Chapter 2
The Current Situation and Perspectives on the Use of Renewable Energy Sources for Electricity Generation

Abstract Deployment of renewable energy sources has been increasing rapidly in recent years. Various types of government policies, the declining cost of many renewable energy technologies, changes in the prices of fossil fuels, an increase in energy demand, among other factors, have encouraged the continuing increase in the use of renewable energy sources for the generation of electricity in several countries from all regions. Despite global financial challenges, renewable energy capacity continued to grow rapidly compared to the cumulative installed capacity from the previous year. In 2013, a total of 25.4 GW of new renewable power capacity was installed. Over 72 % of all new installed capacity in the EU were renewable. It is important to highlight that renewable energy sources are expected to be economically competitive with conventional energy sources for electricity generation in the medium to long-term.

2.1 Introduction

Deployment of renewable energy sources has been increasing rapidly in recent years. Various types of government policies, the declining cost of many renewable energy technologies, changes in the prices of fossil fuels, an increase in energy demand, among other factors, have encouraged the continuing increase in the use of renewable energy sources for the generation of electricity in several countries from all regions. Despite global financial challenges, renewable energy capacity continued to grow rapidly compared to the cumulative installed capacity from the previous year.

In 2013, a total of 25.4 GW of new renewable power capacity was installed. Over 72 % of all new installed capacity in the EU were renewables (see Fig. 2.1). It was, furthermore, the sixth year running that over 55 % of all new power capacity in the EU were renewable (Worldwide Electricity Production from Renewable Energy Sources 2013).

J. Morales Pedraza, *Electrical Energy Generation in Europe*,
DOI 10.1007/978-3-319-16083-2_2

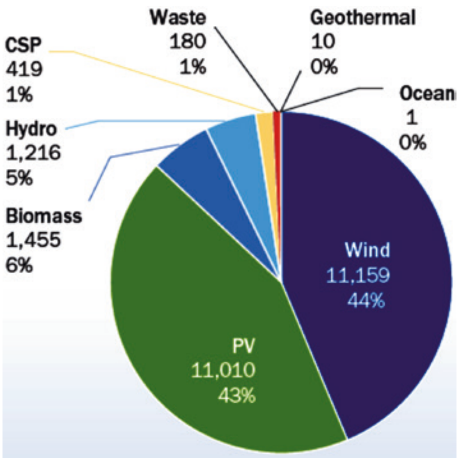

Fig. 2.1 2013 shares of new renewable power capacity installations in MW (Total 25,450 MW). *Source* Worldwide electricity production from renewable energy sources

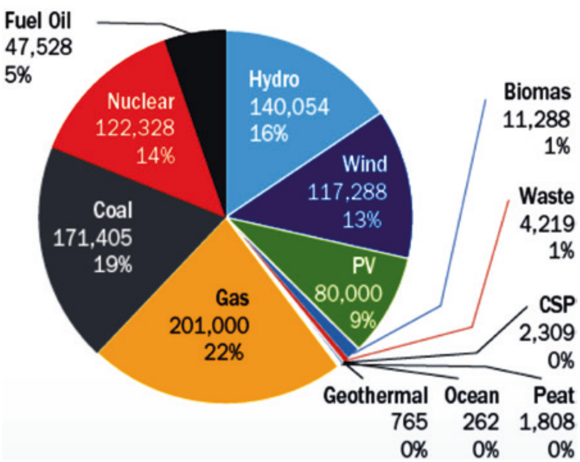

Fig. 2.2 EU power mix 2013. *Source* EWEA 2014

The major increases were registered in wind power with 44 %, followed by solar photovoltaic with 43 %, biomass with 6 % and hydropower with 5 %. The EU energy mix in 2013 is shown in Fig. 2.2. According to that figure, natural gas had the major share with 22 % of the total, followed by coal with 19 %, hydropower with 16 %, nuclear energy with 14 %, wind power with 13 % and solar photovoltaic with 9 %.

The use of decentralized renewable energy (excluding traditional biomass) in meeting rural energy needs of the household or village level has also increased, including hydropower plants, various modern biomass options, solar PV, and wind or hybrid systems that combine multiple technologies.

The development of renewable energy sources, particularly energy from wind, hydro, solar, geothermal, hydrogen, and biomass is a central aim of the European Commission's Energy Policy.[1] There are several reasons for that:

- The use of renewable energy sources for electricity generation has an important role to play in reducing CO_2 emissions;
- Increasing the share of renewable energy sources in the European energy balance enhances sustainability;
- Helps to improve the security of energy supply by reducing the growing dependence of the region on imported fossil fuels.

Undoubtedly, the exploitation of renewable energy sources will help the EU to meet many of its environmental and energy policy goals, including its obligation to reduce greenhouse gases under the Kyoto Protocol (EC 2002a), and the aim of securing its energy supply (EC 2002b, 2005). Despite the reduction in electricity demand renewable energy source deployment has continued during the past years. This is a result of various national support schemes—in particular for solar PV and wind onshore—but also of constant technological improvement, decreasing prices (in the case of solar PV also due to a supply surplus) and greater supplier competition, which have all led to successful cost reductions. According to the EC, the EU is on track to meet its 2020 renewables target. But in 2012 some parties also voiced doubts because the current economic crisis could oblige some EU member states to downsize their renewables policies and thus jeopardize the implementation of their NREAPs approved by the EC.

Renewable energy sources are expected to be economically competitive with conventional energy sources for electricity generation in the medium to long-term. It is important to highlight that renewable energy resources are not only expected to be economically competitive in the near future, but it is an abundant energy source around the world. If this statement is true, then, why many countries have not already switched from fossil fuels to renewables for electricity generation? The main reason is the following: Many countries are deeply dependent on the use of fossil fuels, and consequently, significant barriers exist to mainstreaming renewable energy use. According to the United Nations sources:

- Fossil fuels (coal, oil, and gas) account for 80 % of global energy consumption;
- Total energy sales worldwide amount to about US$1 trillion per year (3 % global GDP);
- Fossil fuel subsidies are about US$150 billion per year;
- New renewable sales are about US$20 billion per year.

[1] The RES Directive defines the energy from renewable energy sources as energy from non-fossil fuel sources that is wind, solar, aerothermal, geothermal, hydrothermal, ocean energy, hydropower, biomass, landfill gas, sewage treatment gas, and biogases. In this book, the different renewable energy sources that have been considered are the following: wind, solar, geothermal, hydro, and biomass.

Table 2.1 New policy scenario expects expansion in global power generation

	TWh	TWh	TWh
	1990	2010	2035
Coal	4,426	8,687	11,908
Oil	1,336	1,000	555
Gas	1,727	4,760	8,466
Nuclear	2,013	2,766	4,366
Hydro	2,144	3,431	5,677
Biomass	131	331	1,487
Wind	4	342	2,681
Geothermal	36	68	315
Photovoltaic	0	32	846
Solar thermal	1	2	278
Wave and tidal	0	1	57
Total	11,818	21,410	36,636

Source IEA World Energy Outlook (2012)

While solar and wind power were growing at 20 % and 30 % respectively in the past years and their costs are decreasing rapidly, their market share is minuscule compared to the scale of oil and gas production. The technical potential for solar energy is the highest among the different renewable energy sources, but substantial technical potential exists for all types of renewables. Even in regions with relatively low levels of the technical potential for any individual renewable energy source, there are typically significant opportunities for increased deployment compared to current levels. In the longer term and at higher deployment levels, however, technical potentials indicate a limit to the contribution of some individual renewable energy technologies. Factors such as sustainability concerns, public acceptance, system integration and infrastructure constraints or economic factors may limit deployment of renewable energy technologies in some regions during the coming years (IPCC 2012).

According to Table 2.1, coal will be the energy source that will produce the majority level of electricity by 2035 followed by natural gas, hydropower, nuclear energy and wind.

The EU has ambitious targets in the field of environment and energy policy. According to the EEA Technical Report No 6/2009 (2009), the new climate-energy legislative package sets mandatory national target corresponding to a 20 % share of renewable energies in overall EU energy consumption by 2020, and a mandatory 10 % minimum target to be achieved by all EU member states for the share of renewable energy in transport consumption by 2020. A significant part of the new renewable energy sources capacity will be wind power and solar PV; Germany, Spain and Italy are the leading countries in the use of these types of renewables for the generation of electricity. However, it is important to highlight that the output of these electricity production forms is variable, and not dispatchable in the traditional sense, and this characteristic is limiting the expansion in the use of these two renewable energy sources for the generation of electricity in other European countries.

It has been estimated, that the renewable energy sources share in electricity sector would be around 35 % in 2020, if the 20 % target for renewable energy sources is achieved. In the EU, renewables accounted for almost 70 % of the additions to electric capacity in 2012, mostly from solar PV and wind power. In 2011, renewables met 20.6 % of the region's electricity consumption and 13.4 % of gross final energy consumption.[2] Renewables made up just over half of total net additions to electric generating capacity from all sources in 2012. By year's end, they comprised more than 26 % of global generating capacity and supplied an estimated 21.7 % of global electricity, with 16.5 % of electricity provided by hydropower. Industrial, commercial, and residential consumers are increasingly becoming producers of renewable power in a growing number of countries (REN 21 2013).

On the other hand, increasing wind and solar PV generation presents vast challenges in the power market and electricity grids. The keys to integrate variable generation into the grid are adequately interconnected electricity markets and smarter grids with more flexible demand (Ruska and Kiviluoma 2011). The 2009 directive on the promotion of the use of energy from renewable energy sources (2009/28/EC) drafted a trajectory on how to reach the targets adopted by the EC for all EU member states. Because each EU member state has different renewable energy potential and energy mix, targets vary between them. EC directive adopted on this subject improves the legal framework for promoting renewable electricity, requires national action plans that establish pathways for the development of renewable energy sources, creates cooperation mechanisms to help achieve the targets cost effectively and establishes the sustainability criteria for biofuels.

Figure 2.3 shows the share of energy from renewable sources in gross final consumption of energy. The countries with the highest percentage are Sweden, Latvia, Finland and Austria.

In the EU, the satisfaction of energy needs is crucially linked to the security of energy supply and commitments to reduce greenhouse gas emissions to the atmosphere. The development of distributed generation and renewable electricity generation technologies are essential to achieve these goals. In the long-term, Europe has a vision of a sustainable energy system where hydrogen and electricity act as the two main energy forms with fuel-cell technology providing the bridge between them. Together, these interchangeable energy carriers provide a unique pathway to gradually decreasing Europe's dependence on fossil fuels, and reducing greenhouse gas emissions and pollutants.

[2] In Germany, renewables accounted for 22.9 % of electricity consumption (up from 20.5 % in 2011), 10.4 % of national heat use, and 12.6 % of total final energy demand.

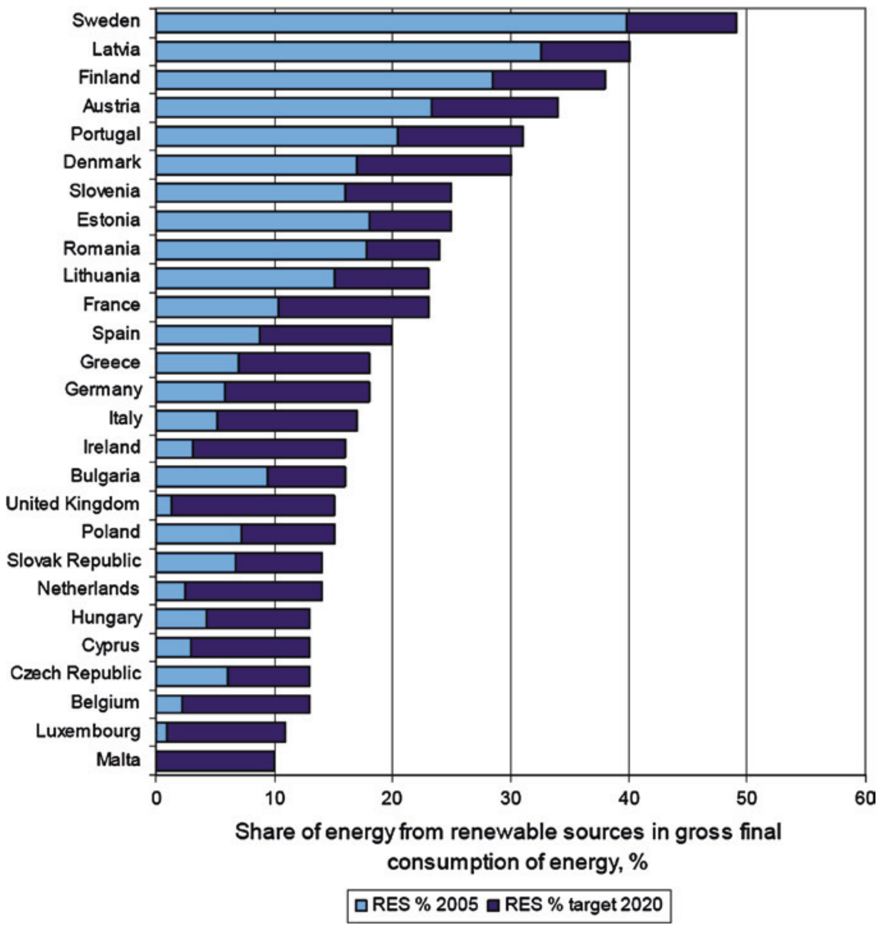

Fig. 2.3 Share of energy from renewable energy sources in 2005 and targets for the year 2020. *Source* Ruska and Kiviluoma (2011)

2.2 The EU Energy Policy on Renewables

According to the Belgium government, the European energy policy is based on four objectives, which have been included in the Treaty on the Functioning of the European Union (TFEU):

- Ensure the functioning of the energy market;
- Ensure the security of energy supply in the EU;
- Promote energy efficiency and energy savings and the development of new and renewable forms of energy;
- Promote the interconnection of energy networks.

The EU aims to achieve these objectives within various policy areas. Energy is a cross-policy theme for the EU, and is a component of other policy areas as well, such as foreign policy, environmental policy, climate policy and competitiveness policy.

At the European Council on 22 May 2014, the following priorities were agreed on in order to achieve these objectives:

- Complete the internal energy market by the end of 2014 and develop interconnections between the energy networks so as to avoid a situation in which certain EU member states find themselves isolated from their energy networks;
- Invest in energy infrastructure in order to ensure security of energy supply in a sustainable manner and at affordable prices;
- Diversify energy supply and develop indigenous energy resources to ensure security of supply, reduce the EU's external energy dependency and stimulate economic growth;
- Enhance energy efficiency.

2.3 Share of Renewable Energy Sources in Gross Domestic Energy Consumption

Global demand for renewable energy continued to rise during 2011 and 2012, despite the international economic crisis, ongoing trade disputes, and policy uncertainty and declining support in some key markets. Renewable energy supplied an estimated 19 % of global final energy consumption by the end of 2011, the latest year for which data are available. Of this total, approximately 9.3 % came from traditional biomass, which is used primarily for cooking and heating in rural areas of developing countries. Useful heat energy from modern renewable sources accounted for an estimated 4.1 % of total final energy use; hydropower made up about 3.7 %, and an estimated 1.9 % was provided by power from wind, solar, geothermal, biomass, and by biofuels. Renewables are a vital part of the global energy mix and should play a major role during the coming decades. Modern renewable energy can substitute for fossil and nuclear fuels in four distinct markets: power generation, heating and cooling, transport fuels, and rural/off-grid energy services. However, this could happen in a number of countries, but not in others.

During the five-year period 2008–2012, installed capacity of many renewable energy technologies grew very rapidly, with the fastest growth in the power sector with the purpose of reducing the use of oil and coal, and in some specific cases nuclear energy. Total capacity of solar PV grew at rates averaging 60 % annually. Concentrating solar thermal power capacity increased more than 40 % per year on average, growing from a small base, and wind power increased 25 % annually over this period. Hydropower and geothermal power are more mature technologies and their growth rates have been more modest, in the range between 3 and 4 % per year as average. Biopower is also mature, but with steady growth in solid and gaseous biomass capacity, increasing at an average 8 % annually (REN 21 2013).

According to Fig. 2.4, the participation of CSP in the generation of electricity increased 18 % during the period 2007–2012.

For 2020, it is expected that the share of renewable energies in gross domestic energy consumption in the EU be not less than 20 %, and a binding 10 % target for the share of renewable energy in transport petrol and diesel, instead of a target of 5.5 % previously approved. This implies that the EU power sector continues its move away from the use of fuel oil, coal, and in some countries, nuclear power for electricity generation, whilst at the same time increasing its total installed capacity to meet increasing power demand. The net growth in the last eleven years of natural gas power (118.2 GW), wind power (74.3 GW) and solar PV (26.4 GW) was at the expense of fuel oil (down 13.2 GW), coal (down 9.5 GW) and nuclear energy (down 7.6 GW).

Figure 2.5 shows the evolution of the renewables target for all EU countries from 2010 and 2020, the country with the best situation to reach the EU target is Estonia, followed by Sweden, Romania and Denmark.

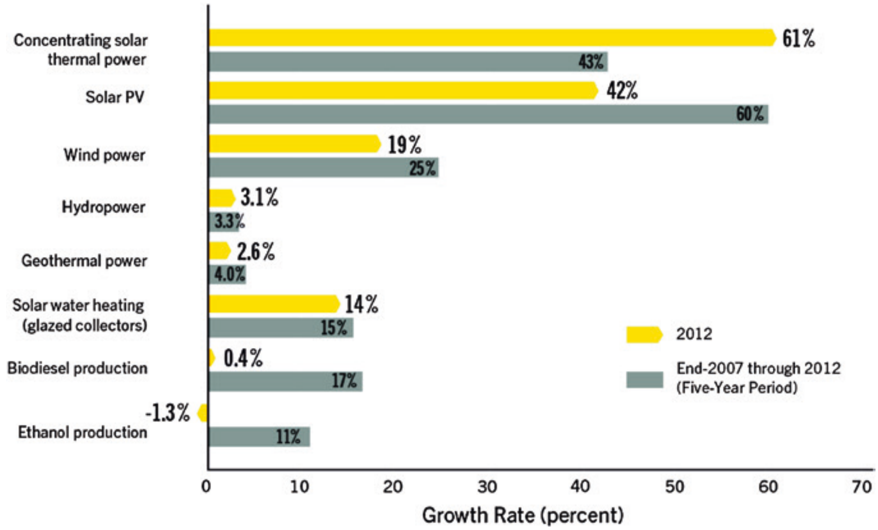

Fig. 2.4 Average annual growth rates of renewable energy capacity and biofuels production (End-2007–2012). *Source* REN 21 (2013)

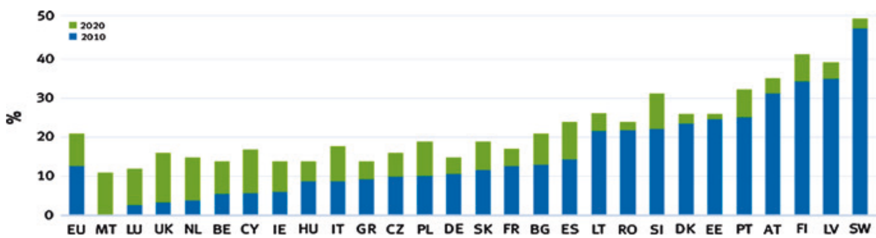

Fig. 2.5 Comparison between EU member states' 2020 renewable target and interim 2010 targets. *Source* EC

2.4 Electricity Generation

Renewable energy sources comprise a heterogeneous class of technologies. Various types of renewable energy sources can supply electricity, thermal energy and mechanical energy, as well as produce fuels that are able to satisfy multiple energy service needs. Some renewable energy technologies can be deployed at the point of use (decentralized) in rural and urban environments, whereas others are primarily deployed within large (centralized) energy networks. Though a growing number of renewable energy technologies are technically mature and are being deployed at significant scale, others are in an earlier phase of technical maturity and commercial deployment or fill specialized niche markets. The energy output of renewable energy technologies can be:

- Variable and—to some degree—unpredictable over differing time scales (from minutes to years);
- Variable but predictable;
- Constant;
- Controllable.

A variety of technology-specific challenges (in addition to cost) may need to be addressed to enable renewable energy to significantly upscale its contribution to reducing greenhouse gas emissions. These are:

- For the increased and sustainable use of bioenergy, proper design, implementation and monitoring of sustainability frameworks can minimize negative impacts and maximize benefits with regard to social, economic and environmental issues;
- For solar energy, regulatory and institutional barriers can impede deployment, as can integration and transmission issues;
- For geothermal energy, an important challenge would be to prove that enhanced geothermal systems can be deployed economically, sustainable and widely;
- New hydropower projects can have ecological and social impacts that are very site specific, and increased deployment may require improved sustainability assessment tools, and regional and multi-party collaborations to address energy and water needs;
- The deployment of ocean energy could benefit from testing centers for demonstration projects, and from dedicated policies and regulations that encourage early deployment;
- For wind energy, technical and institutional solutions to transmission constraints and operational integration concerns may be especially important, as might public acceptance issues relating primarily to landscape impacts (IPCC 2012).

Directive 2001/77/EC (2001) on the promotion of electricity produced from renewable energy sources in the internal electricity market entered into force in October 2001. The Community aims were to increase renewable energy's share of electricity generation from 14 % in 1997 to 22 % by 2010 in the EU-15, and to

21 % in the EU-25, this means an increase between 7 and 8 %, respectively.[3] However, it is important to stress that the EU failed to reach the 21 % target for 2010, with the exception of Germany and Hungary.

From 2004 to 2006, renewable energy's share of total electricity generation in the EU increased by nearly 1.5 %. Germany and five other EU member states increased their shares by more than 2 % during this period, thereby contributing significantly to the development of the renewable energies' total share of electricity generation in the EU. Such growth has occurred primarily via expansion of the use of solid biomass and wind energy.

In June 2010, the European Commission's Joint Research Centre highlighted that provisional Eurostat data showed that in "2009 about 19.9 % (608 TWh) of the total net electricity generation (3,042 TWh) came from renewable energy sources. Hydropower contributed the largest share with 11.6 %, followed by wind with 4.2 %, biomass with 3.5 % and solar with 0.4 %." It went on to conclude "that if the current growth rates of the above-mentioned renewable electricity generation sources can be maintained, up to 1,600 TWh (45–50 %) of renewable electricity could be generated in 2020."

Table 2.2 shows the evolution of the electricity demand in the EU until 2020. From that table can be stated that the demand of electricity will increase 10.4 % during the period 2009–2020.

Table 2.3 shows that the higher average annual percent change during the period 2007–2035 will be registered in solar energy, followed by wind energy.

According to Euroelectric (2012), electricity demand is forecast to grow throughout Europe up to 2020, albeit not in all countries and at lower rates compared to previous estimates. Overall demand in the EU is assumed to grow by 0.6 % per annum until 2020, reaching 3,327 TWh from 3,132 TWh in 2010; this represents an increase of 6.2 %. It is interesting to note, however, that this year's forecast is considerably lower than the forecast made in the 2011 edition, where demand in 2020 stood at 3,467 TWh. This shifting of expectations can be explained, inter alia by the worsening of the economic crisis in 2011 or by the increased role of energy efficiency policies being developed throughout Europe.

Demand is not expected to rise equally everywhere in Europe. Growth will be particularly sustained in Bulgaria, where electricity demand will increase by 6.2 % per annum, and in several other countries, including Cyprus (+3.4 % per annum), Slovakia (+3.2 % per annum), Lithuania (+2.9 % per annum) and Romania (+2.7 % per annum). It will proceed more slowly in Luxembourg (+0.8 % per annum),

[3] Renewables are unquestionably becoming increasingly important for the global power supply. All the same, the continued global increase in demand for electricity during the coming decades will still open up sufficient revenue potential—both for renewables and fossil fuels. Should, however, there be fundamental or unexpected changes in not only the overriding drivers such as demographics and, linked to this, the demand for electricity, but also additional factors such as technological progress, energy efficiency or also consumption patterns, then of course new forecasts and if necessary also policy adjustments will be necessary. In the meantime, it is thus by no means a matter of crowding out or replacing individual sources of energy, but rather of supplementing and enhancing established input patterns (Auer 2013).

Table 2.2 Evolution of electricity demand in the EU-27 (TWh)

Country	2009	2010	2011	2020
Austria	64.0	65.0	66.8	72.8
Belgium	83.6	90.4	86.0	94.3
Bulgaria	30.4	32.5	31.3	52.7
Cyprus	4. 7	4.8	5.0	6.4
Czech Republic	61.6	63.7	65.2	77.5
Germany	534.8	565.0	565.8	507.0
Denmark	34.0	34.7	34.7	38.2
Estonia	8.7	8.3	7.8	10.1
Spain	274.0	278.0	273.1	340.0
Finland	81.3	87.7	84.4	99.0
France	486.7	513.2	478.2	523.1
United Kingdom	347.0	354.0	342.3	346.0
Greece	58.9	59.2	58.6	63.9
Hungary	38.9	39.8	40.2	47.0
Ireland	25.1	25.4	26.8	31.4
Italy	320.3	330.5	332.3	370.0
Lithuania	10.2	10.3	10.4	13.3
Luxembourg	6.2	6.7	6.6	7.2
Latvia	7.0	7.3	7.2	8.9
Malta	2.0	2.0	2.2	2.4
Netherlands	114.1	117.1	118.1	131.7
Poland	135.9	141.6	145.8	171.8
Portugal	52.6	55.0	53.1	52.0
Romania	55.2	50.6	52.3	64.2
Sweden	137.9	147.0	139.2	146.4
Slovenia	12.3	16.1	12.6	14.9
Slovakia	25.4	26.6	26.8	35.2
	3,012.8	3,132.5	3,072.8	3,327.4

Source EURELECTRIC, Power Statistics (various editions). Data source for 2020 for Italy and Malta is GlobalData's Power E-Track

Table 2.3 Renewable electricity generation by energy source during the period 2007–2035

Sources	2007	2015	2020	2025	2030	2035	Average annual percent change 2007–2035
Hydropower	2,999	3,689	4,166	4,591	5,034	5,418	2.1
Wind	165	682	902	1,115	1,234	1,355	7.8
Geothermal	57	98	108	119	142	160	3.7
Solar	6	95	126	140	153	165	12.7
Others	235	394	515	653	773	874	4.8
Total	3,462	4,958	5,817	6,618	7,336	7,972	3

Source IEO

Denmark (+1 % per annum), Belgium (+0.4 % per annum) and France (+0.2 % per annum).

Yet there are exceptions to this trend of growing electricity demand. The most remarkable is without doubt Germany, where, in line with the requirements of the 'Energiewende' (energy transition), total electricity demand is set to decrease by about 1 % per annum, from 565 TWh in 2010 to 507 TWh in 2020; this represents a decrease of 10.3 % for the whole period. Indeed, the trend is set to continue until 2030, when demand is expected to stand at 474 TWh. Other countries with a decreasing electricity demand include Slovenia (−0.7 % per annum until 2020 compared to 2010), Portugal (−0.5 % per annum), and Great Britain (−0.2 % per annum). Growth will be almost nil in Sweden (−0.04 % per annum).

In terms of new power generating installations as a whole, 2011 was a record year in the EU, with 44.9 GW of new capacity connected to the grid, a 3.9 % increase compared to 2010. Wind power accounted for 21.4 % of new installations, the third biggest share after solar PV (46.7 %) and natural gas (21.6 %). More renewable generating capacity was installed in the EU than ever before representing 71.3 % of all new installations. Since 2008, renewable capacity installations have represented more than half of all new installed capacity. In total, 302.6 GW of new power capacity has been installed in the EU since 2000. Of this, 28.2 % was wind power, 47.8 % other renewables, and 90.8 % renewables and gas combined. It is important to highlight that the net growth since 2000 of gas power (116 GW), wind power (84.2 GW) and solar PV (47.4 MW) was at the expense of fuel oil (down 14.2 GW), nuclear (down 13.5 GWe) and coal (down 10.3 GW). A sharp decrease was seen in 2011 in nuclear capacity due to the early decommissioning of a number of nuclear power reactors in Germany as a result of the Fukushima Daiichi nuclear accident. The other renewable technologies (hydro, biomass, waste, concentrating solar thermal, geothermal, and ocean energies) have also increased installed capacity over the past decade, albeit more slowly than wind and solar photovoltaic (EWEA Annual report 2011, 2012).

According to Fig. 2.6, in 2011 natural gas continue to lead the level of new capacities installed for the generation of electricity (51 %), followed by solar PV (22 %), wind (17 %) and coal (7 %). The new capacities installed associated with other energy sources are very small.

It is important to highlight that the electricity generation from renewable energy sources in the EU has increased from 369 TWh in 1995 to 608 TWh in 2009; this represents an increase of 58.5 % (See Fig. 2.7). According to EIA sources, in 2011 the electricity generated by renewables reached around 933 TWh, an increase of 53.5 % respect to 2009. It is expected that this trend will continue during the coming years.

Undoubtedly, hydropower is the dominant renewable energy source in electricity generation, accounting for about 60 % of renewable electricity in recent years. Hydropower's public profile—especially in Europe—is often too low compared with that of the new renewables such as wind power or solar energy. This is surprising as IEA statistics state that the hydropower share of total electricity production worldwide in 2010 came to about 16 %, i.e., much more than wind

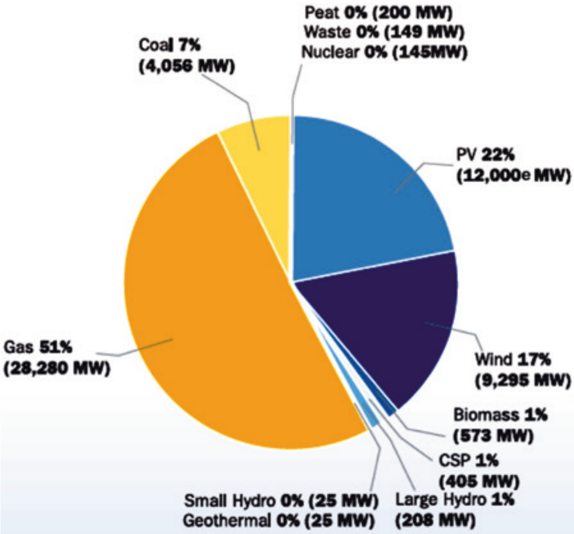

Fig. 2.6 Share of new power installations in EU. *Source* EWEA (2011)

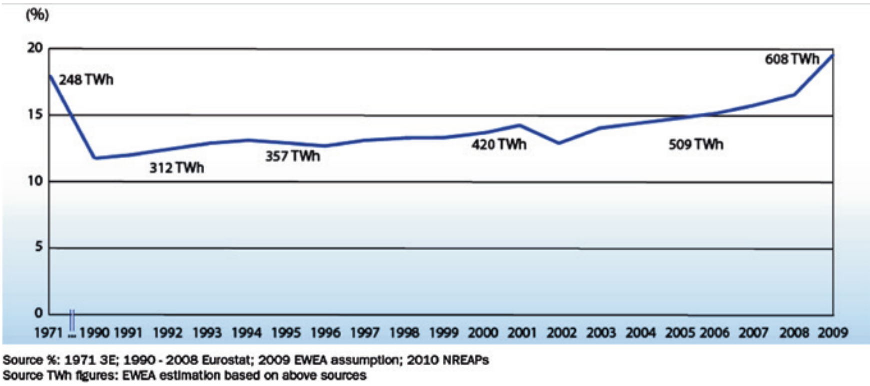

Fig. 2.7 Renewable electricity's share of total EU-27 electricity consumption 1971–2010 (%)

power and bioenergy, which each accounted for 2 %, and solar PV, whose share is barely visible in the statistics. In many other parts of the world hydropower is, therefore, paid a great deal more attention. One important reason for this is the very large contribution that hydropower makes to the electricity supply in many countries that are also significant in terms of volume. For instance, hydropower is not only the overwhelmingly dominant source of electricity in Norway with a 96 % share in domestic power generation, but also in aspiring Brazil, where the share is 84 %. The next countries in the ranking of the top 10 hydropower producers are Venezuela, Canada and Sweden with also high shares of between nearly 50 and 73 %. And even China and Russia, i.e., the world's number one and number five generators of hydropower, achieve shares slightly higher than the global average (16.5 %).

Theoretically, the world's entire demand for electricity could be met by hydropower. Admittedly, this conflicts with the realities of geographically uneven distribution in the world's regions (roughly 50 % in Asia, 30 % in the Americas, 10 % in Africa and 8 % in Europe) as well as with economic rationale, since not everything that is theoretically or technically possible is also economically feasible. For example, the dearth of inexpensive facilities for the storage and transport of electricity limits its viability (Auer 2013).

Despite the important role plays by hydropower in the electricity generation in many countries, the share of hydropower in the renewable electricity mix has decreased significantly from about 90 % in the mid 1990s as other renewable capacity has increased. In the particular case of wind energy, it reached an installed capacity of more than 74 GW in 2009, exceeding the European Wind Energy Association's target of 40 GW by 2010 by over 80 %. The Association now wants to aim for 230 GW by 2020, including 40 GW of offshore wind, which would meet 20 % of the region's electricity demand. If current growth rates continue, all renewables could meet up to 35–40 % of total consumption in Europe by 2020, generating around 1,400 TWh.

Figure 2.8 shows the renewable shares of final energy during 2005 and 2011, with the targets for 2020. According to that figure, Estonia and Romania already reached their shares for 2020, while Austria, Denmark, and France are still far from reaching their targets.

Figure 2.9, natural gas shows the major increase in new installed energy capacity during the period 1995–2010, followed by renewables. It is expected that this trend will continue during the coming years. Continued growth of the renewables sector will require some problems—including access to the grid and public subsidies—to be resolved across the European region.

Table 2.4 shows the evolution of the participation of renewables in the gross electricity consumption during the period 1997–2008 and target for 2010. The highest shares in 2010 were reached by Austria, Sweden and Latvia.

The need for an increase in the EU support for the use of renewable energy source for electricity generation is very clear. Not only because of some of the new technologies, especially wind energy, small-scale hydropower and solar thermal applications, could be economically viable and competitive with respect other energy sources under certain conditions, but because European reserves of some of the fossil fuels are limited and others are located outside of the EU, in some cases in instable political areas. For this reason, since 1997, the EU has had a renewable energy policy, which has enabled significant progress to be made towards the EU's objectives of reducing greenhouse gas emissions to the atmosphere, ensuring security of supply and improving EU competitiveness. Ambitious targets are at the core of the EU's policies to promote energy from renewable energy sources. The EU sets out a strategy included in a document called "Energy for the Future: Renewable Sources of Energy", the EC White Paper of 1997 on renewable sources of energy. The EC White Paper of 1997 set the goal of doubling the share of renewable energy in the EU's energy mix from 6 to 12 % by 2010. It included a

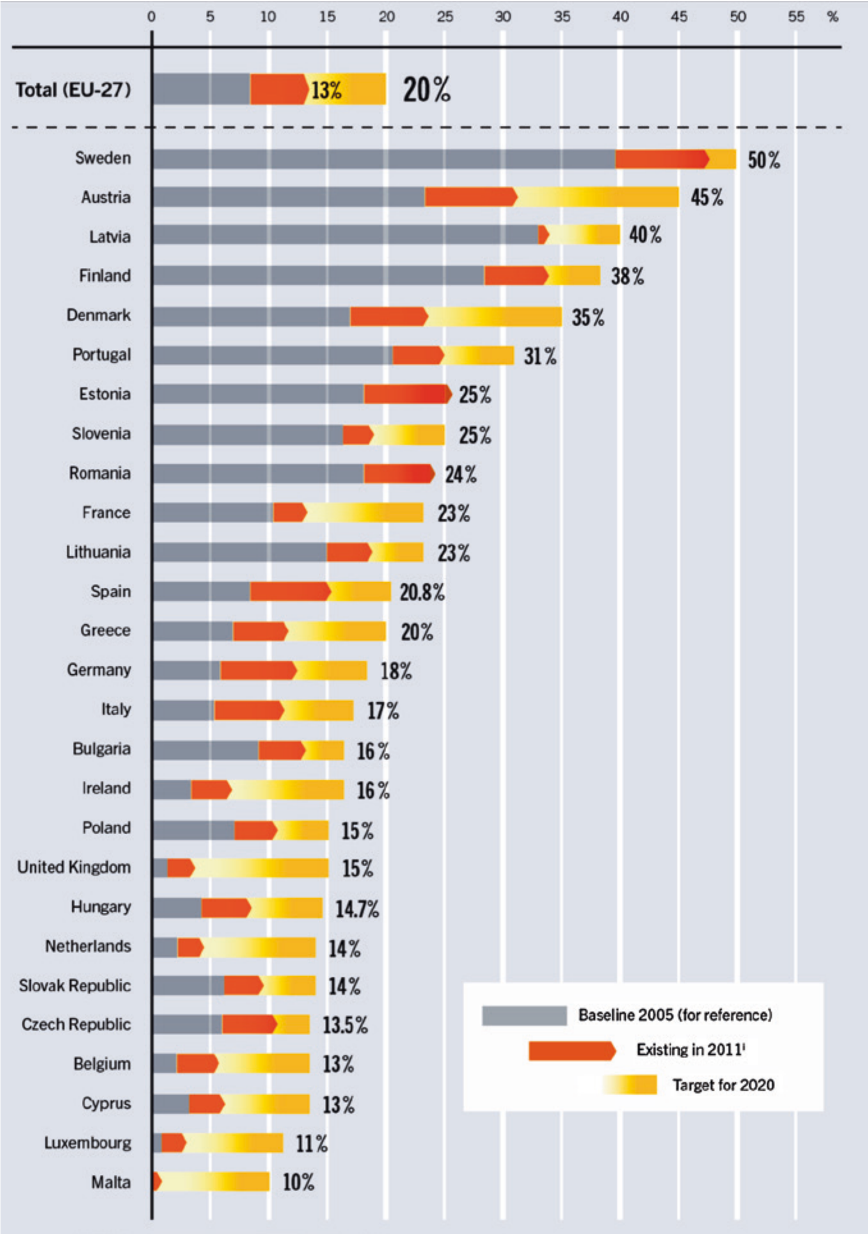

Fig. 2.8 Renewable shares of final energy, 2005 and 2011, with targets for 2020. *Source* REN 21

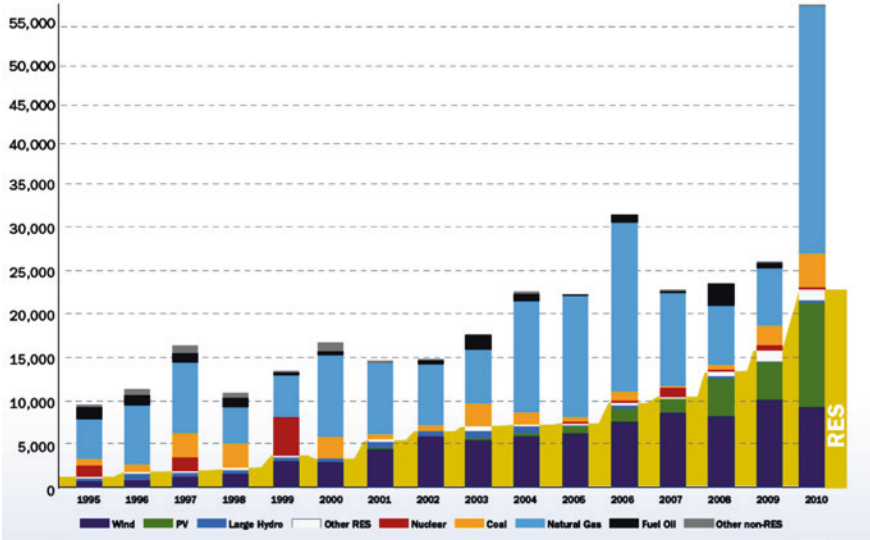

Fig. 2.9 New installed renewable energy sources capacity per year in MW. *Source* EWEA (2011)

target of 40,000 MW for wind power in the EU by 2010, producing 80 TWh and saving 72 million tons of CO_2. Another target of the White Paper was to increase the share of electricity generated from renewable energy sources from 337 TWh in 1995 to 675 TWh in 2010; this means an increase of 100 %.

The EC's White Paper was followed by Directive 2001/77/EC (2001) on the Promotion of Electricity from Renewable Energy Sources. It is the most important piece of legislation ever introduced promoting the use of renewable energy sources for electricity generation within the EU, and has led the 27 EU member states to develop frameworks for investment in renewables, including financial instruments and ways of overcoming administrative barriers and grid access barriers. It is important to stress that the 40,000 MW target were installed by 2005, five years ahead of the Commission's target year (EWEA 2011).[4]

This target is truly ambitious and will require major efforts by all EU member states to achieve them. The contribution of each member state to achieve the EU's target will need to take into account different national circumstances and starting points, including the nature of their energy mix. EU member states should have the flexibility to promote the renewable energies most suited to their specific potential

[4] In 1996, one year before adopting its EC's White Paper target of 40 GWe of wind power by 2010, the EC estimated that 8 GWe would be installed by 2010 in the EU. The 8 GWe was reached in 1999. The EC's target for 2020 was set at 12.3 GWe and was reached two decades ahead of schedule, in 2000. Since 1996, EC has changed its baseline four times. Over the ten year period, targets for wind energy in 2010 and 2020 have been increased almost tenfold from 8 GWe to 78 GWe (2010) and from 12 GWe to 128 GWe (2020) in its latest baseline scenario from 2006. EWEA's 2010 target for wind energy doubled from 40 GWe (in 1997) to 80 GWe (in 2006) (Zervos and Kjaer 2008).

Table 2.4 Evolution of the participation of renewables in the gross electricity consumption during the period 1997–2008 and target for 2010

	Renewable energies' share of gross electricity consumption (%)						Target
	1997	2000	2002	2004	2006	2008	2010 (%)
Belgium	1.0	1.5	1.8	2.1	3.9	5.3	6.0
Bulgaria	7.0	7.4	6.0	8.9	11.2	7.4	11.0
Denmark	8.9	16.7	19.9	27.1	25.9	28.7	29.0
Germany	4.3	6.5	8.1	9.5	12.0	15.4	12.5
Estonia	0.1	0.3	0.5	0.7	1.4	2.0	5.1
Finland	25.3	28.5	23.7	28.3	24.0	31.0	31.5
France	15.2	15.1	13.7	12.9	12.5	14.4	21.0
Greece	8.6	7.7	6.2	9.5	12.1	8.3	20.1
Ireland	3.8	4.9	5.4	5.1	8.5	11.7	13.2
Italy	16.0	16.0	14.3	15.9	14.5	16.6	25.0
Latvia	46.7	47.7	39.3	47.1	37.7	41.2	49.3
Lithuania	2.6	3.4	3.2	35	3.6	4.6	7.0
Luxembourg	2.0	2.9	2.8	3.1	3.5	4.1	5.7
Malta	0.0	0.0	0.0	0.0	0.0	0.0	5.0
Netherlands	3.5	3.9	4.7	5.6	7.9	8.9	9.0
Austria	67.5	72.4	66.0	58.7	56.5	62.0	78.1
Poland	1.7	1.7	2.0	2.1	2.9	4.2	7.5
Portugal	38.3	29.4	20.8	24.4	29.4	26.9	39.0
Romania	30.5	28.8	30.8	29.9	31.4	28.4	33.0
Sweden	49.1	55.4	46.9	46.1	48.1	55.5	60.0
Slovakia	14.5	16.9	19.2	14.4	16.6	15.5	31.0
Slovenia	26.9	31.7	25.4	29.1	24.4	29.1	33.6
Spain	19.7	15.7	13.8	18.5	17.7	20.6	29.4
Czech. Republic	3.5	3.6	4.6	4.0	4.9	5.2	8.0
Hungary	0.8	0.7	0.7	2.3	3.7	5.6	3.6
United Kingdom	1.9	2.7	2.9	3.7	4.6	5.6	10.0
Cyprus	0.0	0.0	0.0	0.0	0.0	0.3	6.0
EU-27	13.1	13.8	13.0	13.9	14.6	16.7	21.0

Tills overview summarises the currently available statistics (cl. sources). These data can diverge from national statistics. The reasons for this Include differences in methods. *Source* Eurostat

and priorities. The way in which EU member states will meet their targets should be included in national action plans to be notified to the EC. The plans should contain sectorial targets and measures consistent with achieving the agreed overall national targets. In practice, in implementing their plans EU member states will need to set their own specific objectives for electricity, biofuels, heating and cooling, which would be verified by the Commission to ensure that the overall target is being met (COM 2007). According to the NREAPs that were submitted by EU member states to the EC in 2010, it is clear that the vast majority of them are taking their responsibilities seriously. According to the NREAPs approved, the EU-27 will exceed its target of meeting 20 % of its gross final energy consumption from renewable energy sources by 2020. However, it is important to highlight that the newest progress report shows that the EU as a whole did not achieve the use of renewable energy sources for the generation of electricity target for 2010 (EC 2011).

According to the Renewable Energy Directive's and the 27 NREAPs approved, 34 % (1,199 TWh) of the EU's total electricity consumption (3,529 TWh) will come in 2020 from renewable energy sources. The contribution of each renewable energy source will be the following:

- Wind energy—14 % (494.7 TWh from 213 GW installed capacity);
- Hydro—10.5 % (370.3 TWh from 136 GW of installed capacity);
- Biomass—6.7 % (232 TWh from 43 GW of installed capacity);
- Solar PV—2.4 % (83.3 TWh from 84 GW of installed capacity);
- Concentrated solar power—0.5 % (20 TWh from 7 GW of installed capacity);
- Geothermal—0.3 % (10.7 TWh from 1.6 GW);
- Tidal, wave, and ocean—0.2 % (5.8 TWh from 2 GW of installed capacity).

Taken together the NREAPs show that the EU-27 will meet 20.7 % of its 2020 energy consumption from different renewable energy sources. Fifteen EU member states plan to exceed their national target, led by Bulgaria at +2.8 % above its target, Spain (+2.7 %), Greece (+2.2 %), Hungary (+1.7 %) and Germany (+1.6 %). Ten EU member states will meet their national target, and just two member states, Luxembourg (−2.1 %) and Italy (−0.9 %), have informed the EC that they envisage using the cooperation mechanisms to meet their national targets. It is encouraging that 25 of the 27-EU countries intend to either exceed or meet their target; this means 92.6 %. This shows that the vast majority of EU countries clearly understand the benefits of using different renewable energy technologies for electricity generation.

According to Ruska and Kiviluoma (2011), in 2020, the total renewable energy electricity production in the EU is estimated to be 1,217 TWh based on NREAPs approved. This production represents 34 % of the projected gross final electricity consumption in 2020 (3,530 TWh). If the NREAPs are implemented, Austria, Sweden, and Latvia will have the largest renewable energy electricity production shares in 2020. In all of these countries, a large part of renewable energy electricity production is hydropower. For the whole EU, wind power's share of the total consumption is projected to be 14 % and solar power share 3 %. Variable generation shares vary considerably between countries and electricity market areas. Ireland has the largest projected wind power share of 37 %, followed by Denmark (31 %), Greece (25 %), and Spain (21 %). Large solar power shares are projected in Spain (8 %), Germany (7 %), and Greece (5 %).

According to Fig. 2.10, the only country that has a balance between the production of electricity using wind or solar power is Cyprus (7 % each). The rest of the countries the participation of wind power in the energy mix is much higher that the participation of solar power for the same purpose.

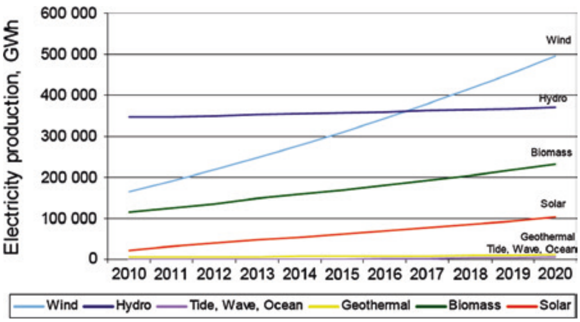

Fig. 2.10 Individual renewable energy source technology's projected trajectory for EU-27 based on NREAPs. *Source* Ruska and Kiviluoma (2011)

To achieve a 20 % share for renewable energies will result in an additional average annual cost of approximately €18 billion—around 6 % extra on the EU's total expected energy import bill in 2020. However, this assumes oil prices of US$48 per barrel by 2020. If this price rose to US$78 per barrel, the average annual cost would fall to US$10.6 billion. With an oil price of around US$130 per barrel, the average annual cost will fall further. If a carbon price of more than €20 were factored in, the 20 % would cost practically no more than relying on conventional energy sources, but create many jobs in Europe and develop new technology driven European companies.

It is important to stress that, according to EWEA (2011), the increase in electricity generated from renewable energy sources is a result of the fact that a majority of newly installed generating capacity is renewable.[5] In 1995, new renewable power installations totaled just 1.3 GW (representing 14 % of total EU power installations in that year). Since 1995, they have gradually increased to 13.3 GW in 2008 (57 % of total EU power installations in that year), and 17.3 GW in 2009 (63 % of total EU power installations in that year). During 2010, a record 22.7 GW was installed. However, due to an exceptional year in new gas installations, the renewable share of new capacity was 41 %.

According to REN 21 (2013), total renewable power capacity worldwide exceeded 1,470 GW in 2012; this represents an increase of 8.5 % respect to 2011. Hydropower rose to an estimated 990 GWe, while other renewables grew 21.5 % to exceed 480 GW. Globally, wind power accounted for about 39 % of renewable power capacity added in 2012, followed by hydropower and solar PV, each accounting for approximately 26 %. The solar PV capacity reached the 100 GWe milestone to pass biopower and become the third largest renewable technology in terms of capacity (but not generation), after hydropower and wind energy. All in all, an estimated 15.9 GWp of solar PV capacity were in place in the EU at the end of 2009. The net capacity addition in 2009 was about 5.5 GWp, which

[5] Generating electricity from renewable energy sources has a high priority in the energy policy strategies at national and European level as well as at a global scale. Challenging goals for this new kind of electricity generation have been set, e.g., at European level by the 'Directive on the Promotion of Electricity from Renewable Energy Source (European parliament and EC 2001) as well as the "White Paper on Renewable Sources of Energy" (EC 1997).

represents an increase of 8 % over the previous year (about 5.1 GWp) and a world market share of about 76 %. Germany played an outstanding role in this regard; it more than doubled its net capacity addition, from about 1.8 GWp in 2008 to about 3.8 GWp in 2009 (BMU 2010).

According to Fig. 2.11, Ireland, Denmark, Estonia, Latvia, Lithuania, Poland, Sweden, Finland and Hungary already reached their targets for wind energy's share in the total projected gross final electricity consumption in 2020. In the case of solar energy, Spain, Germany, Cyprus, Greece and Portugal are the countries with the major share to be reached.

According to Fig. 2.12, the electricity production from renewable energy sources is expected to increase from 19 % in 2010 to 34 % in 2020; this represents an increase of 15 % for the whole period.

Looking ahead towards the end of the decade, renewables are set to overtake fossil fuel as largest generation technologies, reaching 44 % of total installed capacity. Together with nuclear, hydro and other renewables will provide a low-carbon power plant base of 56 % of installed capacity by 2020 (Euroelectric 2012).

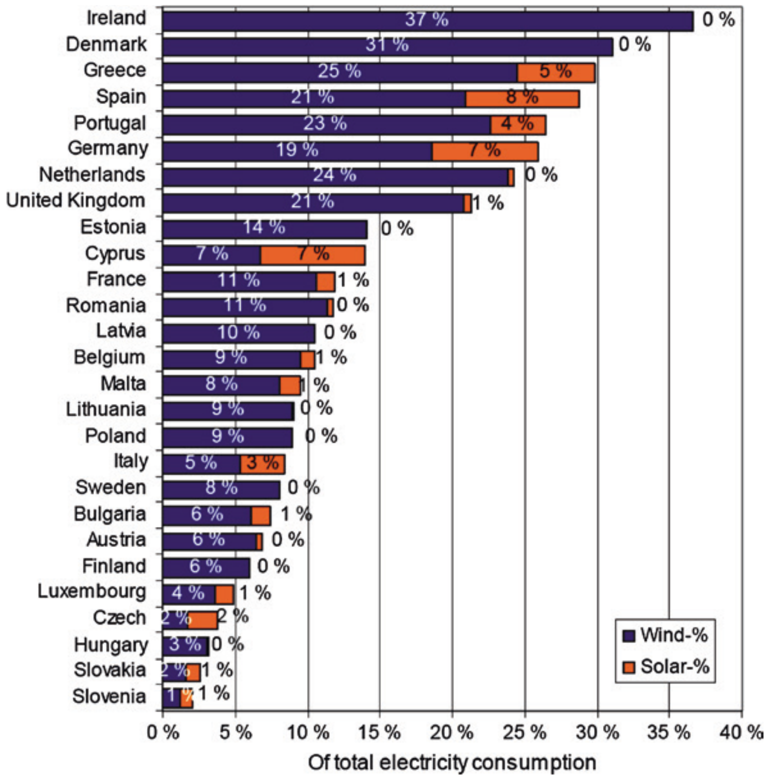

Fig. 2.11 Projected wind and solar power shares of the total projected gross final electricity consumption in 2020. *Source* Ruska and Kiviluoma (2011)

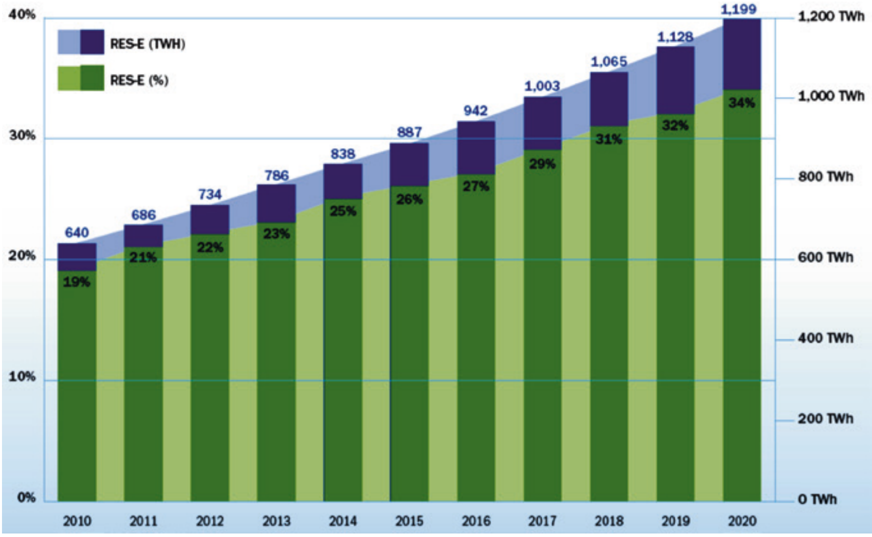

Fig. 2.12 Electricity production from renewable energy sources, according to NREAPs (EU-27). *Source* EWEA (2011)

Renewables have accounted for an ever-growing share of electric capacity added worldwide each year, and in 2012 they made up just over half of net additions to electric generating capacity. By year's end, renewables comprise more than 26 % of total global power generating capacity and supplied an estimated 21.7 % of global electricity, with 16.5 % of total electricity provided by hydropower. While renewable capacity rises at a rapid rate from year to year, renewable energy's share of total generation is increasing more slowly because many countries continue to add significant fossil fuel capacity, and much of the renewable capacity being added (wind and solar energy) operates at relatively low capacity factors.

Even so, wind and solar power are achieving high levels of penetration in countries like Denmark and Italy, which generated 30 % of electricity with wind and 5.6 % with solar PV, respectively, during 2012. In an increasing number of regions—including parts of Australia, Germany, India, and the United States—the electricity generation share from variable resources has reached impressive record peaks, temporarily meeting high shares of power demand, while often driving down spot market prices.

According to Table 2.5, only Germany is included in the top five countries in the use of renewables for the generation of electricity. If hydropower is excluded, then Germany, Spain and Italy are included in the top five countries using renewables for that particular purpose. Three European countries are included in the top five (Sweden, Spain and Italy) according to the level of participation of renewables, excluding hydro, in the generation of electricity. Germany and Sweden are the only two European countries that are included in the top five in the use of

Table 2.5 Top five countries in total renewables capacity installed at the end of 2012

	Renewable power (Incl. hydro)	Renewable power (not Incl. hydro)	Renewable power per capita (not Incl. hydro)	Bio-power	Geothermal power	Hydropower	Concentrating solar thermal power (CSP)
1	China	China	Germany	United States	United States	China	Spain
2	United States	United States	Sweden	Brazil	Philippines	Brazil	United States
3	Brazil	Germany	Spain	China	Indonesia	United States	Algeria
4	Canada	Spain	Italy	Germany	Mexico	Canada	Egypl/ Morocco
5	Germany	Italy	Canada	Sweden	Italy	Russia	Australia
	Solar PV	Solar PV per capita	Wind power	Solar water collector (heating)	Solar water collector (heating) per capita	Geothermal heat capacity	Geothermal direct heat use
1	Germany	Germany	China	China	Cyprus	United States	China
2	Italy	Italy	United States	Germany	Israel	China	United States
3	United States	Belgium	Germany	Turkey	Austria	Sweden	Sweden
4	China	Czech Republic	Spain	Brazil	Barbados	Germany	Turkey
5	Japan	Greece	India	India	Greece	Japan	Japan/Iceland

Source REN 21 (2013)

biopower for the generation of electricity and Italy is the only European country included in the top five for their use of geothermal energy sources for that specific purpose; Russia is the only European country included in the top five for the use of hydropower for the generation of electricity. Due to the level of participation of concentrate solar power in the generation of electricity only Spain is included in the top five countries using this type of energy source, and Germany and Italy are in this group, if solar PV is considered. For the use of wind power for the generation of electricity, Germany and Italy are the only European countries that are included in the top five countries.

However, this continued trend towards greater renewable penetration is not as straightforward if one looks at the actual electricity generation rather than capacity alone. In 2011, renewable electricity (including hydro) represented 22 % of total electricity generation—the same as in 2010 although up two points compared to 2009. This is primarily due to the decreasing hydropower generation in 2011, from 390 TWh to 332 TWh (−17 %), resulting from unfavorable weather conditions across Europe. Notable national cases of decreased hydro generation include Spain (12.3 TWh less or −27 %), Portugal (4.4 TWh less or −27 %) and Italy (6.7 TWh less or −12 %); these three cases alone account for a third of the reduction (23.4 TWh). The drop in hydro was partially compensated by increased generation from other renewable energy sources, which now accounts for 11 % of the total electricity generation (compared to 8 % in 2009 and 10 % in 2010). Looking towards 2020, the structure of the sector will change towards increased renewable generation, with renewables other than hydro more than doubling from 340 TWh in 2011 to 708 TWh in 2020; an increase of 108 %. By 2020, the share of total low-carbon electricity generation will be 56 % (Euroelectric 2012).

In addition, the levelised costs of generation from onshore wind and solar PV have fallen while average global costs (excluding carbon) from coal and natural gas generation have increased due to higher capital costs. As prices for many renewable energy technologies continue to fall, a growing number of renewables are achieving grid parity in more and more areas around the world. China, the United States, Brazil, Canada, and Germany remained the top countries for total renewable electric capacity by the end of 2012. The top countries for non-hydro renewable power capacity were China, the United States, and Germany, followed by Spain, Italy, and India. France and Japan tied for a distant seventh, followed closely by the UK, Brazil, and then Canada and Sweden. Of these 12 countries, the ranking on a per capita basis for non-hydro renewable energy capacity in use puts Germany first, followed by Sweden, Spain, Italy, Canada, the United States, the UK, France, Japan, China, Brazil, and India. In total, these 12 countries accounted for almost 84 % of global non-hydro renewable capacity, and the top five countries accounted for 64 %. Half of the 12 top countries mentioned before are located in the European region.

Renewables accounted for 22.9 % of Germany's electricity consumption (up from 20.5 % in 2011), generating more electricity than the country's nuclear, gas-fired or hard coal power plants (but not lignite plants). Total renewable electricity generation (136 TWh) was more than 10 % above 2011 output, with wind energy representing a 33.8 % share, followed by biomass with 30 % (more than half from biogas), solar PV 20.6 %, and hydropower 15.6 %. Renewables met 12.6 % of Germany's total final energy needs (up from 12.1 % in 2011). Spain has experienced a slowdown in renewable capacity additions resulting from the economic recession and recent policy changes. However, globally it still ranked fourth for non-hydro renewable power capacity, with an estimated 30.8 GW in operation, plus 17 GW of hydro. Renewable energy provided 32 % of Spain's electricity the largest share, followed by solar power. Italy remained in fifth place with 29 GW of non-hydro renewables and 18 GW of hydropower by the end of 2012. Renewables met 27 % of the country's electricity demand, up from 24 % in 2011, with non-hydro renewables accounting for 15 % (24 GW) REN 21 2013).

Austria is the EU country with the highest participation of renewable energy sources in the energy mix with 70 %, followed by Sweden with 63 %, Latvia 59 %, and Portugal 56 %. The EU country with the lowest participation of renewables in the energy mix is Hungary with only 11 %.

After a decrease of electricity production in 2011 (−2.2 %), the volume of produced electricity at EU-27 level decreased once again in 2012 by 0.9 % compared to the preceding year. Belgium (−13.5 %), Portugal (−13.4 %), Denmark (−13.3 %), Netherlands (−9.4 %) and Romania (−9.4 %) are the EU member states that recorded the largest decreases in electricity production.

As regards the structure of electricity production in 2012, the production of conventional thermal electricity decreased by 4.6 % in the EU-27 and accounted for 52.3 % of total production; the production of electricity by nuclear power plants decreased by 2.7 % in the EU-27 and accounted for 27.1 % of the total; the electricity production of hydropower increased by 9 % while the production by wind increased in the EU-27 by 11.5 % and represented respectively 11.7 % and 6.4 % of the total. Norway recorded an increase in total production (+15 %). In Turkey, production increased in 2012 by 3.1 % and in Croatia, production decreased by 2.5 % compared to 2011.

The current situation, without consideration of expected technological change, may be described as follows: The use of renewable energy sources for electricity generation, such as geothermal, upgrading of large-scale hydropower plant or co-firing of biomass is characterized by from an economic point-of-view comparatively low cost and by, in contrast, rather limited future potentials in most countries. Wind energy and in some countries also small-scale hydropower or biomass combustion (in large-scale power plant) represent renewable energy sources for electricity generation with economic attractiveness accompanied by a high additional realizable potential. A broad set of other renewable energy sources for electricity generation technologies are less competitive at present, compare e.g., agricultural biogas and biomass—both if utilized in small-scale power plants, solar PV, CSP, tidal energy or wave power—although, future potentials are in most cases huge (Resch et al. 2006).

When the share of renewable energy sources is analyzed within the EU energy balance in recent years, it is important to take into account the following: The increase in the consumption of renewable energy source for electricity generation has taken place in a context where total primary energy consumption in the EU countries remained stable. The renewable energy's share could even have been greater if some of the years were not marked by a rainfall deficit that significantly slowed down hydraulic production in Latvia, Portugal, Slovenia, Spain, France and Italy. These are the European countries where hydropower production represents a significant share of the renewable energy contribution.

As stated above, the EU did not accomplish the target for the participation of renewables in the EU energy mix in 2010. The main reason for the failure to reach the agreed target—besides the higher costs of renewable energy sources today compared to conventional energy sources—is the lack of a coherent and effective policy framework throughout the EU and a stable long-term vision. As a result, only a limited number of EU member states have made serious progress in this area and the critical mass has not been reached to shift niche renewable production into the mainstream COM (2007).

Other elements that should be considered are the following:

- Using renewable energy sources today for electricity generation is generally more expensive than using hydrocarbons, but the gap is narrowing—particularly when the costs of climate change are factored in;

- Economies of scale can reduce the costs in the use of renewable energy source, but this needs major investment today;
- The use of different renewable energy sources for electricity generation helps to improve the EU's security of energy supply by increasing the share of domestically produced energy, diversifying the fuel mix and the sources of energy imports and increasing the proportion of energy from politically stable regions as well as creating new jobs in Europe;
- The use of renewable energy sources for electricity generation emits few or no greenhouse gases, and most of them bring significant air quality benefits.

Table 2.6 includes an overview on economic and technical specifications for renewable energy power plant for electricity generation, including investment costs, maintenance and operation costs, efficiency, lifetime and typical plant size.

2.4.1 Problems to Overcome During the Use of Renewables for Electricity Generation

The use of new renewable energy sources is expected to suffer an increment of their use as primary sources of energy inside the world energy balance, as well as in Europe to an annual average rhythm of 3.3 %. The wind energy will grow to a higher rhythm, especially in Europe and other countries of the OECD whose governments have adopted urgent measures to promote energy projects based on renewable energy sources. However, the scale use of some of these new renewable energy sources present important limitations related to their geographical location, the intensity of the solar radiation and the meteorological conditions, among others.

Electricity system operators and investors could use pumped hydro energy storage to complement the growing deployment of renewable energy, particularly wind energy. The current grid struggles to push power through when it is being generated in large quantities, and to meet demand when generation is low. Storing energy from wind energy using pumped hydro means the electricity wouldn't have to be sold as it is being made, but could be saved for later.

The main drawback in the use of wind energy for the generation of electricity is the intermittent nature of its source. Wind is extremely variable and there is no guarantee that it will blow when it is most needed. For this reason, large scale integration of wind is a threat to the stability and reliability of the utility grids hosting wind energy conversion systems. Moreover, wind power does not help in providing any of the ancillary services such as regulation reserves, voltage control and frequency control and, therefore, requires a substantial capacity of conventional energy generation that can provide a regulation reserve to follow the wind power.

However, in a power system with abundant hydro generation, wind power balancing is achieved quite economically. During the period of a high wind generation when the load demand can be met by wind generation alone, hydro units can

Table 2.6 Overview on economic and technical specifications for renewable energy power plant for electricity generation

RES-E subcategory	Plant specification	Investment costs (€/kWe)	O&M costs [€/kWe per year)]	Efficiency (electricity) (%)	Efficiency (heat) (%)	Lifetime (average) (years)	Typical plant size (MWe)
Biogas	Agricultural biogas plant	2,550–4,290	115–140	0.28–0.34	–	25	0.1–0.5
	Agricultural biogas plant—CHP	2,760–4,500	120–145	0.27–0.33	0.55–0.59	25	0.1–0.5
	Landfill gas plant	1,280–1,840	50–80	0.32–0.36	–	25	0.75–8
	Landfill gas plant—CHP	1,430–1,990	55–85	0.31 –0.35	0.5–0.54	25	0.75–8
	Sewage gas plant	2,300–3,400	115–165	0.28–0.32	–	25	0.1–0.6
	Sewage gas plant—CHP	2,400–3,550	125–175	0.26–0.3	0.54–0.58	25	0.1–0.6
Biomass	Biomass plant	2,225–2,530	75–135	0.26–0.3	–	30	1–25
	Co-firing	550	60	0.37	–	30	–
	Biomass plant—CHP	2,600–4,230	80–165	0.22–0.27	0.63–0.66	30	1–25
	Co-firing—CHP	550	60	0.2	0.6	30	–
Biowaste	Waste incineration plant	4,300–5,820	90–165	0 18–0.22	–	30	2–50
	Waste incineration plant—CHP	4,600–6,130	100–185	0.14–0.16	0.64–0.66	30	2–50
Geothermal electricity	Geothermal power plant	2,000–3,500	100–170	0.11–0.14	–	30	5–50
Hydro large-scale	Large-scale unit	850–3,650	35	–	–	50	250
	Medium-scale unit	1,125–4,875	35	–	–	50	75
	Small-scale unit	1,450–5,950	35	–	–	50	20
	Upgrading	800–3,600	35	–	–	50	–
Hydro small-scale	Large-scale unit	800–1,600	40	–	–	50	9.5
	Medium-scale unit	1,275–5,025	40	–	–	50	2
	Small-scale unit	1,550–6,050	40	–	–	50	0.25
	Upgrading	900–3,700	40	–	–	50	–
Solar photovoltaic	PV plant	5,080–5,930	38–47	–	–	25	0.005–0.05
Solar thermal electricity	Solar thermal power plant	2,880–4,465	163–228	0.33–0.38	–	30	2–50

(continued)

Table 2.6 (continued)

RES-E subcategory	Plant specification	Investment costs (€/kWe)	O&M costs [€/kWe per year)]	Efficiency (electricity) (%)	Efficiency (heat) (%)	Lifetime (average) (years)	Typical plant size (MWe)
Tidal energy	Tidal (stream) power plant—shoreline	2,670	44	–	–	25	0.5
	Tidal (stream) power plant—near shore	2,850	49	–	–	25	1
	Tidal (stream) power plant—offshore	3,025	53	–	–	25	2
Wave energy	Wave power plant—shoreline	2,135	44	–	–	25	0.5
	Wave power plant—near shore	2,315	49	–	–	25	1
	Wave power plant—offshore	2,850	53	–	–	25	2
Wind onshore	Wind power plant	890–1,100	33–40	–	–	25	2
Wind offshore	Wind power plant—near shore	1,590	55	–	–	25	5
	Wind power plant—offshore: 5…30 km	1,770	60	–	–	25	5
	Wind power plant—offshore: 30…50 km	1,930	64	–	–	25	5
	Wind power plant—offshore: 50 km…	2,070	68	–	–	25	5

Source Resch et al. (2006)

be shutdown and water stored in the upper reservoir. This stored water can be used to generate electricity and meet the load demand during the period of low wind generation.

Nevertheless, there is a limitation due to the stochastic nature of river inflow. The extent to which a hydropower plant can effectively balance the wind power variation usually depends on its storage capacity and river inflow. In a power system dominated by thermal power generation, wind integration is a problem due to the ramping rate limitation on the thermal generators.

Even when there is abundant wind power, the thermal generators may at times have to be operated in a non-optimal operating point, which makes it uneconomical. Pumped hydroelectric energy storage facilities have been considered an attractive alternative for load balancing and energy storage. They can provide ancillary services at high ramp rates, and they can also provide benefits from intraday energy price variation by releasing energy at high demand periods, and buying energy at off-peak periods to pump water into the upper reservoir.

2.5 The Use of Nuclear Energy for Electricity Generation

The installed capacity of nuclear power plants changed in 2011 primarily because of the immediate closure of 8.4 GW of German nuclear capacities following the Fukushima Daiichi nuclear accident, which prompted the government to pass a phase-out bill that will see the country abandoning nuclear energy by 2022. In all other EU member states using nuclear power, except France and the UK, the installed capacity actually grew slightly (0.8 GW) between 2010 and 2011, mainly due to repowering. Nuclear power plants now account for 14 % of the total installed capacity in the EU. Although a total of 1 GW of new fossil-fired power plants went on-stream in 2011, their share of the total installed capacity—about 52 %—did not change because of the simultaneous addition of new renewables capacity.

The electricity produced by nuclear power plants decreased by 2.7 % between 2011 and 2012. The largest share of electricity produced by nuclear energy in the 14-EU member states that have nuclear facilities to produce electricity can be found in France (75.5 %), followed by Slovakia (55.3 %), Belgium (51.3 %), Hungary (46.6 %), Sweden (37.9 %) and Slovenia (35.9 %). Germany that has decided to shutdown its nuclear power plants by 2022 has a share of 16.2 %. According to Fig. 2.13 during the period 2000–2010, nuclear capacity decreased 7,594 MW.

2.6 The Cost Associated with the Use of Renewables for Electricity Generation

The cost of most renewable energy technologies has declined in recent years and additional expected technical advances to be reached during the coming years would result in further cost reductions. Significant advances in renewable energy

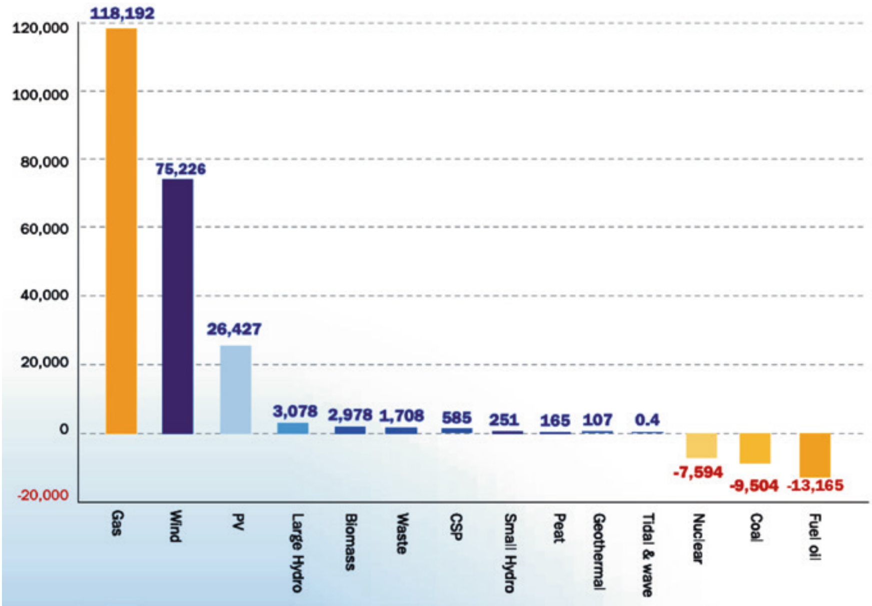

Fig. 2.13 Net electricity generating installations in EU 2000–2010 (MW). *Source* EWEA (2011)

technologies and associated long-term cost reductions have been demonstrated over the last decades, though periods of rising prices have sometimes been experienced (due to, for example, increasing demand for renewable energy in excess of available supply). Further cost reductions are expected in the near future, resulting in greater potential deployment and consequent climate change mitigation. Examples of important areas of potential technological advancement include:

- New and improved feedstock production and supply systems, biofuels produced via new processes (also called next-generation or advanced biofuels, e.g., lignocellulosic) and advanced bio refining;
- Advanced solar PV and CSP technologies and manufacturing processes;
- Enhanced geothermal systems;
- Multiple emerging ocean technologies;
- Foundation and turbine designs for offshore wind energy.

Further cost reductions for hydropower are expected to be less significant than some of the other renewable energy technologies, but research and development opportunities exist to make hydropower projects technically feasible in a wider range of locations and to improve the technical performance of new and existing projects.

The intermittence of wind and solar power can further hinder the economic competitiveness of those energy resources, as they are not operator-controlled and are not necessarily available when they would be of greatest value to the system.

The use of energy storage (such as hydroelectric pumped storage, compressed air storage, and batteries) and a wide geographic dispersal of wind and solar power generating facilities could mitigate many of the problems associated with intermittence in the future.

Renewables are also moving into new applications and industries, including desalination (especially using solar power in arid regions) and the mining industry, whose operations are energy intensive and often in remote locations. Impacts of all of these developments on jobs in the renewable energy sector have varied by country and technology, but globally, the number of people working in renewable energy industries has continued to rise.

The cost of electricity depends on the supply and demand sizes. The supply-side is determined by the unit costs of electricity and the resulting potentials. In a liberalized and competitive market these costs have a major influence on the energy source chosen for electricity generation.

As long as an overcapacity of power plants exists to meet electricity demand, no new power plant is necessary to meet the demand. Accordingly, competition between the different generators is only determined by the variable costs of a plant. With future demand growth and plant replacement, new capacity has to be constructed. Competition between different new generators is influenced by the total costs of electricity generation. In both cases, costs depend on the applied conversion technology and the applied energy source, respectively. By looking closer at a certain energy source another important correlation appears; namely the correlation between costs of electricity generation and the availability of capacity. Because every energy source, fossil, nuclear or renewable, used for electricity generation has limitations, costs depend on previous exploitation and installed capacity. Hence, strategies for a forced market penetration of renewable energy sources for electricity generation in a future electricity market must be based on a detailed analysis of costs and potentials for electricity generation from different renewable energy sources.

On the other hand, demand for renewable energy sources for electricity generation is determined by a number of factors, including:

- **The industrial economic point-of-view**. The price of conventional electricity is set by supply and demand of electricity in general. According to specific market conditions across Europe, this price differs by country and by sub-region. These differences will continue to change due to the ongoing liberalization process. Under the assumption that no other promotional instrument exists, the price of conventional electricity would determine the market penetration of renewable energy sources for electricity generation. In this case only the quantity of green electricity would be produced that could be generated to lower or equal costs than the according conventional price level;
- **Willingness to pay for electricity generated from renewable energy sources**. Voluntary approaches to promote renewable energy sources for electricity generation (e.g., green tariffs) are based on consumers' willingness to pay voluntarily more for green electricity compared its grey counterpart. It is important

to highlight that in Denmark, Luxembourg, Netherlands, Finland and Sweden, the percentage of people who voluntarily sought green electricity is larger than in other countries, and for this reason their demand for renewable energy sources for electricity generation is large compared with other countries within Europe. Nevertheless, there usually exist important divergences between real demand and the aspiration shown in surveys. There is an important interaction between regulatory and voluntary approaches, with huge impact on the latter one (Menges 2003). This interaction relates to the existing asymmetrical relationship between both approaches, which explains the e.g., the relatively poor readiness of German consumers, facing a high regulatory demand for renewable energy sources for electricity generation, to pay more for green electricity, despite their well-known environmental awareness;

- **Quantity-driven strategies (Promotion instruments for renewable energy sources for electricity generation on the demand-side).** To promote renewable energy sources for electricity generation, a mandatory demand could be set by the government. Assuming, a quota for renewable energy sources for electricity generation is introduced, a mandatory (inelastic) demand for electricity from renewable energy sources results (Resch et al. 2006).

In summary, and according to different sources, the following can be stated regarding the cost of the electricity produced by different renewable energy sources:

- **Biomass**: (US$0.029–US$0.09/kWh): Cost estimates vary depending on the combustion method used. In solid waste landfills, naturally occurring anaerobic digestion creates methane used to generate electricity. Similarly, waste generated by lumber mills provides fuel that is essentially free. A slightly more costly source of biomass energy is the anaerobic digestion of animal manure. Conventional combustion technology is the most flexible, but also the most expensive to implement and operate. Although these types of renewable energy resources can eliminate waste products while generating electricity, biomass fuels are bulky and expensive to transport far distances. And unlike other renewable resources, the cost of biomass fuels is not being driven down by technological innovation;
- **Wind**: (US$0.038–US$0.06/kWh): The use of lightweight, but durable materials and more aerodynamic designs have significantly lowered the production cost of the wind turbine. Cost alone is not the only concern when considering wide-scale deployment of wind farms. Susceptibility to failure from mechanical fatigue, the inability to function well in the rain or in cold climates, and the noise created from vibration, should all be taken into account when considering the true cost of using this abundant energy source. Despite the substantial upfront investment required for the generator, it requires a marginal operating cost of less than US$0.01/kWh;
- **Geothermal**: (US$0.039–US$0.30/kWh): The considerable variability of costs for this type of renewable energy resource comes largely from the type of plant constructed and the depth of drilling required. Boasting incredible uptime of

more than 97 %, geothermal plants can operate more efficiently and consistently than coal power plants with uptimes of around 70 %. In comparison to natural gas, the annual reserves available are quite low. Binary geothermal power plants (currently the preferred technology) are small, and can be built in a variety of different places, including acreages and rural farmland. Even though they are smaller, they still carry a higher initial investment than natural gas power plants. Despite the sustainability of its free fuel source, the high cost of well drilling and pipeline construction prevents many of these plants from ever being built;
- **Hydro**: (US$0.051–US$0.11/kWh): Accounting for 16–20 % of worldwide energy production, hydropower is the most practical and universal of these five types of renewable energy resources. While they can only be built in a limited number of places due to the extraordinary amount of space required, hydropower plants are the most efficient source of green electricity and contribute no waste or little emissions into the environment. Environmentalists argue that large hydroelectric power projects destroy marine ecosystems and disrupt fragile habitats. In response to these protests, governments and private enterprise have developed several cutting-edge technologies such as hydrokinetic power systems that generate power without the need for dams;
- **Solar**: (US$0.15–US$0.30/kWh): Solar power systems include solar PV, which convert the sun's energy directly into electricity, and CSP which uses solar energy to heat water in residential and commercial applications. The high cost of these types of renewable energy sources is largely due to the high price of silicon crystals. Silicon prices continue to rise as their widespread production applications are leading to supply shortages. However, newly developed alternative materials could bring the cost down below US$0.05/kWh in the near future.

The environmental benefits of using green electricity unarguably outweigh any financial drawbacks. Nonetheless, it's still prudent to consider the real financial viability of each of these leading types of renewable energy resources as a real alternative to fossil fuel-based energy.

2.7 The Impact on the Use of Renewable Energy Sources in Sustainable Development in the European Region

Historically, economic development has been strongly correlated with increasing energy use and growth of greenhouse gas emissions, and renewable energy sources can help decouple that correlation, contributing to sustainable development. Though the exact contribution of renewable energy sources for sustainable development has to be evaluated in a country-specific context, renewable energy sources offers the opportunity to contribute to social and economic development, energy access, secure energy supply, climate change mitigation, and the reduction of negative environmental and health impacts. In summary, it can be said, according to the Intergovernmental Panel on Climate Change (2012), that:

- Renewable energy sources can contribute to social and economic development. Under favorable conditions, cost savings in comparison to non-renewable energy sources use exist, in particular in remote and in poor rural areas lacking centralized energy access. Costs associated with energy imports can often be reduced through the deployment of domestic renewable energy technologies that are already competitive;
- Renewable energy sources can help accelerate access to energy, particularly for the 1.4 billion people without access to electricity and the additional 1.3 billion using traditional biomass. Basic levels of access to modern energy services can provide significant benefits to a community or household. In many developing countries, decentralized grids based on renewable energy sources and the inclusion of renewable energy on centralized energy grids have expanded and improved energy access;
- Renewable energy options can contribute to a more secure energy supply, although specific challenges for integration must be considered. Renewable energy deployment might reduce vulnerability to supply disruption and market volatility, if competition is increased and energy sources are diversified;
- In addition to reduced greenhouse gas emissions, renewable energy technologies can provide other important environmental benefits. Maximizing these benefits depends on the specific technology, management, and site characteristics associated with each renewable energy project;
- Life cycle assessments for electricity generation indicate that greenhouse gas emissions from renewable energy technologies are, in general, significantly lower than those associated with fossil fuel options, and in a range of conditions, less than fossil fuels employing CCS;
- Most current bioenergy systems, including liquid biofuels, result in greenhouse gas emission reductions, and most biofuels produced through new processes (also called advanced biofuels or next-generation biofuels) could provide higher greenhouse gas emission mitigation. The greenhouse gas emissions balance may be affected by land use changes and corresponding emissions and removals. Bioenergy can lead to a voided greenhouse gas emissions from residues and wastes in landfill disposals and co-products; the combination of bioenergy with CCS may provide for further reductions;
- Water availability could influence the choice of renewable energy technology. Conventional water-cooled thermal power plants may be especially vulnerable to conditions of water scarcity and climate change. In areas where water scarcity is already a concern, non-thermal renewable energy technologies or thermal renewable energy technologies using dry cooling can provide energy services without additional stress on water resources. Hydropower and some bioenergy systems are dependent on water availability, and can either increase competition or mitigate water scarcity;

- Site-specific conditions will determine the degree to which renewable energy technologies impact biodiversity;
- Renewable energy technologies have lower fatality rates. Accident risks of renewable energy technologies are not negligible, but their often decentralized structure strongly limits the potential for disastrous consequences in terms of fatalities. However, dams associated with some hydropower projects may create a specific risk depending on site-specific factors.

It is important to highlight that within the EU renewable energy sources are largely indigenous, they do not rely on the future availability of conventional sources of energy, and their predominantly decentralized nature makes EU countries' economies less vulnerable to volatile energy supply. Consequently, they constitute a key element of a sustainable energy future. However, for renewables to become the "stepping stone" to reaching the dual objective of increased security of supply and reduced greenhouse gas emissions, a change in the way in which the EU promotes renewables is needed. Strengthening and expansion of the current EU regulatory framework is necessary. It is important to ensure that all EU member states take the necessary measures to increase the share of renewables in their energy mix (COM 2008).

Finally, it is important to highlight that with the exception of existing hydroelectric facilities, almost all of the power generation capacity required to supply Europe in 2050 will need to be built in the next 35 years. This is a major undertaking regardless of the energy mix, and would pose a massive challenge even in a high-carbon scenario. Within the EU in 2020, wind power will be the single largest renewable energy source production technique, if the projected trajectory is implemented. Wind power production is expected to exceed hydropower production in 2016–2017. In terms of GWh's, solar and biomass-sourced electricity will experience more modest growth. Hydropower production is expected to increase only slightly. Geothermal, wave, tidal and ocean energies' share of the total renewable energy source electricity production is expected to be only around 1 % in 2020. In addition, the following summing up should be taken into account:

- Renewable energies now account for 10.3 % of total energy consumption (in 2008 it was 9.3 %);
- Renewable energies now cover around 16 % of gross electricity consumption (in 2008 it was 15.2 %)[6];
- Renewable energies now cover 8.8 % of final heat consumption (in 2008 it was 7.4 %);
- Renewable energies now meet 5.5 % of fuel demand (in 2008 it was 5.9 %);
- Investments in 2009 reached €20.0 billion (in 2008 the investment reached €15.3 billion). Global new investment in renewable power and fuels was US$244 billion in 2012, down 12 % from the previous year's record. Despite the setback, the total in 2012 was the second highest ever and 8 % above the

[6] As a result of the economic crisis, energy consumption in Germany decreased by around 6 % in 2009.

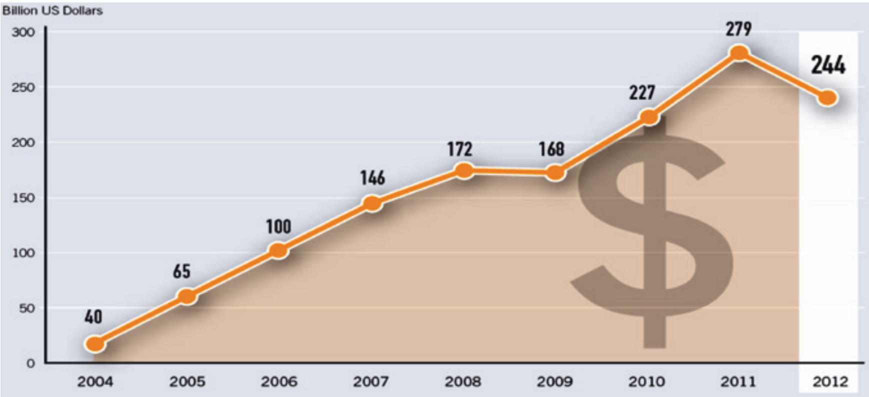

Fig. 2.14 Global new investment in renewable energy during the period 2004–2012. *Source* REN 21

2010 level. If the unreported investments in hydropower projects larger than 50 MWe and in solar hot water collectors are included, total new investment in renewable energy exceeded US$285 in 2012. This is lower than the equivalent estimate for 2011, however. The decline in investment—after several years of growth— resulted from uncertainty over support policies in Europe and the United States, as well as from actual retroactive reductions in support. On a more positive note, it also resulted from sharp reductions in technology costs[7] (Fig. 2.14);

- Value added through the operation of renewable energy installations: €16 billion (in 2008 was €15.3 billion);
- Overall, the use of renewable energies prevented a total of about 108 million tons of greenhouse gas emissions;
- The renewable electricity sector within the European region is a quite advanced sector with already well developed market and business structures. Most of the activities reach beyond general awareness raising and promotion. Issues like favorable, reliable, and forward-looking policy frameworks, investment security, access to electricity grids and fair regulation, operation and maintenance etc. dominate the picture;

[7] The year 2012 saw the most dramatic shift yet in the balance of renewable energy investment worldwide, with the dominance of developed countries waning and the importance of developing countries growing. In the developing world, renewable energy outlays reached US$112 billion, up from US$94 billion in 2011, and represented some 46 % of the world total (up from 34 % in 2011 and 37 % in 2010). By contrast, outlays by developed economies fell sharply (29 %), from US$186 billion in 2011 to US$132 billion in 2012, the lowest level since 2009. This shift reflects two important trends: A reduction in subsidies for wind and solar project development in Europe and the United States; and increasing investor interest in emerging markets that offer both rising power demand and attractive.

- Although the sector is generally very dynamic and well developed, it still faces considerable regulatory, administrative, and grid barriers;
- The dissemination efforts in promoting the use of renewable energy sources for electricity generation in the European region have generally improved considerably, but still need to be given even higher priority; in times of a growing flood of information, information needs to be well targeted, concise and well prepared in order to reach the respective target groups;
- Electricity customers (residential customers and also business firms) are interested in green power products and look for independent eco-labels as a guidance to their purchase decision;
- The prospect of success for voluntary green power offers especially depends on the market condition;
- The regulatory framework should include incentives for distribution system operators to integrate distributed generation. The remuneration schemes for operational and capital expenditures and the benchmarking procedures should take into account the connection and management of distributed generation. Additional incentives should be considered to promote innovation and research and development activities by distribution system operators;
- Deep connection charges that include reinforcement costs should be avoided. Either a shallow charging policy could be adopted or the use of system pricing methodology could be reformulated to allow the financial recognition of the distributed generation contribution to the network costs;
- Participation of distributed generation in ancillary service and balancing markets can be enhanced, if market rules accept aggregation of small individual generators. The timeframe for announcing estimated production in balancing arrangements should become smaller;
- EU member states apply very different, inconsistent and non-transparent procedures and rules for interconnection and connection charging of new distributed generation and renewable energy sources market entrants. This creates unnecessary risk and uncertainty to project developers, and it leads to market distortion. As a result of the above, there is an urgent need for novel, consistent and pan-European approaches to distributed generation, interconnection rules and connection charging across the whole of the EU;
- Current national systems for tracking electricity, mainly focus on national markets, vary considerably among countries and their design and interaction with related policies lead to significant volumes of multiple counting and loss of information;
- The design of a tracking standard for electricity is a delicate issue for market participants and should be developed carefully in order to produce useful results, e.g., for electrical disclosure, but at the same time not to create negative impacts on the liquidity of electricity markets:
- The preferred tracking system should feature an efficient mechanism for explicit tracking, preferably based on certificates, combined with an option to use a residual mix, consisting of statistical generation data, which is corrected by those attributes that have been tracked explicitly;

- Wind power, solar PV and geothermal sectors will achieve the European targets set in the EC White Paper. Other sectors need more incentive from the individual EU member states;
- In different EU member states there still exist a variety of different, non-transparent cost allocation and cost reimbursement principles for grid integration of renewable electricity system and operation. Practical guidelines to harmonize existing legislation in this context are presented in the recommendation report of the project GreenNet-EU-27 (2005–2006);
- From the grid-operators' points-of-view, at present there exist no incentives for large-scale grid integration of renewable electricity, since the corresponding grid-related costs are hardly eligible in the grid regulation/grid tariff determination procedures. Practical guidelines to overcome these disincentives are also outlined in the recommendation report of the project GreenNet-EU-27 (2005–2006);
- Comprehensive quantitative analyzes (renewable electricity modelling, and empirical renewable electricity case studies) provide evidence that the overall costs of large-scale intermittent grid integration of renewable electricity (including system operation costs and grid reinforcement/extension costs) are still below 10 % of the long-run marginal costs of the renewable electricity generation technology itself;
- Solar photovoltaic policy measures and starting positions vary strongly from country to country. Therefore, close cooperation, deepened cross-national discussions and actions are absolutely necessary, also after finishing the project. Although the core group of the Photovoltaic Policy Group already gathered eight countries, it is desirable that the results are disseminated and used in non-participating EU countries.

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http://www.springer.com/978-3-319-16082-5

Electrical Energy Generation in Europe
The Current Situation and Perspectives in the Use of Renewable Energy Sources and Nuclear Power for Regional Electricity Generation
Morales Pedraza, J.
2015, XXXI, 640 p. 268 illus., 180 illus. in color., Hardcover
ISBN: 978-3-319-16082-5