (heat and/or electricity) for single, individual apartments, houses and sites. In fact, a high number of technologies are available in this segment. Besides providing heat or electricity separately, more and more small-scale appliances can do both, generating heat and electricity, for example, in cogeneration (micro-gas turbines, stirling engines) or in combinations, such as in hybrid solar thermal–photovoltaic collectors.

With respect to technology development, the need for downscaling of the size and capacity of the appliances is a great technical challenge. In Germany, new built family homes with a high insulation often have very low heating requirements below 5 kW heating capacity. The operation hours may go below 4,000 h per year. Such small-scale systems, also fulfilling high requirements of energy efficiency, are a big technical and also economic challenge.

With respect to the energy carrier and fuel and the technology type, the technologies can be divided into three groups.

- solar technologies (photovoltaics, solar thermal collector systems)
- biomass technologies (pellet boiler, wood log boiler, plant oil boiler)
- combined heat and power plants, based on a variety of fuels (fuel cell systems, stirling engine and micro-CHP).

The main energy technologies in this market segment are characterized in Table 2.1. The table shows that with small-scale technologies, both electricity and heat/cold generations are possible. The use of combined heat and power mode in private households is still unusual, but possible. The combination of technologies, for example a pellet boiler together with a solar thermal collector, or a PV installation together with a geothermal heat pump, may yield additional benefits for household, such as a higher share of renewable energy supply or a self-autonomy in energy supply. The downscaling of size and costs of the small-scale technologies is still a technical challenge in, but will certainly show progress in the next years.

Table 2.1 Technical and economic key characteristics of the main small-scale energy technologies for energy provision to individual houses, buildings and sites

Technology	Characteristics and use	Economic features and market
Photovoltaics	Direct conversion of solar radiation into electricity, fluctuating energy resource No wastes, no residues Modular from small to large scale Implemented and distributed worldwide with high capacity at 91 GW in 2012 [5]	Relatively high investment costs at 1,000–2,000 EUR/kW Generation costs high at 18–45 EURcent/kWh (2012), but steep decline and technology learning of 20% [6] Energetic amortization between 1 and 3 years [7]
Wind energy converters (small scale)	Direct conversion of wind energy into electricity No wastes, no residues highest installed capacity in China and the USA [8] Attractive for island situations and remote areas Risk of vibrations and shakings to buildings	Investment costs high at 2,000–3,000 EUR/kW High generation cost levels at 18–29 EURcent/kWh [9]
Solar thermal collector systems	Conversion of diffuse solar radiation Modular set-up well approved for hot water generation and heating resistance Durability of material against strong solar radiation necessary. strong solar radiation Simple and sophisticated systems for households available	Competitive, well approved and economic technology Market well established Available from just a few to several thousand Euros
Solar-hybrid PV plus solar thermal systems	Combined photovoltaic and solar thermal systems Modular First implementation in Europe and other developed countries Advantage for PV through cooling effect	More expensive Higher maintenance requirements Small market share
Heat exchange systems (geothermal, air)	Thermal transfer between media of different temperature Driving energy source from geothermal energy, air or excess heat Suitable for low temperature heating systems (underfloor, wall heating)	Relatively high investment costs Economic solution with own renewable energy supply (e.g. through PV or geothermal energy) COP and costs often not as good as expected

(continued)

Table 2.1 (continued)

Technology	Characteristics and use	Economic features and market
Micro-CHP units	Electricity generation on a small scale and decentral Large range of fuels from (bio)gas to solid biomass Combination of several units to a cluster and virtual networks Suitable for energy system services High overall resource efficiency up to 95 %	High investment costs Additional revenues possible through electricity sales Market penetration still small
Pellet and wood fuel heating boilers	Wide range of suitable and advanced technologies available High energy efficiency above 90 % Suitable also for very low capacities Increased particle emissions can be reduced through filters [10]	Investment costs still slightly higher Fuel costs for biomass fairly low, further development not clear Well-established market Filters for particulate matter control are becoming successively available at highly variable costs starting at 930 US$ per ton of removed PM with a cyclone [11]

2.4.2 SWOT analysis of the Small-Scale Renewable Energy Portfolio

All of these renewable energy technologies find their role in specific applications and frame conditions and show benefits as well as drawbacks. A SWOT analysis, compiling arguments and indicators on '**S**trengths', '**W**eaknesses', '**O**pportunities' and '**T**hreats' for the service delivery and for future development, may therefore provide a balanced view of the capacities and potentials of the technologies. For the small-scale appliances and technologies, the results of such a SWOT analysis are given in Table 2.2.

The different small-scale energy technologies are suitable for meeting different requirements, however, at specific costs. Costs for energy services need to be calculated on an annualized cost basis to be able to compare different technologies with a different need for investments on one side and fuel costs on the other side. This cost comparison of the most available technologies for heat provision for a new, low-energy family house (150 m^2) with a heat demand of 57.5 kWh/m^2 and year (45 kWh/m^2 × year for heating and 12.5 kWh/m^2 × year for warm water) shows a cost range between 16 and 22 $EURcent_{2010}$ per kWh [11].

The total annual costs of renewable pellet boilers are still slightly higher (1,700 EUR/a) than conventional gas boilers (around 1,400 EUR/a). Interestingly, fuel costs are considerably higher for gas boilers (524 EUR/a) than for pellet boilers (687 EUR/a). In contrast, the share of investment costs is lower. This also means that the costs for the boiler options with conventional gas are more susceptible for changes in fuel costs than the renewable biomass boilers. However, the possible price development cannot be projected clearly for both conventional natural gas and renewable wood pellets, as too many uncertainties exist. In total, the renewable heating options often display higher overall costs than the benchmark technology, the natural gas boiler. The lower fuel costs in part compensate for this increase upfront capital costs.

2.4.3 Medium- to Large-Scale Renewable Technology Options for Heating, Cooling and Electricity Generation

Many technologies show a better technical and also economic performance (per unit) at larger scale. This is also the case for renewable energies, particularly for thermal bioenergy power plants. This is considered the 'economies of scale' or the 'scale effect'. Also for renewable energies, an efficient energy generation is very important.

Especially bioenergy and geothermal plants therefore often are designed for co- and polygeneration, meaning to run the plants in combined heat and power mode (CHP) to product heat, cold and electricity simultaneously. This utilization mode

Table 2.2 Strengths, weaknesses, opportunities and threats (SWOT analysis) for small-scale energy technologies for energy provision to individual houses, buildings and sites

Technology	Strengths	Weaknesses	Opportunities	Threats
Photovoltaics	Modular Scalable No emissions at operation	High costs Fluctuating and variable energy generation Need for backup capacity	'Everybody's' technology for small scale and larger power demand, Cost reduction and technology learning very likely	Free standing PV power plant parks use agriculture land
Small-scale wind energy converters	Clean and efficient renewable electricity generation	Relatively high specific investment costs Fluctuating with wind Turbulences in urban areas affect efficiency	Electricity generation for farms and larger industrial plants in peripheral regions Suitable for island and remote areas	Shaking and vibrations at buildings Security concerns Missing standardization
Solar thermal collector systems	Modular Scalable Easy installation Well approved	Fluctuating Variable energy (Water) storage may be needed	Ideal for private homes and heating grid systems	No threats !
Solar hybrid systems PV plus solar thermal	See PV and solar thermal Increased efficiency for PV	Larger area needed to meet heat demand	Electricity generation also at low area availability	More complex maintenance
Heat exchange systems (geothermal, air)	Enables use of low-grade temperature Variable sources of driving energy	Coefficient of performance (COP) often low	Ideal for low temperature energy systems Use of cheap excess heat as driving force	Use of non-renewable electricity for driving energy
Micro-CHP units	High overall efficiency up to 95 % Decentral electricity generation	High investment costs Need for stable and constant energy demand	Electricity generation for self-use Use for energy system services for system stabilization	Low or unstable heat demand leads to few electricity generation Operation with discharge of heat energy
Pellet and wood heating boilers	Efficient option for renewable heating Safe and reliable technologies	Unclear price development	Use of regional resources Reduction in environmental impact through filters	Fine particle emission in urban areas

has a particular higher overall performance than the energy generation through two separate processes, one for heat and one for electricity.

For medium to large scale levels of energy services, for example, to a larger number of buildings or industry units, or even whole cities, several renewable energy technologies are available, especially biomass and biogas heat and power plants (biomass CHP), wind energy or geothermal heating and combined heat and power plants. Also, some of the small-scale technologies (see previous chapter) like photovoltaics (ground mounted at an industrial or commercial scale), or solar thermal power plants, can be scaled up to larger units serving the same purpose.

Biomass CHP plants are often using solid (dry) biogenic fuels such as wood from forests and industry or herbaceous materials like straw or grass from agriculture and landscape management. Wood has established as the main energy carrier. Many plants are found with 10–50 MW combustion boiler capacity, but also capacities in the range of 100–150 MW are found, for example, in the forest-rich Scandinavian countries. Unlike the small-scale boiler systems, in the medium- to larger-scale plants mainly wood chips are used as fuels. Depending on the size of the biomass plant, 30–150,000 tons of biomass per year has to be provided to the power plant, which is a real logistical challenge and has to be planned and organized well. Wood chips allow easy provision pathways and handling and fairly robust conditions for the combustion unit. Various types of CHP plants are in operation, most of them with a steam generation cycle and conventional power unit (turbine and generator). A large group of units are focusing on electricity generation with condensing boilers and steam generators, and others are more optimized for heat generation and low temperature levels, for example, through organic Rankine cycle (ORC) electricity generation systems. Some countries have expertise in using straw and herbaceous material for combustion or gasification such as Denmark or Brazil (for using the bagasse of sugar cane). Recently, also gasification processes for producing a secondary energy carrier in the form of a 'production gas' have attracted much interest.

Worldwide around 4.3 EJ of biomass is used in modern technologies in heat or CHP generation for the building sector [4]. In some countries, biomass is the main energy source for specific industries, like in Brazil, where biomass accounts for 34 % of final energy consumption in the cement industry and 40 % in the iron and steel industry [4].

Biogas plants are a special form of bioenergy plants using mainly wet and easily digestible forms of biomass and biomass residues, such as manure or green plants from agriculture or landscape management, remainders from food production such as trester, or biowaste from households and industry. Biogas plants can be dimensioned to various scales (50 kW–5 MW), serving for energy provision of single houses to larger city districts. The biogas can be used in CHP plants either for electricity (and heat) generation or for producing a high-grade fuel by upgrading the low-calorific-grade biogas with a heating value H_u at around 5–7 kWh/Nm^3, to a high-calorific 'bio-methane' and 'substitute natural gas' (SNG) with a heating value H_u of up to 11 kWh/Nm^3. For both pathways, it is an interesting option to connect to a district network, either for heat in a district heating (water) network or for biogas in a gas grid. The advantage is that the biogas can be converted (to electricity) at locations where also the side products such as heat can be utilized efficiently.

Biogas plants using energy plants, such as maize from agriculture, are thought to contribute to the competition in the agriculture sector with food production and are therefore considered less or even non-sustainable.

Biofuels are different forms of (liquid or gaseous) fuels used to power engines and motors mostly of vehicles or stationary machines. Biofuels are made out of a large variety of plants and biomass, from energy plants from agricultural land to wastes from various resources. With a high number of different technologies, the biomass resources can be converted into secondary or the final product. The characteristics and corresponding indicators are also manifold and can therefore not described here in more detail.

Hydropower is the most abundantly used form of renewable energy for generating electricity worldwide, using the potential difference of water between a higher and a lower level. Hydropower plants are either using the running water of streams and rivers without dams (run-off hydropower plants) or using dams to capture a greater amount of water (conventional hydroelectric or pumped storage power plants). Dispatchability is a key feature of pumped storage power plants and has been used for years to fulfil energy systems services in this regard.

Wind energy is developing strongly in recent years. Wind energy shows its potential through the direct conversion of wind energy into electricity without the production of waste or detrimental side products. In 2011, around 40 GW of new wind power capacity was installed worldwide, which is more than for any other renewable technology, contributing to a global wind capacity of around 238 GW in 2011 [4]. The annual growth rate of wind power capacity is at around 26 %. The highest installation of new capacities was in China, followed by the United States, India, Germany and the U.K. The EU represents 23 % of the global wind energy market [4]. Most of the installations are onshore in wind-prone areas. Offshore wind parks are evolving, but at a fairly slow pace due to contraints in implementation. In order to capture more wind and increase the range of onshore wind energy, the generators are now often installed at heights of hundred metres and more with capacities reaching 3–7.5 MW per unit. Through one medium-sized (2–2.5 MW) wind turbine around 3,400–5,000 MWh of electricity can be produced (wind speed: 5.5 m/s or more, 1,700–2.000 full load hours) providing up to 4,000 households with renewable electricity for a whole year. Therefore, wind energy generators are an indispensable element of a renewable energy strategy of cities, regions and countries.

Geothermal heat and CHP plants receive their energy from the earth's molten core that reaches the surface. On the way, this energy heats the ground and earth as well as underground water sources (aquifers). In some parts in Europe, the temperature increases by around 3 °C per 100 m depth. The theoretical potential of geothermal energy is very large. However, up to now, it has not been used very extensively, unless very favourite conditions prevail as at some sites in Iceland, New Zealand, the Philippines or Italy.

Ideally, the geothermal heat comes to the surface through hot springs like in many sites in Iceland. However, most resources have to be recovered from sources several hundreds or even thousands of metres deep in the earth crust. In order to take advantage from this underground energy source, the heat has to be transported to the surface by a liquid transport medium. This may be available underground in the form of steam or hot water (water aquifers) or it has to be pumped from the surface to the depth, where it heats up, and is then returned to the surface again. The potential of the heat resource can also be increased by stimulating the geological site and the heat transfer into the liquid, for example, by hydraulic fracturing. These systems are called 'enhanced geothermal systems' (EGS).

The heat acquired in this way can then be used directly to heat buildings or provide heat for other needs, for example, process heat in industry. It is equally attractive to use geothermal energy for power generation, because it is then available around the clock. Geothermal power plants could therefore make a major contribution to the base load supply of renewable power. They are, similar to bioenergy, considered a 'flexible' renewable energy, as it can be turned on and off as needed and thus provide energy system services (ESS). During geothermal power generation, also large quantities of heat are generated. In the majority of cases, this heat can only be used by the buildings nearby if they are connected to a local heating network. A large increase in the numbers of local heating grids is therefore a decisive prerequisite if the considerable potential of geothermal energy is to be developed.

2.4.4 SWOT analysis of the Medium- to Large-Scale Renewable Energy Portfolio

The medium- to large-scale renewable technologies are decisive for a low-carbon and renewable energy system. Each technology has its own role in the system. Strengths, weaknesses, opportunities and threats for development (SWOT analysis) for the technologies are compiled in Table 2.3.

2.4.5 New, Innovative and Unexplored Renewable Energy Options and Pathways

The renewable energy sector is developing fast. There are numerous other options to recover energy from natural and renewable resources. Many of these options are not lifted or even discovered yet. This is in part due to the economics of these technologies, which are still more expensive as others. Also, the technologies might not be developed yet to a full extent. This potential and reservoir has to be discovered and unrevealed yet. In the following chapter, a few of these technologies are described in brief.

Table 2.3 Strengths, weaknesses, opportunities and threats (SWOT analysis) for medium- to larger-scale energy technologies for energy provision to city districts or larger building units

Technology	Strengths	Weaknesses	Opportunities	Threats
Biomass CHP plants	Well-known and sustainable renewable energy provision Options for generation of a diverse range of products (polygeneration)	Low energy density of resource Higher frequency of transport needed	Connecting to a district heating network Gasification technology opens new options	Sustainable provision of biomass resource not secured Insufficient access of clients to the heating network puts economy at risk
Biogas plants	Production of methane as a high value energy carrier Potential for electricity and fuel production Big variety of resource and substrates available	Low overall efficiency due to low heat use Dependency on energy plants for high share of technology	Upgrading of biogas to a high value substitute natural gas (SNG) Generation of a valuable transport fuel Use of residues and wastes from industry and households	Risk of high competition to food production
Hydropower	Well-known and cost-efficient energy technology High potential for electricity generation Dispatchable technology suitable for energy system services (ESS)	Big intervention in land and environmental integrity necessary for new plants	Repowering through new turbines brings more capacity More pumped storage systems for ESS	Destruction of land and environment through new plants
Wind energy (onshore and offshore)	Direct conversion to electricity with no wastes High energy yield	Only at wind-prone sites Impact on land integrity and visibility	Backbone of a renewable energy system Conversion to gas (H_2, CH_4) at excess production (Power2Gas)	Impact on birds, flying animals and sea life Shrinking acceptance of population for wind turbines
Geothermal heating and CHP plants	Flexible renewable energy resource Potential for cogeneration of heat and power (CHP) Option for dispatchable plant operation	High risk of geological, water and other environmental problems Higher yields only at very specific locations	Options for low-temperature technologies (ORC, Kalina)	Geological stimulation and 'fracking' with high environmental impact Earthquakes Settlings, impact on buildings, etc. Dwindling acceptance

Ocean energy technologies show a tremendous theoretical potential.

However, they have not been developed to a commercial level yet and are in an early stage of development. The potential, coming from all forms of ocean energy, wave, current, tide and thermal energy technologies, provides a vast and very big energy resource.

It is frequently stated that 0.1 % of ocean energy could provide all of the world's energy demand. Several projects and technologies have been developed and installed yet, from Puerto Rico (deep sea solar thermal power plant) to the 'Pelamis' wave energy converter in the Aguçadoura Wave Farm in Portugal to PowerBuoys® projects in Australia and the United States, but a technical and economic breakthrough has not been seen yet.

Solar thermal power plants with concentrating solar collector systems, usually known as CSP, are not really new. First, even very big projects (of up to 354 MW) have been developed in the 1980 in the Mojave Desert, California, USA. However, CSP plants do not play the role for electricity generation today as possible and as expected. Solar thermal power plants with concentrated solar power make use of direct normal irradiance (DNI) and focus the sunlight with lenses, mirrors and tracking systems to a beam and a receiver system, where the solar energy is converted through various ways into electricity. The most advanced technologies are parabolic trough and solar tower systems, which have up to now being built in various locations worldwide, especially in Spain (Andasol) and also India. Fresnel and also solar dish systems are other technical options but not equally used today.

Hydrogen as a renewable energy carrier can be produced from various renewable resources, mainly from electricity through electrolysis. This pathway has a possibly large potential as high capacities of renewable wind and solar plants are being built, which may produce electricity at times when it is not used in the energy system. During these times, this electricity can then be converted into hydrogen and being used as storage. Together with CO_2, this hydrogen can also be used to generate methane gas (CH_4). This pathway is based on the Sabatier process, also commonly known as 'power to gas' (P2G) technology. Hydrogen can also be directly generated by micro-algae through an alternative regeneration pathway for NADH in the photosynthesis. This pathway, however, has no or marginal technical relevance.

Single energy technologies are not a suitable solution to the energy problems. All energy technologies, if fossil based or renewable, can only meet the demand requirements in a combination or portfolio, where each technology has to fulfil certain rules. In the electricity sector, it is compulsory to equalize the amount of energy needed (demand) with the amount of energy supply, and the energy inflow has necessarily to be as big as the energy outflow. In the heat sector this is not necessarily the case, heat energy in excess is often discarded and wasted without any use. But in order to save this energy or use it sustainably, a good match of demand and supply is crucial.

This task can mainly be assured through integrated systems of renewable energy technologies, for example, in form of 'combi power plants', virtual power plants and networks' or even large-scale distributed systems like the Desertec

Table 2.4 Overall characteristics of renewable energy technologies

	Resource Potential	Fluctuating feature	Flexibility and dispatchability	GHG mitigation potential >35 %	Future cost reduction potential	Specific risk potential
Solar PV	+++	Yes		++	+++	–
Solar warm water	+++	Yes		+++	≈	–
Solar CSP	+++	Yes	Yes	+++	+++	–
Hydropower	++		Yes	+++	≈	+
Wind	++	Yes		+++	++	+
Solid biomass	+		Yes	≈	≈	++
Biogas	+		Yes	≈	≈	++
Biofuels	≈			≈	≈	++
liquid biofuels 1st generation	≈	no	yes	≈	≈	++
liquid biofuels 2nd generation	++	no	yes	++	+	≈
Geothermal energy	++		Yes	++	+	++
Ocean energy	++		Yes	++		–

+++ excellent/very high potential
++ good/high potential
+ medium potential
≈ even distribution of favourable and negative effects
– negative effects

project (www.desertec.org), a large network of solar, wind, biomass and other renewable energy technology systems across Europe and North Africa.

2.5 Renewable Energy Systems—Benefits, Challenges and Pitfalls

The present energy system is not sustainable. For the growing world population, we need more energy and we need more sustainable energy. Renewably energy systems are therefore the future! They provide the important supply side of sustainable energy systems. Simultaneously, the complementary pillars, energy efficiency and energy savings, have to be developed further.

A paradigm shift from fossil-based system to a renewable energy system is necessary—and possible. This was shown for the German energy system in a very detailed investigation [12]. This is not mainly due to a restriction in (fossil) energy resources; especially with coal and also with natural gas (including the latest findings on shale gas), the resource base for fossil fuels is still big, and lasting for a considerable number of years and decades. The argument for a rapid shift towards renewable energy comes more from the rising carbon (CO_2) level in the atmosphere and the successive pollution with greenhouse gases. The constant mobilization of carbon from fossil deposits into the atmosphere is the real problem. Additionally, the shift towards renewables releases the real local and regional strengths of the different world regions. This can be solar energy in the desert regions, wind and ocean energy at the coastal zones, or bioenergy in the more central continental zones of the temperate and (sub)tropical regions. This shift will also mobilize the regional economic potentials and will trigger the innovation and development process of the countries.

It can be stated that eventually not just one renewable technology will solve the energy problem, it is always a matter of a technology mix and an energy portfolio. Each technology has its strengths and weaknesses, its opportunities, even sometimes threats. These overall characteristics of renewable energy technologies are described in Table 2.4 in a qualitative, recapitulatory way.

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